Nuclear Proliferation and Safeguards

June 1977

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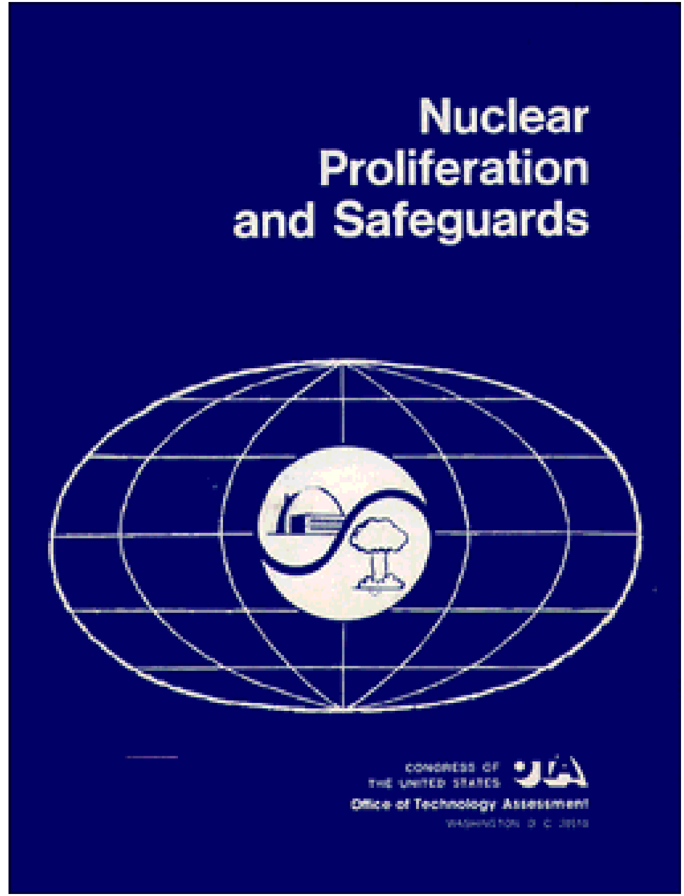

Congress of the United States
OFFICE OF TECHNOLOGY ASSESSMENT
WASHINGTON, D.C. 20510

Honorable Abraham A. Ribicoff
Chairman, Committee on Government
Affairs
United States Senate
Washington, D. C. 20510

Dear Mr. Chairman:

On behalf of the Board of the Office of Technology Assessment, we are pleased to forward this report Nuclear Proliferation and Safeguards.

The report consists of two volumes: the first covers the findings and analysis, the second consists of the appendices of supporting documentation. It was prepared by the Office of Technology Assessment in response to your Committee's request.

In accordance with OTA policy, this report provides a balanced and impartial analysis of the various initiatives proposed to reduce or eliminate nuclear weapons proliferation. The technical, institutional and political options discussed in the report are set in the context of both alternative energy perspectives and the various nuclear reactor fuel cycles to which they relate. We hope that this report will be useful to your Committee and the entire Congress in debating and resolving the best course for the country in prevention of the spread of nuclear weapons capabilities.

Sincerely,

Edward M. Kennedy
Chairman

Sincerely,

Marjorie S. Holt
Vice Chairman

cc: Honorable John H. Glenn
Honorable Charles H. Percy

Congress of the United States
OFFICE OF TECHNOLOGY ASSESSMENT
WASHINGTON, D.C. 20510

EMILIO Q. DADDARIO
DIRECTOR
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June 30, 1977

Honorable Edward M. Kennedy
Chairman
Technology Assessment Board
Off ice of Technology Assessment
United States Congress
Washington, D. C. 20510

Dear Mr. Chairman:

The enclosed report, Nuclear Proliferation and Safeguards, presents OTA’s analysis of the risk of further spread of nuclear weapons, and the relation of that risk to the peaceful use of nuclear technology.

This assessment, prepared under the direction of the OTA Energy Program, was requested by Senators Abraham Ribicoff, John Glenn, and Charles Percy of the Senate Committee on Government Operations. The purpose was to provide a comprehensive analysis of technological factors and potential options to assist Congress in evaluating national and foreign policy relevent to nuclear proliferation.

In addition to extensive internal review, the report has been reviewed by the Nuclear Proliferation and Safeguards Advisory Panel, the Energy Program Advisory Committee, the Technology Assessment Advisory Council, and others. The report addresses the motivations for nations and non-state groups to obtain nuclear weapons and the routes they could follow in doing so. A balanced analysis of the policy options available for combatting the problem is presented. The options are arranged to correspond with the responses that follow from three different perceptions of the risks of proliferation relative to the need for nuclear energy: energy priority, non-proliferation priority, and shared priority.

The study concludes that the complex and difficult problem of proliferation is controllable only by hard and controversial choices by many nations over which the U.S. has only limited influence. Within these limits, however, there are many options for reducing the probability of proliferation. The desirability of these options depends not only on their effectiveness and feasibility, but also on perceptions of the importance of non-proliferation relative to other national choices.

Proliferation has emerged as a major concern in both the Congress and the Executive Department. Several bills have already been introduced in Congress, and the President has elevated non-proliferation to one of his highest foreign policy objectives. The OTA report should prove useful to the Congress in its consideration of these bills.

Sincerely,

EMILIO Q. DADDARIO
Director

Enclosure - 1

Acknowledgments

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Preface

This study has been undertaken in response to a request from the Senate Committee on Government Operations (now the Committee on Governmental Affairs) to help provide Congress with the capability to “independently evaluate the policymaking activities of our Government and other nations and be prepared to take legislative actions” with regard to nuclear proliferation and safeguards.

This report has been prepared by the Energy Program of OTA with the assistance of an advisory panel of 16 members from industry, Government, and academia, who have reviewed draft material for each section of the report and have periodically met to comment on the course of the study and provide guidance to the staff. The advisory panel provided advice and critique throughout the assessment, but does not necessarily approve, disapprove, or endorse the report, for which OTA assumes full responsibility.

The Technology Assessment Board approves the release of this report, which identifies a range of viewpoints on a significant issue facing the U.S. Congress. The views expressed in this report are not necessarily those of the Board, OTA Advisory Council, or of individual members thereof.

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Introduction

Since the first detonation of a nuclear explosive, the world has lived with the spectre of nuclear proliferation. Thirty-two years later, six nations have demonstrated their possession of nuclear explosives and perhaps two dozen more have the economic and technical prerequisites to soon follow suit if they so choose. In the decade following 1964, an intangible barrier held the number of nuclear weapons states constant and separated the nuclear-armed great powers (symbolized by the five permanent seats of the United Nations Security Council) from the rest of the international community. In 1974, India breached this barrier by detonating its own nuclear device.

Several recent international trends have aroused concern that other nations may adopt India's example. The growing demand for nuclear energy, partly as a result of the 1973-1974 quadrupling of world oil prices, has resulted in the dissemination of nuclear facilities and technology whose complex and ominous relationship with nuclear weapons has become increasingly clear. The general spread of scientific and technical knowledge has also increased the availability of information on nuclear-weapons design and fabrication. At the same time, the international political influence of the great powers has declined as part of the erosion of the post-war alliance system, the emergence of new, ambitious regional powers, and the widening split between industrialized and nonindustrialized countries. Finally, the appearance of increasingly violent and sophisticated terrorist groups has added another element of fear and uncertainty to the nuclear proliferation issue.

This combination of phenomena has spawned a widespread feeling that time is running out; that unless decisive action is taken in certain critical areas very soon, an inevitable chain of events will lead to a gathering proliferation momentum. This concern is reflected in the decision of the new Administration to make proliferation control a very high-priority objective. Similarly, Congress already has under active consideration a number of bills designed to address one or another aspect of the problem.

At the root of the concern over proliferation is the fear that the spread of nuclear weaponry poses a grave and mounting threat to global stability. This threat could materialize in at least four ways. First is the obvious danger that nuclear weapons might actually be used. As is frequently pointed out, the statistical probability of use increases with the spread of weapons, other things being equal. Second, newly established nuclear powers could enter a nuclear arms race which might be politically destabilizing and, in itself, increase the

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likelihood of an outbreak of war. Third, the expanding quantity and distribution of weapons will increase the opportunities for theft, illicit sale, and sabotage. Finally, proliferation could undermine the present structure of the international political system as the acquisition of weapons alters the distribution of power.

Nuclear weapons proliferation may thus heavily impact U.S. foreign policy, whose overriding objective in recent years has been the maintenance of global political stability. This goal has been viewed as the basic precondition for the pursuit of other U.S. interests. Efforts to control proliferation may conflict with normal U.S. foreign relationships; they may raise specific and contentious issues with other nuclear supplier states, most of which are U.S. allies, and with user states, mostly in the Third World. Ironically, the one major set of relationships which is largely unaffected by proliferation is that between the United States and its Communist adversaries.

Past Approaches to Proliferation Control

Although concern over nuclear proliferation has reached new heights, recognition of the need to control it is not new. U.S. foreign policy has exhibited three relatively distinct phases in its posture toward nuclear weapons control.

The first U.S. response to nuclear weapons was essentially to try to close the lid to Pandora's box. This so-called "secrecy-denial" stage was typified by a bill introduced in September 1945 by Senator Brien McMahon. It sought "to conserve and restrict the use of atomic energy for national defense, to prohibit its private exploitation and to preserve the secret and confidential character of information concerning the use and application of atomic energy."

It quickly became apparent that such a total monopoly on nuclear technology for the indefinite future was not feasible. Instead of the McMahon bill,' Congress passed the somewhat more flexible Atomic Energy Act of 1946. This Act declared that until "effective and enforceable international safeguards against the use of atomic energy for destructive purposes have been established, there shall be no exchange with other nations with respect to the use of atomic , energy for industrial purposes." The Act imposed heavy penalties for disclosure of military or industrial nuclear information, thus cutting off cooperation with Great Britain and Canada despite their assistance in the wartime development.

International control was also proposed by the United States in June 1946, in what came to be known as the "Baruch Plan. " The main points called for were:

- The creation of an International Atomic Development Authority which would be entrusted with all phases of the development and use of atomic energy.
- Cessation of the manufacture of atomic weapons and disposal of existing bombs. These steps would be taken upon the establishment of an adequate system for the control of atomic energy, the renunciation of the bomb as a weapon, and the formulation of a procedure for handling violations of the rules of the control.

The U.S.S.R. countered the Baruch Plan with a ban-the-bomb approach. The Soviet draft convention as introduced by Gromyko contained provisions for the prohibition of the production, storage, and use of atomic weapons and for the destruction of all such weapons within 6 months after the entry into force of the convention. Although discussions concerning the Baruch proposals continued for several years, irreconcilable differences between the United States and the U.S.S.R. made agreement impossible.

By the end of 1953 it was clear that the secrecy-denial policy had failed in both denial and control. Great Britain had exploded its first atom bomb and both the United States and U.S.S.R. had tested hydrogen bombs.

When its initial nuclear policy proved inadequate, the United States shifted its emphasis from denial to active promotion of peaceful uses of atomic energy. The new policy was initiated on December 8, 1953, by President Eisenhower in a speech before the United Nations General Assembly. That speech, whose theme stressed exploiting the good rather than the evil inherent in the atom, became known as the "Atoms for Peace" proposal. The "Atoms for Peace" program required safeguards to ensure that nuclear materials, equipment, and assistance would not be diverted from peaceful to military purposes. The International Atomic Energy Agency (IAEA), which came into force in July 1957, was assigned the responsibility for administering safeguards. The intent was to channel the apparently inevitable spread of nuclear technology into controlled nonmilitary uses.

An unintended consequence of the "Atoms for Peace" program was a blurring of the line between the peaceful and military exploitation of atomic energy. Nuclear technology and materials which are intended for peaceful purposes can be utilized, to varying degrees, in making the nuclear weapons. Accumulated technology and experience from the acquisition of nuclear power reactors has significantly lowered the technical barriers to proliferation of nuclear weapons. With time, it became apparent that a major international effort to prevent proliferation was essential. The Non-Proliferation Treaty (NPT) was put into effect in 1970 as a response to that critical requirement, and represents the third stage of U.S. policy toward proliferation.

Despite its successes to date, the NPT is not by itself a complete solution for effective control of proliferation. Among the approximately 50 nations that have not yet ratified the NPT are a number of those considered to be the most likely candidates for proliferation (the so-called "Nth countries"). International speculation already attributes a clandestine nuclear weapons capability to Israel and possibly South Africa. There is, moreover, considerable concern that some countries may ratify the NPT as a way of acquiring nuclear technology and facilities. Having obtained the prerequisites for producing weapons, they may then abrogate the treat y when it suits their purposes. As a consequence, there is a renewed sense of urgency on behalf of efforts to gain a more adequate understanding of this complex phenomenon. The result may be a new set of policy initiatives so distinct from those of the past as to constitute a fourth phase of proliferation control.

Key Factors for New Policy Initiatives

As yet, political leaders and analysts of proliferation have reached no real consensus as to the content of the next stage of policy. Three major factors or issues appear to be at the crux of the debate.

The first issue concerns the likelihood and rate of proliferation. This in turn rests on judgments concerning:

(1) the strength of incentives and opportunities for potential Nth countries to "go nuclear" compared to the strength of disincentives and barriers;
(2) the relative likelihood of alternative routes to proliferation (diversion of nuclear material from commercial power systems, construction of indigenous facilities to produce weapons material, and direct purchase or theft); and
(3) the capability and will of non-state adversaries to procure and use nuclear weapons.

The second issue concerns the nature and seriousness of the consequences of proliferation. Despite widespread concern over nuclear proliferation, some still contend that it will have a comparatively benign impact on international politics by, in effect, foreclosing resort to military force in conflict situations. Alternatively, it can be argued that proliferation will proceed at a slow to moderate rate and may jeopardize regional, but not global, stability. Even the majority who view the possibility of a proliferated world with foreboding may disagree on the precise dimensions of the threat.

The third issue relates to differing assessments of the political and economic costs and benefits of particular policy options. The matter is made more complex by the fact that some proposed policies involve fundamental transformation of domestic political, economic, and social systems, plus equally drastic international innovations, including the endowment of global institutions with significant governmental authority. Judgments concerning the desirability of any of these options will hinge not only on their specific merits but also on other factors, such as the need for nuclear energy, the ethics and advisability of intervening in the domestic affairs of other nations, and widely varying assessments of the extent of U.S. influence, real and potential.

Definition of Proliferation

No real consensus exists even on the interpretation of the word "proliferation." The phrase is a deceptively simple one. By implication the Non-Proliferation Treaty (NPT) defines proliferation as the manufacture or acquisition of nuclear weapons or other nuclear explosive devices by countries which do not now possess them. Conventionally, the actual detonation of a device has determined the transition from non-nuclear weapons to nuclear weapons status. Recently, this approach has been questioned on the grounds that there are many stages in the acquisition of a nuclear weapons capability. A nation can make all the preparations for the construction of a weapon or the testing of a device without actually "proliferating." If it is possible to come within hours of a bomb and still not violate the NPT, the traditional definition conceals more than it reveals.

In this report, the definition of proliferation has been broadened to encompass any country that has acquired the capability to very rapidly produce a nuclear explosive device, i.e., a nation that has all the components of an explosive on hand ready for assembly. The critical element is political will. A country which has decided to acquire the components of a nuclear weapon, and has done so, is a nuclear weapons state even if the mechanics of assembling, arming, and detonating the device remain to be completed.

This does not mean, however, that the actual detonation of a device has no significance; quite the contrary. In the case of some potential Nth countries, there might be some doubt as to whether an assembled, but untested, device would actually explode. Even where no such doubt exists, there are other important considerations. The very fact that a nation has decided not to demonstrate its capability communicates a certain restraint to nervous neighbors, allies, and adversaries. As long as a device remains untested, its existence is surrounded with doubt and ambiguity—a matter of some political consequence.

Purpose and Nature of This Study

Proliferation constitutes one of the most complex and difficult issues in the public policy domain. This study seeks to facilitate an understanding of the problem and its implications, in terms of both a comprehensive overview and a detailed indepth analysis of key elements. Technological, institutional, economic, and political aspects, and the linkages among them, are examined. Policy options are outlined and analyzed in terms of three major perspectives corresponding to different weighings of the key factors discussed above. The objective is not to recommend a particular perspective or policy, but to provide the reader with the tools for informed policy choice. This report is, in particular, intended to lay the groundwork for an informed consideration by Congress of possible legislative action concerning proliferation. It is not a study of nuclear power or a comparison of its economic, social, or environmental impacts vis-a-vis alternative energy sources.

The entire report is summarized in chapter II, along with the major issues and findings. This chapter also includes an introduction to nuclear technology designed to provide a background for the nontechnical reader.

Chapter III draws on the material presented in the subsequent chapters and summarized in chapter II to present policy options available to the U.S. Government. These are analyzed as a function of different perspectives of the key factor discussed above.

An examination of the motivations for acquisition of nuclear weapons by other nations, now and in the future, is presented in chapter IV. The motivations for non-national groups to obtain nuclear weapons are explored in chapter V, along with the likelihood and nature of use by such groups. This chapter also examines the civil liberties implications of various measures that might be undertaken to control this threat.

A nation or non-national group must be able as well as willing to construct a nuclear fission explosive device. The requirements are discussed in chapter VI. Also examined are the ramifications of one possible excuse for weapons testing—peaceful nuclear explosions.

The fissionable nuclear material required to construct a weapon might be obtained by three possible routes, as described in chapter VII. One is to divert the material from a commercial nuclear power facility either covertly or by abrogation of safeguards agreements. A second is to build facilities (probably clandestinely) to produce the required material. A third is to purchase or steal either the material or actual weapons.

Safeguards play a critical role in the control of attempts to acquire nuclear weapons material. The technology and procedures of both domestic and international safeguards are analyzed in the first part of chapter VIII. The second part of the chapter deals with the international institutions involved in detecting and controlling attempts to develop nuclear weapons. An analysis of factors that could influence a nation in its selection of a route to weapons, i.e., objectives, abilities, and political situations, is presented in chapter IX.

Any control measures must also be cognizant of the characteristics of the international nuclear industry, as described in chapter X.

Chapter II

Issues, Findings, and Executive Summary

Chapter II

Issues, Findings, and Executive Summary

This chapter is comprised of three sections: issues and findings; a description of nuclear technology; and an executive summary. The first section presents selected issues and findings of the report under the following headings:

- The Problem—the desirability and accessibility of nuclear weapons; and
- The Control—possible control measures.

PROLIFERATION ISSUES AND FINDINGS

The Problem

Issue 1

Are More Countries Likely To Acquire Nuclear Weapons, and If So, Will This Proliferation Jeopardize U.S. and Global Interests?

Findings

The technical and economic barriers to proliferation are declining as accessibility to nuclear weapons material becomes more widespread. Consequently, the decision Whether or not to acquire a nuclear weapons capability has become increasingly a political one. The choice will turn on whether a nation views the possession of such a capability as being, on balance, in its national interest.

That balance will be affected by certain global trends. The diffusion of global power and the erosion of bipolar alliance systems and great power security guarantees tend to increase the incentives to proliferation. On the other hand, a number of states have long had the capability to acquire nuclear weapons but have been persuaded by a variety of political considerations to refrain. These disincentives may also be persuasive in the future to the growing number of countries which find nuclear weapons within their capability. With internationally derived incentives and disincentives broadly offsetting one another, the decision on acquiring a nuclear weapons capability will tend to hinge on the particular circumstances of each Nth country and the policy pursued by present nuclear weapons states, especially the United States.

Press reports indicate that at least two states (Israel and South Africa) are at the verge of acquiring or have already acquired nuclear weapons. Several other countries are close to a weapons capability and a few may choose to attain it over the next few years.

As for the consequences of proliferation, it can be argued that proliferation will have a stabilizing effect on international politics due to the deterrent value of nuclear weapons. The alternative, and more persuasive possibility, is that further proliferation will jeopardize regional and global stability, increase the

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likelihood of nuclear war (local or general), exacerbate the threat of nuclear armed non-state terrorism, and greatly complicate U.S. relations with new (potential or actual) nuclear weapons states. The extent to which proliferation has a disequilibrating effect on international politics also impacts directly on American foreign policy, which has had the maintenance of global stability as its overriding objective in recent years. From this perspective, the threat to American interests derives not so much from the mere number of Nth countries but from the probability that proliferation will tend to be greatest in regions with the highest potential for international conflict, e.g., the Middle East, Southern Africa, and East Asia. (See chapters 111 and IV.)

Issue 2

What Will Be the Proliferation Impact of the International Spread of Plutonium Recycle Facilities?

Findings

Reprocessing provides the strongest link between commercial nuclear power and proliferation. Possession of such a facility gives a nation access to weapons material (plutonium) by slow covert diversion which would be difficult for safeguards to detect. An overt seizure of the plant or associated plutonium stockpiles following abrogation of safeguards commitments could, if preceded by a clandestine weapons development program, result in the fabrication of nuclear explosives within days, Furthermore, such a plant reduces a nation's susceptibility to international restraints (sanctions) by enhancing fuel cycle independence. Finally, plutonium recycle is the most likely source for both black market fissile material and direct theft by terrorists,

Most nations expect to have their nuclear fuel reprocessed despite these obvious complications for the task of preventing further proliferation, and several (none of them Nth countries) are constructing large reprocessing plants. There have been increasing doubts as to the economic feasibility of reprocessing in the United States, but other countries perceive reprocessing as being attractive. Their more limited energy resources make the energy of plutonium more valuable, and possibly less-stringent regulatory requirements may make the facilities less expensive. In addition, if nuclear energy is to be a long-term option, reprocessing will eventually have to be an integral part of the fuel cycle, although uranium resources may be adequate to last until about the year 2000 even without reprocessing. Hence, nonproliferation strategies that involve a total renouncement of reprocessing will be difficult and probably expensive to implement.

Reprocessing in the United States and other weapons states is not a direct proliferation issue (except for terrorists). Other supplier states such as West Germany and Japan are also unlikely to use their commercial facilities to procure weapons material. The less advanced countries that might misuse facilities have been precluded from importing them by supplier agreements (except for Brazil and Pakistan who already have contracts and are resisting pressure to cancel them). The technology is uncomplicated enough for some Nth countries to develop on a commercial basis, but this endeavor would almost certainly be commercially uneconomical if other energy sources are available. A double standard approach to reprocessing would further strain relations between suppliers and importers. Multinationally controlled facilities may be necessary to alleviate this tension if reprocessing does become widespread in the supplier states (see chapters III, V, and X).

Issue 3

How Will U.S. Decisions on Domestic Plutonium Recycle Affect Efforts To Curb the International Spread of Reprocessing?

Findings

Decisions on the future of reprocessing and plutonium recycle in the United States must be made in the near future because of the imminence of operation of the large plant at

Barnwell, S.C. Nonproliferation will clearly be best served if no one reprocesses. Other nations, however, have a stronger interest in reprocessing (as described in Issue 2) and will be unsympathetic to efforts to convince them to refrain. If the United States alone refrains, the nonproliferation effort could actually be damaged because the resulting unavailability of fuel cycle services would induce more nations to build their own facilities. If the United States does not refrain, however, the credibility of its efforts to dissuade others will be diminished, There is general agreement that Nth country possession of reprocessing plants would be inconsistent with efforts to contain proliferation. The key factors shaping positions on this issue are:

- The effect of a double standard, where supplier states build their own reprocessing plants but deny exports to other nations: Importing states have expressed resentment over discriminatory export policies, and this policy would be certain to annoy some. It is significant, however, that few Nth countries will have enough reactors in this century to make an indigenous reprocessing plant more economical than having the service provided by a supplier state.
- The ability of the United States to persuade other nations to forgo reprocessing: A U.S. decision to refrain would have slight impact on other suppliers unless accompanied by costly political and economic pressure. Their commitment to reprocessing and to early deployment of breeder reactors (which require reprocessing) is much stronger than that of the United States. Importing states, however, are more likely to be impressed by such a gesture (see chapters III, VII, and X).

Issue 4

Would Deployment of Fast Breeder Reactors (LMFBRs) Be Compatible With a Policy To Curtail Proliferation?

Findings

The LMFBR is the highest priority energy development program in most nuclear supplier states. It was chosen because, of all the long-term options for essentially inexhaustible energy, it may well be most economic. It is also in a relatively advanced state of development, and thus the most likely to be available for widespread deployment by the end of the century.

Proliferation, however, was not a major consideration in the elevation of the LMFBR to its present priority. Certain characteristics of the LMFBR system as presently envisaged will conflict with efforts to control proliferation. These are:

- National possession of a full LMFBR cycle would eliminate all technical barriers to acquiring weapons material. It would also provide virtual immunity to an international embargo on fuel shipments because the LMFBR produces more than enough plutonium to refuel itself.
- Even a national LMFBR tied into an international fuel cycle (e.g., fuel leasing or multinational fuel centers) increases the opportunity for proliferation. Many nations could eliminate their dependence on the international or foreign fuel services by constructing indigenous fuel fabrication and reprocessing plants or by processing the fresh fuel or partially spent fuel within the reactor.
- Some of the plutonium produced by the LMFBR is of extremely high quality for weapons.
- The LMFBR requires reprocessing, which creates opportunities ‘for dive;sion of plutonium by nations or non-state adversaries.

An overall assessment of the desirability of the breeder must weigh its benefits as an energy source against its liabilities relative to proliferation, as well as other problems in comparison with alternative energy sources (see chapter VII, “Diversion From Commercial Power Systems”).

Issue 5

Do Uranium Enrichment Facilities Have a High Potential for Proliferation?

Findings

Any enrichment plant can theoretically be used for the production of weapons material while simultaneously providing immunity from international nuclear fuel embargoes, but only one type of enrichment plant—the centrifuge type—increases opportunities for proliferation on the same scale as reprocessing plants. Diffusion plants are economical only on a very large scale, so this enrichment route is out of the question for all but the largest and most highly developed countries.

The nozzle method is currently under development in South Africa and Germany. It promises to cost less than diffusion and be fundamentally simpler. It does demand highly precise manufacturing techniques, and its operation requires about twice as much power as a diffusion plant of the same capacity. This makes it commercially impractical for nations lacking low-cost power such as hydroelectricity, Despite its simplicity, it does not appear to be a good choice for a small facility dedicated to weapons material production.

By contrast, centrifuge plants may be sufficiently economical in small sizes for many nations to find them commercially attractive. These plants could only be developed by technically advanced nations, but could be purchased and operated by less advanced nations.

If sold to less advanced nations, centrifuge plants would be exceptionally vulnerable to clandestine diversion. Moreover, as with a reprocessing plant, a centrifuge facility could be seized and used to produce weapons material in a short time.

Advanced enrichment techniques could not be developed except by technically advanced countries. Barring an unforeseen breakthrough, commercial laser isotope separation (LIS) facilities will probably not be feasible for even advanced countries until the late 1980's or early 1990's, and then only if a number of very difficult problems are solved. The United States, U. S. S. R., and France, among others, are actively developing LIS technology. The proliferation potential for LIS and other advanced technologies stems from the high enrichment achieved per stage. Thus, it may be possible to produce weapons material in a very few steps. In addition, LIS facilities may be economical on a very small scale, making them attractive purchases for nations with small nuclear programs. The United States, by guaranteeing enrichment services at a low fee or at cost might slow down the spread of advanced enrichment technologies (see chapter VII, "Dedicated Facilities").

Issue 6

How Feasible Would it be to Use Commercial Nuclear Reactors as a Source of Weapons Material?

Findings

- The power reactors presently available for export (LWR and CANDU) do not involve material that could be used directly for nuclear explosives. A nation would also have to have a reprocessing or enrichment facility to use its nuclear system as a source of weapons material.

- Spent fuel from either reactor type does contain plutonium, which could be recovered in a small indigenously developed reprocessing plant. This opportunity can be decreased by fuel leasing or buy-back arrangements which prevent the long-term storage of spent fuel by Nth countries. This would restrict the availability of spent fuel to that in the reactor, the use of which would probably result in the loss of the reactor as a power source.

- Reactors and short-term spent-fuel storage facilities can be effectively safeguarded. Consequently, diversion from them would have to take the form of overt nationalization (i.e., seizure).

- The additional expertise a nation acquires in operating its own reactor would be useful should if decide to develop weapons.

Abandoning nuclear power would reduce, but not eliminate, the possibility of further weapons moliferation. Countries could still construct facilities dedicated to the production of weapons material or, alternatively, they might be able to purchase or steal either material or a finished weapon (see chapter VII) .

Issue 7

Could a Nation Acquire Nuclear Weapons Without Diverting Fissile Material From Its Commercial Nuclear Power Facilities?

Findings

None of the countries which now have nuclear weapons diverted fissile material from their power facilities. They all built facilities specifically dedicated to the production or reprocessing of nuclear weapons material.

The only dedicated facility option open to a nation which is not technologically advanced is a small, natural uranium-fueled plutonium production reactor, producing about 10 kg of weapons-grade plutonium per year (enough for one or two explosives), and a small reprocessing plant. The total capital costs of these facilities would be several tens of millions of dollars. Such a facility might escape detection, especially if the nation were not considered to be among the five or six most likely Nth countries.

A technologically advanced nation would be able to build a dedicated facility to support a large weapons program, but it is unlikely that the existence of such a facility could be kept secret (see chapter VII, "Dedicated Facilities").

Issue 8

How Plausible is the Direct Acquisition of Fissile Material or Weapons by Purchase or Theft?

Findings

If plutonium becomes a commonly traded commodity, minimal intermittent black market transactions seem plausible, simply because the large amounts of material that could be circulating would be difficult to safeguard perfectly. Theft of existing weapons would be more probable if proliferation continues and security in the new nuclear states is lax. (See chapter VI.)

Issue 9

How Critical is Nuclear Power to Future Global Energy Requirements?

Findings

Projections of growth in global nuclear energy use have been repeatedly revised downwards in recent years. The lowest projections presently available are the most plausible. Nevertheless, many governments, especially in Europe and Japan, still feel that nuclear energy will be crucial to their well-being as global oil and gas reserves are depleted. Many developing countries are also counting heavily on nuclear energy. Coal, another major alternative to oil and gas, is abundant in some countries but fraught with environmental hazards. The economics of other resources (e.g., solar) are more speculative. Hence, nuclear power is likely to be a significant factor for at least the next few decades (see chapter X).

Issue 10

How Difficult Would It Be for a Nation To Construct a Nuclear Weapon?

Findings

Many nations are capable of designing and constructing nuclear explosives which could be confidently expected, even without nuclear testing, to have predictable and reliable yields up to 10 to 20 kilotons TNT equivalent (using UZSS, UZSS, or weapons-grade plutonium) or in the kiloton range (using reactor-grade plutonium).

A national effort to achieve the above objective would require a group of more than a dozen well-trained and very competent persons with experience in several fields of science and engineering. They would need a high explosive field-test facility and the support of a modest, already established, scientific, technical, and organizational infrastructure. If the program is properly executed, the objective might be attained approximately 2 years after the start of the program, at a cost of a few tens of millions of dollars. This estimate does not include the time and money to obtain the fissile material or to establish the infrastructure assumed above.

The success or failure of a national effort will depend more on the strengths and weaknesses of the particular people involved in the effort than on specifics of the technological base of the country (see chapter VI, “Nuclear Fission Explosive Weapons” for further details.)

Issue 11

Is a Non-State Adversary Group Likely To Turn to Nuclear Means of Extortion or Violence?

Findings

There is no evidence that any non-state group has ever made any attempt to acquire weapons material for use in a nuclear explosive. The incidents that have occurred to date involving nuclear material or facilities have mostly been low-level incidents of vandalism or sabotage. However, the present record of nuclear incidents was assembled in an era when nuclear reactors were relatively few. The expansion of nuclear power, the advent of plutonium recycle, and trends towards increased violence could lead non-state adversaries to attempt large-scale nuclear threats or violence.

Non-state adversary groups have not yet gone to the limits of their ability to cause harm by non-nuclear means. Historical analysis of adversary tactics suggests reasons for this restraint. However, non-state adversaries, particularly terrorists or revolutionaries, may not behave in the future as they have in the past. The psychological impact of the threat or use of nuclear weapons would be enormous, and an adversary group may decide to attempt to exploit this leverage.

The entire subject of adversary actions involving massive threats or destruction has apparently just started to receive systematic study. When considering if non-state adversary groups will turn to massive extortion or violence, all routes to the same end--conventional explosives, other chemicals, nuclear and biological agents-should be considered. (See chapter V.)

Issue 12

How Difficult Would it be for a Non-State Adversary Group To Acquire Nuclear Material for a Nuclear Explosive Device?

Findings

It would be extremely difficult, verging on impossible, for a non-state adversary group to convert material diverted from LWR or CANDU fuel cycles to explosive’s material, unless the spent fuel is commercially reprocessed to recover and recycle the plutonium.

In the LWR with plutonium recycle as presently planned, material suitable for nuclear explosives or easily convertible to weapons-useable material will be found at the reprocessing plant, in transit between the reprocessing plant and the fuel fabrication plant, and at the input area of the fuel fabrication plant. There are technologies and configurations (coprecipitation and collocation) under consideration that could eliminate most opportunities for the diversion of material easily converted to weapons material.

In the United States at present, the NRC is reportedly in the process of upgrading security at licensees handling plutonium or highly enriched uranium, requiring them to meet a threat of two or more insiders in collusion with several heavily armed attakers from the outside. Present safeguards and physical security may place undue reliance on one element of physical security-armed guards. It is not clear how well presently designed safeguards system can handle the problem of several insiders acting in collusion, or outsiders attacking with guile and deception rather than straightforward armed assault.

Some observers have also expressed doubts about the effectiveness of guard forces in handling diversion attempts, partly because of the questionable status of their exact legal powers. The subject of a Federal security force to protect plutonium and highly enriched uranium should be reopened, especially in view of the increased threat levels licensees are being required to meet.

Both ERDA and NRC have very promising safeguards programs in the development stage, but their ultimate effectiveness cannot be assessed at this time.

A vital point to note is that non-state adversaries are highly mobile, and capable of finding and attacking the weakest targets. No nation, however invulnerable its own facilities, can feel secure against non-state adversary nuclear threats and violence unless all facilities handling weapons-grade material worldwide are equally well protected. Physical security is generally left to the discretion of the individual nation, although supplier states are insisting on a minimum level as a condition for export. The International Atomic Energy Agency has no physical security enforcement powers, (see chapters V and VIII).

Issue 13

Could a Non-State Adversary Design and Construct Its Own Nuclear Explosive?

Findings

Given the weapons material and a fraction of a million dollars, a small group of people, none of whom have ever had access to the classified literature, could possibly design and build a crude nuclear explosive device. The group would have to include, at a minimum, a person capable of searching and understanding the technical literature in several fields, and a jack-of-all-trades technician. They would probably not be able to develop an accurate prediction of the yield of their device, and it could be a total failure because of either faulty design or faulty construction. If a member of the group is careless or incompetent, he might suffer serious or fatal injury. However, there is a clear possibility that a clever and competent group could design and construct a device which would produce a significant nuclear yield (see chapter VI “Nuclear Fission Explosive Weapons” for details).

Issue 14

What Are the Civil Liberties Implications of Safeguarding Nuclear Power, in Particular, Plutonium Recycle?

Findings

The civil liberties implications of safeguards turn on the scope of a security clearance program, the standards and procedures used in employee clearance, the scope and intrusiveness of domestic intelligence activities, and the nature of a recovery effort should a diversion occur.

There is disagreement among experts as to whether a safeguards program can be adequate for security without fundamentally infringing upon civil liberties. One position believes adequate safeguards will necessarily violate basic liberties for employees and political dissidents. A second position treats safeguards as an acceptable extension of existing clearance programs and blackmail threat responses in other fields of high security. A third position believes safeguards could be installed without doing serious damage to civil liberties, but only if a "least intrusive measures" approach is adopted and a zero-risk goal is rejected.

Although a safeguards system that would be extremely respectful of civil liberties can be designed, three potential dangers exist:

1. A gradual erosion of civil liberties as the safeguards system is "strengthened,"
2. A shunting aside of civil liberties during a recovery operation if weapons material were diverted and a convincing threat received; and
3. A public demand for Draconian safeguards in the future, even at the expense of civil liberties, if a diversion followed by a convincing threat or an actual act of destruction occurred.

Measures can be envisaged that would reduce the probability of the above three occurrences. Continued public monitoring of safeguards systems for civil liberties infractions, new technologies or configurations (e.g., coprecipitation or collocation), and response planning integrated at the local, State, regional, and Federal levels with authority clearly delineated could reduce the probability of civil liberties infractions in a strong safeguards system.

The Control

Issue 15

What is the Outlook for Control of Proliferation?

Findings

It is not too late to contain proliferation at a level which can be assimilated by the international political system. However, there are no single or all-purpose solutions; no short cuts, A viable nonproliferation policy will require the coordinated, planned use of a wide variety of measures: (a) political, economic, institutional, technological; (b) unilateral, bilateral, multilateral, international; and (c) executive and legislative.

Components of a nonproliferation policy would include: (a) Steps designed to tip the balance of political incentives and disincentives regarding the acquisition of weapons in favor of disincentives; (b) A comprehensive safeguards regime to prevent the diversion of nuclear material from civilian energy programs to weapons use; (c) Controls over exports, particularly with regard to enrichment and reprocessing capabilities, in conjunction with arrangements for the return of spent fuel to the supplier or any international repository; (d) A broad range of domestic and foreign policy supporting actions, including steps to upgrade physical security measures to prevent theft of nuclear materials, expansion of reactor-grade uranium production to obviate the need for reprocessing, and arms control negotiations; and (e) Steps to assure that other countries can meet their energy requirements without resorting to enrichment and/or reprocessing national facilities.

Moreover, because each Nth country is to some degree unique, policy must be tailored to fit particular national circumstances. This is especially true because of the potential for serious conflict between nonproliferation and other foreign policy objectives. The nature and severity of that conflict will vary from one Nth country to another, a fact which policy must take carefully into account, (Chapters 111 and IV.)

Issue 16

What Influence Can the United States Exert Upon Potential Weapons States?

Findings

In the long run two general rules apply: (a) Solutions to the proliferation problem will have to be found primarily, though not exclusively, through multilateral actions, and (b) The extent of U.S. influence will vary from country to country.

As American preeminence in the international market for nuclear fuel, facilities, and technology has been allowed to erode, the ability of the United States to unilaterally determine the ground rules of international nuclear cooperation has diminished. With the entrance of other suppliers into the market, importers have the option to turn to non-U.S. sources. If the United States were to remove itself from the global market entirely, other suppliers could quickly replace the withdrawn capacity. As a consequence American actions will tend to be most effective in a multilateral context—particularly in conjunction with other suppliers. The effectiveness of this approach has been demonstrated in the negotiations which led to the NPT, and more recently in the Suppliers' Conference.

There remains, however, significant scope for the unilateral assertion of U.S. influence—both in terms of positive inducements and negative sanctions. The recent successful U.S. effort inducing South Korea to abandon plans for purchasing a French reprocessing facility is an instance of the effective use of unilateral influence. Some of the more obvious levers available to Washington include:

- security guarantees;
- assistance to civilian nuclear energy programs;
- foreign economic aid (including U.S. influence in international lending institutions);
- military assistance programs;
- political pressures and diplomatic persuasion;
- mediation of international disputes with proliferation implications;
- controls on the export of sensitive nuclear technology;
- assistance concerning non-nuclear energy sources; and
- domestic policy initiatives (e.g., concerning reprocessing) which might enhance the credibility of U.S. efforts to persuade other countries to take similar steps.

The single most effective instrument of U.S. influence would be the capability to guarantee adequate low-enriched uranium exports to meet the needs of overseas users while, at the same time, providing for the collection and return of spent fuel.

An effective effort to assert U.S. influence will combine the carrot and the stick, with principal reliance on the former for the longer term. Such an effort wiIl also take into account the wide variation in leverage available to Washington when dealing with one Nth country or another. Thus U.S. influence with nations dependent upon American military or economic assistance (e.g., South Korea) is very substantial but where such dependence is lacking (e.g., Argentina) U.S. influence declines.

Issue 17

What Influence Can the United States Exert Upon Other Supplier States?

Findings

Efforts by the United States inducing other supplier states to pursue policies supportive of nonproliferation will generally be most effective if they are formulated in a multilateral context and emphasize positive inducements. Possible measures include:

- political-diplomatic persuasion (e.g., the Suppliers' Conference),
- tie-in agreements guaranteeing U.S. enrichment services at nondiscriminatory prices to reactor customers of other suppliers,
- joint-venture enrichment and/or reprocessing facilities,
- market sharing agreements,
- multinational enrichment and/or reprocessing facilities,
- international fuel storage repositories, and
- a multilateral study of alternatives to reprocessing.

The problem of reprocessing is extremely difficult for two reasons. First, other supplier states (such as Germany) have already made a basic national decision in favor of reprocessing and the breeder. They regard this policy as a vital element in their efforts to assure" adequate energy in the future. European breeder

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technology is the most advanced in the world. Second, other major suppliers are also America's principal allies and trading partners. The linkages of mutual interest and dependence are so extensive as to render most attempts to apply coercive pressures self-damaging. Consequently, U.S. efforts to obtain a global moratorium on reprocessing will encounter stiff European and Japanese resistance. The one area where agreement is demonstratively possible concerns control on exports of reprocessing facilities.

Issue 18

How Effective Are International Atomic Energy Agency Safeguards?

Findings

(a) Safeguards for reactors can be very effective. Nuclear material is contained in a relatively small number of discrete items, the fuel elements. Exact item accountability can be accomplished without great difficulty.

(b) Safeguards procedures for reprocessing plants, enrichment plants, and other fuel-cycle facilities which handle very large flows of nuclear material are in the experimental stage. It will be difficult to detect significant diversion of uranium or plutonium using nuclear material accountancy alone, even if the most advanced analytical techniques and accountancy methods are used. The task is further complicated by restrictions on IAEA inspection effort, inspector access, and the full use of IAEA surveillance devices.

(c) Containment and surveillance must play a key role in safeguards and must be regarded as more than supplementary to materials accountancy. Effective safeguards systems for enrichment and reprocessing plants will have to include the most advanced online monitoring and real-time accounting systems as well as highly reliable, instantaneously reporting, tamper-indicating surveillance equipment.

(d) A credible safeguards system provides a significant deterrent to diversion, by both increasing the chances of detection and establishing standards of legal behavior that buttress the position of political groups opposed to proliferation.

(e) No safeguards system can prevent an overt national seizure of a facility and its operation for weapons purposes.

Issue 19

Are Multinational Fuel-Cycle Facilities (MFCFS), on Balance, a Useful Approach for the Control of Proliferation?

Findings

The primary intent of MFCFS is to remove sensitive facilities (particularly enrichment and reprocessing) from national control. A part owner/operator of such a facility will find it much harder to tamper with equipment for purposes of diversion or to seize the plant outright even if on its own territory. It also offers economies of scale to nations with only a few reactors and improved security against non-state adversary actions.

A great many political, economic, and institutional questions must be resolved before the concept can be considered viable. Member nations may not find acceptable sites in other members' territory. Another problem is the possibility that membership in a sensitive facility could provide sufficient access to the technology for members to recreate it indigenously. Thus MFCFS could spread the very problem they are intended to prevent.

Issue 20

Are Sanctions a Useful Instrument of Nonproliferation Policy Toward Nth Countries?

Findings

Provisions for modest sanctions (e.g., the cutoff of nuclear assistance) already are contained in U.S. and IAEA nuclear agreements with nonweapons states, and a variety of stronger sanctions can be postulated. To be most effective, sanctions should be applied jointly or multilaterally rather than unilaterally. Threats should be accompanied by inducements and rewards designed to relieve the pressures toward proliferation. A sophisticated approach will also combine automatic with more discretionary and flexible sanctions,

Depending upon the prospective proliferator, a significant degree of vulnerability to one or more of the available levers is likely to be present. In cases such as Taiwan, where the Nth country is dependent on the United States for security support as well as nuclear imports, the scope for the imposition of unilateral U.S. sanctions is substantial. In other cases, such as that of Brazil, resort to sanctions could probably prove futile. Sanctions could be more effective in all cases as an instrument to prevent proliferation than as a means to punish or "roll back" proliferation after it has occured. The most effective channel for imposition of unilateral sanctions will probably be the Suppliers' Conference. Because user states comprise a majority of IAEA membership, there are serious questions as to whether the agency could muster the political will to impose sanctions on a recipient—particularly if the circumstances surrounding the alleged violation are at all ambiguous.

Issue 21

Would an Arms-Reduction Agreement by Present Nuclear States Significantly Strengthen the International Norm Against Proliferation?

Findings

A meaningful multilateral arms reduction by the nuclear weapons states would demonstrate a commitment to the objective of nonproliferation and, in particular, to the Non-Proliferation Treaty, The extent of the impact of this demonstration is not clear, but the public stance of some of the non-weapons states indicates that it could be substantial. A corollary benefit might be a reduction in the prestige attached to nuclear weapons.

Issue 22

To What Extent Can Improvements in Technology Help Contain or Limit Further Proliferation?

Findings

There is no technological fix that can eliminate the problem of proliferation, but concepts under development could, if successful, make diversion from commercial facilities much more difficult or even close to impossible.

One of the most promising medium-term approaches is the nonproliferating reactor. This concept is a fundamental y new approach both to reactor design and to nonproliferation. By incorporating nonproliferation requirements into the design of the reactor, the diversion routes which are present in current and projected power reactor systems could be largely eliminated. This approach deserves a thorough assessment and open-minded comparison with other alternatives to determine if it should be funded at an expanded scale.

Less radical changes are alternate fuel cycles (thorium) and modifications to present fuel cycles (e.g., coprecipitation and tandem cycles). New approaches are also being developed in safeguards technology. Integrating safeguards systems into facility designs would considerably strengthen safeguards effectiveness. Greater R&D emphasis on nonnuclear energy sources, especially those most appropriate for developing countries, could reduce the dependence on nuclear power and postpone or even eliminate the eventual need to move to more sensitive systems (such as fast breeders).

Issue 23

Can the Non-Proliferation Treaty (NPT) Play a Useful Role in Containing Proliferation?

Findings

The NPT has important weaknesses. It lacks universal adherence and a party can, under some conditions, legally withdraw with only 3 months notice. Nonparties to the treaty include a number of the strongest candidates for the acquisition of nuclear weapons. Moreover, the sanctions provided for in the treaty are not particularly impressive and there is a serious question whether even they could be enforced in the event of a violation.

Nevertheless, the NPT remains a key component of an effective nonproliferation policy. The fact that there have been no known violations of the treaty suggests that it acts as an important constraint upon Nth countries. It embodies a basic international consensus that proliferation poses a serious threat to global well-being and should be contained. It also provides an agreed framework of mutual rights and obligations constituting a fundamental bargain between supplier and user states. As such, it sets forth a standard by which to measure and perhaps influence the behavior of states. For example, the NPT may provide some of the impetus behind current efforts by the superpowers to negotiate a new arms control agreement.

Two additional features of the NPT give it particular significance. First, by allowing the IAEA to impose safeguards on their domestic nuclear programs, the nonweapon parties to the treaty relinquish a significant measure of their sovereignty. This establishes an important principle upon which to build stronger international arrangements for controlling proliferation. Second, in addition to providing a statement of principles and objectives, the NPT encompasses an institutional mechanism (IAEA) for their implementation. The NPT is more than a treaty: it is an ongoing program. (Chapters 111 and VIII "International Control of Proliferation.")

Issue 24

What Issues Require Priority Attention, i.e., What Developments Threaten to Foreclose Future Options?

Findings

The following subject areas require immediate consideration by policy makers and legislators if the course of proliferation is not to be determined by default.

- Domestic (U. S.) reprocessing.
- US. enrichment capacity.
- Upgrading of supplier (export) controls.
- Sanctions and inducements to be applied to Nth countries.
- Research and development priorities (LMFBR vs. other breeders and non-nuclear sources).

NUCLEAR TECHNOLOGY DESCRIPTION

Strong forces bind together the basic particles—protons and neutrons-that constitute the nucleus of the atom. Some of this binding energy is released when a neutron strikes a heavy nucleus and causes it to split, or fission, into two lighter elements plus more neutrons. The total mass of the products is slightly less than that of the original nucleus, This mass difference is converted into energy according to the relationship E=mc2. The neutrons may, in turn, initiate other fissions, (Neutrons that have been slowed down by a moderator such as water or graphite are more likely to cause fissions.) Thus, a *chain reaction* can begin. In a nuclear reactor, the chain reaction is *controlled* to be just self-sustaining, with one of the extra neutrons, on the average, initiating a new fission. In a nuclear explosive, the chain reaction is carried on by fast neutrons in a multiplicative and uncontrolled mode. These different conditions-sustaining or multiplicative-depend on a number of parameters, including the quantity, chemical form, concentration, and geometrical arrangement of the *fissile* material and the amount, properties, and arrangement of the nonfissile material which is present.

Most materials, even when in pure chemical element form, contain a mixture of *isotopes*-atoms of the same element that have different numbers of neutrons in their nuclei and hence different masses.] Only a relatively few isotopes are fissile, and, in fact, only one fissile isotope occurs in nature—uranium-235, or, as it is usually written, U^{235}. Two other fissile isotopes are important in any discussion of nuclear power—uranium-233 (U^{233}) and plutonium-239 (Pu^{239}). These isotopes do not occur in nature, but are bred when the *fertile* nuclei U^{238} and thorium-232 (Th^{232}) absorb neutrons to become U^{239} and Th^{233}, and then undergo two successive radioactive decays to Pu^{239} and U^{233}.

The power reactors in common use today use uranium as fuel; the fissile concentration is well below that necessary for a nuclear explosive. Specifically, it is impossible, not merely impractical, to use a light water reactor (LWR) or a Canadian CANDU reactor uranium fuel in a nuclear fission explosive without an expensive and technologically advanced enrichment facility. (See chapter VII for further discussion of this point.)

Uranium fuel goes through many operations both before and after its use in the reactor. These operations constitute the nuclear fuel cycle. Figure 11-1 shows the fuel cycle for the most common reactor, the light water reactor (LWR).

From the mine, the uranium ore is sent to a mill where uranium is recovered from the ore in the form of an oxide. The next step, after conversion of the oxide to uranium hexafluoride, is *enrichment*. At the enrichment plant, the concentration of U^{235} is increased from the naturally occuring value of 0.7 percent to about 3 percent. Most present-day enrichment plants use the gas *diffusion* process, but most new plants in the construction and planning stage will use the gas *centrifuge* method. After enrichment, the uranium goes to a fuel fabrication plant to be formed into fuel elements which will be combined into fuel assemblies and inserted into the reactor.

After the fuel has been in the reactor for a time (typically several years), it contains too little uranium-235 and too many neutron-absorbing (and radioactive) fission products to be useful. The fuel is then removed and placed into pools of water for cooling. In an LWR, the *spent fuel* does not have to be reused, but it still has about 0.9 percent uranium-235, a higher concentration than occurs in nature, plus about 0.5 percent plutonium-239 which is bred from the abundant uranium-238. If it is deemed economical and desirable to recover the unused fissile material, the spent fuel will be sent to a *reprocessing plant*. There, the uranium and plutonium are chemically separated from waste products and (under present plans) from each other. The uranium may be reenriched while the plutonium is sent directly to a fuel fabrication plant, The plutonium is then mixed with uranium (both uranium and plutonium being in oxide form), to form *mixed oxide fuel*.

The fuel cycle for other reactors may differ in the necessity for, and nature of, the various stages in the light-water reactor fuel cycle just described, For example, the Canadian CANDU reactor uses natural uranium, and recovery of plutonium from its spent fuel is not at present economical. Hence, the CANDU fuel cycle excludes both the enrichment and reprocessing steps.

A future reactor concept is the breeder, a reactor that would create more new fissile fuel than it burns to produce power. Most development work has concentrated on the liquid metal fast breeder reactor, (LMFBR) which will yield enough plutonium to refuel itself and excess plutonium to contribute to the fueling of new reactors. The breeder fuel cycle would eliminate the enrichment step but absolutely requires the reprocessing step.

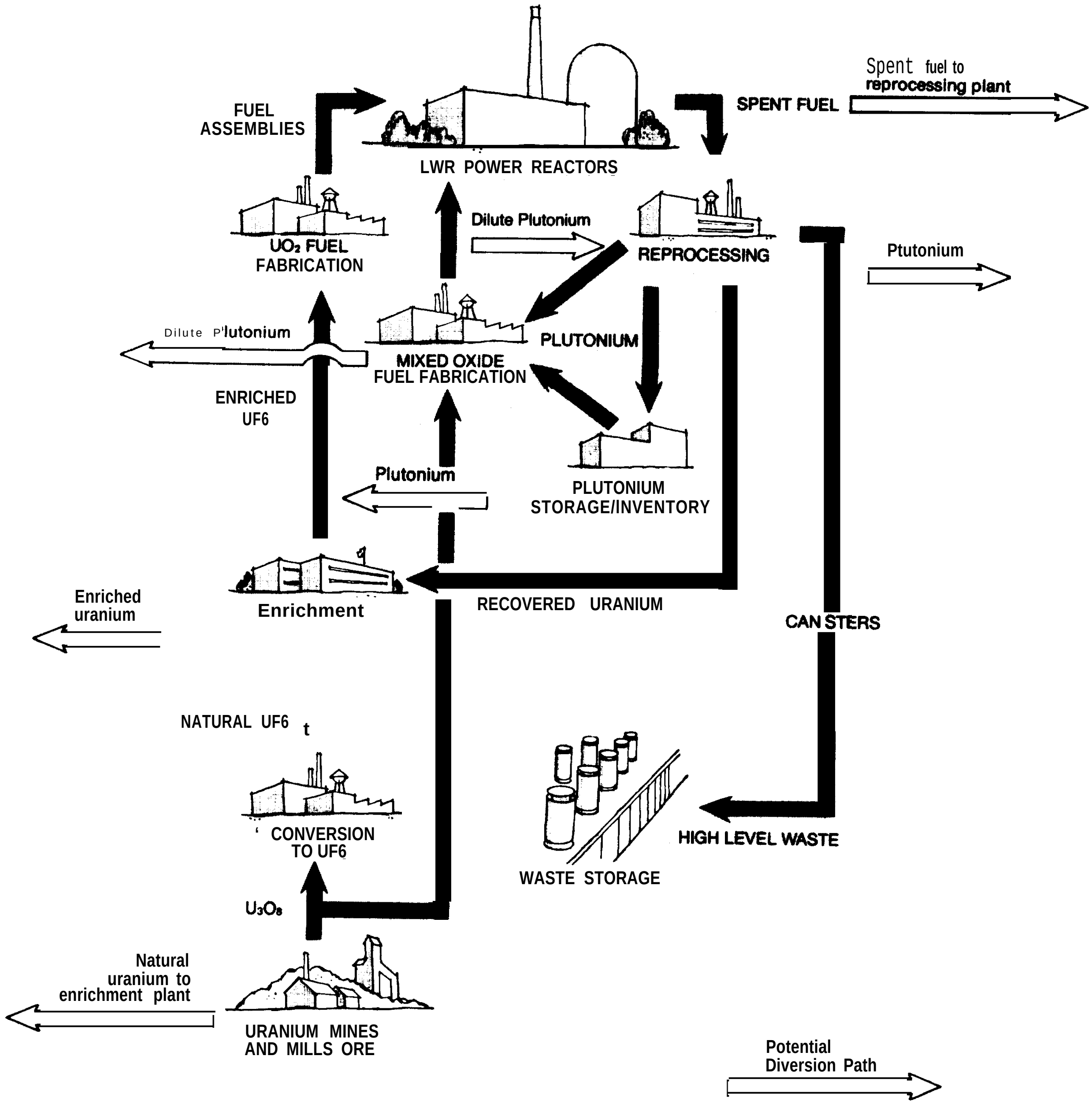
All the reactors mentioned so far use uranium as a fuel, with fissile uranium–235 to produce power and with fertile uranium–238 to breed another fissile isotope, plutonium–239. Another fuel cycle may be based on the element thorium, The isotope thorium–232 is fertile and breeds fissile uranium–233.

In most of the fuel cycle for commercial nuclear power reactors, the concentration of

[1]Isotopes are specified by the total number of neutrons and protons they contain and a symbol indicating the chemical elements. For instance, the isotope with 92 protons and 143 neutrons is uranium - 235, or, as it is usually written, U^{235}.

Figure 11-1.

Light-Water Reactor Fuel Cycle



SOURCE: OTA

fissile fuel is low. By contrast, the concentration of fissile material in a nuclear weapon is quite high—typically pure plutonium, or uranium enriched to about 90 percent in the isotope uranium–235. (See chapter VI for a discussion of the minimum concentration of fissile material that can be used to construct a nuclear explosive of practical weight.) The object in designing a weapon is to initiate a chain reaction that will cause a large number of nuclei to fission in a very short period of time. This condition will be obtained only if a certain minimal amount of nuclear material called the critical mass is present. With less than this quantity, an explosion will never occur. No specific number can be assigned to the critical mass—it varies with a number of parameters, including, for example, the particular fissile isotope and its concentration and chemical form. A nuclear weapon initially contains one or more subcritical masses of fissile material. Detonation of the weapon requires a means of rapidly moving the subcritical mass or masses into a condition of supercriticality sufficient to produce a significant nuclear yield before it blows itself apart.

There are two basic methods of assembling the fissile material in a nuclear weapon. The first is to shoot two (or more) subcritical masses into each other. This is a *gun-type weapon.* The second is to surround a subcritical configuration of fissile material with high explosives and use them to compress the material into a supercritical mass. Such a device is called an *implosion weapon.*

Note that the highly concentrated fissile material required for weapons is exposed at only one portion of the nuclear fuel cycle described above-at the reprocessing and fuel fabrication plants and the transportation link between the two. These areas are thus the most vulnerable to the diversion of nuclear material from a power program to a weapons program. However, there are other possible crossovers between peaceful and destructive *uses* of nuclear energy that are not that direct and obvious as described in chapter VII.

EXECUTIVE SUMMARY

Incentives and Disincentives

As the technological and economic barriers to proliferation have diminished, the decision whether or not to acquire nuclear weapons has become principally political. It will hinge on a complex balance of incentives and disincentives which, though unique for each country, exhibit sufficient similarities to permit generalization.

General incentives that might lead a government to select the nuclear weapons option include the following:

1) Deterrence.—Several states on every list of potential new nuclear weapons states (Nth countries) have reason to fear direct attack or long-term deterioration of their security vis-a -vis neighbors or regional adversaries.

2) Increased International Status.—As a symbol of modernity and technological competence, nuclear weapons are often viewed as a source of status, prestige, and respect. Aside from its symbolic significance, a nuclear weapon capability will augment national military and political power in real terms,

3) Domestic Political Requirements.—Nuclear weapons may bolster a government's domestic political support for many of the same reasons they can enhance a nation's international reputation. The Indian detonation may have been motivated in large part by such considerations.

4) Increased Strategic Autonomy .—Even if it is already protected by an alliance, a nation may feel it has more options to pursue national objectives as a nuclear state than as a non-nuclear state. France is an example of this reasoning.

5) Strategic Hedge Against Military and Political Uncertainty.—Uncertainty about the reliability of allies and the intentions and capabilities of adversaries may make nuclear weapons attractive,

6) Possession of "A Weapon of Last Resort." —Nuclear weapons may be perceived

by a state such as Israel as offering an ultimate guarantee against extinction.

7) Leverage Over the Industrialized Countries .—Certain developing countries may conclude that acquiring nuclear weapons is a means of compelling the advanced nations to take more serious account of the interests of the less developed.

General disincentives that might discourage a state from acquiring nuclear weapons include the following:

1) Resource Diversion.—It is argued that a nuclear weapons program is not an optimal use of limited national resources, and that the loss of the opportunity to pursue economic or social programs outweighs the benefits of a nuclear weapons program.

2) Adverse Public Opinion.—In a number of countries (e.g., Japan) prevailing public opinion appears to oppose development of nuclear weapons,

3) Disruption of Established Security Guarantees.—Reliance on security guarantees constitutes one of the most important elements in many countries' strategy for coping with adversaries. If the acquisition of nuclear weapons jeopardizes that guarantee, the effect may be counterproductive in terms of national security.

4) Infeasibility of a Desired Nuclear Strategy .—The nation may be unable to attain the desired nuclear capability in an appropriate time frame, or because of a lack of resources.

5) Adverse International Reactions.—Anticipation of censure from the international community (including the superpowers) would constitute a significant disincentive.

6) Adverse Reactions by Adversaries.—Proliferation may stimulate an adversary to take a variety of measures, including the acquisition of a countervailing nuclear force.

7) Advocacy of Neutralist Aims.-Countries like Sweden and Switzerland eschew a nuclear weapons capability, in part because it would be perceived as degrading their arms control and neutralist positions.

A review of the existing nuclear weapons states suggests that the desire to maintain or enhance the nation's security and international influence were the primary incentives behind their original weapons programs. Economic disincentives, even for less developed nations such as China and India, were not compelling, Similarly, for Nth countries, security and political influence are the dominant incentives. Thus far, however, these have been offset by disincentives, notably concern about adversary responses, the economic costs of diverting resources to weapons development, and possible alienation of the superpowers with a resulting loss of nuclear and economic development assistance.

The Non-State Adversary

Subnational groups might be as interested as nations in obtaining nuclear weapons. Potential nuclear non-state adversaries span a wide spectrum, from the isolated lunatic, to the criminal, to the organized revolutionary group. The actions they might conceivably undertake range from hoaxes to the construction and detonation of a crude nuclear explosive device. Strictly speaking, token acts of violence do not constitute nuclear adversary actions, although it is useful to study such occurrences for indications of trends towards more serious acts.

Concern about the potential nuclear non-state adversary has continued to grow since the late 1960's, although incidents involving nuclear material or facilities that have occurred so far have been mostly low level acts of vandalism or sabotage. There is no evidence that any non-state group has attempted to acquire weapons material for use in a nuclear explosive.

However, the lack of serious malevolent nuclear actions is not a cause for complacency about the future. The expansion of nuclear power, the advent of plutonium recycle, and trends towards increased violence could lead non-state adversaries to attempt large-scale nuclear threats or violence.

Terrorist groups might decide to use nuclear means to cause widespread damage or kill large numbers of people, but so far terrorists have not even gone to the limit of their non-nuclear capability to destroy and kill. On the basis of the historical record and the theory of terrorism, it is not clear that causing massive casualties is attractive to terrorists; indeed it could even be regarded as counterproductive. Therefore, some experts have argued that mass murder will probably not be contemplated by terrorist groups capable of making elementary political judgments.

Several factors could cause terrorists to break the previous patterns. A desperate insurgent group might decide to strike one catastrophic blow, Nihilist groups may emerge, whose goals would be well served by pure massive destruction. On the other hand, the primary attraction for terrorists to go nuclear may not be to cause mass casualties. Almost any nuclear action by terrorists would cause great alarm, attract widespread attention, and possibly win concessions.

Whether organized crime should be counted among likely nuclear non-state adversaries remains a matter of debate, centering around its interest in doing so rather than its capability to undertake nuclear actions. The acquisition of a nuclear capability of its own, however, would mean that organized crime had decided to defy the nation in which its normal and highly profitable activities take place. It is easier to imagine organized crime playing a middleman role in a nuclear materials black market. Some observers have argued that organized crime would steer clear even of supplying nuclear material for nuclear weapons, because this activity might evoke a level of response that would jeopardize all their activities.

Some perpetrators of nuclear hoaxes have manifested desires of becoming nuclear non-state adversaries, but none have demonstrated the required capabilities. If hoaxers did have access to nuclear material, it is not clear that they would escalate from hoax to action.

Psychotics have probably been responsible for many of the low-level nuclear incidents and hoaxes that have occurred so far. Psychotics have also been the perpetrators of many known schemes of mass murder. Thus, in terms of intention alone, some psychotics are potential nuclear non-state adversaries. In terms of capability they probably rank lowest of all the categories of potential non-state adversaries. However, there are some brilliant psychotics who have technical knowledge and skill. If such an individual had the will to cause mass destruction and had access to nuclear material, he would constitute a formidable adversary.

Whether any of the current potential non-state adversaries will decide to go nuclear cannot be answered at this time. There is a vast area of uncertainty between what can be done and what will be done. This area could be reduced if analysts had a better understanding of how potential adversaries themselves perceive the usefulness of nuclear actions. Moreover, in the case of terrorists, there is at present no clear understanding of how they could exploit a nuclear action or threat to effect an irreversible political gain of magnitude comparable to the action or threat.

The nuclear non-state adversary might not arise from those groups currently identified as potential nuclear adversaries. International terrorists are a new entity that emerged in the past decade. It is difficult to say what new entities may emerge in the coming decade. It is disquieting to realize that most new terrorist groups have not been detected prior to their first terrorist act.

Among current adversaries, new tactics may be invented to effectively exploit the leverage that a nuclear capability would give. If an individual or a group did successfully carry out a scheme of nuclear extortion or violence, other individuals or groups would probably try to imitate their act.

Moreover, the growth of a transnational terrorist network over the past several years means that no nation, however invulnerable its own nuclear facilities, can regard itself as invulnerable to nuclear non-state adversary action.

Civil Liberties Implication of Safeguards

Whether a safeguards program to protect special nuclear material in a plutonium industry would jeopardize civil liberties has been a growing topic in the plutonium recycle debate. The concern is not only to protect rights of privacy, free expression, and fair procedure for employees of a plutonium recycle industry, but also to ensure that residents of nearby communities, political critics, and society at large are not subjected to unacceptable levels of surveillance in order to prevent diversion attempts, or to even more harsh and intrusive techniques if recovery of diverted material had to be undertaken. Judgments on what safeguards measures would be reasonably required and what their civil liberties implications would be is, in the first instance, a matter of public policy for elected officials and the public, and only later an issue that might produce judgments of constitutionality or interpretive modifications from the courts.

Concern over the civil liberties implications of plutonium recycle first arose when projections of the size of the industry were much higher than they are now. It now appears that only about 20,000 employees will be required to have clearances for work in the fuel cycle. Transportation of pure plutonium could possibly be eliminated by arrangements such as collocation or coprocessing. Both lowered growth and potential technological innovations affect perceptions of civil liberties problems.

It is generally accepted that protecting plutonium facilities from diversion efforts would represent a genuine security need, that there is no way to structure an adequate safeguards program that would not actually or potentially have some civil liberties impact, and that there is no way for society to eliminate all the motivations under which terrorists or deranged persons might try to divert plutonium for their purposes. As a result, safeguard measures of the kind used in other high-security contexts would have to be applied here.

Such safeguards fall into four categories: employee screening, material protection, threat analysis, and recovery measures. In each, there are possible techniques ranging from those raising minimal threats to civil liberties to those that, if used, would raise far more serious questions,

The debates over what safeguards would be needed and how these would affect civil liberties has produced three main positions:

Position One maintains that a plutonium economy would require such extensive security safeguards and have such high impact on civil liberties that basic freedoms would be jeopardized. It assumes that Congress and the public would insist upon a rigorous, virtually zero-risk program, especially if actual incidents heightened concern. Furthermore, preventive intelligence programs would inevitably be expanded to cover anti-nuclear groups and protest movements and lead to a rise in surveillance, databanks, and infiltration of dissenters, not just terrorists. Finally, should there be a successful diversion and blackmail threat, sweeping incursions of personal and press freedoms would take place. To avoid creating risks of such dangers, and because it is believed there are alternative ways of conserving and securing energy that do not raise comparable threats to civil liberties, advocates of this position call for a rejection of plutonium recycle in the United States on civil liberties grounds.

Position Two maintains that safeguards can be adopted that would be both effective for security purposes and acceptable in terms of civil liberties, just as other high-security activities are now safeguarded. Believing that plutonium is a necessary and safe energy source, the notion is rejected that threats from a handful of terrorists or deranged persons should force this nation to forgo plutonium recycle. Because persons working in this industry would do so voluntarily, there would be nothing improper in using techniques such as personnel clearances or on-the-job surveillance. Diversion and bomb threats should be treated with the same professional skills that would be used for other terrorists threats, whether with chemical, biological, or nuclear material or in hostage situations. Preventive intelligence activities would be put under clear legislative guidelines and supervisory checks. Position Two concludes that plutonium recycle should be allowed to proceed and that continually improved safeguards systems should be developed as the industry grows.

Position Three would also go ahead with plutonium recycle but only if the philosophy of a safeguards program were that some small risks of diversion would be accepted in order to avoid major risks to civil liberties. They would limit safeguards measures to those meeting specific criteria of effectiveness, limitation, and capacity for control against abuse. A least intrusive measure standard would be followed. This position would require such standards to be developed in public proceedings, written into legislation, monitored by independent review, and regularly audited.

These sets of assumptions and judgments could be significantly affected by alterations in a plutonium system or in safeguards options. Transportation risks might be reduced if the policy of collocating reprocessing and fuel fabrication plants were adopted. Coprecipitation of plutonium and uranium at the reprocessing plant would also eliminate the transport of pure plutonium. Such measures, coupled with the use of hardened facilities, could reduce the pressures to use intrusive preventive intelligence measures.

However, some observers believe that the fundamental civil liberties problems would still remain, especially in a recovery operation.

These three approaches on civil liberties not only rest on sociopolitical judgments about liberty and security but also mirror the main positions on plutonium recycle in terms of safety and economy. Thus, the civil liberties aspect is one portion—though a very important part-of the total judgment about plutonium recycle. If plutonium recycle does go forward, a most important task will be the close and steady monitoring of the safeguards program to keep it consistent with United States civil liberties.

Nuclear Weapons

Assuming that a nation or a non-national group had the will to design and construct a nuclear weapon, would it also have the ability? This chapter examines the manpower, time, money, and equipment necessary to design and construct the explosive, assuming that enough fissile material had been obtained by one of the routes discussed in chapter VII.

These requirements depend upon the complexity of the nuclear weapon. An assessment of the minimal program necessary to produce a nuclear weapon is of special relevance to nuclear proliferation. This chapter will examine only relatively small weapons development programs and thus will consider only low technology designs, i.e., equivalent to 1945 U.S. technology.

A minimal *national* program is an effort to produce, *without nuclear testing,* a first weapon which is very *confidently* expected to have a *substantial nuclear yield,* This program will call for a group of more than a dozen well-trained and competent persons with experience in several fields of science and engineering. They would need a high explosive field test facility and the support of a modest, already established, scientific, technical, and organizational infrastructure.

If these requirements are met and the program is properly executed the objective might be attained approximately 2 years after the start of the program, at a cost of a few tens of millions of dollars. This estimate does not include the time and money to obtain the fissile material or to establish the infrastructure assumed above.

Some details of the effort would depend on which of the two general types of weapons—gun or implosion—were built. Contrary to common belief, the construction of a gun-assembly weapon presents difficulties roughly equivalent to those of an implosion weapon.

The success or failure of producing a militarily effective nuclear explosive, via the effort described above, is far more dependent on the competence of the people involved than on the technological problems themselves. In trying to evaluate the potential of a specific nuclear weapons development program a detailed knowledge of the strengths and weaknesses of the personnel is more valuable than details of the technological base of the country. However, some general statements can be made about what it is possible to achieve with the national effort described above.

The material for a nuclear weapon might be plutonium, or uranium with a high concentration of either one of two uranium isotopes—U^{233} or U^{235}. Using either form of uranium or weapons-grade plutonium it is possible to design low-technology devices that would reliably produce explosive yields up to the equivalent of 10 or 20 kilotons of TNT. With reactor grade plutonium it is possible to design low-technology devices with probable yields 3 to 10 times lower than those mentioned above (depending on the design), but yields in the kiloton range could be accomplished.

Militarily useful weapons with reliable nuclear yields in the kiloton range can therefore be constructed using low technology and reactor-grade plutonium.

The national program just described is at the upper end of a range of minimal efforts to construct a nuclear fission explosive. At the low end, a small group of people (possibly terrorists or criminals), none of whom have ever had access to classified literature, could possibly design and build a crude nuclear explosive device. They would not necessarily require a great deal of technological equipment or have to undertake any experiments. The group would have to include, at a minimum, a person capable of searching and understanding the technical literature in several fields, and a jack-of-all-trades technician. Again, it is assumed that sufficient quantities of fissile material have been provided.

The actual construction of even a crude nuclear explosive would be at least as difficult as the design itself. In contrast to the national effort, the small group of people described above would probably not be able to develop an accurate prediction of the yield of their device. It could be a total failure, because of either faulty design or faulty construction. A great deal depends on the capability of the group; if it is deficient, not only might the device itself be a total failure, but a member of the group might suffer serious or fatal injury.

However, there is a clear possibility that a clever and competent group could design and construct a device which would give a significant nuclear yield.

Sources of Nuclear Material

A nation that wants nuclear weapons must develop an appropriate source of fissile material. The amount of material needed for an explosive is about 5 to 10 kg of plutonium or uranium-233 or 15 to 30 kg of highly enriched uranium, that is, uranium that contains about 90 percent or more of the isotope uranium-235. Uranium enriched to as low as 20 percent could be used in nuclear weapons, but much more material would be required. The exact quantity of uranium depends on its form and on the type of weapon—implosion or gun assembly.

Fissile material might be obtained by one of three general routes. Most attention has recently been focused on diversion of material from a civilian nuclear power program. A nation might evade safeguards on a nuclear facility or use an unsafeguarded facility, possibly after the abrogation of safeguards agreements.

The second route is the construction of facilities specifically designed to produce nuclear weapons material. Examples of such dedicated facilities are a small reactor to produce plutonium or an enrichment plant to yield highly enriched uranium. A third route is the purchase or theft of fissile material or even a complete weapon. Each of these routes is subject to constraints, and will be evaluated differently by different nations or groups depending on their resources, capabilities, political situations, and intentions.

DIVERSION FROM COMMERCIAL NUCLEAR POWER SYSTEMS

Although a nation could remove the fissile material needed for nuclear weapons from its commercial power systems, no present nuclear weapons state has followed this path. The difficulty of such diversion depends on the type of reactor system and the safeguards applied to the system. The reactor type determines the necessity for and nature of various fuel-cycle facilities. These facilities might include enrichment, fuel fabrication, and reprocessing plants to separate plutonium and uranium from spent fuel. The opportunities for diversion from all such facilities will be assessed here as a function of the reactor system.

The two classes of nuclear power reactors available on the world market today are light water reactors (LWRS) developed by the United States and Canadian heavy water reactors (CAN DUS). Others which could be deployed in the near future are the high temperature gas-cooled reactor (HTGR) and the advanced gas cooled reactor (AGR). Most development effort is being focused on the liquid metal fast breeder reactor (LMFBR), but commercialization is not expected for at least 10 years.

Light Water Reactors

Nuclear fuel convertible to weapons-grade material could be diverted from any point in the LWR fuel cycle, but the difficulty of conversion (chemical or isotopic separation), and hence the usefulness of the material to the diverter varies markedly from point to point. The most attractive points are those where plutonium appears in separated form: in the reprocessing plant; in transport to a mixed-oxide fuel fabrication plant; and at the input area of the fuel fabrication plant. These steps are necessary to the LWR fuel cycle only if plutonium, in the spent fuel is to be recycled back into the reactor. Plutonium recycle is not essential to the operation of LWRS, but may be undertaken to reduce the demand for uranium and the need for enrichment.

If spent fuel is not reprocessed, the LWR fuel cycle includes only the steps through spent fuel storage. This is known as a once-through or throwaway cycle. Theft of spent fuel, followed by subsequent extraction of the plutonium, is only barely credible for a highly organized, well-financed, and technically competent non-state adversary group with a secure base of operations. This action would expose the group to radiation hazards, and to a significant possibility of discovery because of the time required for chemical processing. Isotopic enrichment of fresh fuel to weapons material is not credible for a non-state adversary.

In the LWR cycle without commercial reprocessing, the national diverter would have to divert spent fuel for reprocessing or fresh fuel for enrichment. A small reprocessing plant capable of separating enough plutonium for several explosives per year is within the capability of many countries even if an economical commercial plant is not (see section on “Dedicated Facilities”). Removal of the spent fuel could probably not be done covertly, however, since effective safeguarding of LWRS and their spent fuel pools appears feasible with relatively straightforward improvements in IAEA techniques and procedures. If a nation did decide to divert spent fuel openly, it would have to choose between maintaining normal power output from the reactor and producing so-called weapons-grade plutonium. When operated normally, a 1000 MW(e) LWR discharges about 240 kg of plutonium in 31,000 kg of spent fuel annually. Because this plutonium contains about 25 percent of the isotope Pu^{240} it is not ideal for weapons, although reliable weapons can be made using such material. The nation that wanted weapons-grade plutonium (with 7 percent or less Pu^{240}) would have to operate the reactor differently, sacrificing around one-half the power and producing about one-quarter as much plutonium per kg of fuel. This mode of operation approximately triples fueling requirements.

The front end of the once-through cycle contains only natural- and low-enriched uranium. Enrichment to a considerably higher fraction of U^{235} would be necessary for weapons. This would be expensive and difficult for most nations, which lack commercial enrichment facilities. Nations possessing a commercial facility (especially a centrifuge plant) could covertly dedicate a portion of it to weapons grade enrichment, use the same technology to construct another facility for weapons grade production, or abrogate safeguards and overtly convert some or all of the plant to the production of highly enriched uranium. Covert diversion from a centrifuge enrichment plant would be difficult to detect with safeguards alone, judging by present constraints on safeguards procedures (see chapter VIII "Safeguards Technology"). Overt conversion of a commercial centrifuge plant could quickly yield large amounts of highly enriched uranium.

In a LWR fuel cycle that includes plutonium recycling, the material at the output of the reprocessing plant, the first stages of the mixed-oxide fuel fabrication plant, and the transportation link between the two plants, is vulnerable to both the national and non-state diverter. As presently envisaged, this material is pure plutonium oxide ($Pu0_2$) which can be used directly in a nuclear explosive. Once plutonium oxide is mixed with uranium oxide at the fuel fabrication plant, the material becomes significantly less attractive to the non-state diverter, because of both the time-consuming chemistry required to separate the plutonium and the logistics of diverting a large mass of material.

For the national diverter, a reprocessing plant provides immediate access to weapons material. A large reprocessing plant will be extremely difficult to safeguard effectively against covert diversion by the national diverter. Enough plutonium for several explosives per year could be extracted from the process stream within the error limits of material accountancy. Furthermore, however effective international safeguards may become in their job of detecting covert diversion, they cannot prevent a nation from seizing its own reprocessing plant. Once the political decision is made to seize the plant or its plutonium stockpile the nation can have a reliable explosives in a matter of days to weeks, even using reactor-grade plutonium.

The CANDU

Separated fissile material is not exposed anywhere in the CANDU fuel cycle because no reprocessing occurs. The diversion points in the CANDU cycle are the reactor itself and the spent fuel storage pool. As in the case of the LWR, nonstate theft of spent fuel followed by reprocessing is only barely credible. National diversion and subsequent reprocessing of CANDU spent fuel, however, is technically possible for many nations.

Whether a nation wishes to remove material openly or secretly, it will find the CANDU more vulnerable to diversion than the LWR without plutonium recycle. The CANDU is refueled continuously without having to be shut down, and the fuel bundles are small. Thus, fuel bundles need only be pushed through the reactor faster than normal to obtain weapons-grade plutonium.

International Atomic Energy Agency safeguards systems for CANDU reactors and storage pools (possibly involving resident inspectors) can probably be designed and implemented so that significant diversion of spent fuel bundles will be extremely unlikely to remain undetected. Thus, diversion from the CANDU is also likely to be overt.

A nation that decides to divert openly from a CANDU reactor may be less vulnerable than the operator of a LWR to such sanctions as withholding of fuel services. The CANDU uses natural uranium and does not need enrichment. However, it does rely upon a supply of heavy water, which might be subject to an embargo.

The LMFBR

The diversion-prone points in the LMFBR cycle are qualitatively the same as those in the LWR cycle with plutonium recycle, but its plutonium is more abundant and concentrated. Moreover, weapons-grade plutonium is produced in one portion of the LMFBR. An additional advantage to the national prolifera - tor is that the breeder gives it an independent - supply of fuel, making it less vulnerable to sanctions. Another breeder reactor concept—the gas cooled fast reactor (GCFR)—may be even more attractive to the nation that wants nuclear weapons because it breeds slightly more plutonium than the LMFBR.

Thorium Fuel Cycle

Power reactor fuel cycles starting with thorium as the natural resource have received much less attention than the uranium/plutonium fuel cycles discussed above, In this fuel cycle the thorium produces a fissile isotope, uranium-233. Except for the HTGR, light water breeder reactor (LWBR), and the molten salt breeder reactor (M SBR), thorium/uranium fuel cycles have involved only paper studies. Yet thorium cycles offer a number of potential advantages, such as the possibility of more efficient use of resources through thermal breeders or near breeders. Thorium fuel cycles also present barriers to diversion. The fresh fuel can be rendered unuseable for weapons by denaturing, that is, by mixing uranium-233 with the non-fissile isotope uranium-238. In addition, separated U233 is dangerous to handle because of the penetrating gamma radiation emitted by one of the decay products of U^{232}, an unavoidable impurity in U^{233}.

Comparison of Reactor Systems

The relative value of these opportunities for diversion depend on the intention and capability of the diverter. Four general categories of proliferators can be envisioned:

1. Nations desiring a major weapons force;
2. Nations satisfied with a small and not necessarily sophisticated nuclear capability;
3. Nations wishing the option of rapid development of nuclear weapons in the future; and
4. Non-state adversaries limited to a few crude devices.

The factors that these diverters would consider include:

1. The production rate and quality of fissile material;
2. Ability to withstand international embargoes and sanctions;
3. Impact of diversion on the fuel cycle;
4. Cost of the facilities;
5. Ease of conversion of diverted material to weapons material; and
6. Opportunities for covert diversion.

Figure II-2 ranks the various systems in terms of their resistance to each of these proliferators.

Research Reactors and Critical Assemblies

A substantial diversion or theft potential exists outside the commercial power industry, because of (a) the large number of research reactors throughout the world that are either fueled with highly enriched uranium or produce significant amounts of plutonium, and (b) the critical assemblies in several countries that use plutonium. (Critical assemblies are experimental facilities that run at zero power,) Critical assembly plutonium is essentially uncontaminated by fission products and is of high quality for use in weapons.

Alternate Fuel Cycles

Present commercial and near-commercial fuel cycles have been conceived and developed with essentially no thought given to their implications for proliferation or to the difficulties of safeguarding them. However, ERDA has recently set up a study in the Office of Nuclear Energy Assessments, Division of Nuclear Research and Applications, to investigate and evaluate alternate fuel cycles. The criteria for evaluation of alternate cycles are: (a) potential for preventing proliferation; (b) safeguard potential; (c) technical feasibility; (d) economics and resource utilization; (e) commercial feasibility; and (f) introduction date. In evaluating the potential for preventing proliferation, the study will emphasize deterrence to diversion or theft of nuclear material for the purpose of making an explosive weapon. Both domestic and foreign applications will be considered.

The schedule calls for a final report in October 1978, with a developed set of proliferation criteria and an assessment of selected alternate fuel cycles. Supplemental funds of $4 million

Figure II-2.

Reactor Systems Resistance to Proliferation

(Note that a high rank means the system is least susceptible to diversion.)

Reactor System	Availability	1. Major Force	2a. [illegible]	2b. Major (un	Option	Non-State Adversaries
Light Water Reactor (enrichment)	Present	5	6	7	1	“1
Light Water Reactor (spent fuel)	Present	4	3	1	4	4
Light Water Reactor (reprocessing)	Present	6	5	8	5	6
CANDU	Present	8	7	2	2	2
High Temperature Gas Reactor	Near Term	7	4	6	6	7
Advanced Gas Reactor	Near Term	3	2	3	3	3
Liquid Metal Fast Breeder Reactor	R&D (advanced)	9	9*	9	9	9
Gas Cooled Fast Reactor	R&D	10	10’	10	10	10
Light Water Breeder Reactor	R&O	1	1	4	7	8
Molten Salt Breeder Reactor	R&D) (present inactive)	2	8*	5	8	5

“May not be an option for cost or technological reasons.

SOURCE: OTA

for FY 77 have been requested from Congress by ERDA, and the program has been budgeted at $7 million for FY 78.

In order for the results of this program to be most useful, the alternates that are selected for study should be balanced between relatively short-term payoff technical modifications of existing cycles and radically new approaches, specifically including continuation of study on the nonproliferating- reactor concept discussed below.

Nonproliferating Reactors

One of the most intriguing concepts being studied by ERDA is funded at $250,000 for FY 77 by the Division of International Security Affairs (ISA). This is the concept of nonproliferating reactors through strict design requirements, this approach seeks to eliminate the diversion paths available in current and projected reactor systems and their associated fuel cycles. Several key design criteria are: (a) the system shall contain only a small amount of fissile material at any given time after startup; (b) there shall be no access to the fuel during the lifetime of the reactor; (c) any diversion of fuel will cause the reactor to shut down; (d) the reactor shall be refuelled by the addition of fertile (i.e., nonfissile) material only; (e) the reactor shall not operate as a breeder, but as a sustainer producing only enough fissile material to keep itself running. Conceptual studies of three reactor systems have been funded by this program. This program is the first attempt to design reactors with nonproliferation as a specific design criterion. As such, it deserves continued funding at an expanded scale, a wide hearing, a thorough assessment, and an open-minded comparison with other alternatives. There are apparently no plans by ISA to continue funding this program in FY 78. If this promising new approach is to receive further attention it apparently must do so under aegis of the Alternate Fuel Cycle Program, described above.

DEDICATED FACILITIES

All nations which now possess nuclear weapons have obtained the fissile material from facilities specifically dedicated to the production or separation of this material, Thus, a commercial nuclear power program is not a prerequisite for a nuclear weapons program. The main advantage of a dedicated facility is that it provides a reliable, possibly secret and/or legal source of weapons material. As safeguards are improved and extended over all imported nuclear facilities, and as greater restraints are placed on the sale of enrichment and reprocessing plants, nations embarking on a nuclear weapons program may be constrained to follow this route.

Construction of a dedicated facility (which is, of course, not safeguarded) constitutes a violation of the Non-Proliferation Treaty (NPT) by parties to that treaty. Nations that are not party, however, can quite legally build and operate weapons facilities, even while importing safeguarded nuclear material or technology from NPT nations,

A nation which decides to build a dedicated facility has two basic options:

1. Construct a plutonium production reactor plus a reprocessing plant to separate the plutonium from the spent fuel.
   A variant on this option is to feed a dedicated reprocessing plant with spent fuel from an already existing research or power reactor. (This is the route India took with the unsafeguarded Cirrus research reactor.)
2. Construct an enrichment plant to produce weapons-grade uranium from natural or low-enriched uranium.

The choice between these options depends upon a number of factors peculiar to each country, including its technological base, production schedule, the existence of any civilian nuclear facilities, and the number of weapons

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wanted. These factors, especially the technological base, will also affect the time, personnel, and cost required for construction of dedicated facilities.

Dedicated facilities are smaller and can be simpler in design than corresponding commercial facilities. The technology for reactors and reprocessing plants is not classified, with several detailed plans of such plants available to the public. These facts make construction of certain dedicated facilities within reach of many nations. In particular:

1. The construction of a reactor producing about 10 kg of plutonium per year and a small reprocessing plant is within the capabilities of many developing nations. The total capital cost would be several tens of millions of dollars, and about 5 years would be required to construct the facilities and produce and separate the first 10 kg of plutonium. The reactor would be fueled by natural uranium, moderated by graphite, and cooled by air. Very pure Pu^{239} would be produced.
2. Crude, imperfectly shielded, but technically feasible reprocessing plants based on the techniques of solvent extraction or ion exchange can be built for a quick emergency response program at a cost of one to several million dollars. The nation would have to have access to spent fuel from a reactor to feed into such a plant. Such a facility would not be suitable for a sustained weapons program.
3. A low-cost, low-detection-risk option for a nation already possessing a commercial centrifuge facility may be to build a small "add-on" centrifuge facility, either on or off the site, for the production of highly enriched uranium.
4. A reactor producing about 100 kg of plutonium per year and fueled by natural uranium would be a suitable dedicated facility for an open weapons program in an at least moderately advanced nation.
5. There are no enrichment techniques presently suitable for dedicated facilities in any but technically advanced nations. (An exception might be an "add-on" to a purchased commercial centrifuge facility, as discussed in #3, above.) Laser isotope separation (LIS) is unlikely to be feasible for use as a dedicated facility (barring an unforseen break-through) before the late 1980's or early 1990's and then probably only for technically advanced nations.

In brief, many nations might be able to build a dedicated facility to produce fissile material for a weapons program, For example, about 40 nations already possess one or more research or power reactors and thus have experience with nuclear programs. (See appendix V of volume II.)

It is unlikely that a dedicated facility to support a large weapons program (about 10 explosives per year) could remain undetected. However, a dedicated facility to support a small weapons program (one or two explosives per year) could present a detection problem for intelligence agencies, especially if the nation were not among the five or six Nth countries most likely to be under intensive surveillance.

PURCHASE AND THEFT

A third potential route to proliferation is by the direct acquisition of weapons or fissile material from another country. A nation or group could purchase these items from an illegal black market, covertly buy or trade them from a friendly nation in what is termed a gray market, or steal another nation's weapons. Any of these methods bypasses the need for the expensive and demanding technologies entailed by the commercial power and dedicated facilities routes. If this type of transaction emerges, the scope of proliferation could be extended to technologically limited nations and non-state adversaries who would otherwise have found the task difficult and risky. The pace of proliferation could be further accelerated by the relative ease of obtaining weapons, a general sense that the nonproliferation regime was crumbling, and a specific concern that one's enemies might be covertly arming.

Nuclear black market commodities might be fissile material, weapons designs, or weapons. Of these, the most likely to drive a black market is the fissile fuel plutonium: If plutonium is extensively recycled numerous opportunities would exist to divert this substance. Only a very small fraction of the plutonium need be taken from a full plutonium fuel cycle to produce material for many bombs per year. An alternative source might be material intended for research purposes and military weapons.

The most probable customers for material used directly in a nuclear weapon are less developed nations or countries faced with an emergency that foreclosed other routes to nuclear weapons. This material might also interest terrorists or criminals bent on extortion. The suppliers might be employees of a reprocessing plant who gradually withdraw amounts below safeguards detection limits, or criminals or non-state adversaries who stage armed attacks on plutonium shipments or stockpiles. The size of a nuclear black market would be small compared to that of the illegal drug market, but profits could still be large enough to make emergence of such a market credible. Establishment of contact between diverse suppliers and buyers for isolated transactions would be difficult. Once initiated, however, this contact could be the nucleus for a sustained market, especially if supply and demand are high.

In a gray market, transactions are technically legal but are kept secret because of anticipated negative responses, including sanctions and preemptive attacks. In order for the transaction to be legal, the buyer will always be a government. The nation might be interested in such commodities as weapons, fissile material, or technical assistance, although weapons would probably be supplied only under extreme national emergencies. The country might more commonly receive nuclear technical assistance,

One potential supplier would be another nation motivated by the need to obtain a vital resource such as oil or by the desire to curry favor with a key nation. Another supplier conceivably could be a corporation that is subjected to pressure to assist a nation in which it has considerable investments or sales expectations. Most corporations, however, will have high resistance to such pressure in matters as serious as nuclear weapons proliferation. A third supplier could be an appropriately trained individual, peddling himself as a scientific mercenary.

The gray market involves more natural partners (national allies) than the black market, and it may be more easily established although less widely spread. Participants in both markets must take high risks and thus must have strong motivations. Both markets may be detected by enhanced intelligence activities, and once located, could be halted only by the cooperative efforts of many nations. The black market in plutonium might be largely eliminated by a ban on reprocessing. An adverse feature of this ban, or any other measure that decreases employment in the nuclear industry, is its tendency to create a potential supply of scientific mercenaries.

Theft is the most direct route to nuclear weapons. A detailed assessment of military security was not made for this report, but some observations can be made. Weapons are protected internally against unauthorized use in the United States, but might be rebuilt to bypass these mechanisms. The psychological value of a successful theft would be considerable even if the weapons were actually unuseable. Security for weapons is considerably more stringent than for commercial facilities, but even so, the need for upgrading is recognized by the Department of Defense. A well-trained Commando raid of about 8 to 20 attackers using an imaginative plan and assisted by insiders could be difficult to resist without rapid reinforcement. Intelligence activities could make an important contribution by providing warning of such an attack. Massive attacks that are essentially acts of war would be even more likely to succeed, but would be easy to track, Strong political or military responses would be required to assure return or destruction of the weapons. Physical security used by other weapons states seem to present about the same obstacles to theft as those of the United States, but new nuclear states may be more vulnerable.

Control of Proliferation

Attempts to acquire nuclear weapons by any of the three routes just discussed are subject to four general levels of control effort. The first is detection of the attempt, either by safeguards which watch for diversion from commercial nuclear material flows, or by intelligence activities which can spot dedicated facilities or illegal nuclear transactions. The second level is the response to the detection of such activity in order to force its reversal and deter others from like actions, Sanctions administered by other nations are one method of response. The third level is the restriction of nuclear systems to those that present the lowest risks for proliferation. Supplier agreements can coordinate a ban on sales of enrichment and reprocessing plants and emphasize the development of new systems. The final level is creation of an international climate, through treaties and commitments, wherein nations will not want to proliferate or will find it difficult to do so for political reasons. Each of these levels has produced institutions and arrangements to perform the needed functions. Many of the components would benefit from strengthening, but together they present an effective, though not insurmountable, barrier to proliferation,

The first part of this chapter will survey the safeguards technology to detect diversion, The second part will discuss the various institutions and arrangements that assist in the levels of proliferation control.

SAFEGUARDS

The objective of domestic safeguards in the United States is to detect, deter, prevent, and respond to theft or sabotage by a non-state adversary. The objective of international safeguards such as those applied by the International Atomic Energy Agency (IAEA) is to detect diversion of nuclear material by a nation from its own nuclear facilities. In addition, international safeguards should assist the national safeguards system in detecting nonstate diversion.

United States Domestic Safeguards

The three basic elements of the U.S. system are physical protection, material control, and material accountancy. Physical protection elements are those that prevent unauthorized outsiders from entering a facility or seizing control of a transport vehicle, and prevent nuclear material from leaving by an unauthorized route. Examples are armed guards, barriers, and portal monitors. Material control measures consist of procedures for access to and transfer of special nuclear material. They are aimed at preventing any two insiders acting in collusion from removing nuclear material from the facility. Materials accounting for nuclear material is similar to accounting systems for other valuable materials, involving complete records of the movement of material and the taking of periodic physical inventories. The physical protection and material control systems are the primary safeguards measures in the United States.

Safeguards were not given high priority by the public or the Government until recently. Several years ago, safeguards began to attract widespread interest and increased funds were provided, but, a sudden surge of interest and money cannot quickly compensate for years of complacency.

The United States has three major nuclear programs, and three agencies (ERDA, NRC and the Department of Defense) with safeguards responsibility for these programs.

Because NRC has primary responsibility for commercial nuclear facilities, it has been the focus of this report. The NRC safeguards tasks can be considered in four classes; the first three are of present concern but the fourth allows time for further study.

1. Protection of Shipments of Privately Owned Strategic Nuclear Material.—The Nuclear Regulatory Commission requirements on shipments of strategically significant amounts of special nuclear material (i.e., 5 kg or more of highly enriched U^{235} or 2 kg or more of plutonium or U^{233}) are currently less stringent than those recently adopted by

ERDA for shipment of its own material. One critical element of effective safeguards is secure communication during transportation. ERDA has such a system (SECOM), but its use is at present restricted to transport of ERDA material. There appear to be no serious legal, economic, or institutional reasons why shippers of privately owned nuclear material cannot employ the ERDA communications and control system. Transportation security for NRC licensees would be further upgraded by the use of specially designed, penetration resistant tractor-trailers similar in performance to ERDA's and accompanied by escort vehicles.

2. Protection of Production Facilities That Possess Strategic Special Nuclear Materials.—NRC sets requirements to protect those privately owned facilities licensed for possession of strategic quantities of plutonium or highly enriched uranium. NRC also inspects the facilities to ensure licensee compliance to its regulations. Controversy over whether or not safeguards are presently adequate at these facilities centers around what level of threat safeguards should meet. Although this report has not assessed safeguards at specific facilities, it can make some observations about the methods of assessment now being used.

In current assessments, more attention has been given to the size of a potential non-state adversary group than to any other single attribute. Although some historical data on size of threats are useful as a guide, an estimate of the numbers of attackers is inescapably a matter of judgment. A study in progress at the RAND Corporation suggests a range of anywhere from 7 or 8 to about 15 attackers as a prudent estimate, without speaking in terms of a maximum threat. NRC has reportedly ordered its licensees to upgrade physical security to meet a threat of two or more insiders acting in collusion with several heavily armed attackers from the outside.

In addition to numbers, other important parameters to consider are armament, tactics, and the characteristics of the facility itself. Present safeguards and physical security may place undue reliance on one element of physical security-armed guards, It is not clear how well presently designed safeguard systems can handle the problem of several insiders acting in collusion, or outsiders attacking with guile and deception rather than straightforward armed assault.

Moreover, guards at nuclear facilities presently have only civilian arrest powers, which are quite limited and vary from state to state. Serious consideration should be given to ways to clarify the power of the guards. The question of using a Federal security force to protect nuclear material needs reopening, particularly in light of the increased threat levels licensees are being required to meet.

It should also be recognized that there could be an alternative to reliance on onsite guards for standoff of an armed attack, A crucial question, which deserves serious review, is the extent to which safeguards systems can be designed to sufficiently *delay* attacking adversaries so that the burden of engagement and arrest falls on off site response forces rather than onsite guards.

3. Protection of Power Reactors Against Sabotage.—The question of reactor sabotage was judged peripheral to the main focus of this study: the proliferation of nuclear weapons. This report has therefore not assessed the adequacy of U.S. domestic security at power reactors.

4. Protection of Future Facilities That Would Process Plutonium-Containing Fuel or Other Concentrated Weapons Material.—It is not clear whether NRC will decide to license plutonium processing facilities, or if so, when. The only such plant which could start operations within the next few years is the Allied-General Nuclear Services spent-fuel reprocessing plant at Barnwell, S.C. Other facilities to produce plutonium oxide or to fabricate plutonium for breeder reactors exist only on paper and are 5 to 10 years from completion.

Several safeguard concepts have been put forth in recent years to meet the problems posed by large-scale concentrated weapons material in processing and fabrication facilities. These are listed and briefly assessed below :

a. *Massive Spiking*

Massive spiking is the addition of lethal amounts of radioactive material to fresh fuel as a barrier to theft. Studies indicate that this technique is not cost effective compared to massive containment and stringent physical security for domestic safeguards use. Massive spiking would not be useful at all in restraint of national proliferation.

b. *Light Spiking*

Spiking of highly enriched uranium with low levels of radioactive material should be given further study.

c. *Denaturing of Plutonium*

The concept of denatured plutonium—plutonium which, because of its isotopic composition, is not suitable for explosives—is fallacious. (See chapter VI "Nuclear Fission Explosive Weapons".)

d. *Storage and Transport* of *Plutonium in Dilute Mixed-Oxide Form*

If plutonium dioxide were always mixed with a large quantity of uranium oxide, when stored and transported, its usefulness to the non-state adversary would be considerably reduced. A group would have to steal large amounts of mixed-oxide material and undertake time-consuming chemistry to separate the plutonium. However, the dilute mixed-oxide form would constitute much less of a barrier against national diversion.

e. *Collocation* of *Reprocessing* and *Fuel Fabrication Plants*

The collocation of reprocessing plants and mixed-oxide fuel fabrication plants would eliminate the transport of pure plutonium oxide. The advantages and disadvantages of this safeguard measure have not yet been assessed in any systematic way. However, if coprecipitation is employed at the reprocessing plant so that its output is dilute plutonium oxide in uranium oxide, colocation would probably not offer significant additional safeguard advantages.

f. *Advanced Materials Accounting System*

No substantial economical improvement in the sensitivity of materials accountancy can be expected unless real-time material control can be implemented. Two such systems are being developed: DYMAC at Los Alamos Scientific Laboratory and RETIMAC by NRC at Lawrence Livermore Laboratory. Considerable development work and in-plant demonstration is required before the effectiveness and costs of real-time material control can be reliably assessed. However, even once developed, such systems could not do the entire safeguards job, Physical security, containment, and surveillance will still play crucial roles in both domestic and international systems.

g. *Integrated Safeguard Systems*

The most effective safeguard systems would be those in which the various elements are integrated with one another and into the design of new facilities. Such systems demand not only development of hardware and computerized control but, also, development of methodologies to assess their effectiveness against both outside attack and embezzlement by insiders. The input to this assessment must be reliable data on the individual elements of the system. It is therefore important to continue experimental programs to provide information on the penetration resistance of barriers, the reliability of alarms, and the efficacy and safety of techniques such as foams and reactive sensors that delay and confuse the adversary.

IAEA Safeguards

The objectives of the IAEA safeguard systems is to detect national diversion.

Materials accountancy is considered to be the safeguards measure of fundamental importance by the IAEA. Containment and surveillance are regarded as important complementary measures.

The materials accountancy system is based on records and physical inventories made by the facility operator and subsequently verified by the IAEA inspector. Containment is the use of physical barriers to restrict and control access to or movement of nuclear material. Surveillance means instrumental or human observation to detect access to or movement of nuclear material. It is generally accepted that there are unavoidable limitations on material accountancy due to measurement errors: containment and surveillance will therefore have to be assigned much greater importance in the design of safeguards.

The role of IAEA in the issue of physical security is an advisory one. Physical security systems are the prerogative of the individual nation. As part of an effort to upgrade physical security worldwide, ERDA physical-security review teams visited a large number of countries in 1975-76. The result of the visits are classified by ERDA because of the classified nature of physical security measures in foreign states: ERDA further stated that laws, regulations and factors peculiar to each nation made it difficult to draw even general observations about the visits.

IAEA Safeguarding of Power Reactors.—It is difficult to evaluate the present effectiveness of IAEA safeguards on power reactors because information about critical IAEA procedures and policies is either not available outside the Agency or is classified by the IAEA as “Safeguards Confidential.” Some of this information may become available in the Director General’s proposed Special Safeguards Implementation Report to the Board of Governors. The report is expected in September 1977, after several delays totaling over a year.

On the basis of the available information, it appears credible that IAEA will develop and implement improved equipment and techniques to make undetected diversion from light water reactors or their spent fuel storage pools very unlikely. Safeguarding onload reactors, such as the CANDU which is refuelled without being shut down, is substantially more difficult.

A great deal of research is being done on surveillance and containment to safeguard CANDU reactors, but not enough information is available at present for a reliable assessment. The IAEA may decide to request the right to station resident inspectors at these reactors. Such a move would greatly increase IAEA costs and workload.

IAEA Safeguarding of Enrichment and Reprocessing Plants.—To date, IAEA has not safeguarded any type of enrichment plant (including pilot plant), nor has it undertaken the routine application of safeguards on a long-term basis to any commercial reprocessing plant.

As now proposed, IAEA inspection procedures for enrichment plants (especially centrifuge plants) leave open a path for a nation to obtain highly enriched uranium for weapons. The nation might convert one section of its centrifuge plant to a high enrichment loop. Detection of this loop would be difficult: the IAEA inspector is currently denied access to the cascade area (that is, the area where the actual enrichment takes place), and is not allowed to monitor any new equipment that goes in and out of this area. Reconfiguration of the plant would have to be deduced from measurements of other inputs and outputs to the cascade area. Furthermore, materials accounting is currently not accurate enough for a large plant to assure the inspector that a significant diversion has not taken place. Despite objections that permitting IAEA inspectors inside the cascade area will expose commercial secrets, doing so would greatly enhance the effectiveness and credibility of IAEA inspection.

Present material accounting systems (both U.S. and IAEA) for use in large commercial reprocessing plants are not sensitive enough to reliably detect diversion of the order of tens of kilograms of plutonium. More importantly, detection may occur weeks or months after the diversion. The IAEA requires materials accountancy to be supplemented by containment and surveillance measures. Advanced containment and surveillance systems are currently in the conceptual design stage. The aim is to develop systems that will be effective and reliable, indicate attempts to tamper, and eventually be able to report in real time to both a central inspector station and IAEA headquarters in Vienna. Such systems are essential to the credibility of IAEA safeguards on reprocessing plants.

The IAEA will not be immediately confronted with the safeguarding of very large enrichment or reprocessing plants. Given adequate manpower, and technical and financial support, the safeguards system should be able to improve as the size of facilities under safeguards increases. It is not, however, possible to conclude at this time that this effort will be successful. There are a number of unresolved technical and political problems, any one of which might preclude truly credible safeguards against covert diversion for these types of plants.

INTERNATIONAL INSTITUTIONS, AGREEMENTS, AND SANCTIONS

Safeguards on nuclear facilities can be only as strong as the agencies that apply them, and only as effective as the responses that enforce them. The entire climate for international safeguards is governed largely by the institutions and agreements that are described below.

International Atomic Energy Agency and Euratom

The International Atomic Energy Agency (IAEA) operates a safeguards inspection system required for all nuclear material of non-nuclear weapons states party to the Non-Proliferation Treaty (NPT), and on all exports by members to nonmembers. These safeguards are aimed at detecting whether a nation has diverted nuclear material from its own facilities, so an adversary attitude toward the nations is assumed. The IAEA has no power to enforce physical protection, recover diverted material, or detect dedicated facilities or illegal transactions.

IAEA response to possible evidence of a national diversion is limited. The evidence initiates a sequence of reports and efforts to resolve the discrepancy. If these fail, the matter is referred to the Board of Governors, who must weigh the evidence and such factors as the effectiveness of the Agency's procedures and inspectors, the quantity and quality of missing material, and political factors within the state in order to decide whether a nation has indeed removed some nuclear material. If the Board decides this is the case it sends a report to its members and to the UN, but it has essentially no other recourse.

This noncompliance path has not yet been tested. If governments perceive the risks of detection to be low, however, they may be enticed to try to divert. Some of these attempts would be detected, even in an enrichment or reprocessing plant. Once a state is caught in an attempted diversion, it may apply political pressure or attempt to stall the Agency's efforts to reconcile the problem. The Agency's response to the first attempt will be especially crucial and must be strongly supported by its member states.

Besides the limited response to violations, IAEA safeguards face other problems: they are somewhat restricted by proprietary interests of many nations; they are hampered by failure of facility designs to integrate the application of safeguards; they are dependent upon inspector quality and morale. On the other hand, the very acceptance by nations of Agency inspectors in their nuclear facilities represents a considerable concession, The IAEA safeguarding efforts are certainly not perfunctory and they are making a credible effort to prepare for the expanded work load ahead.

Eurakmn is the multinational agency of the European Economic Community that performs the safeguards functions for its member states. The Euratom safeguards system is less formally structured than the IAEA system, and Euratom's inspection access rights are stronger and still exercised by its inspectors. Euratom and the IAEA have been moving to coordinate their inspections, but important differences remain to be resolved,

Sanctions

Sanctions can be used either to deter or reverse a nation's efforts to obtain nuclear weapons. To be effective, sanctions must enjoy firm and widespread support within the international community, especially by the nuclear suppliers. Sanctions lose their credibility if they are not applied or are successfully flouted. Sanctions could include the termination of nuclear assistance or trade, a cessation of economic assistance, a general trade embargo, or termination of military support or security guarantees. Because these measures will impact differently on different countries, they must be applied on a selective basis. The history of sanctions in other cases is not encouraging but, given a strong international norm against proliferation, the threat can be made credible. Sanctions will be an important element in proliferation constraint, but their deterrent effect can be overcome by sufficient incentives such as a threat to national survival. The defusing of proliferation pressures therefore remains a critical concern, no matter how severe the sanctions.

The Suppliers' Conference and Multinational Facilities

In 1974, after extended negotiations, 10 nuclear exporting nations announced agreement on export procedures designed to coordinate fulfillment of supplier obligations under the NPT. The designated procedures and the so-called "Trigger List" of sensitive exports represented the first major agreement on uniform regulation of nuclear exports by actual and potential nuclear suppliers. It established the principle that nuclear supplier nations should regulate the international market for nuclear materials and equipment in the interest of nonproliferation.

In response to the Indian nuclear detonation a second series of supplier negotiations began. On January 27, 1976, the seven participating nations exchanged letters endorsing a uniform code for conducting international nuclear sales. The provisions strengthened the 1974 agreement with regard to the Trigger List equipment, retransfer of exports, and physical security requirements for the protection of exported materials and facilities. The new agreement indicated the importance that nuclear supplier states attach to strengthening the international barriers against proliferation. The Conference also served to elevate the issues of nonproliferation and nuclear exports to the highest political levels within participating governments. Subsequent to the agreement, there has been a notable strengthening of the nonproliferation posture of Canada, West Germany, and even France. Previous agreements to export reprocessing facilities to Pakistan and Brazil have been cast into doubt.

There is a danger that the success of the Suppliers' Conference could lead user states to view it as a cartel designed to preserve the continued preeminence of the supplier states in the international nuclear market. The result could be a weakening of the sense of bargain which makes the NPT acceptable to many non-nuclear states.

Multinational Fuel Cycle Facilities (MFCF) have been proposed as a way to supply reprocessing services without having the plants under national control. This would greatly reduce opportunities for diversion by any one nation. However, MFCFS might weaken the arguments against reprocessing in general and disseminate the technology to do it. Nevertheless, MFCFS do show promise as a means of forestalling national reprocessing. A number of economic and political issues must be resolved first. The IAEA is presently conducting a study addressed at many of these. Another application of the MFCF concept would be for spent-fuel storage, which would be much easier to implement than reprocessing. It would also make a clear contribution to nonproliferation while not foreclosing eventual multinational reprocessing.

The Non-Proliferation Treaty (NPT)

A major factor constraining nations from nuclear weapons development has been the NPT. The Treaty was designed to prevent the diversion of nuclear material in commercial power systems to weapons purposes by the imposition of safeguards, and to gain a formal commitment by the nonweapons states to remain weaponless. These considerable intrusions into national sovereignty were obtained by guaranteeing access to peaceful nuclear technology and obligating the weapons states to pursue disarmament. Over 100 nations have ratified the NPT, but some of the key countries have not. The greater restrictions on nonweapons states compared to weapons states has caused some discontent, as has the lack of progress towards nuclear disarmament. The NPT prevents only its ratifiers from developing weapons, and parties can, under extraordinary circumstances, withdraw on only 3 months notice and quite legally produce their own. Nevertheless, it is a significant deterrent in that most members would find it politically difficult to resign, and it has helped create a climate that makes proliferation an act outside the pale of international propriety.

Comparison of Routes to Nuclear Materials

The two previous sections have described three routes to obtain fissionable nuclear material suitable for weapons, and the restraints on those routes. The route that would be selected by a particular nation or non-state adversary will depend on various characteristics of the country concerned.

1) Technological Capability: If its ability is high, a nation can consider any route. A low capability limits the proliferator to a purchase or theft.

2) Availability of Nuclear Facilities: The ability of a proliferator to divert nuclear material depends on the type of facility it owns or can readily acquire.

3) Urgency of Need: If the proliferator must have the weapons on a short time-scale, it may have to openly abrogate safeguards on its own nuclear facilities or obtain weapons by purchase or theft.

4) Critical Resources: If a nation has large quantities of uranium, it would be less vulnerable to sanctions if caught diverting and less liable to be detected if it constructs a dedicated facility.

5) Political Relationships: Acceptance of safeguards or vulnerability to sanctions will, at least, force a nation to travel a route with the least chance of detection. On the other hand, alliance with a more advanced nation may provide the nation with technology or resources for a dedicated facility.

6) Perceptions of Controls: If a nation perceives safeguards to be effective, it will be less likely to attempt diversion.

The interaction of all these factors will determine the optimal pathway each nation or subnational group would use to obtain nuclear weapons. This interaction will be strongly influenced by the particular objectives a nuclear weapons program is designed to serve. In chapter VI, four such objectives were identified,

a) Nations desiring a major weapons force.

b) Nations satisfied with a smaller, perhaps less sophisticated force.

c) Nations wishing the option of rapid development of nuclear weapons in the future.

d) Non-state adversaries limited to a few crude devices.

A major weapons program can be defined as one that produces at least 10 high-quality weapons per year. Only a country with a relatively extensive technological base can realistically consider such a program. Such a nation would not select a route as unreliable or intermittent as an illegal nuclear market. It could pursue either of the other two routes, but would probably be unable to keep its intentions secret for long. The diversion of sufficient quantities of nuclear material from a commercial nuclear power program would necessitate open abrogation of safeguards, unless the nation already had an un-safeguarded facility. Sanctions such as nuclear embargoes might effectively hamper a nation from continuing along this route unless it had its own uranium reserves and a natural uranium or fast breeder reactor. Construction of a plutonium production reactor dedicated to production of weapons material might have more appeal, in that it would be legal for a nation that is not a party to the NPT, and its production capabilities could be kept secret even if the existence of the facility itself could not be.

The nation that wants a small number of unsophisticated weapons might procure the material from any of the three routes, If it needed the weapons quickly it might purchase the required goods on a black or gray market, if available, or might consider overt diversion from a reprocessing or enrichment plant. If its needs are not urgent, a country might be able to obtain the nuclear materials secretly. If it owned a reprocessing plant it might be able to covertly divert sufficient material. The country might, however, be unwilling to risk detection if it perceived the safeguards to be effective. In that case it could construct a plutonium production reactor, especially if uranium were available. The reactor would be on such a small scale that it could easily escape detection. A final alternative for a country that possessed a centrifuge enrichment plant would be to rework a portion of it into a high enrichment loop or to build a small "add on" to the existing plant.

The nation wishing only an option for future nuclear weapons development might require commercial nuclear power reactors with eventual diversion in mind. A reprocessing plant would be essential for it to extract the weapons material from spent reactor fuel. If it could not obtain such a facility, it might build one of it own to hold in reserve. A small reprocessing plant for weapons is far easier to design and build than a commercial plant.

The non-state adversary can obtain nuclear material either by black market transactions or by armed attack on shipments or stockpiles of plutonium in commercial power program. The non-state adversary would probably not be able to use material from other points in the fuel cycle because construction of the facilities required to convert such material to weapons grade most likely would be beyond the group's capabilities.

This brief analysis shows that all three routes are plausible under some conditions. The least predictable is purchase/theft. If such a route comes into existence, it could satisfy three of the four categories of proliferators. It might also serve the major force nation wanting a few bombs in hand to forestall the preemptive attack that might occur if its intentions became known before its program was complete. Hence, a high priority must be given to controlling this type of transaction. Diversion from commercial power systems can be largely controlled if Nth countries do not have their own reprocessing or enrichment plants. A reprocessing plant in particular provides instant access to weapons material for any nation willing to abrogate its safeguards agreement and many opportunities for covert diversion by those that are not. The dedicated facility route is the least subject to control. Many nations are capable of this route because of ready access to sufficiently detailed plants and the availability of the modest resource requirements. One of its few disadvantages is its high cost which is not offset by power production. More attention should be directed to possible means of detecting those nations embarked upon a dedicated facility route.

International Nuclear Industry

Control of nuclear weapons proliferation depends to a large extent on the nature and scope of the future international nuclear industry. Key factors to understand are the real and perceived need for nuclear energy in general, and for proliferation-prone facilities (such as breeders or reprocessing plants) in particular. Also important are the motivations of and relationship between the nuclear suppliers, as these will determine the efficacy of any attempts to control proliferation.

Nuclear power has been widely expected to replace oil and gas as a major energy source to meet the growing consumption of most nations, especially as production of these fossil fuels decline and their prices rise. Expectations for nuclear energy were boosted by the oil price increases in 1973, but have fallen sharply since then; costs for nuclear plants and fuels have risen as demand has fallen, and opposition to them has grown in many countries.

Nuclear energy is mainly suited to the production of electricity, the form of energy with the highest growth rate. Although electricity may be inappropriate for many applications, such as low temperature heat, the very high growth rate worldwide results from strong social and economic forces that will not be quickly and easily reversed. Some nuclear powerplants can be replaced by coal plants. World coal resources are many times that of oil, but the costs of extracting, transporting, and using vastly increased quantities of coal in an environmentally acceptable manner may be very high.

The perceived need for nuclear power varies from country to country and depends on many factors. Nuclear power is chiefly appropriate for a nation having a large and growing electricity demand and no cheap alternatives, including conservation. A number of industrialized nations fit this description. Less developed countries (LDCS) may want nuclear power to diversify their energy sources or to provide for a future when there may be no alternative. However, the LDCS may also find that their financial resources are too limited, their electric grids too small, and their technical infrastructure too immature to support such a large and complex power source. The disadvantages may be great enough so that LDCS should be encouraged to find alternatives (such as imported coal), especially those LDCS that are considered high proliferation risks,

In the face of such variable factors governing the need for nuclear power, projections of its growth are very uncertain. The most recent official estimate is one that ERDA produced in 1976, by modifying downward a projection by the IAEA and the Office of Economic Cooperation and Development (OECD). The results are as follows:

World Nuclear Capacity (1000 MW)

Year	1975	1980	1985	1990	2000
US.	39	67	145	250	510
Other Nations	29	100	230	425	1030
Total	68	167	375	675	1540

These figures are considerably lower than previous projections, and many observers expect this trend to continue. Actual installed capacity could be substantially lower. Those LDCS with a heavy commitment to nuclear power are Brazil, Argentina, Mexico, India, Iran, Taiwan, and Korea. Several others expect to be heavily dependent by 2000.

Possession of a nuclear reactor alone, especially if it is safeguarded, does not greatly facilitate the acquisition of nuclear materials for a national weapons program (see chapter VI). Other elements in the nuclear fuel cycle impinge more heavily on proliferation control: the availability of uranium supplies affects the need for reprocessing plants and the breeder reactor; the capacity for enriching uranium will influence such measures as guaranteed fuel supplies; the dissemination of enrichment and reprocessing facilities gives their operators the means to produce weapons materials and also reduces their vulnerability to international sanctions. The supply and demand for all those items must be well understood.

Uranium reserves as presently estimated should not constrain the nuclear power growth projected above until about 2000. At about that time, it may become impossible to guarantee a lifetime supply for new reactors unless a new source of fuel has been determined. This could come from breeder reactors or from new technology that permits the extraction of low grade ores not now counted as economically recoverable. If growth in the demand for nuclear power is substantially lower than presently anticipated or if, as some expect, uranium resources are much larger than projected by the IAEA, there will be no constraint until well into the next century,

More enrichment capacity may be needed by the late 1980's, but there appears to be no inherent difficulty in supplying this. The timing of the need for spent fuel reprocessing is much less clear. Plants are now being built in the United States, Europe, and Japan, but capacity is far below need if all fuel is to be reprocessed, Unlike enrichment, reprocessing is not a vital part of the LWR fuel cycle. Justification for reprocessing as a means to extend fuel supplies may evaporate if nuclear growth slows or if uranium reserves prove adequate. The plants could be indigenously developed by many countries if desired, however. Consequently, export bans on reprocessing plants would be less effective than those on enrichment facilities.

The U.S. share of the total reactor export market has dropped sharply in recent years, as other suppliers have emerged and as U.S. policy has both restricted certain exports and engendered doubts as to the reliability of American commitments. The competition among the nuclear suppliers is quite keen, especially as many of them need a foreign market to fill their excess manufacturing capacity. If the United States unilaterally withdrew from the market, the other suppliers are capable of quickly filling the void.

The suppliers of reactors and enrichment services are as follows:

Reactors	*Enrichment*
U.S.A.	U.S.A.
Canada	U.S.S.R.
West Germany	France
United Kingdom[a]	United Kingdom
France	Netherlands[b]
Sweden[a]	Japan (proposed)
Italy[a]	South Africa (proposed)
Japan[a]	
U.S.S.R.	Brazil (proposed)

[a]Not expected to be major exporter.
[b]Location of URENCO trilateral facility.

If the United States, as expected, continues to export reactors and associated equipment as well as engineering, construction, and enrichment services, the export value will total about $2 billion per year until 1990, with possible variations depending on the policies of other supplier and importing nations.

Policy Implications

Perspectives

The growing debate over policy concerning proliferation hinges in large part on differing perceptions of the problem. There are three basic issues in dispute.

1) Is reliance on nuclear power to meet national and global energy needs unavoidable, or can adequate alternative sources of energy be developed?

2) Must the spread of nuclear power inevitably result in the proliferation of nuclear weapons, or can that potential linkage be broken?

3) Does proliferation really constitute a serious problem from the perspective of U.S. interests? Based on different answers to these questions, three major overviews or perceptions of the proliferation problem can be identified.

The first perspective rests on the basic assumption that reliance on nuclear energy is unavoidable and proliferation may be inevitable, but the latter need not pose a serious threat to vital U.S. interests. There is a corollary view that proliferation will occur only slowly, if at all. *In* either case, exaggerated fears concerning proliferation should not be allowed to jeopardize real U.S. interests, which involve the development of nuclear power as an energy source and the restoring of American preeminence in the global market for nuclear facilities, fuel services, and technology. This would require the United States, infer *alia,* to initiate commercial reprocessing, and to expand its enrichment capacity to service overseas customers and encourage rather than constrain nuclear exports. Moreover, if the United States seeks to exert effective leverage in support of nonproliferation objectives, it must do so from a position of predominance in international nuclear commerce.

The second perspective begins by accepting the proposition that there is an indissoluble link between the spread of civilian nuclear energy and proliferation. Where the previous perspective adjudges the need for nuclear energy as overriding and imperative, this perspective disagrees and assigns primary importance to containing proliferation—which is seen as posing a lethal threat to U.S. and global security. Since proliferation can only be stopped if the growth of the nuclear industry is curtailed, the primary task of policy is to reemphasize the use of nuclear power as an energy source and to develop alternatives. The alternatives would consist of developing coal as a transitional fuel, and long-term reliance on such renewable and environmentally benign energy sources as solar, wind, and organic conversion supplemented by conservation and recycling.

The third perspective assumes that the potential linkage between civilian nuclear energy and proliferation can be broken, i.e., it is possible to obtain the benefits of the commercial atom without entering into a Faustian bargain involving the spread of nuclear arms. This will require policies designed to:

(1) Promote an international political climate in which the incentive to "go nuclear" is minimized.

(2) Improve national and international institutions and procedures through which nuclear facilities and materials can be effectively safeguarded against national and subnational diversion.

(3) Strengthen national and international controls over the availability of weapons-grade nuclear material and the technology and facilities required to produce it.

(4) Develop and apply sanctions designed to reverse any proliferation which does occur and to deter other would-be proliferators.

(5) Develop reactors and facilities which, due to their technological characteristics, are inherently less susceptible to use for weapons-related purposes.

Pursuant to these objectives, a wide range of policies have been proposed or actually implemented (enumerated below). While some of the following policies will be congenial to advocates of all three major perspectives, this inventory is associated primarily with proponents of the third perspective, because the premise that nuclear energy and weapons can be decoupled opens the way for a detailed consideration of policies to achieve that result.

To be successful, policies must affect either the motivation of a Nth country contemplating the nuclear weapons option or the availability of materials and technology required. The former class of policies will be designated demand policies and the latter supply policies.

Demand Policies

One group of demand policies are those designed to weaken the incentives toward proliferation by non-weapon states. These include efforts to:

(1) Strengthen the security of Nth countries by means of a declaration by the nuclear weapon states foreswearing the use of such weapons against any non-nuclear state, security guarantees, alliances, deployment of U.S. troops and military facilities overseas, military assistance, and the overseas deployment of U.S. nuclear weapons and delivery systems.

(2) Reduce the prestige associated with a nuclear weapons capability by superpower arms control agreements; by dampening the rhetoric of the strategic balance and the accompanying impression that the United States views nuclear weapons as the sine qua *non* of its own security; and by attempts to increase the salience of conventional armaments and nonmilitary instruments of power.

(3) Resolve international disputes in which one of the protagonists might conclude that a favorable outcome could be achieved with the acquisition of nuclear weapons.

Attempts to implement these proposals will encounter a number of difficulties, the most serious being that they may conflict with other important U.S. foreign policy objectives, including attempts to scale down American military and security involvements overseas,

Other demand policies seek to strengthen the disincentives that confront Nth countries contemplating the nuclear weapons option. These include efforts to:

(1) Maintain the high technical and economic costs of acquiring nuclear weapons by subjecting all transfers of sensitive nuclear technology, materials, and facilities to strict controls.

(2) Increase the political costs by reinforcing the existing international norm against proliferation,

(3) Provide the external conditions (e.g., economic assistance) that would tend to strengthen the hand of those domestic political forces within Nth countries opposed to the nuclear weapons option.

(4) Develop sanctions designed to raise the costs (economic, political, or security) of any decision to acquire nuclear weapons. Examples include a cutoff of nuclear materials and assistance, a curtailment of bilateral economic and military assistance, a U. N.–imposed trade embargo, and even the threat of military force.

A variety of difficulties will confront any effort to implement these policies—the most serious being a nationalistic reaction on the part of the target states. This will be particularly true in the case of sanctions imposed by one or both of the superpowers. Under the circumstances, accusations of imperialism, neocolonialism, and great power hegemony will be unavoidable. These considerations suggest the limitations of unilaterally imposed disincentives and sanctions. Sanctions will generally make their most effective contribution to a nonproliferation strategy if they are applied in the context of a collaborative effort. The effectiveness of even multilateral disincentives and sanctions is not assured. For the majority of nations possessing limited economic and technological capabilities and lacking an indigenous uranium supply, strong multilateral measures will probably suffice to foreclose the nuclear option for the foreseeable future. On the other hand there are nations, like Argentina, which possess or soon will possess the requisite capabilities and indigenous uranium sources. If Argentina decides to produce nuclear weapons, the international community can raise the cost but probably cannot prevent it short of a resort to military coercion.

Supply Policies

There are several major categories of supply policies. The first involves controls over exports of nuclear materials, technology, and facilities. The major provisions agreed to at the Suppliers Conference have already been outlined. A number of steps might be taken to strengthen that agreement, including a requirement that importers accept full fuel cycle safeguards (or NPT membership) and that a combination of automatic and presumptive predetermined graded sanctions be imposed in the event a recipient state violates or abrogates the terms of an export agreement. Related steps might involve the creation of an international exporters' cartel with guaranteed market shares, so as to prevent export competition at the expense of safeguards, and the imposition of particularly stringent controls over exports to high risk areas (e.g., the Middle East).

Export controls are difficult to implement successfully. Not only must the natural rivalry of exporters be dampened, but importers must be persuaded that the terms are fair and the burden acceptable. If not, they may evade controls by constructing national nuclear facilities—the worst possible outcome from a nonproliferation perspective. In areas prone to conflict and instability even extraordinary safeguards and other precautions may prove ineffective.

A second major category of supply policies encompasses efforts to control the spread of reprocessing plants. It is generally agreed that diffusion of national reprocessing facilities will significantly increase opportunities for proliferation, but there are two schools of thought concerning what policies should be adopted to deal with the situation. The first, a "containment" view, rests on the assumption that the growth of a global reprocessing industry is virtually inevitable and can only be contained and managed. Specifically, reprocessing plants can be confined to the present supplier countries and multinational fuel cycle centers. A strategy designed to achieve this outcome might include some of the following elements: (1) Steps to reestablish the United States as a reliable international supplier of low-enriched reactor fuel and spent fuel services; (2) An agreement by all suppliers to refrain trom the export of both plutonium and reprocessing facilities and technology; (3) Establishment of an international spent fuel regime under existing IAEA statutory authority. If the containment approach is judged inadequate, the logical alternative is to eliminate reprocessing entirely. Proponents of this approach are generally convinced that the spread of reprocessing / recycle is not inevitable, and that its proliferation-related costs outweigh any energy benefits. A policy to implement this approach would comprise the same elements as for containment, with two exceptions. (I) Plans for domestic civilian reprocessing would be suspended until the exhaustion of commercially useable uranium reserves, and (2) Alternate fuel cycles, alternate reactor types, and technologies for extracting the energy in spent fuel without separating plutonium would be explored on a high priority basis.

Both these approaches will have to overcome major obstacles with regard to waste disposal and political resistance on the part of U.S. public opinion (e.g., with regard to the expense of the program). An attempt to institute a global moratorium on reprocessing will encounter strong objections from European supplier nations and Japan which are already committed to reprocessing.

Enrichment controls constitute a third type of supply policy. Like reprocessing, enrichment technology and facilities provide a means of acquiring bomb-grade material. Unlike reprocessing, maintenance of an adequate enrichment capacity cannot be avoided if the civilian nuclear energy industry is to meet the rising demand for electrical power. The proliferation potential in an expansion of enrichment capacity can be dealt with in two ways: by supplier controls over exports of technology and facilities, and by confining enrichment plants to the existing supplier states or multinational centers.

A fourth set of supplier policies concerns efforts to strengthen the nonproliferation regime. This would involve policies designed to make a commitment to nonproliferation more attractive to non-nuclear weapon states on the one hand, and steps to strengthen the control aspects of the regime on the other, In the former category are the following initiatives: (1) Negotiate a comprehensive test ban and a new strategic arms control agreement by the superpowers; (2) Accord preferential treatment to NPT signatories (e.g., concerning enrichment services); (3) Expand the participation of non-nuclear states in decisions regarding peaceful nuclear activities within an international framework. Policies in the latter, or control, category include: (1) Link nuclear exports and economic aid to adherence to the NPT by the recipient state; (2) Strengthen IAEA safeguards (e.g., by extending the application of existing safeguards to prevent intelligence efforts and capabilities with regard to proliferation; and (3) Encourage the creation of nuclear-free zones in appropriate regions.

Other major types of supply policies include: (1) Global and regional arrangements, including multinational fuel cycle centers and schemes for the internationalization of various stages of the fuel cycle; (2) Assistance to other countries in the development of non-nuclear energy sources; (3) Technological measures including efforts to develop a non-proliferating reactor; and (4) Measures to neutralize the non-state adversary threat, including efforts to upgrade physical security measures in the United States and abroad.

Policy Implementation

A taxonomy of available policies has been presented. The next logical step is to order those policies in terms of either their priority or the logical time sequence in which they might be addressed. In a simple three-stage time sequence, the criteria for distinguishing between the categories might be urgency, time required for implementation, and feasibility (in terms of technical difficulty, economic and political cost, and whether the desired initiative can be taken unilaterally by the United States or whether it requires collateral actions by other governments).

A preliminary effort to categorize major policy areas in terms of these criteria produced the following ranking (in terms of priority):

Stage I

- Export controls
- Enrichment
- Strengthen national intelligence capabilities
- Forego plutonium recycle

Stage II

- Contain plutonium recycle
- Weaken incentives
- Strengthen disincentives
- Neutralize non-state adversaries
- Assistance regarding non-nuclear energy sources
- Strengthen the nonproliferation regime
- Sanctions
- International spent-fuel storage regime

Stage III

- Global and regional arrangements

Existing bilateral and international agreements impose constraints upon policy.

Nevertheless, the choice, both at general and specific levels of policy, remains open to a significant degree. However, projected growth rates in the global nuclear industry, trends in international politics, and imminent technological innovations threaten to foreclose major options. It will constitute a major failure of our public institutions if the choice is made by default-a mindless product of the course of events. When the stakes are so high, it is imperative that the choice be conscious and informed.

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Chapter Ill

Policy Implications

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Chapter III

Policy Implications

INTRODUCTION

It is the task of this chapter to examine possible policy responses to the proliferation phenomenon. To date, disagreement over policy has stemmed, in large part, from fundamentally different perceptions of the problem.

Most agree that global interest in, and demand for, nuclear energy will probably increase. Many governments see the atom as vital to meeting their future energy needs and economic growth objectives. Thirty-three countries have or are building nuclear power stations. At the same time, expressions of public opposition or reservations regarding nuclear power have become more widespread and articulate. In the absence of ameliorative policy measures, the spread of civilian nuclear energy will increase the potential for weapons proliferation. Technological, economic, and time barriers to acquiring nuclear weapons are declining, and prospective innovations in enrichment technology promise to accelerate the process. A number of nonnuclear countries already have the industrial capability to produce their own nuclear arms.

General agreement on these observations ceases when certain basic issues arise. Is civilian nuclear power an unavoidable and necessary means of meeting national and global energy needs or can viable alternative sources of energy be developed? Must the spread of nuclear power inevitably result in the proliferation of nuclear weapons, or can that linkage be disrupted? Does proliferation really constitute a serious problem from the perspective of U.S. interests?

One can delineate three major overviews of the proliferation problem from different evaluations of these issues. The first case assigns clear priority to energy supply, the second to nonproliferation, and the third assumes a shared priority. In each case, U.S. objectives can be defined, available policy options outlined, and probable costs and gains assessed.

It should be noted that these perspectives are not monolithic. They are umbrella categories encompassing diverse groups and viewpoints which, nevertheless, share a dominant orientation with regard to proliferation. The discussion of each perspective begins with an explication of the rationale, objectives, and policy prescriptions set forth by proponents of the perspective, and ends with a critique of that material.

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ENERGY PRIORITY PERSPECTIVE

Rationale

To the extent that proliferation control and increased nuclear energy output prove incompatible, priority must be assigned to the latter. If nuclear power and proliferation are unavoidably linked, as many adherents of this viewpoint believe, the world will have to live with proliferation.

This perspective rests on three basic assumptions. The first is that substantial proliferation is probably unavoidable for a variety of reasons:

(a) If the world is to make a successful transition from oil and gas to other energy sources, increasing reliance upon nuclear power is unavoidable. The facilities and knowledge required to develop this energy source have an inescapable potential for application to weaponry.

(b) A large and growing number of countries have the technical and economic resources to construct reactor and reprocessing facilities for the purpose of fabricating nuclear weapons.

(c) Powerful political incentives, including considerations of national security, prestige, and self-sufficiency, operate in support of a decision to acquire a weapons capability.

(d) Any nation that decides to establish a nuclear weapons program can probably purchase the necessary fuel, facilities, and expertise from a choice of foreign suppliers. Efforts by the United States to impede the sale of such items will probably result in the American share of the nuclear export market being captured by other suppliers who may impose less stringent safeguard requirements upon importers. Some also export reactor types more vulnerable to diversion.

The second assumption is that further proliferation can have stabilizing, and therefore constructive, consequences for international politics. Possession of nuclear weapons should have the same sobering effect on new nuclear powers as it has had upon the superpowers. It is argued that the principal result of proliferation will be to largely eliminate military aggression as a national foreign policy option. If countries such as Israel, Yugoslavia, Pakistan, South Korea, Taiwan, and Kuwait, which may have credible reasons to fear military attack by a neighbor, were to possess even a rudimentary nuclear capability, their security would be measurably enhanced. The result would be to at least partially defuse some of the globe's most volatile flashpoints.

According to the third assumption, even if proliferation resulted in the actual use of nuclear weapons by one or more of the new nuclear powers, the conflict need not escalate to include involvement by the great powers. The erosion of cold war alliance systems and post-Vietnam doubts in the United States over the desirability of expanding, or even maintaining, security guarantees overseas, tend to both stimulate proliferation and to reduce the likelihood of American involvement in a local nuclear conflict. Proliferation itself tends to reduce the need for security guarantees and accompanying overseas military installations, and with them the danger of escalation. Finally, the virtually invulnerable deterrent capability maintained by the superpowers renders a deliberate attack against them by a nascent nuclear power unambiguously suicidal, thereby obviating the necessity of a panicky or hair-trigger U.S. response to a localized nuclear flareup.

There is a variant of this perspective which is of at least equal importance. Though based on somewhat different assumptions, it shares the priority accorded nuclear energy production as compared to proliferation concerns. Proponents argue that disincentives to proliferation have proven strong in the past and appear to be getting stronger. The first decade of the nuclear era (1945-1955) witnessed the advent of three nuclear weapons states, the second decade two, and the third decade one. Consequently, supporters of this viewpoint contend that any further proliferation will probably occur at a rate sufficiently moderate to be assimilated by equilibrating processes of the international political system—just as past proliferation has been. Arguments that proliferation can be a source of international stability and that it need not lead to escalation of local conflicts further buttress this viewpoint.

Objectives

The basic policy objective from this perspective is to prevent exaggerated fears over proliferation from jeopardizing *real* U.S. interests, which include developing nuclear power as an energy source and preserving American access to the global market for nuclear facilities, fuel services, and technology. Moreover, if the United States seeks to exert effective leverage in support of nonproliferation objectives it must do so from a position of predominance in international nuclear commerce.

Policy

On the basis of these assumptions and objectives, strenuous superpower efforts to stuff the proliferation genie back into the bottle are deemed costly, futile, and even unnecessary. Proponents of this perspective do not advocate an immediate and wholesale abandonment of efforts to impede proliferation. They do urge that the United States recover its former position as a reliable supplier of nuclear reactors, fuels, and services, From a position of preeminence in the expanding global nuclear market Washington can bargain for political and economic benefits, including the imposition of safeguards.

The President of the American Nuclear Energy Council, Craig Hosmer, has contended that the proliferation threat is confined to a few countries and should not be exaggerated. With a view to strengthening the U.S. position in international nuclear markets, the Council and the Atomic Industrial Forum have argued, *inter alia:*

(1) The United States should initiate commercial reprocessing, expand its enrichment capacity, and develop waste and storage facilities so as to be able to offer overseas customers full fuel-cycle services.
(2) "Self-imposed unilateral constraints" on nuclear exports are "counterproductive and ineffective" and should be avoided.
(3) Government-sponsored nuclear export financing should be provided.
(4) A further tightening of export licensing criteria and procedures is inadvisable. Multinational fuel-cycle facilities are less desirable than U.S. national facilities. The basic contention is that all steps required for the full commercial development and exploitation of the peaceful atom should be taken. Government regulations that would inhibit this enterprise should be kept to a minimum.

While a strengthened American position as a global nuclear supplier offers an opportunity to attempt to exert influence on behalf of nonproliferation, such an effort is realistically regarded as a holding action which might delay, but not prevent, the spread of nuclear weapons.

Critique

The problems associated with this approach are not difficult to identify. Most analysis find it hard to view the prospect of "life in a nuclear-armed crowd" with equanimity. The most obvious danger is that these weapons will come under the control of a national leader who is irresponsible, fanatic, or psychopathic. A government led by such an individual may not feel the same constraints upon the use of these devices as have the present nuclear powers.

Many prospective Nth countries would probably be unable to provide adequate physical security for nuclear materials even with responsible leadership, thereby increasing the danger of theft or sabotage by terrorists. Similarly, they would be unable to apply elaborate permissive action links or fail-safe devices if a sophisticated delivery capability were available—thereby increasing the danger of an unauthorized or accidental nuclear strike. The prospect of *coups d'etut* and civil wars provides further grounds for concern. In addition, several potential Nth countries (e.g., Israel, South Korea, South Africa, and Taiwan) are, or perceive themselves to be, facing a clear and present threat to their very existence, It is difficult to be confident that any nuclear-armed state, pushed to the brink of extinction, would not choose to use those weapons. Even if the resulting conflict remains localized, the damage both to the immediate arena of conflict and to the global environment may be severe indeed. If, contrary to prior expectations, the conflict does draw in the superpowers, the possible consequences need no elaboration. In addition, if the impression becomes widespread that the United States has resigned itself to further proliferation, the result may be a self-fulfilling prophecy. Such a posture might tip the political balance in favor of "going nuclear" in a number of countries where that decision might otherwise be postponed indefinitely.

If extensive proliferation does occur, adjustments across the whole range of U.S. foreign policy will be required. Professor Robert Tucker of Johns Hopkins University has suggested that the emergence of localized balances of terror will permit U.S. foreign policy to revert to a modified form of isolationism. At a minimum, continued proliferation would seem to necessitate a careful review of U.S. overseas defense commitments and a very cautious approach to military intervention if the United States is to avoid being drawn into regional nuclear conflicts.

Moreover, as one analyst suggests, costs to U.S. foreign policy may be considerably more severe than implied in the benign term isolationism: "The spread of nuclear weapons will reduce our ability to control events. It will have a dissolvent effect on alliances, expose our own overseas forces to huge risks, and ultimately impose large costs in shaping our own offense and defense to protect the continental United States against small terror attacks by national, as well as subnational, groups."

He also points out an evident discrepancy in the argument that U.S. nuclear exports are required to give this country leverage on behalf of nonproliferation objectives: "There is an obvious muddle in the. . . view that we can't influence events on the one hand, but on the other hand that we do have an important influence that we can retain only by continuing to export. . . In short, we can retain our leverage only if we never use it." Finally, material presented elsewhere in this study suggests that in the foreseeable future international nuclear exports will not be as large as has been generally predicted. Consequently, it becomes more difficult to argue that the economic benefits from nuclear exports will outweigh the proliferation liabilities.

A final criticism concerns the assumption of some adherents of this perspective that there is a necessary link between the spread of nuclear energy and proliferation. This connection is unproven; to state that the opportunities for proliferation will increase is not to demonstrate that those opportunities will actually be used. None of the present nuclear weapons states used a civilian nuclear energy program to provide material for weapons. The same general comment applies to the next major perspective analyzed below.

NONPROLIFERATION PRIORITY PERSPECTIVE

Rationale

This viewpoint begins by accepting the proposition underlying the first perspective: that there is an indissoluble linkage between the spread of civilian nuclear energy and proliferation. However, where the Energy Priority Perspective adjudges the need for nuclear energy as overriding and imperative, the Nonproliferation Perspective disagrees and assigns primary importance to containing proliferation —which is seen as posing a lethal threat to U.S. and global security.

Proliferation cannot be stopped unless the growth of the nuclear energy industry is curtailed. Such a development is deemed desirable, both for its effects on proliferation and in its own right. The possible consequences of heavy reliance upon civilian nuclear energy are judged to include environmental damage, severe waste disposal problems, inefficiency (e.g., low capacity factors), potentially catastrophic accidents, a massively expensive energy infrastructure, increasingly centralized electrification with a concomitant centralization of political and economic power, the emergence of a garrison state necessary to secure nuclear facilities from theft and sabotage, proliferation, and eventually—a nuclear war. In view of this grim menu of external costs, nuclear energy is held to be unacceptable, now or in the future, as a successor to oil and gas. This is particularly true because nuclear energy opponents deem it possible to develop adequate non-nuclear alternatives to petroleum at an acceptable economic and environmental cost.

In addition, nuclear power as a high-technology, capital-intensive, centralized energy source is seen as particularly ill-adapted to the needs of the majority of the world's population in the predominantly poor and agrarian Third World. Extensive reliance on nuclear energy would be inconsistent with efforts by these countries to reduce their economic and technological dependence upon the industrialized nations.

If the United States turns away from nuclear energy, it is assumed that other nations will follow. The assumption is made because of traditional U.S. leadership in this field, and because of the continued dependence of other countries' nuclear programs upon American material and political support, The international market is dominated by U.S. reactor designs, and the United States is still the principal global supplier of nuclear fuel. An American rejection of nuclear energy could be expected to strengthen antinuclear political forces within other nuclear supplier states.

It is contended that it is not only possible to discontinue the spread of civilian nuclear energy but essential that it be done, for reasons related to the security, safety, environmental, and political effects of this mode of power generation.

Objectives

The objective is to reduce the prospect for further proliferation by deemphasizing the use of nuclear power as an energy source and by developing alternatives.

Policy

From the above assumptions, it logically follows that the problem of proliferation can best be attacked indirectly by: 1) curtailing the further growth of civilian nuclear energy programs or, if this fails, 2) phasing out those programs entirely. Appropriate policies in support of the first, less dramatic, alternative might involve a decision to cease Government support of domestic nuclear industry expansion and redirect public resources toward the following:

- A program to develop coal as an environmentally acceptable fuel.
- A national energy conservation effort.
- The development of ''soft" energy sources. These would involve such

renewable and environmentally benign sources as solar-thermal, wind, and organic conversion supplemented by conservation and recycling. Other characteristics of such a "soft path" might include reduced use of electricity; energy technologies appropriate to the end use; small decentralized systems; pricing of energy to reflect true replacement and distribution costs in order to encourage conservation; and a target of eventual zero or negative growth in aggregate energy consumption.

- An offer to assist other countries to pursue the same soft path.
- The maintenance of a nuclear energy research program with particular emphasis upon fusion, nonproliferating reactors, and waste disposal.
- A decision to forgo any new contracts for nuclear exports except under the strictest limitations and safeguards. Existing contracts would be honored, but energetic rewrite efforts would be made to incorporate stricter safeguards (e.g., a requirement that the importing country accept full fuel cycle safeguards).
- Efforts to directly impede proliferation, including steps to weaken the incentives and strengthen the disincentives of potential Nth countries vis-a-vis the nuclear option; actions designed to strengthen the NPT "regime;" agreements among nuclear exporters concerning joint controls; and steps to curb the non-state adversary threat (see below for a detailed presentation of these measures).

Policies appropriate to an actual phase-out of nuclear energy would include all those actions just mentioned with two modifications: 1) the civilian nuclear energy infrastructure would be dismantled; and 2) no future export commitments would be undertaken.

Critique

Any effort to implement this perspective will confront several formidable obstacles:

1. The initial effect of even a partial U.S. withdrawal from the nuclear energy market might be counterproductive with regard to proliferation. American export markets would presumably be taken over by other suppliers, possibly with a more relaxed attitude toward safeguards and other export controls. Only if all suppliers could eventually be persuaded to join in renouncing nuclear power, or at least exports, would U.S. actions prove useful as a curb on proliferation.
2. There is no guarantee that a combination of coal, conservation, and soft energy sources can provide an adequate energy source at acceptable economic and environmental cost. Crucial technical and economic points are in dispute among relevant specialists and among governments-especially those of the industrialized world. If a major commitment to the soft path is made and supply proves inadequate, a severe electric power shortage could result. Coal is abundant, but environmental considerations may severely curtail its use.
3. The sheer magnitude of the investment in nuclear energy made to date has created a formidable array of economic and political interests having a stake in nuclear power. These will constitute a powerful obstacle to any attempt to phase out the nuclear industry.
4. Any shift away from nuclear power carries the risk of antagonizing the Third World countries, many of which view nuclear power as their best long-term hope for economic development. Moreover, those countries which had signed the Non-Proliferation Treaty could credibly claim that the Treaty's promises of assistance in developing peaceful nuclear energy had been violated. At a minimum, it would be necessary to accompany a domestic switch to non-nuclear sources with a major increase in foreign aid to assist Third World countries in making their own adjustment.
5. The link between centralized energy production and centralized political authority is speculative. In fact, features of the soft path (e.g., a ceiling on energy consumption) may require an authoritarian economy and polity.

6. A strategy of greatly increased reliance on coal and conservation may prove inadequate in carrying the industrialized countries through a transition from oil and gas to essentially limitless sources (e.g., fusion) without major sacrifices or dislocations. If coal and conservation prove inadequate or unsatisfactory the burden will fall upon soft energy sources. Successful implementation of the soft path will probably require concomitant and profound, though not necessarily undesirable, changes touching nearly all aspects of national life. These might include a transition to a planned "organic growth" or even "steady state" economy, zero population growth, decentralization, income redistribution, changes in the industrial infrastructure with major social implications, and a substantial modification of such prevailing values as individualism, materialism, and growth. Clearly, some such changes may occur under alternative "hard path" (i.e., high energy, heavy reliance on central station electricity production) energy scenarios. However, the hard path is designed to preserve, insofar as possible, existing lifestyles.

A decision to dismantle the domestic nuclear industry and reject all further export commitments would incur all the difficulties listed above in an intensified form. A thoroughgoing commitment to a soft path would also probably require a substantial reduction in projected rates of growth in global energy production and use in the foreseeable future. This in turn may imply steps toward world income redistribution, a global ceiling on population growth, and other comparable measures. Finally, even the complete abandonment of civilian nuclear energy would not entirely foreclose other routes (dedicated facilities, purchase, and theft) to obtaining a weapons capability.

SHARED PRIORITY PERSPECTIVE

Rationale

This perspective rests on three assumptions:

- The potential link between civilian nuclear energy programs and proliferation can be disrupted, i.e., it is possible to obtain the benefits of the peaceful atom without entering into a Faustian bargain involving the spread of nuclear arms.
- Proliferation beyond the current roster of weapon states is undesirable in terms of U.S. interests and international peace and stability.
- United States policy can contribute significantly to international efforts to curb proliferation.

It is the first assumption that particularly distinguishes the Shared Priority Perspective. The question facing policy makers is how to minimize the risk that the spread of nuclear weapons will accompany the growth of civilian nuclear facilities and technology.

Objectives

The basic goal of this perspective is to decouple civilian nuclear energy and proliferation, i.e., to inhibit proliferation while proceeding to exploit the commercial atom. This will require policies designed to:

- Promote an international political climate in which the incentive to "go nuclear" is minimized and the disincentives maximized.
- Improve national and international institutions and procedures through which nuclear facilities and materials can be effectively safeguarded against national and nonstate diversion.
- Strengthen national and international controls over the availability of weapons-grade nuclear fuel and the technology and facilities required to produce it.

- Develop sanctions designed to deter and even reverse steps toward acquiring nuclear weapons.

Policy

Pursuant to the above objectives, a wide range of policies have been proposed or actually implemented. These will be examined in detail in the next section. A critique of the Shared Priority Perspective will be subsumed under a critique of these individual policies.

There is broad agreement over the general advantages and drawbacks of most of these options. However, on the question of plutonium reprocessing and recycling there is a fundamental divergence. The first, or moratorium, school of thought contends there is a basic incompatibility between reprocessing and nonproliferation: civilian nuclear energy and proliferation can only be effectively decoupled if there is an international agreement to forgo reprocessing, at least until commercial uranium supplies are nearly exhausted,

The alternative, containment, school argues that a complete moratorium on reprocessing is unnecessary and impractical, given the presumed attractions of the breeder. The development of reprocessing facilities can be controlled and managed so as to prevent a proliferation spinoff. This would be achieved primarily by locating reprocessing plants only in the present supplier countries and in multinational fuel-cycle centers in supplier and, perhaps, user states.

Specific policies designed to implement these two approaches will be outlined and analyzed below.

A NONPROLIFERATION POLICY INVENTORY

Introduction

The following is a taxonomy and analysis of specific policies which hold promise as part of a comprehensive effort to curtail further proliferation. Some of these policies will be congenial to proponents of all three of the major perspectives previously outlined. However, this inventory is associated primarily with proponents of the third Shared Priority Perspective. The logic of the first perspective suggests that the sort of detailed menu of policies that follow is probably ineffective and/or unnecessary. The second perspective would tend to view them as perhaps desirable, but as insufficient and thus ultimately ineffective. The premise that nuclear energy and weapons can be decoupled, which underlies the third perspective, opens the way for a detailed consideration of policies to achieve that result.

To be successful, policies intended to weaken the link between commercial nuc ear power and proliferation must affect either the motivation of a potential Nth country to acquire nuclear arms or the availability of materials and technology required. The former class of policies will be called demand policies and the latter supply policies.

The discussion of these policies will be organized according to the following topic outline:

- Demand Policies
  - Weaken Incentives
    - Strengthen the security of Nth countries
    - Reduce the prestige attached to nuclear weapons
    - Resolve international disputes
    - Critique
  - Strengthen Disincentives
    - Maintain technical and economic costs of the nuclear option
    - Increase the political costs
    - Strengthen domestic antiproliferation forces in Nth countries
    - Sanctions
    - *Critique*
- Supply Policies
  - Reprocessing
    - Containment

Demand Policies

Weaken Incentives

The following initiatives are designed to weaken the incentives toward proliferation on the part of nonweapon states.

Strengthen the Security of Potential Nth Countries.—Actual or perceived vulnerability to external threat has been identified as an important possible incentive to proliferation. Each of the present nuclear weapon states was at least partially motivated by security concerns in deciding to exercise the nuclear option.

For purposes of nonproliferation, the task is to find non-nuclear mechanisms to strengthen the security of potential Nth countries. These might include the following:

- A declaration by each of the nuclear weapon states foreswearing the use of such weapons against any non-nuclear state. A contributing step would be a unilateral or joint "no-first-use" pledge by the nuclear weapon states.
- The deployment overseas of U.S. troops and military facilities. Besides strengthening the host country's military capability, such deployments serve as a "tripwire" to increase the likelihood of American involvement should any attack occur.
- The provision of conventional weapons under military aid and sales arrangements.
- The overseas deployment of nuclear weapons and their delivery systems. America's NATO partners pilot nuclear-armed fighter bombers and man tactical nuclear weapons, while the warheads for these systems remain under U.S. control.
- Alliances, which provide explicit, comprehensive, binding, and credible guarantees to the partners. Examples include the extension of the American nuclear umbrella to Western Europe through NATO, and the mutual assistance treaty with Japan.
- Security guarantees extending the nuclear umbrella of one or more nuclear weapon states to protect a potential Nth country against an attack or threat of attack by another nuclear power. From the perspective of a non-nuclear state, the general guarantee presently offered by the United States is unsatisfactorily vague. Former Secretary of State Dean Rusk stated the American position that a non-nuclear country ''specifically threatened with the use of nuclear weapons would have the entire international community, including the United States, register its support in whatever appropriate way would be necessary in the circumstances. "

The joint obligations incurred by the United States as a signatory of the Non-Proliferation Treaty are equally unimpressive. The treaty is silent concerning security guarantees. United Nations Security Council Resolution 225 provides that assistance to any non-nuclear nation threatened with nuclear aggression will be given "in accordance with the Charter, " i.e., through the Council, where each of the guarantors (as well as France and China) has a veto. A non-nuclear state (e.g., West Germany) that feels threatened by one of the guarantors (i.e, the Soviet Union) will take little comfort from this arrangement.

Reduce the Prestige Attached to Nuclear Weapons.—Prestige considerations have been identified as an important possible motivation for proliferation on the part of non-nuclear states. Consequently, the incentive to proliferation can be lessened by reducing the prestige and symbolic importance attached to nuclear weapons in international politics. Possible means of doing so include the following:

- Eschew statements which suggest that nuclear weapons accord the United States, or other weapon states, a special claim to influence or respect. Try to dampen the rhetoric of the strategic balance and the accompanying impression that the United States views nuclear weapons as the sine qua non of its own security.
- Attempt to increase the salience of conventional as opposed to nuclear weaponry by such steps as revisions in NATO force structures and military planning.
- Attempt to increase the salience of nonmilitary instruments of power—most notably economic power. A step in this direction might be a proposal to give explicit recognition to the importance of Japan by creating a sixth permanent seat on the U.N. Security Council for that country, with analogous gestures in the direction of another economic great power—West Germany. The emergence of new economic powers like Saudi Arabia might be acknowledged by expanding the Group of Ten to include them, and by providing them an important voice in the governance of the International Monetary Fund and World Bank.
- Initiate new efforts to achieve superpower arms control agreements, The relevance of strategic arms limitation and a comprehensive test ban to nonproliferation will be discussed subsequently.

Resolve International Disputes.—A third set of incentives for proliferation relates to the existence of international disputes in which one of the protagonists might conclude that a favorable resolution could be achieved if it acquired nuclear weapons. The response from a nonproliferation standpoint is easy to conceptualize but very difficult to implement. What is required is the identification and resolution of such disputes through mediation and other forms of diplomatic interposition. This would seem to require, at a minimum, a policy of placing special emphasis on settling disputes with a proliferation potential, and of seeking (when appropriate) to impartially dampen conflicts rather than strengthening one party against another.

Critique.—The difficulties which would confront any attempt to implement these proposals are well known. Security guarantees, alliances, and the overseas deployment of troops require, at a minimum, the willingness of the United States to undertake the requisite responsibilities. But the noninterventionist mood of post-Vietnam American foreign policy (e.g., the Nixon Doctrine) makes any significant expansion of Washington's global security role very problematical. The dilemma is intensified by the fact that the United States is particularly reluctant to enter into closer ties with several of these prominent Nth countries. Alternatively, the nationalism of some other potential weapon states make it difficult for them to accept the sort of entanglement with the great powers implied in alliances, guarantees, and the presence of foreign troops.

Similar concerns bear on military weapons assistance. Congress has exhibited increased uneasiness regarding the emergence of the United States as the world's leading exporter and donor of arms. It is difficult for a nation to avoid embroilment in the quarrels of others if it is a principal arms supplier to one or more of the parties involved. Even a policy of assisting in the peaceful resolution of international disputes can lead to a new or increased commitment of American money, men, and prestige in diverse theaters. This is not an outcome that many modern critics of American globalism would welcome.

This suggests that a U.S. effort to control proliferation may conflict with other national goals and priorities. It may, in fact, conflict with other concerns of American foreign policy in a very direct way. The new Administration has suggested that it will try to reemphasize U.S. identification with some of those governments particularity insensitive to civil liberties, but several of the nations which might fall into this category are also the most likely Nth countries, e.g., South Korea, Chile, and South Africa. This creates a difficult dilemma. Should the United States provide military and security assistance to such regimes in the interests of nonproliferation, or should it act upon the principles of a democratic foreign policy even if the result is to stimulate proliferation? The potential for Nth country extortion of the United States in this situation is obvious. The solution is not.

The higher the priority accorded nonproliferation, the higher the potential costs in terms of other foreign policy objectives. Moreover, the proliferation issue promises to further complicate the already difficult relationship between the United States and the developing Third World. The situation is somewhat analogous to that which arose as a consequence of increased U.S. concern over assured oil imports. Some Third World nations have benefited immensely, but they are few in number and tend to be countries that were relatively well-off (e.g., Saudi Arabia). Similarly, the beneficiaries of rising American concern over proliferation will also be few and, almost by definition, among the most successful and advanced of the Third World states (e.g., Taiwan). They will often be states with an acute security problem, and therefore with the potential for drawing the United States into a possibly dangerous conflict situation.

Other proposed initiatives for the reduction of the symbolic importance of nuclear weapons and pledges of no-first-use present a different set of difficulties. If conscientiously implemented, they would require far-reaching changes in American foreign policy, including higher priority to arms control, greater attention to the developing Third World, and a probable diminution of American influence, power, and perhaps even wealth relative to the non-nuclear states. Moreover, it will not be easy to diminish the political and symbolic importance attached to nuclear weapons. Power remains the principal arbiter of international relations, and the contribution of nuclear weapons to national power in real terms is undeniable. Even if the entire catalogue of initiatives (above) designed to reduce the prestige associated with a nuclear weapons capability were implemented, the impact might be minimal.

These considerations help explain why no-first-use pledges have generated little enthusiasm on the part of non-nuclear weapon states, that rely on an alliance relationship with the United States for their security. The net effect of such a pledge would seem to be to diminish the deterrent effect of the American nuclear umbrella. By the same token, an offsetting Soviet pledge would lack credibility in the eyes of these states. Steps to give allies access to nuclear weapons, even under ultimate U.S. control, must be undertaken with extreme care. They may otherwise serve to validate the utility of such weapons, and thus confirm an incentive for proliferation.

Strengthen Disincentives

Other types of demand policies seek to strengthen the *disincentives* that confront potential Nth countries contemplating the nuclear option. Possible initiatives for this purpose include the following.

Maintain the High Technical and Economic Costs of the Nuclear Option.—A major disincentive for any nation contemplating a weapons program has been the expense and technological sophistication required to obtain weapons-grade material and fabricate a bomb. The spread of commercial nuclear power and the evolution of reactor fuel-cycle technology threaten to erode such restraints. The policy response to this situation can take three forms:

- Prevent, insofar as possible, the international dissemination of enrichment and reprocessing facilities and technology. This would probably require development in the near future of multi-national enrichment facilities (see below) and/or an expansion in production capacity of American, Soviet, and European enrichment plants. Increased enrichment capacity would make it possible to ensure those states contemplating or augmenting light water reactor programs a long-term secure supply of reactor fuel at reasonable prices, thus obviating the need to construct national facilities. Curtailing the spread of sensitive nuclear capabilities would also require conscientious implementation of the suppliers agreement banning the export of enrichment and reprocessing plants. An agreement to institute a moratorium on the construction of commercial reprocessing and breeder reactor facilities, if feasible, would also help preserve existing technological barriers to proliferation.
- Subject all transfers of nuclear technology, materials, and facilities to strict safeguards. Such safeguards, if effective, may compel a nation covertly seeking a weapons capability to construct dedicated fuel-cycle facilities (including a reactor, enrichment, and/or reprocessing plants) using its own resources and technology, and at its own expense. If full fuel-cycle safeguards are in effect, as with NPT signatories, any dedicated facilities will have to be clandestine, with a consequent increase in the difficulties and costs.
- Institute strict controls on the replication or retransfer of‘ exported facilities or technology.

Increase Political Costs.—A second appreach to strengthen disincentives is to increase the political cests of selecting the nuclear option. This means, in the first instance, initiatives designed to reinforce the existing international norm against proliferation. Specific examples would include a United Nations General Assembly resolution, an appropriate public declaration by a group of (preferably nonweapon) states, efforts to obtain additional signatures and ratifications to the NPT, and any other steps which would tend to strengthen the NPT “regime”-a subject that will be examined subsequently. Other political costs can be more stringent, involving outright hostility and retaliatory or compensatory actions by other states. Ways of confronting would-be proliferators with the more severe costs will be examined in the section on “sanctions” below.

Strengthen Domestic Antiproliferation Forces.—In addition to the climate of international opinion, it is argued that a nonproliferation strategy must be cognizant of the domestic political situation within key Nth countries and how that situation might be affected by external (i.e., foreign) influences. For example, if it seems clear that a decision to “go nuclear” will be followed by various negative economic consequences (e.g., a cessation of foreign aid), the result may be to stimulate domestic interests concerned with economic development to oppose any nuclear weapons program. Similarly, if the same nation is offered ready access to international sources of safeguarded nuclear fuel, technology, and facilities for electrical power generation, the effect may be to reinforce an incipient division between a nuclear energy lobby and a bomb lobby or to inhibit the latter by imposing a web of political and institutional constraints. The task of American policy would be to provide the external conditions to strengthen the hand of those domestic political forces opposed to the nuclear weapons option.

Sanctions.—A fourth means of strengthening disincentives involves the use of sanctions. Sanctions and disincentives, while closely related, are not synonymous. Disincentive is a broader term referring to the whole range of constraints that confront a government considering the nuclear option. These include such general factors as technological and economic considerations, characteristics of the international system, domestic political influences, and the like. Sanctions, on the other hand, refer to those disincentives which are the product of an active policy to inhibit proliferation. Sanctions are deliberately designed measures to augment and strengthen other disincentives. Sanctions can have three functions: as a deterrent prior to a proliferation decision, as a punishment in response to a proliferation decision, and as an example to deter other would-be proliferators in the future.

Sanctions can take a multitude of forms; what they have in common is the imposition of a penalty designed to raise the costs (economic, political, or security) of any decision to "go nuclear". Possible sanctions include the following:

- Economic penalties, including the discontinuation of economic assistance, restrictions on investment, reduced access to overseas (e.g., American) markets, and financial pressures exerted through international banks.
- Political pressures, including a possible joint U.S.-U.S.S.R. declaration stating that the acquisition of a nuclear weapons capability by a non-nuclear state would constitute a serious threat to world peace and security, requiring consultation concerning possible joint action by the two superpowers.
- A clear message to the allies and clients of each superpower that the continued extension of security guarantees would be jeopardized if they acquired or attempted to acquire nuclear weapons.
- A cutoff of nuclear materials and a withdrawal of U.S. technical personnel from nuclear-related projects.
- A curtailment of U.S. military and technical assistance.
- International sanctions ranging from a termination of IAEA nuclear assistance to a U. N.-imposed trade embargo.
- The unilateral or multilateral application of military power, including the forcible removal or destruction of Nth country nuclear weapons facilities.
- A threat (or pledge) by one or more nuclear states to provide offsetting nuclear weapons to the adversary of any non-nuclear nation that selects the nuclear option.

Critique.—The policy options available to strengthen disincentives are easier to enumerate than to implement. Almost any attempt to raise barriers to proliferation will tend to provoke a nationalistic reaction, particularly when such actions are initiated by one or both of the superpowers. Under such circum - stances rices, accusations of imperialism, neocolonialism, and great power hegemony will be unavoidable. Any efforts to influence or manipulate the domestic political process within Nth countries will be particularly difficult without arousing a counterproductive nationalist backlash. Some options, at best, offer only limited possibilities. Efforts exerted through alliance systems will have little impact on major Nth countries outside such systems (e.g., South Africa). There is little foreseeable prospect for significant additions to the NPT now that Japan has ratified. In addition, efforts to manipulate the domestic political situation in an Nth country, besides being a high-risk tactic, may prove ineffective simply because significant organized antinuclear sentiment is lacking. Moreover, the postulated distinction between a nuclear energy lobby and a bomb lobby may prove more theoretical than real. This is not to suggest that antinuclear sentiment is an unimportant factor in some countries, e.g., Japan and Sweden, but simply that foreign manipulation of that sentiment, even where it is substantial, is very difficult.

The most serious difficulties involve the application of sanctions. Some, particularly those requiring the use of military force and/or other joint action by the U.S. and U. S. S. R., lack credibility. This is important because the primary value of sanctions is their deterrent effect. Once an Nth country has defied a threatened sanction and constructed a weapon, sanctions serve only as punishment and to set an example for future offenders. The damage, i.e., the spread of nuclear capability to another state, has been done—unless the sanctions include actual military action to remove the weapons facilities. If a

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threatened sanction is defied with impunity, all sanctions will tend to lose their credibility. Ironically, the very prospect of coercive sanctions may cause an Nth country to proliferate so as to reduce its vulnerability to such external pressures. In that case, the more credible the sanction, the more likelihood that it will stimulate precisely the response it was designed to forestall.

Another serious problem will arise if implementation of sanctions proves incompatible with other important policy objectives and principles. The hazards of trying to manipulate security guarantees, in this regard, has already been suggested. These difficulties reach their most acute form with regard to counterproliferation strategies and military sanctions. Many would view proposals or promises to supply nuclear weapons to adversaries of a proliferator as tantamount to more proliferation. From this viewpoint, the superpowers would, and should, eschew any such pledge, Military sanctions for the purpose of enforcing international safeguards appear contrary to the major principles of American foreign policy and diplomatic conduct. Other limitations on the imposition of sanctions may involve ambiguities or extenuating circumstances surrounding the offending act, the danger of a damaging counterreaction by the target country, a lack of public (and congressional) support for sanctions. These and other related considerations are reviewed elsewhere in this report.

These considerations suggest the limitations of unilaterally imposed disincentives and sanctions. In circumstances where the United States can exert overwhelming leverage, unilateral pressures will be effective, as the recent successful effort to induce South Korea to rescind its order for a French reprocessing plant suggests. But where such leverage is not present (e.g., with regard to Argentina), attempts to impose unilateral sanctions may be ineffective or worse. The conclusion is obvious; sanctions will generally make their most effective contribution to a proliferation strategy if they are applied in the context of a collaborative effort. Attempts by the United States to exert economic pressure would be of limited utility without the approval and cooperation of the OECD countries. Credible American threats to resort to military action in extreme cases are almost inconceivable without at least the tacit acquiescence or support of the U.S.S.R. In the early 1960's, the U.S.S.R. was reliably reported to be contemplating a military strike against Chinese nuclear facilities. After Soviet inquiries revealed that the United States would view such an action with disfavor, the project was abandoned.

Efforts to raise the political costs of building nuclear weapons will be successful in direct proportion to whether an Nth country can expect the condemnation of the United States alone, the United States and U.S.S.R. together, or the preponderance of the international community. A clear international consensus will, by itself, constitute an important disincentive, but it will also serve as the necessary context or framework for specific sanctions. The task of policy is therefore to generate such a consensus and then to formulate specific policies, which utilize and build upon that agreement.

It should be noted that the effectiveness of even multilateral disincentives and sanctions is not assured. For the majority of nations possessing limited economic and technological capabilities or lacking an indigenous uranium supply, strong multilateral measures would probably suffice to foreclose the nuclear option for the foreseeable future, On the other hand are nations, like Argentina, which possess or will soon possess the requisite capabilities and indigenous fuel sources. If Argentina decides to produce nuclear weapons, the international community can raise the cost but cannot prevent it, short of military coercion.

Supply Policies

Reprocessing

Because they provide access to bomb-grade nuclear material, reprocessing technologies and facilities have been the focus of much recent attention. It is generally agreed that the diffusion of reprocessing plants will significantly increase the opportunity for proliferation. Therefore, from a nonproliferation perspective it is unfortunate that a state might decide to acquire such a capability for a variety of reasons. These include: an assured nuclear fuel supply; anticipation of commercialization of the breeder and the depletion of uranium reserves; a "hard sell" competition among suppliers involving reprocessing as a "sweetener' and a desire for nuclear weapons. These motivating factors must be countered with policies adopted by suppliers if the spread of reprocessing plants to an increasing number of countries is to be prevented. Such policies might aim to manage the fuel at both ends of the fuel cycle either within the supplier states or within some multinational body, or else to forego plutonium recycle altogether and eliminate the need for reprocessing. Both options need further elaboration.

Containment.—This approach is based on the assumption that the growth of a global reprocessing industry is virtually inevitable for reasons cited above. If the spread of reprocessing cannot be halted, it can be contained and managed. Specifically, reprocessing plants can be located in the present supplier countries and in multinational fuel-cycle centers in supplier and user states. The objective would be to prevent the emergence of national facilities within the user states—particularly those of the Third World, A policy strategy designed to achieve this outcome might include some or all of the following elements:

First the United States would reestablish itself as a reliable supplier of enrichment services, and other supplier states would be encouraged to do the same. An adequate guaranteed fuel supply would be offered as a quid pro quo for restraint (i.e., a moratorium on the construction of national reprocessing and enrichment facilities) on the part of user countries. Steps to upgrade U.S. supply capabilities might include:

- Increase domestic uranium exploration and production, and augment stockpiles with added imports.
- Expand enrichment capacity, beginning immediately with the Portsmouth add-on or its equivalent (e,g., a centrifuge plant).
- Maintain R & D and demonstration programs concerning the technological, economic, and safeguards aspects of reprocessing, with a view to future commercialization.
- Facilitate exports of reactors and reactor fuel by establishing a consistent and easily understood set of procedures and criteria for export licensing.
- Provide user states with guaranteed fuel supplies under binding letters of commitment.
- Provide fuel to user states at non-discriminatory or even concessionary prices.

If these efforts are insufficient to restore Us. credibility as a reliable supplier in the eyes of the importing states, an international fuel bank or "extraterritorial SWU" reserve might be established under international control.

Second, all supplier states would agree to refrain from the export of plutonium, highly enriched uranium, and enrichment or reprocessing facilities and technology.

Third, suppliers would offer spent fuel services. These might include:

- Fuel leasing, buy-back, or exchange provisions. The basic concept in each case is to obtain the return of spent fuel containing unseparated plutonium. The user state would receive a new supply of low-enriched uranium fuel in return.
- Assistance to user countries in arranging for spent fuel storage and waste disposal in the United States or overseas. This would require expansion of U.S. spent fuel repositories, and the development of the technology and facilities required for permanent waste disposal,
- Access to reprocessing in order to dispose

of spent fuel, This assumes the initiation of commercial plutonium reprocessing and recycle.

. Demonstration projects for spent fuel and reprocessing technologies.

An international spent fuel regime could be established under existing IAEA statutory authority. Spent fuel or excess national stocks of separated plutonium would be placed in IAEA custody pending use. The United States has already approached other suppliers and the IAEA Secretariat in support of this concept, and a working group of nuclear suppliers has been studying it. This will require, in turn, the construction of international fuel storage facilities (the United States could provide the first site).

To induce other suppliers to cooperate in these measures the United States could offer them tie-in agreements, guaranteeing enrichment services at nondiscriminatory prices to their reactor customers, opportunities to invest in new U.S. private-sector plant capacity, and joint-venture reprocessing facilities. Competition in the provision of fuel-cycle services and facilities could be moderated through market sharing agreements, the provision of such facilities and services to all users on equal terms, establishment of multinational reprocessing facilities, and possible mechanisms for international supervision.

The spent fuel issue is rapidly emerging as one that requires urgent attention. Most nations with nuclear power reactors in operation or on order lack adequate spent fuel repositories. That fact, plus any fuel return requirements imposed by suppliers, makes it necessary to transfer the fuel to locations where it can be stored and perhaps reprocessed. England has shown some interest in receiving spent fuel from other countries (e.g., Spain), but only if allowed to reprocess it. The United States currently faces the problem of whether to permit the transfer for reprocessing of spent fuel derived from U.S. supplied material. The bilateral agreements under which fuel was originally exported give the United States a veto over its ultimate disposal (see below).

Critique.—An analysis of the containment approach suggests a number of potential difficulties. First, its applicability may be constrained in the short term by limitations on U.S. enrichment capacity and in the long term by possible limitations on U.S. domestic supplies of uranium, The Administration's decision to construct a centrifuge facility in lieu of the previously planned Portsmouth add-on using the proven diffusion technique, introduces another element of uncertainty. Centrifuge facilities of this size exist only on paper. Consequently, their reliability and other performance characteristics have yet to be verified in practice. Second, the costs of an integrated program encompassing expanded enrichment capacity, fuel buy-back, and provision for adequate storage and waste disposal facilities would be impressive, Domestic political resistance to the price tag and to provisions for making the United States a global repository of spent nuclear fuel and wastes may be very strong. Third, it may be difficult to persuade nuclear importing states to accept arrangements which will keep the present international nuclear oligopoly intact, Present suppliers would retain both their market preeminence and technological leadership. Steps to strengthen the United States as a "reliable supplier" by concessionary exports of fuel will have the effect of subsidizing the global spread of nuclear energy-a somewhat ironic outcome from a nonproliferation perspective. The final and perhaps most important criticism from a nonproliferation standpoint is that a containment approach tolerates the growth of a global reprocessing industry, and thereby tends to legitimize the use of plutonium as a commercial fuel. Against this background, nascent weapons states may find it easy to argue that their own reprocessing facilities are essential for energy independence. The containment approach also tends to diminish the incentive to develop technological alternatives to reprocessing.

Rejection of Plutonium Recycle.—If the containment approach is judged inadequate, the logical alternative is to eliminate reprocessing entirely, The Carter Administration has apparently opted for this course by deciding to cease Federal Government support of civilian production and use of plutonium.

Proponents of this approach tend to assume that the spread of reprocessing/recycle is not inevitable; that the proliferation-related costs outweigh the energy benefits; that the economic rationale for reprocessing is questionable in any case; that reprocessing and plutonium storage cannot be safeguarded; that U.S. policy can serve as an example to other states; and that other countries are unlikely to forgo reprocessing unless the United States does so.

A policy to implement this approach would comprise the same elements as for containment, with two exceptions. (a) Plans for domestic civilian reprocessing would be suspended until commercially useable uranium reserves are exhausted or the breeder is successfully commercialized. Alternatively, both reprocessing and the breeder could be abandoned permanently. (b) An effort would be made to develop technologies for extracting the energy in spent fuel without separating plutonium, e.g., tandem cycle and coprecipitation. Such research might be undertaken as part of an international study. If the results were successful, the benefits of the new technology could be made available to other countries. If the technology proves unworkable, the nuclear industry would resort to a throwaway cycle.

Critique.—A policy to forgo plutonium recycle will encounter difficulties analogous, but more intense, than those involved with a containment approach. Demands on enrichment capacity will be increased. Thus uncertainties concerning uranium supply projections cast some doubt on the viability of a reprocessing ban beyond the immediate future. The political task of persuading other nuclear suppliers to abandon their reprocessing plans will be very difficult indeed.

The waste disposal and spent fuel storage problems will clearly be exacerbated. The problem is illustrated by the Administration's current dilemma over spent fuel transfer. To the extent that efforts to dissuade other supplier states from reprocessing succeed, a means for elimination of plutonium in spent fuel is lost, or at least indefinitely postponed. The United States would also be forgoing a known technology (reprocessing) in favor of untried ones (e.g., tandem cycle) which, at the very least, would mean the deferral of our ability to recover the energy value from spent fuel should reprocessing prove economical. It would also mean relinquishing leadership in technology development of direct relevance to IAEA safeguards, multinational fuel-cycle facilities, and the breeder. Furthermore, a decision to forgo reprocessing would probably be the death knell for the LMFBR, the most technologically advanced of all the inexhaustible energy sources.

The most serious obstacle to a reprocessing ban or moratorium is a political one. Pressure by the United States to put a halt to reprocessing will encounter strong resistance from Japan and those European suppliers that have already committed themselves to reprocessing and have small facilities in operation or under construction. These nations view reprocessing and the breeder as a vital element in their effort to assure adequate energy supplies in the future. Unlike the United States, they do not have substantial domestic reserves of uranium. Controlling the export of such facilities and technology is the one area in which agreement has proven possible. Beyond this, the present Administration's approach is apparently to seek agreement from other suppliers to at least impose a moratorium on commercial reprocessing and on the construction of new facilities. Agreement in even this limited area will be difficult. Moreover, mutual interest and dependence among the United States, Europe, and Japan are so extensive that most efforts to apply coercive pressures become counterproductive.

Enrichment

Like reprocessing, enrichment technology and facilities provide a means of acquiring bomb-grade material. The spread of national enrichment facilities would therefore have ominous implications for proliferation, similar to those associated with reprocessing. Both have been the focus of supplier export control negotiations. As with reprocessing, motives for acquiring an enrichment plant can include an assured fuel supply (energy independence) and a desire for nuclear weapons.

There are important differences. First, enrichment is a considerably more difficult and demanding technology. Consequently, the inherent technological and economic barriers to its spread are somewhat higher than with reprocessing. This situation may erode, depending upon the outcome of technological innovations still in the development stage. More important, commercial reprocessing could be deferred for perhaps two or three decades without greatly damaging the nuclear energy industry. There is enough uranium to meet industry's needs for that period, but an increase in enrichment capacity cannot be delayed if the civilian nuclear energy industry is to keep pace with the rising demand for electrical power.

The proliferation potential inherent in an expanded enrichment capacity can be dealt with in two ways: by supplier controls over exports of technology and facilities, and by confining enrichment plants to the existing supplier states or multinational centers,

Critique.—There are a number of possible difficulties associated with the establishment of multinational facilities; these will be dealt with subsequently. Efforts to control the spread of enrichment facilities and technology will encounter difficulties similar to those for reprocessing.

Export (Supplier) Controls

Bilateral Agreements.[1]—The fundamental mechanisms for international nuclear cooperation between the United States and other nations or international organizations since the mid-1950's have been Agreements for Cooperation, commonly known as "bilateral agreements." A variation, which involves commitments by the United States and another specified nation to the IAEA, is known as a trilateral or tripartite agreement. These agreements provide the framework for technical cooperation and export of U.S. nuclear materials and facilities to other countries, and for safeguarding of exported items against theft, diversion, or illicit use. Provisions have varied from one country to another and over time, More recent agreements tend to include stricter constraints.

The principal provisions of recent agreements for cooperation relevant to proliferation are the following:

(1) *Exchange of information:* The agreements provide for the exchange of information dealing with peaceful applications of atomic energy relating to reactors, radioactive isotopes and source material, special nuclear material, and health and safety considerations. Restricted data (i.e., classified information) and associated materials and equipment cannot be exchanged.

(2) *Access to special facilities:* The agreements for research and development commit the Parties to make specialized research facilities and reactor testing facilities available for mutual use if it can be conveniently arranged.

(3) *Cooperation between persons;* Provisions of the agreements permit companies in the U.S. nuclear industry to deal directly with the governments, nuclear industries, and utilities of the agreement nations on matters concerning nuclear exports.

(4) *Transfer of materials and equipment:* Research agreements provide for the transfer of specified amounts of source material, heavy water, byproduct material, radioisotopes, and special nuclear material for purposes other than reactor fueling.

(5) *Supply of special nuclear materials (SNM):* Research and power agreements provide for contracts under which the United States will either supply enriched uranium from U.S. ores or will enrich natural uranium supplied by the agreement nation. The agreements set general limits on the amount of SNM (e.g., manium-235) to be transferred. There is usually a further restriction that the quantity of enriched uranium transferred shall be limited to the amount needed for the full loading and efficient operation of the reactors covered under the agreement. Some agreements also provide for the transfer of

[1]See "United States Agreements for Cooperation in Atomic Energy: An Analysis, " prepared for the Committee on Government Operations, U.S. Senate, by the Congressional Research Service, Library of Congress, January 1976, pp. 36-53.

plutonium under terms and conditions to be agreed upon.

(6) Reprocessing of *spent fuel:* Agreements require that reprocessing of fuel supplied or enriched by the United States shall be performed only in facilities acceptable to both parties, and only upon a joint determination that the safeguard requirements of the agreement can be effectively applied. Further, any alteration of spent fuel elements removed from a reactor must take place in mutually acceptable facilities. Pending the required joint determination, the agreement nations can only remove and store spent fuel.

(7) *Guarantees:* Agreements include two guarantees. The first is an assurance of peaceful use, which typically provides that:

> No material, including equipment and devices, transferred to the government of . . . or authorized persons under its jurisdiction by purchase or otherwise pursuant to this Agreement or the superseded Agreements, and no special nuclear material produced through the use of such material, equipment and devices, will be used for atomic weapons, or for research on or development of atomic weapons, or for any other military purpose.

The second guarantee refers to retransfer of exported materials and facilities. Typically, the agreements provide that:

> No material, including equipment and devices, transferred to the Government of . . . or to authorized persons under its jurisdiction pursuant to this agreement or the superseded agreements will be transferred to unauthorized persons or beyond the jurisdiction of the Government of . . . except as [ERDA] may agree to such a transfer to the jurisdiction of another nation or group of nations, and then only if, in the opinion of [ERDA], the transfer is within the scope of an agreement for cooperation between the Government of the United States and the other nation or group of nations.

(8) U.S. *safeguard Tights;* Under the agreements the United States is entitled to review the design and operation of facilities and to apply safeguards—including the right to send U.S. inspectors into the territory of the agreement nation. The agreements typically specify the rights of the United States as follows:

> To designate, after consultation with the Government of ..., personnel who, accompanied, if either Party so requests, by personnel designated by the Government of. ..., shall have access in . . . to all places and data necessary to account for the source material and special nuclear material which are subject to . . . this Article to determine whether there is compliance with this Agreement and to make such independent measurements as may be deemed necessary.

In the case of noncompliance with these provisions, the United States is empowered to suspend or terminate the agreement and to require the return of any materials, equipment, and facilities provided under the agreement.

(9) *IAEA Safeguards:* An early purpose of U.S. agreements for cooperation was to provide the IAEA with experience in the application of safeguards. Consequently, the agreements included a commitment by the Parties to apply IAEA safeguards to materials, equipment, and facilities transferred from the United States. These international safeguards are carried out either under a trilateral agreement among the Parties and the Agency, or as provided in an agreement between the agreement state and the Agency pursuant to the NPT. The United States will suspend its own safeguard rights only if it determines that the international safeguards are adequate.

As noted above, recent bilateral agreements tend to contain stricter provisions regarding proliferation than do earlier ones. Further steps in this direction might include the following. First, earlier agreements could be renegotiated in at least some cases, to make them consistent with the guidelines agreed to at the London Suppliers Conference (see below). Second, the agreements might be further upgraded to include provisions similar to the list of suggested measures for strengthening the Suppliers Agreement (below). The most important of these would be requirements for full fuel cycle safeguards and provisions for spent fuel return, in conjunction with guaranteed supplies of reactor fuel, Multilateral Approaches.—Export controls have been frequently identified as a potentially fruitful area for a multilateral approach. The recent agreement under which West Germany will export an entire fuel cycle to Brazil (with safeguards) has generated widespread concern that competition among nuclear suppliers will lead to the uncontrolled spread of sensitive nuclear materials, technology, and facilities, To prevent a competitive dilution of safeguards, the nuclear supplier states began negotiations in London to define uniform standards and controls to be applied to exports. Reportedly, the Suppliers' Conference resulted in an agreement on eight such criteria or conditions to be applied on a "best effort" basis. These include:

- a requirement that IAEA safeguards be applied to all exports;
- a requirement that recipients give assurances that exports will not be used to make explosives;
- a requirement that recipients provide adequate physical security for exported nuclear facilities and materials;
- a requirement that recipients apply the above conditions to any retransfer of exports to a third country;
- the exercise of "restraint" regarding the possible export of "sensitive" items (relating to fuel enrichment, spent fuel reprocessing, and heavy water production);
- encouragement of multilateral facilities for reprocessing and enrichment;
- assurances that facilities constructed from sensitive technology exports be safeguarded; and
- a requirement that the supplier's consent be obtained prior to any retransfer of sensitive facilities, materials, or technology.

Subsequently, Ottawa announced that it would require recipients of Canadian nuclear exports to accept full fuel-cycle safeguards—the first supplier state to do so. In a dramatic change of policy, France decided to ban future exports of enrichment and reprocessing facilities and technology. A large question mark hangs over the existing French agreement to supply a reprocessing plant to Pakistan. The United States has threatened to cut off further economic assistance to Pakistan if the deal is not canceled. Pakistan has publicly defied this demand and France has said it will proceed with delivery if Rawalpindi insists. However, the French Government has not objected to U.S. efforts to change Pakistan's position.

The principal American representative to the Suppliers' Conference has characterized the negotiations as "an evolutionary process," and it is not hard to identify a number of ways in which the existing agreements might be supplemented and strengthened.

- Replace the present "best effort" formula with a formal binding agreement or a more compelling informal understanding.
- Follow the Canadian lead and insist on full fuel-cycle safeguards or NPT ratification as a condition for all nuclear exports.
- Expand the recipients' pledge not to use imports for making weapons to a general unqualified pledge to forgo nuclear weapons.
- Draw up a joint plan of action incorporating graded sanctions to be imposed in the event a recipient state violates or abrogates the terms of either an export agreement or the NPT (if it is a signatory).
- Require that safeguards apply for the useful life of facilities built as a result of exported technology, and to any application of exported technology to other nuclear facilities.
- Apply uniform safeguards to the provision of fuel-cycle services.
- Require participation in an international (IAEA) storage regime for spent fuel if, and when, it can be established.
- Establish multinational enrichment sites.
- Forestall the construction of national reprocessing plants. Steps towards this end might include a ban on all exports of reprocessing facilities and technology, a ban on nuclear exports to any country planning or implementing reprocessing, and a requirement that any reprocessing take place in the supplier state. Spent fuel would have to be returned to the supplier

under fuel-leasing or buy-back arrangements. In exchange, the user state would receive low-enriched uranium already fabricated into new fuel elements. Recent U.S. agreements to buy back irradiated fuel constitute an important step in this direction.

U.S. Government influence over nuclear exports is also exerted through decisions by the Export–Import Bank with regard to export financing, insurance, and guarantees. Since nuclear exports are publicly subsidized or financed in each of the supplier states, it might be useful if the directors of the national export credit associations of the supplier nations met to coordinate policies.

A final approach to export control would involve an effort to diminish competition among supplier states by creating an international exporters' cartel, with a guaranteed market share for each exporter. As an inducement to other suppliers, the United States could settle for less than the 50 percent share it would receive if shares were apportioned according to manufacturing capacity.

Special Precautions.—There are certain nations or regions which, because of regional conflict, national instability, or irresponsible leadership, appear to warrant special concern with regard to nuclear exports. In such instances it may be desirable for the nuclear exporting states to either require special precautions besides conventional international safeguards and physical security measures, or avoid all nuclear exports to the territory. The area of greatest immediate concern with regard to regional conflict is the Middle East (Egypt and Israel), where Washington has already imposed special export conditions including a fuel buy-back option, the right to veto reprocessing of spent fuel from U.S. supplied facilities, and a requirement that any reprocessing that is permitted must take place outside the recipient country.

Critique. —Policy proposals involving supplier cooperation and coordination confront formidable political obstacles. Exporting states will have to perceive sufficient common interest and danger to overcome initial rivalry and suspicion. Each will have to curb its desire to capture as large a part of the export market as possible, and restrain the inclination to view nuclear exports as a source of political influence and prestige. The problem was illustrated in the negotiations that led to the recent suppliers' agreement. From the perspective of other suppliers (notably Germany and France), U.S. efforts to control exports appeared suspiciously like an attempt to protect its dominant share of the international nuclear market against rising foreign competition. Nevertheless, the modest success of the London negotiations, in conjunction with recent Canadian and French policy changes, offer grounds for some optimism in this regard. Moreover, both Great Britain and the U.S.S.R. have exhibited consistent support for supplier safeguards.

Export controls, if pushed too hard, could prove counterproductive, and U.S. negotiators insist that the Suppliers' Conference has progressed as rapidly as political realities will permit. A premature attempt, for example, to substitute a formal public and binding agreement for the present informal understanding would probably result in no agreement of any kind being reached.

The reaction of nuclear importing nations is of an even greater concern. If the conditions attached to the purchase of nuclear facilities, materials, and technology are thought to be too onerous, an importing nation may opt for a national nuclear industry (including enrichment and/or reprocessing facilities) which will permit increased independence from overseas suppliers. Brazil has already chosen this path. If the country in question has not ratified the NPT, these indigenous facilities would be entirely exempt from safeguards—with obvious implications for proliferation. Furthermore, steps to hedge the availability of civilian nuclear exports with growing restrictions and conditions could be construed as a violation of NPT Article IV. More important than the legalities is the possibility that such restrictions would be widely viewed as analogous to the resented unequal allocation of benefits and costs between nuclear and non-nuclear weapons states under the NPT regime (see below). Cartels are seldom popular with their customers: witness the tensions between OPEC and industralized oil consumers. While OPEC can attempt to justify its price exactions by stating that they ameliorate or at least modify global power and income inequalities, a nuclear cartel could not make the same claim.

As a consequence, the political viability of export controls for more than the short term is very much in doubt. The minimum requirements for success would seem to be: (1) a perception by suppliers that the opportunity costs of controls are equitably distributed among them, and (2) a perception by importers that controls do not unreasonably hinder diffusion of the benefits of civilian nuclear energy-either in terms of energy supply or cost .

A second problem area concerns sanctions and enforcement. At present, the basic U.S. position on sanctions remains the same as articulated by then Secretary of State Kissinger, i.e., that violations of bilateral agreements or IAEA safeguards should lead to a cutoff of nuclear assistance to the offending country and the return of supplied material and equipment. This conforms to the standard provisions in U.S. Bilateral Agreements for Cooperation. The credibility of this threat was not enhanced by either the mild U.S. reaction to India's nuclear explosion, or the subsequent proposal by the Ford Administration to resume limited exports of nuclear fuel to India. What seems required at the outset is a joint suppliers' statement that any violation of a safeguards agreement would be viewed as an extremely grave matter, resulting in consultations among suppliers and leading to the coordinated application of prearranged sanctions. Sanctions might include, in addition to a cutoff of nuclear assistance by the suppliers and a withdrawal of IAEA assistance, a severance of all economic ties with the offender, a suppliers' initiative to obtain a formal condemnation of the violation by the United Nations General Assembly, and Security Council consideration of possible further punitive actions. These sanctions should be enumerated in at least general terms in each export agreement. More drastic sanctions are reviewed elsewhere in this study.

Agreement on, and enforcement of, even the relatively mild sanctions listed above will be very difficult. To be viable, sanctions must fulfill four criteria: they must be credible; they must be strong enough to serve as an effective deterrent; they must enjoy the support of the suppliers who will enforce them; and they must be sufficiently acceptable to the recipient states to be incorporated in export agreements in the first instance, Such conditions are not easily met.

In theory, sanctions could also be applied against a supplier that fails to implement an agreed course of action following a safeguards violation. In this instance, all the difficulties of implementing sanctions are compounded. If the offending supplier is an ally, the United States will be extremely reluctant to jeopardize a vital political and security relationship; if the U.S.S.R. is the culprit, any attempt to impose sanctions will be dangerous and probably futile.

Another difficulty arises from the fact that export controls ideally should be retroactively applied to the 30 existing nuclear export agreements of which the United States is a party. All nuclear exports require a NRC or Commerce Department license, and this in turn provides a lever to institute the new criteria. Even so, unilateral, retroactive revision of a bilateral agreement is hazardous. The danger is that such action would antagonize importing states and further undermine the already damaged reputation of the United States as a reliable supplier. The problem would be ameliorated to the extent that the United States moved in concert with other suppliers, and the licensing lever is used to initiate negotiations with importing states concerning the proposed revisions rather than to simply impose those provisions on a unilateral, take it or leave it, basis, Moreover, bilateral agreements are increasingly being supplanted or supplemented by multilateral institutions and processes, e.g., the Suppliers' Agreement and IAEA safeguards.

The proposal that extraordinary precautions be taken with exports to particular countries or regions poses its own set of difficulties, In an area prone to international conflicts, civil wars, and coups, safeguards may be irrelevant. Safeguards applied to the reactor provided South Vietnam would probably not have constrained the present Government had the facility been captured with its fuel supply intact. Where terrorism has reached military dimensions, as in the Middle East, it is hard to imagine how any set of physical security safeguards can be entirely credible. Governments and even nations are most likely to face threats to their very survival in unstable areas. As previously noted, a regime in extremis is unlikely to be inhibited by safeguards or other nominal disincentives to proliferation. In such an area, there may also be more than the usual quota of extremely ambitious or fanatic leaders—with indeterminant but unreassuring implications for proliferation. Such areas have the added liability of possibly being the focus of U.S,-Soviet rivalry, with the consequent danger that the superpowers will be tempted into a competitive dilution of safeguards requirements in the quest for regional influence. Finally, the notion of special safeguards is inherently discriminatory, i.e., it contravenes the concept of uniform safeguard standards uniformly applied which underlies all blueprints for multilateral export controls. If the principle of uniformity is eroded by special exceptions, it will be difficult to avoid a competitive erosion of safeguards by suppliers.

Assistance Regarding Non-Nuclear Energy **Sources**

Nonproliferation will be abetted to the extent that potential Nth countries can be induced to rely upon non-nuclear energy sources. There are both general and specific policy initiatives available to the United States for this purpose. Items in the former category include:

- R & D programs regarding energy systems appropriate to the decentralized, low capital, low maintenance requirements of the less developed countries.
- International collaborative efforts to explore the potential of conservation and renewable energy sources. Recent proposals for an international energy conference would be appropriate in this regard.
- Establishment of an International Energy Institute (possibly as an IAEA adjunct) to serve as an ongoing institutional focus of such efforts.

More country-specific steps might include:

- Assistance to individual governments in assessing their present energy needs and in devising energy development and delivery strategies.
- Technical assistance in developing whatever non-nuclear energy sources are most appropriate to a particular country's situation.
- Steps to ensure that foreign assistance and export credit arrangements are equally favorable for non-nuclear and nuclear energy sources. In each of these instances, preference could be accorded those states prepared to accept export restraints.
- Guaranteed supplies of U.S. coal.

The impact of these measures could be enhanced if some means were devised to assist nations choosing among nuclear and non-nuclear energy sources. This might involve creating a new international organization, possibly as an adjunct to the World Bank, which would systematically assess the comparative technological, economic, and administrative characteristics of alternative energy systems and provide technical assistance to requesting countries. That assistance could take three forms: a data bank, help in evaluating the relative utility of alternative systems in terms of specific national requirements and characteristics, and assistance in constructing the system or systems selected. If such a process helps stimulate increased interest in, and reliance on, non-nuclear energy sources, the pressures for proliferation may be eased.

Critique.—While development of non-nuclear energy sources has clear utility with regard to a diversion route to proliferation, its relevance to dedicated facilities and purchase/theft routes is less direct. Similarly, to the extent that proliferation is motivated by such factors as national security and prestige, provision of alternative energy supplies will be an ineffective response.

Technological Measures

It is clear from chapters VII and VIII that there is no "technological fix" that can eliminate the proliferation problem. Nevertheless, technological barriers can be raised both by enhanced safeguards and by an emphasis on nuclear systems that are inherently less vulnerable to diversion.

Safeguards technology could be quickly upgraded by both the IAEA and NRC. Possible improvements include a more extensive use of multiredundant cameras, seals, and portal monitors, with full-time remote alarm systems monitoring by inspectors. Controls to prevent procedural lapses can be made more stringent; no safeguards system can be fully effective if the equipment is inadvertently left off or doors left unlocked.

A new generation of safeguards technology now under development also shows promise. This includes advanced versions of seals, cameras, isotopic analyzers, and portal monitors. Real time accounting systems would also enhance the timeliness of detection at reprocessing plants.

Development and implementation of new reactor and fuel cycle systems that are inherently less vulnerable to proliferation will be more difficult and take longer than developing new safeguard systems. The first step might be to redesign the LWR core of existing reactors for a throwaway cycle. Changes in enrichment or core design could optimize performance for a cycle without reprocessing. The HTGR might also be considerably improved from a nonproliferation standpoint if designed for low enriched (6 percent) fuel. A cycle using denatured UPSS in LWRS coupled with multinational reprocessing and breeding centers appears to substantially reduce opportunities for diversion, Reprocessing could be made less vulnerable if techniques such as coprecipitation are used. The gas-core nonproliferation reactor mentioned in chapter VII seems to have the greatest promise of all technological developments, but is also one of the most problematical. Thorium thermal breeders are clearly superior to the plutonium fast breeders in resistance to diversion.

Most of these R & D programs could be performed quite effectively by ERDA or NRC if they are given the mandate. International implementation may be considerably more difficult. The IAEA is bound by present agreements as to the level of safeguarding. Improvements in existing equipment can be made fairly easily, but such modifications are subject to negotiation with the host country. New reactor systems would have to be clearly superior to existing or planned systems on many counts besides nonproliferation before other suppliers would turn to them.

The most difficult question concerns the LMFBR. It is a nearly ideal instrument for the production of large quantities of high-grade SNM, It may also be the best hope for virtually unlimited quantities of moderate-priced energy. A fundamental reassessment of the entire LMFBR program on an international scale may be warranted, but given the enormous effort already invested in this enterprise, any reexamination will encounter major political, bureaucratic, and budgetary obstacles-side from the technical questions of reactor design.

Strengthen the Nonproliferation Regime

The NPT constitutes the centerpiece of what may be labeled the international nonproliferation or safeguards regime. The treaty is not without its critics—including those governments, like India and Brazil, which have refused to become signatories. The most persistent objection by the non-nuclear states is that the treaty is inherently discriminatory, allocating the bulk of obligations to the nonnuclear weapons states and the privileges to the nuclear weapons countries. Other critics, generally within the nuclear nations, have complained that the safeguards system provided for in the treaty is too weak to provide an effective barrier to proliferation. They note that a number of Nth countries have not ratified the NPT, nor are they likely to do so. Even with regard to NPT parties, constraints upon the IAEA with regard to inspector access, the lack of power to search for clandestine facilities and stockpiles, and the inability to pursue and recover stolen material leave the present safeguards system with limited authority.

Policy proposals for strengthening the nonproliferation regime are diverse and reflect each of these viewpoints. The first four subheadings that follow address ways of making the Treaty more attractive to non-nuclear states. The next three constitute means of strengthening the Treaty's control aspects, and the last three fall in a gray area between these two categories.

Nuclear States Arms Control

The nuclear weapons states have a commitment under the NPT to "pursue negotiations in good faith on effective measures relating to the cessation of the nuclear arms race at an early date and to nuclear disarmament", including a Comprehensive Test Ban. At a minimum, this would seem to require both an agreement in the next round of SALT negotiations providing for some actual reduction in armaments, and a ban on underground nuclear explosions. The apparent relaxation of Russian opposition to onsite inspection offers grounds for some optimism concerning a test ban.

Improve the Benefits Available to an NPT Signatory

The United States has taken a few steps in the direction of preferential treatment for NPT parties since late 1974, in the areas of IAEA medical research and technical assistance programs. Article IV of the NPT recognizes the "inalienable right" of all parties to full participation in all peaceful nuclear activities. The same article obligates those parties "in a position to do so" to contribute to civilian nuclear applications in the non-nuclear states, with particular attention to the needs of the developing countries. In practice, however, the nuclear nations have provided more nuclear technology and materials to states which are not full parties to the NPT (e.g., Israel, Egypt, Saudi Arabia, India, Pakistan, Brazil, and Argentina) than to the signatories. If adherence to the treaty is to be made more attractive, this situation must change, Equipment, materials, services, information, and technical assistance would be provided on a preferential basis—including concessions or other appropriate financial arrangements—to NPT parties.

Evaluate Peaceful Nuclear Explosions (PNEs)

The NPT contains a provision that "benefits from any peaceful application of nuclear explosions will be made available to non-nuclear weapon states party to the Treaty . . . through an appropriate international body. " This paragraph has been inoperative, primarily because of differing perceptions of the value and practicality of PNEs. To resolve the issue, it has been suggested that an international moratorium on PNEs be instituted pending the completion of a study on their desirability by the U,N. Secretary General or some other neutral and prestigious entity. An international institutional framework could be created, depending upon the outcome, to provide and regulate PNE services or to ban them altogether.

Enhance the Role of the Non-Nuclear States

Participation by non-nuclear weapon states in decisions concerning peaceful nuclear activities—within an international or multinational framework—may be enhanced in order to reduce the sense of discrimination many of them feel under the NPT. Means to achieve this end are described below.

Link Nuclear Exports to NPT

Another previously mentioned means of strengthening the NPT regime involves a link between nuclear nation exports and the Treaty, i.e., a condition for the export of nuclear materials and technology would *be* adherence to the NPT by the importing state. Alternatively, the nuclear weapons states could decide to permit exports of nuclear materials and technology to non-NPT signatories only if they accept the application of IAEA safeguards, both to the imported material and to all nuclear facilities and activities within their borders,

Link Economic Aid to NPT

On a broader level, it has been suggested that the United States and other industrialized countries condition all their economic assistance on the recipient nation's adherence to the NPT, and agree to curtail all exports of nuclear fuel, technology, and facilities to any NPT party found in violation of the Treaty. This would complement a general tightening of safeguard requirements on exports by nuclear supplier nations, (See above for a discussion of export controls.)

Strengthen IAEA Safeguards

IAEA safeguards constitute another important dimension of the nonproliferation regime. The ideal safeguards system would provide a universal and uniform set of requirements, standards, and procedures both for international exchanges of nuclear materials and technology and for national nuclear energy activities. Although the ideal probably remains beyond reach, a significant upgrading of the existing system can be envisioned.

- Assure that IAEA funding, staffing, and technical competence are augmented at a rate commensurate with the global expansion of civilian nuclear energy production. This will require, inter alia, a high-quality recruitment and training program for inspectors and salaries sufficient to attract the best people available. It may also require a substantial and sustained increase in U.S. financial support for the Agency.
- Develop new funding mechanisms to augment existing annual assessments and voluntary contributions, e.g., an IAEA tax levied on the output of all nuclear powerplants.
- Provide the IAEA with authority to search for "undeclared" nuclear facilities, i.e., to conduct unannounced field investigations with full access to the territory of non-nuclear states. The Treaty of Tlatelolco[2] provides a possible model in this regard. With regard to "declared" facilities the objective would be to secure maximum inspection frequencies and access rights for inspectors. In the case of reprocessing facilities, resident round-the-clock inspection will be necessary.
- Obtain the agreement of the U. S. S. R., France and China to allow IAEA inspection of their civilian nuclear facilities—inspection of U.S. and U.K. facilities has already been authorized in principle.
- Extend the application of existing safeguards to prevent the acquisition, through imports or diversion, of plutonium for military non-weapons purposes (e.g., a nuclear submarine propulsion program).
- Consider a U.N. General Assembly resolution calling for political sanctions against NPT violators, e.g., a suspension of the offending country's membership in the United Nations and its specialized agencies.
- Seek prior international agreement on a common plan of action and graded sanctions to be applied in the case of a safeguards violation or the abrogation of an agreement. The present limited repertoire of sanctions available to the IAEA would be strengthened.
- Institute a standard text for multilateral and bilateral safeguards agreements, as

[2]The Treaty of Tlateloleo (The Treaty of the Prohibition of Nuclear Weapons in Latin America) was opened for signature in 1967. It establishes the first nuclear-weapon-free zone in a densely populated area. The treaty has been ratified by 21 Latin American states. In addition the United States, Great Britain, France, and China (but not the U. S. S. R.) have signed Protocol II whereby they pledge themselves to respect the zone and not to threaten to use nuclear weapons against countries within it.

was done in the case of NPT safeguards agreements. Such standardization would be an essential concomitant of any effort by the supplier states to require recipients to submit all their peaceful nuclear activities to safeguards.

- Improve the interface between IAEA safeguards and national materials accounting systems, e.g., by developing and applying standardized measuring and accounting systems.
- Develop improved standardized seals and monitors, and lift current restrictions on operation of cameras and recording devices.
- Reserve U.S. safeguard rights with regard to American nuclear exports as a fallback to international safeguards.

Expand IAEA Functions

In addition to strengthening the IAEA's capability to perform existing safeguard tasks, the Agency might be upgraded through the assignment of new or expanded functions. These might include the following:

- Develop techniques and facilities for the international transport of nuclear fuel, waste storage and disposal, and storage of excess plutonium in conjunction with national governments.
- Draw up standards for the design, construction, and operation of reactors and other fuel-cycle facilities.
- Establish and manage an international storage regime for fresh and spent fuel.
- Develop safety, environmental, and health standards for multinational fuel-cycle facilities (parks),
- Establish standards and designs for physical security systems and devices. The agency might provide physical security for its own facilities, and evaluate and approve the plans of individual countries for national facilities.
- Provide technical assistance, including applied research services, to civilian nuclear programs in the less developed countries.
- Provide an international clearing house both for nuclear energy and safeguards data and technology.
- Assess the environmental effects of nuclear facilities near international boundaries.

Intelligence Capability

A necessary, though not sufficient, condition for an effective nonproliferation regime is possession of timely and accurate information about actual or prospective proliferation. Safeguards are designed to provide this information with regard to diversion of SNM. Efforts to foreclose dedicated facility and purchase-theft routes to proliferation will necessitate some reliance upon covert intelligence-a capability that rests almost entirely with national governments. The principal sources of information in this area include political reporting from embassies, other human intelligence, monitoring of communications, overflights, and satellites. For example, one method of trying to detect a clandestine reprocessing facility consists of atmospheric sampling for Krypton–85. The adequacy of the existing U.S. (and foreign) capability in this field cannot be judged without extensive access to classified material. Clearly, however, an effective nonproliferation policy will require an intelligence capability sufficient to cope with the magnitude of the threat at any particular time. Moreover, if effective international (as opposed to merely national) responses to clandestine proliferation are to be developed, some sort of pooling or coordination of nuclear intelligence may be necessary.

Nuclear Free Zones

Nuclear Free Zones constitute another approach to strengthening the NPT regime. They totally ban the presence of nuclear weapons within the prescribed geographical area. Although a large number of such zones have been proposed, the only one presently in existence applies to Latin America under the Treaty of Tlatelolco. Whereas the NPT is seen as a product of the great powers, most nuclear free zone proposals, including that for Latin America, have been initiated by the non-nuclear states of the region concerned-a political fact of some importance. A nuclear-free zone proposal has some chance of success if it enjoys general acceptance in the area concerned, does not significantly alter the regional balance of power, and is based on a genuine search for common interest. At present, only portions of Latin America, Africa (excluding Egypt and South Africa), and possibly Southeast Asia fulfill such criteria.

Critique

Formidable political obstacles will confront efforts to implement many of the above proposals. Nationalism will pose a formidable barrier to the intrusion of an international agency in search of undeclared facilities, and political resistance on the part of the Soviet Union, France, and China to proposals for IAEA inspections may be insuperable. The political difficulties involved in coordinating policies among nuclear exporters and in imposing conditions upon importing countries have already been noted. Similarly, agreements to coordinate nuclear intelligence on the part of two or more governments will require political and diplomatic acumen of a high order. Any attempt to penalize an NPT violator by suspending it from membership in the United Nations and its related agencies carries with it the danger of weakening what global institutions we have. It must be noted, however, that the international community has demonstrated an increased willingness to take that risk with regard to some of the present Nth countries, e.g., South Africa and Taiwan. As the recent Senate confirmation hearings on the new Director of the Arms Control and Disarmament Agency suggest, arms control agreements that successfully bridge the gap between international adversaries and domestic constituencies are extraordinarily difficult to negotiate. The fact that only one partial nuclear free zone agreement has been achieved despite a profusion of proposals is indicative of the difficulties of overcoming divergent political interests and outlooks, Finally, the success of efforts to bolster IAEA safeguards with new and stronger sanctions will depend on whether governments have the political will to take action when a violation is detected. As of yet, that will remains untested.

These problems reflect a basic political reality—the weakness of international organizations within a nation-state system. Safeguards can presently be applied only with the cooperation of the subject state; they cannot be imposed. Truly compulsory safeguards would require a substantial diminution of sovereign prerogatives in the nuclear field-a formidable task. In fact, the IAEA may be hardpressed to simply maintain its existing technical standards and integrity in an international environment conditioned by political pressures and constraints.

The difficulties with proposals to bolster the nonproliferation regime are not all political. The assumption concerning a link between horizontal and vertical proliferation, which underlies the arms control proposal outlined above, cannot be verified. All that can be said with certainty is that a number of non-weapons countries have cited continued vertical proliferation as grounds for possibly reevaluating their commitment to the NPT. At a minimum, successful SALT and CTB agreements would remove one possible justification for an Nth country selecting the nuclear option. Proposals to study PNEs also raise grave doubts in the minds of many who see this as injecting new life in a concept which is slowly dying a well-deserved death. It can be persuasively argued that the best approach to PNEs is to continue efforts to convince non-weapons states that such devices hold no benefits for them.

Global and Regional Arrangements

Until very recently, the bulk of the policy proposals designed to curb proliferation have fallen in the category of negative or denial strategies. There is a growing recognition, however, that any durable solution to the problem will have to be built on an affirmative, voluntary consensus. Suggestions regarding how such a consensus may be achieved have centered on proposals for multinational or international control over various phases of the nuclear fuel cycle.

International Management

A recent blueprint for internationalization proposed the following steps to be accomplished sequentially:

- International management and control of reprocessing, plus international regulation and protection of plutonium transport.
- Creation of an international PNE facility, to explore the utility of this technology and to provide PNE services to non-nuclear nations if and when they prove feasible and useful.
- Definition of enriched uranium and plutonium as international "public goods" to be produced only under international licensing and regulatory authority. Such a step would become possible only with the prior ending of production of all fissionable material for military purposes.
- Management of enrichment facilities as an international public utility with national facilities operating under international license and regulation.

Multinational (Regional) Fuel-Cycle Facilities

Proposals for multinational arrangements tend to emphasize the creation of regional nuclear fuel-cycle facilities or "parks" in which critical elements of the fuel cycle would be colocated. Precedents already exist in Europe for multinational enrichment and reprocessing facilities. With their regional emphasis, proposals for multinational arrangements can be regarded as a half-way house between bilateralism and internationalism. Multilateralism and internationalism are not mutually exclusive, and the concept of collocation plays an important part in both.

The advantages and limitations of multinational centers are analyzed in chapter VIII. Two features deserve further emphasis, however.

First, by calling for joint participation and shared responsibility by nuclear and non-nuclear states in the international or multinational management of nuclear activities, these approaches offer to correct the discrimination and paternalism which burden the existing NPT regime. In exchange for an agreement to forgo the nuclear weapons option the non-nuclear nation is offered a seat at the top table of nuclear institutional diplomacy. Durable nonproliferation becomes possible if the nuclear nations are willing to pay for it in the coin of shared power and prestige. The underlying assumption is that the nationalistic desire for equality and status will be a principal motivation for future proliferation, nuclear weapons being valued primarily for their political impact as symbols of power and modernity.

Second, multinational and international arrangements are also synonymous with strategies of interdependence, as opposed to "independence" (autarchy), in the effort to meet global energy needs. This has crucial implications for nonproliferation. The effectiveness of IAEA safeguards will be greatly augmented if the electric power of the nation being safeguarded is dependent on outside services or supplies. With a nation's power supply hostage to good behavior, few, if any, other nonproliferation sanctions would be required.

Critique.—The difficulties which will be encountered in any effort to internationalize management and control of civilian nuclear activities are self-evident. Internationalization will require a substantial derogation of national authority over a matter generally considered to be among the most vital of national interests-energy supply. A decision by the U.S. Government to move decisively in this direction would require considerable courage and imagination.

Regional fuel-cycle facilities would encounter many of the same difficulties, although they might not be as severe,

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Regional arrangements would generally not run as clearly contrary to nationalistic tendencies and might not arouse the same degree of opposition from industrial and commercial interests that internationalization probably will in some advanced nuclear nations. Nevertheless, even where the objective is accepted in principle by all the major participants in a multinational enterprise, major disagreements can arise. These may concern, inter *alia,* allocation of production benefits and management/operations responsibilities, wide variations in industrial and industry-government relations within countries, technology transfer, and waste disposal, A fundamental problem of multinational facilities involves siting. Participating nations may feel they are less than full partners if the facility is located in another's territory. Moreover, the concept has encountered skepticism from some Third World states uncomfortable with the complexity of such centers and suspicious that these facilities will be dominated by the advanced nuclear supplier countries. With all this in mind, it may be advisable to confine the first multinational centers to one stage in the fuel cycle, possibly spent-fuel storage. This would provide a relatively modest and noncontroversial means of testing the viability of the concept. An interim measure might involve designating existing storage sites in the supplier states as IAEA repositories under the Agency's management.

Measures Concerning Non-State Adversaries (NSAS)

The emergence of international terrorism by non-state entities in recent years has spawned nightmare images of nuclear highjackings and blackmail. The danger is increased by the fact that IAEA safeguards are not designed to deal with such a threat. Existing physical security measures are inadequate in many countries, and there are no agreed standards or methods to which such measures must conform. To deal with this situation, initiatives in at least four areas bear consideration:

- Creation of a U.S. technical assistance program for other nations, designed to upgrade their physical security measures;
- Negotiation of a convention establishing uniform international standards and methods with regard to physical security devices;
- Negotiation of an international convention to control terrorism and hijacking;
- Consideration of steps which might be taken to alleviate the grievances of dissident groups with terrorism potential; and
- Contingency planning with regard to actions which might be taken in response to an actual NSA event.

Critique. -Of these four proposals, the last three pose special difficulties. The United Nations has been the scene of strenuous efforts for several years to negotiate an international convention against terrorism—without success. If a more explicit link develops between terrorism and nuclear proliferation, perhaps the situation will change. Attempts to satisfy the grievances of radical groups are fraught with the danger of blackmail, but the matter may still be worth exploring, Possible responses by governmental authority after a nuclear incident pose another potential peril—to civil liberties.

Policy Implementation

Thus far we have presented a taxonomy and analysis of available policies under three basic perspectives. The next logical step is to order those policies in terms of their priority, or the logical time sequence in which they might be addressed. What follows is a sample categorization of available policies arranged in terms of a three-stage time sequence. The criteria for distinguishing between the categories are urgency, time required for implementation, and feasibility (in terms of technical difficulty, economic and political cost, time required, and whether the desired initiative can be taken unilaterally by the United States or requires collateral actions by other governments). Stage I, for example, includes items judged to be urgent and feasible at a relatively low cost in the near term. They tend to require initiatives that the United States can take

Figure III-1 Previous Policy and Future policy **Priorities**

Previous Policy ("The basic premise of U.S. nuclear cooperation for over 20 years has been worldwide cooperation in the peaceful uses of nuclear energy under effective controls.")

- Weaken incentives of Nth countries
  - mediation of disputes
  - security guarantees (limited)
  - maintain high technical and economic costs of nuclear option
- Sanctions: political pressures (selective)
- Strengthen national intelligence capabilities
- Export controls (seek agreement with other vendors):
  - ban on export of facilities or technology for enrichment or reprocessing
  - exports subject to IAEA safeguards
  - ban on reexport of exported fuel and facilities
  - require importers maintain adequate physical security measures
- Prohibitions against use of assistance for any nuclear explosions
- Encouragement of multinational regional facilities concept
- Support for NPT and IAEA

Stage I

- Export Controls
- Enrichment
  - reliable supplier
  - fuel services (e.g., spent-fuel storage)
- Strengthen national intelligence capabilities
- Forego plutonium recycle

Stage II

- Contain plutonium recycle (If rejecting Pu recycle proves infeasible)
- Weaken incentives
  - non-use pledge regarding non-nuclear weapons states
  - security guarantees
  - reduce the prestige and symbolic importance of nuclear weapons
- Strengthen disincentives
  - strengthen the international political norm against proliferation
  - strengthen anti-proliferation domestic political forces
- Neutralize non-state adversaries
- Assistance regarding non-nuclear energy sources
- Strengthen the nonproliferation regime
  - more adequate implementation of SALT and CTB agreement
  - study of PNE practicability
  - increased participation indecisions concerning peaceful nuclear activities by non-nuclear states within an international framework
  - link U.S. nuclear exports to NPT adherence
  - nuclear free zones
  - increase benefits of NPT adherence
  - strengthen IAEA safeguards capabilities
- Sanctions
- International spent-fuel storage regime

Stage III

- Global and regional arrangements
  - enriched U and Pu as international "public goods"
  - enrichment plants as international public utilities
  - MNFCFS
  - international reprocessing facilities

SOURCE: OTA

Figure III-2.

Scope for Congressional Action
(legislative and budgetary powers)

- Export Controls
  - Criteria (require, resolve/reoommend)
    - Unilateral and multilateral
    - Immediate and delayed
    - New and old bilateral agreements (i.e., renegotiation requirements)
    - Licensing procedures
  - Sanctions
    - Unilateral
    - Multilateral
  - Organizational authority and responsibility
    - Establish presidential authority to change or delay application of criteria
    - Executive branch authorization/veto
    - Executive branch reorganization and allocation of authority
    - Congressional review export decisions (licensing)
  - International Negotiations
    - Resolutions re bilateral and multilateral agreements
    - Content
    - Timetable
  - Allocate negotiating authority among executive departments
  - Require reports to Congress re negotiating progress
- Statements of U.S. Policy ("sense of Congress")
- Arms Control and CTB
  - Resolutions
  - Senate Treaty Approval/Disapproval
- U.S. as a Reliable Supplier
  - Enrichment capacity appropriations
  - Commercial reprocessing appropriations
  - Privatization
- Improve International Safeguards
  - Appropriations to strengthen IAEA
  - Appropriations for ERDA safeguards and physical security training and R & D
- Investigations of Executive branch performance
- Plutonium Reprocessing
  - Authorize or reject budget support
  - Licensing

SOURCE: OTA

unilaterally. Stage I focuses on export controls and services intended to forestall developments that might make proliferation unmanageable in the short term; Stage 11 on establishing an international political climate conducive to nonproliferation and to strengthening the NPT framework; and Stage 111 on multinational and international arrangements.

Figure HI-3. Selection Criteria for Policy Priorities

Policy	Urgency	Time Required	Feasibility	Stage
Export Controls	1	1	2	1
Enrichment — reliable supplier —fuel services	1	2	2	1
Strengthen National Intelligence Capabilities	1 (?)	1 (?)	1(9)	1(?)
Forego Pu Recycle	1	1	1	1
Contain Pu Recycle	2	2-3	2	2
Weaken Incentives — non-use pledge — security guarantees — reduce prestige of nuclear weapons — strengthen security of nth countries through alliances etc.	1	1-2	3	2
Strengthen Disincentives —strengthen international political norm —strengthen anti-proliferation domestic political forces	1	2	2-3	2
Non-State Adversaries	2	2-3	1-2	2
Assistance re Non-Nuclear Energy Sources	2	2	1	2
Strengthen NPT Regime — increase benefits of NPT adherence —strengthen IAEA safeguards capabilities —implement SALT and CTB — increase participation in international decisions re peaceful nuclear activities —link U.S. exports to NPT — nuclear free zones — PNE's	2	2	1-3	2
Sanctions	2	2	3	2
International Spent Fuel Storage Regime	2	2	3	2
Global and Regional Arrangements — international reprocessing facilities — enrichment plants as international public utilities — MNFCF'S — enriched U and Pu as international public goods	3	3	2-3	3

SOURCE: OTA

CONCLUSIONS

The preceding discussion indicated that a broad range of general and specific policy options are presently available to help control proliferation. Major options may soon be foreclosed by projected growth rates in the global nuclear industry, trends in international politics, and imminent technological innovations. It will constitute a major failure of our public institutions if the choice is made by default—a mindless product of the course of events. Where the stakes are so high, policy must be conscious, informed, and deliberate.

There is, as yet, no consensus regarding such basic issues as the role of nuclear power in meeting future global energy needs, the relationship between civilian nuclear power and proliferation, and the implications of proliferation for U.S. national interests. Different judgments on these issues will lead to different perspectives concerning the overall problem and different policy prescriptions.

Despite this lack of consensus, some general propositions concerning policy can be identified:

- There is scope for policy; proliferation is still amenable to an intelligent, determined response, A permanent cutoff at the present number of nuclear weapon states is probably unachievable, but a curtailment after two or three additional states is not.
- There is no single solution, no short cut. An effective policy response to proliferation must be devised along political, economic, institutional, and technological dimensions. Such a policy will require unilateral, bilateral, multilateral, and international approaches.
- Because there is no generic Nth country, a nonproliferation policy must be country-specific to a significant degree. In this regard, the State Department might develop (and keep current) a nonproliferation strategy paper for each Nth country.
- Solutions will have to be found primarily, though not exclusively, through multilateral actions. The scope for effective unilateral action by the United States is declining as part of a relative diminution of U.S. global influence and its fading preeminence in the international market for nuclear reactors, fuel, and fuel services. Nevertheless, the United States is, and will remain, in a position to exert considerable influence—particularly in coordination with other suppliers. It is worth noting, in this regard, that the joint-suppliers approach has already recorded some significant achievements.
- Policy regarding proliferation will probably conflict with other foreign policy objectives, particularly concerning efforts to limit U.S. commitments overseas. A major task will be to reduce the extortion potential seemingly inherent in the possibility an Nth country might decide to acquire nuclear weapons. How this conflict is resolved will depend in large part on the relative priority assigned to nonproliferation as compared to other foreign policy concerns.
- Sanctions can serve to deter proliferation in advance and, to a much lesser extent, remedy it after the fact. But they have limited utility if applied unilaterally. Attempts by one state to coerce another almost inevitably generate resistance and a nationalistic backlash. Sanctions are more likely to be effective when applied jointly or multilaterally and when combined with incentives and inducements. When employed in such a sophisticated manner with regard to both suppliers and/or users, sanctions can contribute importantly to a nonproliferation policy.
- There is no nuclear system or technological device available now or under development which can, in itself, prevent proliferation. There has been little effort in this direction, however, and potential

technological innovations can contribute importantly to a solution. Promising areas for research and development include nonproliferating reactors (e.g., gas core), uranium-thorium cycles, and safeguard systems integrated into the design of the plant.

- A decision with regard to closing the nuclear fuel cycle (i.e., reprocessing and recycle) has profound implications for nonproliferation policy. Three basic policy options confront the United States with regard to reprocessing: (1) whether to initiate domestic reprocessing; (2) whether to export reprocessing facilities and technology (under safeguards), and; (3) whether to discourage reprocessing exports by other suppliers. Dissemination of reprocessing facilities to nonweapon states will not only give their operators the means to produce weapons material, but also will reduce their vulnerability to international sanctions. If reprocessing spreads to a large number of countries and plutonium becomes a common article in international commerce, opportunities for proliferation will be unavoidable, Whether an international agreement to control reprocessing will require suppliers to forgo their own domestic reprocessing is a matter still in dispute. A viable compromise between national reprocessing and no reprocessing might involve multinational fuel-cycle facilities.

- An effective policy designed to prevent proliferation through diversion or takeover of civilian nuclear power facilities will include arrangements for the return of plutonium-bearing spent fuel. Methods include fuel leasing, buyback, and exchange. Serious consideration will have to be given to the possibility of making the return of spent fuel a requirement of all bilateral and international nuclear assistance agreements. This in turn will necessitate the development of codified "rules of return. " Spent fuel collected by the United States could be stored in IAEA-maintained repositories, as envisaged in Article XII (a) (5) of the Agency's statute.

- If the incentive for other nations to acquire national reprocessing plants is to be reduced, the United States will have to establish itself as a "reliable supplier" of low-enriched uranium. Other suppliers could be encouraged to take similar steps. Reliable supplier status presupposes a willingness to enter into binding agreements both to provide uranium enrichment services and to construct any additional enrichment capacity required. The more attractive the terms under which enrichment services are offered, the more likely their success in forestalling national facilities.

- The decision to accord the breeder reactor high priority in government-sponsored R & D will have to be carefully reconsidered in light of its proliferation implications, The unfavorable characteristics of the breeder from a proliferation standpoint will have to be weighed against its potential as an energy source in determining the future of the program.

- It may be necessary to establish new institutional structures on the international level to:

  —manage selected stages in the nuclear fuel cycle;
  —govern future user-supplier arrangements;
  —implement sanctions and possibly facilitate cooperation in the detection of violations;
  —provide nonweapon countries with an opportunity for participation and influence in the international development of civilian nuclear energy.

- Although the exact relationship between vertical and horizontal proliferation is uncertain, progress on arms control by the weapons states could remove an incentive, or at least an excuse, for proliferation.

- Policy regarding proliferation must be formulated in conjunction with national security, foreign, and energy policies. It will also cut across the division between domestic and foreign policy. Consequently, it is important to determine the priority to be accorded proliferation concerns as compared to major issues within these other policy areas.

- No system of safeguards against diversion is perfect. A good safeguards system can raise the costs and risks of diversion to the point where it becomes unattractive to a potential proliferator compared to other routes.
- The NPT remains an important component of an effective nonproliferation policy. The fact that there have been no known violations of the Treaty suggests that it acts as an important political constraint upon Nth countries. It also provides an agreed framework of mutual rights, obligations, and expectations constituting a basic bargain between supplier and user states.
- An effective nonproliferation policy will be expensive. Some items:
  - —lost revenues from providing uranium enrichment services at nonprofit or concessionary terms;
  - —costs of fuel buy-back;
  - —costs associated with re~'recessing moratoriums or abandonment (including waste management);
  - —compensation to Brazil and Pakistan in return for voiding reprocessing contracts;
  - —lost revenue from foregone exports.
- A viable nonproliferation policy will have to determine how these costs are to be allocated. It should be noted, however, that because the economics of reprocessing are unclear a reprocessing moratorium might save more money than it would cost.
- The United States should make contingency plans to deal with nuclear thefts, extortion attempts, and other nuclear emergencies due to the activities of terrorists and other non-state adversaries.

This chapter began by outlining three perspectives toward proliferation and energy, From a policy makers viewpoint, the implication of the Energy Priority Perspective is that the problem, while significant, is not of compelling importance. Consequently, there is only a modest need for policy devoted exclusively to containing proliferation. The Nonproliferation Priority Perspective, on the other hand, assigns the highest importance to such a policy. Virtually, all of the measures discussed in the preceding policy inventory would be endorsed by proponents of this outlook. But, at the same time, these measures would be condemned as inadequate; policy must go much further to encompass the actual curtailment of the nuclear industry.

Both the Ford and Carter Administrations have developed policies based explicitly or implicitly, on the Shared Priority Perspective. Thus, the present Administration has set as its dual objective obtaining the benefits of the peaceful atom while preventing proliferation. This is an immense and complex task with a successful outcome anything but assured.

Still, the broad components of a policy to control proliferation are reasonably clear. There would be steps designed to tip the balance of incentives and disincentives confronting potential weapon states in favor of disincentives. This would be an attempt to modify the political calculus governing Nth country policy-making. Efforts would be made to develop a comprehensive international safeguards regime, sufficient to virtually foreclose the diversion route to nuclear weapons, The viability of safeguards rests on the belief that any violation will entail high political and other costs. Consequently, safeguards serve as a close complement to disincentives. Export controls, particularly with regard to enrichment and reprocessing capabilities, would be instituted in conjunction with arrangements for the return of spent fuel to the supplier or an international repository, Such restraints serve to restrict a nation's physical access to sensitive nuclear materials. As such, they erect obstacles to the construction of dedicated facilities and reinforce the impact of incentives, disincentives, and safeguards. Sanctions would be devised to deter and even reverse proliferation occurring by any route. Sanctions would thus serve as a backup to each of the controls listed above, as well as a deterrent to future would-be proliferators. Technological remedies would be explored, including alternate fuel cycles, nonproliferating reactors, and more sophisticated safeguards equipment. Finally, these initiatives will require a broad range of supportting domestic and foreign policy actions, including steps to upgrade physical security measures, expand reactor-grade uranium production, and emphasize arms control negotiations.

Chapter IV

Incentives and Disincentives for Proliferation

Chapter IV

Incentives and Disincentives for Proliferation

An analysis of proliferation suggests a number ot broadly applicable incentives and disincentives for acquiring a nuclear weapons capability. The usefulness of those generalized incentives (or disincentives) for gaining insights into the motivations of specific Nth countries varies from country to country. Moreover, such a list can be representative, but not exhaustive. In the majority of instances, however, the decision to proliferate will, explicitly or implicitly, be based on some composite of the factors listed below. This composite varies over time with the unique characteristics of each country and the evolution of its national affairs.

Before examining general incentives and disincentives it may be helpful to identify specific countries of particular importance in assessing the past and future course of proliferation. This includes states in three categories: weapon states, major refrainers, and Nth countries. The list of countries under the latter two headings is necessarily selective.

Weapon States	*Selected Major Refrainers*	*Selected Potential Weapon States (Nth Countries)*
Us.	Sweden	Argentina
U.S.S.R.	Japan	Brazil
UK	Fed. Rep. of Germany	Israel[a]
France -		South Africa
China		Iran
India[b]		Pakistan
		Taiwan
		South Korea

[a] Widely reputed to already possess one or more weapons.
[b] Has exploded a nuclear device but apparently has not converted that device into an actual weapon.

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GENERAL INCENTIVES

Deterrence

The primary incentive for many states to acquire nuclear weapons would be to deter external efforts to undermine or destroy the existing regime or governmental system. A state would have a particularly strong incentive to acquire a nuclear capability if it feared it could not succeed in sustaining its independence by conventional military or diplomatic means. Several countries on every list of potential new nuclear weapons states (e.g., South Korea, Israel, and South Africa) have had reason to fear direct attack or long-term deterioration of their security *vis-a-vis* non-nuclear neighbors or regional adversaries. On the same list are other countries (e.g., Taiwan and Pakistan) that are concerned about threats to their security from states that have demonstrated a nuclear weapons capability.

For many Nth countries, the effectiveness of nuclear weapons as a deterrent to adversaries seem questionable. This is because of the likelihood that a small number of nuclear weapons would have limited effectiveness in regional conflicts between Third World states. This would seem particularly true where the bulk of the population is dispersed in rural villages and where the terrain lends itself to small unit guerrilla-type operations.

Despite such considerations, the relatively less sophisticated political and military strategies of the majority of Nth countries do not preclude the acquisition of a capability for deterrent purposes, one that U.S. analysts would judge as ineffective by Western standards.

Increased International Status

There can be little doubt that a nuclear weapons capability is an important symbol of modernity, technological competence, and thus a source of status and prestige. In a world in which a minority of states control most of the wealth, power, and expertise, the rest struggle for economic independence, self-respect, and a place in the sun. Nuclear weapons may serve to bolster a nation's self-confidence and win respect from or engender fear in neighbors, adversaries, and the world's great powers. By some readings, though not all, the single Indian explosion contributed materially to many of these objectives.

Aside from its symbolic significance, a nuclear weapons capability may also be an actual source of power. Over time a new nuclear state could probably increase its influence within regional security arrangements, in U.N. Security Council and General Assembly deliberations, and other international forums. This would probably not happen rapidly or by conscious choice of other participating states, Instead, it would be a rather natural evolutionary result of enhanced prestige and subtle alterations in the psychological orientation toward the emergent nuclear nation. The translation of military power into political power may be gradual and subtle, but it is real nonetheless.

Domestic Political Requirements

This point is closely related to the preceding in that international status can serve to bolster a government's domestic political standing. Moreover, the demonstration of technological and administrative achievement associated with the construction of nuclear weapons may offset or distract from the frustrations of national poverty and the difficulties of economic and political development. Benefits of a nuclear program might range from enhanced political stability to the retention of qualified scientists (not only in the nuclear field) who would otherwise be tempted to emigrate to countries with stronger scientific establishments. Many analysts have interpreted the Indian detonation as being motivated in large part by domestic political considerations.

Economic Considerations

In the past, a nuclear weapons program has sometimes been characterized as having a technology-forcing function, in that it stimulated the development of related economically beneficial technologies. This proposition carries less weight today because of the enlarged global commitment to civilian nuclear energy, i.e., the commitment to nuclear energy is adequate by itself to realize any technology spinoffs.

Economic concerns generate pressures toward proliferation in another way. In the future, some states that are unwilling to rely on the United States or the Soviet Union for security may develop global or at least continental economic interests. They may conclude that the protection of expanding economic interests requires enhanced military capabilities —including nuclear weapons. Paradoxically, the success of the development programs of some large Third World states could provide proliferation incentives as. strong as those caused by their present frustrations.

Increased Strategic Autonomy

It is a truism that sovereign states seek to achieve and maintain freedom of action, even with regard to allies. Within an alliance, a nuclear-armed nation may perceive itself (or be perceived by others) as having more options for pursuing national objectives than a non-nuclear state, This relative autonomy differs by situation and objective. It can be argued, however, that a nuclear capability generally contributes to the enhancement of strategic autonomy. This is one of the central reasons ascribed to the development of France's nuclear force.

Strategic Hedge Against Military and Political Uncertainty

Uncertainties concerning the capabilities and intentions of both adversaries and allies can generate a sense of political and military vulnerability y. States may seek nuclear weapons as a hedge against such an apprehension. Concerns about the cohesiveness of Western alliances have increased during the past decade, as there has been less convergence of political interests and increased stress due to differing economic situations and policies. The nuclear parity of the United States and the U.S.S.R. has seemingly lowered the credibility of the U.S. nuclear guarantee in many Western capitals.

"A Weapon of Last Resort"

In an extremely adverse situation where a nation is on the verge of defeat, a limited number of nuclear weapons could be used as a "weapon of last resort." The objective would be to terminate hostilities on terms other than total defeat or, perhaps, to employ punitive measures at the moment of defeat. Nuclear weapons are valued not only for their deterrent effect, but also for their actual battlefield utility. Isreal is often cited as a country which might desire (or have) nuclear weapons not to prevent the outbreak of a conflict as much as to place ultimate limits on military operations. The "weapon of last resort" concept may be the most broadly acceptable rationale for nuclear weapons because it is directly related to the survival of the nation in a specific and clearly defined situation.

As an Instrument of the Third World

Frustrated Third World nations may view nuclear weapons as "equalizers" in their relations with the industrialized world. The emergence of additional nuclear weapons states will complicate the ability of existing nuclear countries to calculate political outcomes, tending to make them more restrained when pursuing their national interests, Moreover, it is argued, concern about the escalation of a regional nuclear conflict into a global conflict will make developed countries more receptive to the economic development concerns of the Third World.

No one would pretend or expect a nuclear explosion to actually solve any of the very serious economic and social problems of the less developed countries or remove the basic inequity of the world's economic system. Still, the acquisition of nuclear weapons might be perceived by some governments and political elites as a means of commanding the attention of the industrialized world. The frustrations of national poverty and the difficulties of economic and political development might therefore prompt a government to seek a nuclear "solution. " Explicit threats to proliferate if aid or reform of the world economic system is not forthcoming seem unlikely, but not inconceivable. It is also possible to imagine a scenario in which an impoverished nuclear weapons state falls into desperate economic straits and tries to use its nuclear capability to coerce the international community into rendering aid.

Peaceful Nuclear Explosions (PNEs)

The potential benefits of peaceful nuclear explosions (PNEs) were aggressively stressed in the late 1950's in the United States. This view has been subsequently and vigorously echoed in the Soviet Union. These statements by the superpowers, coupled with the conclusions of several international conferences during the 1960's and early 1970's on the peaceful uses of atomic energy, fueled the expectation of numerous developing nations concerning the benefits of nonmilitary nuclear explosions, However, enthusiasm has waned rapidly in the United States as additional studies and tests concluded that the expense and environmental hazards of PNEs are not matched by economic or scientific benefits. The U.S.S.R. has continued a PNE program, claiming a variety of possible applications, although their enthusiasm for such a program may be declining. Despite these trends, many developing countries retain a view that the benefits of such devices exceed their costs. Consequently, the desire to obtain such benefits provides an incentive to develop a nuclear explosive capability. However, a low-technology device, which would be the initial product of a weapons program, is not credible as a PNE for cost and radiological reasons described in chapter VI.

GENERAL DISINCENTIVES

As with the preceding incentives, the general disincentives which inhibit or constrain the proliferation process apply with varying degrees of importance to any particular Nth country.

Diversion of Resources

The classic argument in developed and developing countries is that a nuclear weapons program is not an optimal use of limited national resources. The opportunity cost of foregone economic or social programs are thought to significantly exceed the benefits of acquiring nuclear weapons. The growth of the nuclear power industry and the concurrent decline in the incremental cost associated with a weapons program has tended to somewhat reduce the strength of this disincentive in many countries, Moreover, the diversion of resources argument did not prevent either the Peoples Republic of China (PRC) or India from acquiring a nuclear explosive/weapons capability.

Adverse Public Opinion

While domestic public opinion adverse to nuclear weapons development is far from universal, it remains one of the most important constraints on the acquisition of nuclear arms. Examples most often cited are Japan, Sweden, Switzerland, and Canada, The almost monolithic public opposition to nuclear weapons in Japan is attributable largely to the use of two weapons on that country during

World War II. A strong tradition of neutrality and advocacy of humanitarian ideals characterize the basis for Swedish and Swiss public opinion against the acquisition of a nuclear capability. Such traditions have also characterized India, illustrating that these constraints are not absolute but can be expected to change as national circumstances dictate.

Disruption of Assured Security Guarantees

The disruption of established security guarantees is another disincentive to going nuclear. Reliance on nuclear guarantees constitutes one of the most important elements in many national strategies for coping with the superior military capability of adversaries. In this situation, operating under the umbrella of a superpower's nuclear armaments constitutes a logical and strategically sound approach. Some proliferation analysts are concerned that the erosion of U.S. nuclear guarantee credibility (due to perceived shifts in the political will to employ a military response in situations in which the United States is not directly threatened), has decreased the strength of this disincentive.

Infeasibility of a Desired Nuclear Strategy

The inability to attain a desired nuclear weapons capability within a given time or resource limitation is another disincentive to the acquisition of nuclear arms. While a token- or modest-force deployment may have political utility in some instances, it may not solve a country's requirement of deterring a rival through deployment of a survivable second strike force. A rudimentary, highly vulnerable nuclear force usable only for a first strike may even tempt an adversary to launch a preemptive attack. Other disincentives associated with the infeasibility of a desired nuclear strategy may derive from limitations associated with delivery systems. Range, penetration requirements, and command-control limitations may lead to the conclusion that a nuclear force is not sufficiently effective to warrant development and deployment.

Adverse International Reactions

Another disincentive to proliferation could be the anticipated adverse reaction by other nations, especially the superpowers. However, the United States and the U.S.S.R. have not developed an agreed position or even made arrangements for consultations with regard to any future proliferation events. The reaction of Washington and Moscow to a near-nuclear country's crossing the threshold therefore could vary from mild to strong and positive to negative. In the case of India, the United States voiced mild disapproval but did not undertake any clearly linked diplomatic response or attempt to develop a multilateral forum for the condemnation of the act. There was no apparent condemnation from the Soviet Union at all. The lack thereof was interpreted in most quarters as a judgment on the part of the U.S.S.R. that a nuclear-armed India was a useful factor in constraining Chinese actions. Nevertheless, the prospect of a strong negative response to proliferation by one or both superpowers may restrain some of the near-nuclear countries. Fear of such an adverse response is most effective with Nth countries which are dependent to some degree upon at least one of the superpowers for military, economic, or technical aid. Judging from the Indian experience, a potential proliferator need not fear censure from the international community as a whole. If such a reaction could be expected, it might constitute a significant disincentive.

Adverse Reactions by Adversaries

One of the greatest disincentives is the anticipated response by an adversary—a response that might range from a diplomatic protest to a preemptive attack designed to destroy a nuclear weapon manufacturing capability or to inflict a military defeat. The adversary might also acquire its own nuclear force. This could be very destabilizing in a regional context, since the majority of nuclear states would probably not have the resources to develop a full second strike capability and token forces might thus encourage preemption in crisis situations.

Advocacy of Neutralist Aims

Near-nuclear countries, such as Sweden or Switzerland, that advocate neutralist positions eschew the acquisition of a nuclear weapons capability because they see it as seriously degrading the credibility of their arms control and neutralist positions. Judging from the actions of India and the Peoples Republic of China—both self-proclaimed leaders of the nonalined—the need to be consistent in this regard is questionable. New Delhi and Peking rationalized their decision to acquire nuclear-weapons with the argument that their effectiveness in arms control negotiations would be enhanced and the Third World strengthened if they possessed nuclear arms.

There is an additional concern in those Nth countries where domestic political stability is a serious problem. A national nuclear weapons stockpile would be a national target for seizure by revolutionary groups, terrorists, or coup factions. If such a group obtained possession of all or part of a nations nuclear arms, its potential for coercing the government would be very substantial.

MOTIVATIONS OF EXISTING WEAPONS STATES

General

This section reviews the motives that led the existing nuclear weapons states to acquire such a capability. After a brief description of the origins of the U.S. and Soviet programs, four case studies are developed describing the considerations that led the United Kingdom, France, the People's Republic of China (PRC), and India to justify acquisition of nuclear weapons. The common features and outstanding differences among them are identified in a brief concluding net assessment. Brief analyses of the factors which influenced the Federal Republic of Germany (FRG), Japan, and Sweden to decide not to proceed with nuclear developments are included in appendix 1, volume II.

The U.S. and Soviet Programs

The United States Decision To Acquire Nuclear Weapons

The decisionmaking process by which the United States acquired its initial nuclear weapons capability shows the influence of strategic (i.e., military-security) considerations, scientific and technological factors, economic motives, and other drives. There can be little doubt that the dominant motives were strategic with respect both to the initial fission-bomb decision and to that involving the H-bomb somewhat later. Although it is true that President Roosevelt had to be persuaded that the nascent American nuclear program held sufficient scientific promise to warrant the investment of men, money, and technological resources necessary for its successful completion, he made it clear from the onset that it was the military potential of nuclear fission *vis-a-vis* the Axis Powers which most interested him.

So too with President Truman's decision to build the H-bomb. After the explosion of the Soviet "Joe I" A-bomb in 1949, it was clear that the nuclear program of the U.S.S.R. had progressed more rapidly than many had expected. In the context of the prevailing international climate of the postwar world, Truman believed that a U.S. failure to proceed rapidly with the development of thermonuclear weapons would amount to a surrender of leadership in the nuclear field to the Soviet Union with resulting dangers for American security.

The Soviet Decision "To Acquire Nuclear Weapons

Like that of the United States, Soviet nuclear decisionmaking has been dominated by strategic considerations, especially by the dynamics of the postwar bipolar competition. It is worth recalling that Soviet military doctrine and practice have always stressed the necessary connection between the possession of superior military power and the successful achievement of political objectives. It was thus untenable that Western developments in military technology should not at least be paralleled by developments in the U.S.S.R. Consequently, a nuclear research program was initiated in the Soviet Union as early as 1942. The first Soviet graphite reactor went into operation in December 1946, and, following several earlier claims that Soviet scientists had solved the problem of the atomic bomb, the first U.S.S.R. atomic device to be fully tested was exploded on August 29, 1949. Work on thermonuclear weapons was already underway, and the Soviet's first such device was detonated only 4 years later. Stalin has been accused by his critics, both in the West and within the U. S. S. R., of failing to appreciate the significance of nuclear weapons for military strategy. His repeated stress on "the permanent operating factors" of war helped to prolong the preeminence of ground-force oriented military thinking in the U.S.S.R. Still, in retrospect it is clear that he was at least implicitly aware of the importance of nuclear weapons for the future world "correlation of forces," and acted accordingly.

The Case of Britain

The Decisions

In April 1940, the British Government established the Maud Committee to explore the feasibility of constructing a uranium bomb. Based upon the committee's affirmative findings and prediction that the bomb's destructive power could prove decisive in war, the Government decided to proceed with development; but the press of war caused Britain to defer its independent quest in favor of cooperative development with the United States. After the war the Attlee Government sought to perpetuate Anglo-American nuclear cooperation, but was rebuffed by the passage of the U.S. Atomic Energy Act of 1946, which explicitly prohibited the transfer of nuclear weapon materials or information to any other nation. The British responded by initiating their military nuclear program in 1947. The first British nuclear explosion was recorded on October 3, 1952, followed by their first hydrogen bomb test on May 5, 1957.

The Rationale

The British decision in the late 1940's to acquire nuclear weapons was dominated by considerations of security and international influence.[4]

Nuclear weapons were thought to provide a powerful military deterrent, constituting a potent instrument of national security. They were seen as giving Britain a voice in world councils and have been seen as enabling London to exert some leverage over its powerful American ally within NATO. Their development was also viewed as maintaining the country's scientific and technological momentum.

The strongest motivation for acquiring nuclear weapons was probably British uncertainty about its American alliance. The memory of American isolationism in the interwar period led thoughtful Britons to question if they might once again have to face great odds alone. s Concern over U.S. reliability surfaced again in 1956, when the Suez Crisis demonstrated that there could be a wide divergence between American and British policies. The 1957 Defense White Paper noted that the national nuclear force would provide protection against the day when American and British policies might diverge as they had in 1956.

Special Circumstances

The British decision to acquire nuclear weapons can be traced to the U.S. decision to terminate the Anglo-American sharing of

[3] Part of the following material has been drawn from a report submitted to the DOD.

[4] Andrew J. Pierre, *Nuclear Politics: The British Experience with an Independent Strategic Force 1939-1970,* (London: Oxford University Press, 1972), p. 1.

[5] Robert M. Lawrence and Joel Larus. *Nuclear Proliferation: Phase II* (Lawrence, Kansas: University of Kansas Press, 1974), pp. 2-4.

nuclear technology that had developed during World War 11. In all probability, however, London would have eventually opted for some sort of independent nuclear weapons capability regardless of Washington's policy. The British moved to acquire national nuclear arms, in part to reestablish themselves as an international force just at the time the empire was beginning to crumble, and in part to demonstrate their continued progress and value to a powerful American ally. While the first goal proved elusive, the second was partially realized with the 1958 Bilateral Agreement for Nuclear Sharing between the United States and the United Kingdom. Preservation of that special relationship has been a continuing goal of British foreign policy.

The Case of France

The Decision

Although the French force de *dissuasion* is linked to President De Gaulle in the public mind, the decision to develop a nuclear arsenal was made under the Fourth Republic. The French Atomic Energy Commission, created in 1945, had developed the expertise and facilities to begin a weapons program by 1954. We know comparatively little about how the decision was actually made, but a major role was apparently played by lower-level scientists and officials who took important steps toward a bomb capability without being clearly directed to do so from the Government above. The first French nuclear-test detonation took place on February 13, 1960.

The Rationale

The French public rationale for acquiring a national nuclear force is highly sophisticated and was developed after the fact in the 1960's. As articulated by President De Gaulle and others, it holds that a small nuclear force is capable of deterring nuclear attack by a superpower under certain circumstances. Such arguments contended that it was unrealistic to assume that America would risk nuclear destruction, except in response to a direct Soviet threat to the continental United States. French strategists therefore contended that France should have the capability of "tearing off an arm, " that is to deliver nuclear strikes against a limited number of Soviet cities. This would presumably accomplish three objectives. First, it would compel Soviet planners to contemplate the cost to the U.S.S.R. of any aggression against Europe. Second, it could, under certain circumstances, trigger an American strike against the Soviet Union to preempt a Soviet attack. Third, a French national force would, by its very existence, make it impossible for the superpowers to fight a limited nuclear war in Europe without risk to their respective homelands.

Some French theorists made even more elaborate claims for French nuclear forces in the 1960's. General Pierre Gallois argued that the proliferation of nuclear weapons, particularly the French national force, would contribute to international stability by constraining the aggression of existing nuclear powers.[6]

The arguments in the Gallois book have been widely quoted and cited around the world, showing up particularly in India before that country's nuclear explosives decision.

In addition to such strategic formulations, French spokesmen also advanced the rationale that the possession of nuclear weapons would give Paris a voice in NATO Councils at least on a par with London's. Anglo-American amity, as reflected by the special working relationship established between the United States and the United Kingdom in nuclear matters, was a persistent source of irritation and resentment to the French. An illustration of this phenomenon was France's response to the Nassau Agreement between the Anglo-Saxon Powers in 1962. The French perceived that agreement both as a manifestation of a U.S. attempt to perpetuate dominance over its NATO partners, and as a reflection of the British proclivity to accord higher priority to their U.S. connection than to the goal of European cooperation in security matters.

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6 Pierre Gallois, *The Balance of Terror*, (Boston: Houghton Mifflin, 1961).

Other arguments for a French nuclear force voiced by French officials in the 1960's included the need to offset West German economic dominance of the European Economic Community, and the importance of maintaining a high-level scientific and technological capability.

Special Circumstances

The postwar period had been difficult for France. Defeat and occupation in World War 11 were followed by the loss of the colonial empire in Indochina, North Africa, and elsewhere, and the retreat from Suez under U.S. and Soviet pressure. President De Gaulle felt these stings to French pride acutely, and viewed the acquisition of a nuclear weapon capability as a means of restoring national elan.

The Case of the People's Republic of China

The Decision

We know much less about the Chinese decision than about our other cases. The Chinese exploded their first bomb on October 16, 1964, and it is reasonable to assume that they had already attached high priority to a nuclear weapons project seven or more years earlier. In the aftermath of the Peking-Moscow split, oblique references were made to a 1957 Sino-Soviet nuclear cooperation agreement, which may have been intended to include assistance on weapons. In any case, in 1963, the Chinese charged that the U.S.S.R. had abrogated the 1957 agreement and that Soviet technical assistance had been phased out in 1959– 1960. Although this disruption and withdrawal of key personnel delayed Chinese progress, the nuclear weapons program received priority attention and culminated in the 1964 detonation.

The Rationale

Chinese public statements have at all times tended to deprecate the significance of nuclear weapons. While this might be taken to show an ignorance about military strategy, Chinese investment in nuclear and thermonuclear bombs suggests that other explanations for these statements must be found. At times, it has simply made sense for Peking to present this view because it saw its own nuclear arsenal as not yet comparable to that of an American or Russian adversary. At other times, it served domestic political and ideological purposes to stress "man over weapons, " or "red over expert. " Denigration of nuclear weapons as "paper tigers" served to bolster the morale both of Chinese forces and Third World revolutionary movements (e.g., in Vietnam) confronting adversaries with superior military equipment, including nuclear arms.

The Chinese rationale for acquiring nuclear weapons must be inferred as there has been no open discussion of how Chinese weapons might be employed. Initially, they were probably sought to deter American attack and neutralize the ability of the United States to use nuclear threats in confrontations with China, notably during the Korean War, the Taiwan Straits Crisis (1954-55), and the Quemoy and Matsu Crisis (1958). Peking's determination to acquire a nuclear weapon capability was hardened by the realization that the U.S.S.R. was not prepared to risk military confrontation with the United States to achieve purely Chinese objectives in Asia. Later, nuclear weapons came to be viewed primarily as a deterrent to Soviet attack. China has focused its ballistic missile program upon intermediate range ballistic missiles (IRBMs) with the range to strike Soviet, but not overseas, targets. They serve other purposes as well, notably as support to China's drive for great power status and international influence, and as a deterrent to the introduction of nuclear weapons in any local Asian conflict by an outside power.

The Chinese reject the NPT as an instrument of the "imperialist nuclear monopoly," and prior to obtaining their own capability, encouraged other "progressive" countries to acquire nuclear weapons in the interest of breaking that monopoly. Since 1964, however, such endorsements of nuclear proliferation to other states have disappeared. Also, China has gone beyond other weapon states in repeatedly affirming that it will never be the first to introduce nuclear arms into a conflict.

Special Circumstances

The Sine-Soviet split had a profound effect on the Chinese nuclear program. Withdrawal of Soviet assistance forced the PRC to fall back on its own resources, and no doubt slowed the development of a nuclear arsenal, Meanwhile, deterioration in Sine-Soviet relations caused a change in China's reasons for acquiring such an arsenal. The force that was once seen as a deterrent to U.S. aggression and a means of perhaps forcing a withdrawal of U.S. forces from Asia came to be viewed principally as a deterrent to a Soviet attack.

The Case of India

The Decision

An understanding of Indian motives in detonating a nuclear explosion on May 18, 1974, may provide a better insight into the phenomenon of proliferation than the other case studies outlined above. This is due in part because of the recentness of the Indian explosion, but also because many of the near-nuclear countries most likely to acquire weapons before 1985 are developing countries like India. It should be noted, however, that in certain important aspects India is atypical of the Third World, e.g., its very large cadres of scientific manpower.

Although officials in New Delhi declare that India has no intention of developing nuclear weapons, the 1974 "peaceful" nuclear explosion raises the possibility that India could acquire a modest nuclear weapons capability within a very few years. The major constraint would appear to be the availability of special nuclear material (SNM).

Rationale

Various official and unofficial arguments have been advanced in favor of India exercising the nuclear weapon option. Some of these may be taken at face value, but others may mask deeper motives, It is sometimes contended that India needs nuclear weapons to maintain a strategic military balance against China, which could otherwise be achieved only by sacrificing India's position of nonalinement (i.e., by dependence on the Soviet Union's nuclear guarantee).[7] Another argument has been directed at an alleged double standard on the part of the superpowers, who seek to deny nuclear weapons to India but not to themselves. Two at least equally serious motivations involve the acquisition of a weapon, first, as a source of domestic political prestige for the regime by rekindling national pride through a demonstration of Indian technological achievement, and second, as a means of providing at least symbolic confirmation of Indian preeminence in the subcontinent, *vis-a-vis* Pakistan.

Special Circumstances

The inherent difficulty in maintaining governmental authority over so vast and disparate a nation may have inclined the regime towards dramatic initiatives to command popular attention and support; the detonation of 1974 may have been such a move.

India has prided itself on a pacifist tradition, having effectively used Gandhi's nonviolent tactics to win independence from Britain. It was one of the earliest states to proclaim a policy of nonalinement and has long been a recognized leader of that movement. On the other hand, India was one of the first nations in the less-developed world to invest in a major nuclear research program. The incipient tension between these two developments is reflected in India's present anomalous status as a nuclear explosive, but not nuclear weapons, state. The tension is reinforced by the fact that India, as one of the largest Third World states, is a natural aspirant to great power status. The recent change of government in India would seem likely to shift the political balance in favor of

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[7] K. Subrahmanyam, "India: Keeping the Option Open," in Lawrence and Larus, op. cit., p. 133.

the former tendency and against the latter for the time being.

Net Assessment of Existing Nuclear States

A review of the cases presented above suggests that two incentives stand out: security-deterrence considerations, and the desire for international influence and status. Only China among these six countries can be said to have initially developed nuclear weapons in direct response to a threat of attack, For the others the more credible danger was a deterioration in their security over time vis-a-vis possible adversaries. The result could have been a growing vulnerability to coercive diplomacy, and with it a loss of international influence and freedom of action. The culmination of this process, short of war and actual conquest, could be victimization by nuclear blackmail. Beyond these two basis concerns, the motivations for selecting the nuclear weapons option become more diverse befitting the particular circumstances of the nations concerned.

It is noteworthy that none of these states were dissuaded by economic costs or by possible international censure associated with nuclear weapons. The emergence of China and India as nuclear weapons is of particular relevance to the future course of proliferation, since most Nth countries are to be found among the roster of Third World nations. The fact that two poor and modestly industrialized countries could embark on an explosives program indicates the accessibility of the new technology and the extent to which even a relatively undeveloped nation can command the resources for its application.

A thorough assessment of proliferation should give some attention to those nations that clearly possess the capability to construct nuclear weapons but, for one reason or another, have not done so. Appendix I of volume II contains brief case studies of three major "refrainers": The Federal Republic of Germany, Japan, and Sweden.

CASE STUDIES OF NTH COUNTRIES

Introduction

As previously noted, a viable analysis of the prospect for future proliferation must take into account factors peculiar to each potential weapons state. What follows are brief illustrative assessments of three Nth countries: Argentina, Pakistan, and Taiwan. Additional case studies are included in appendix I, volume II.

Argentina

Background

Argentina is a country of 25 million people living in territory extending almost half the length of South America and including an area of over 1 million square miles. It is the second largest nation in South America in area and population, surpassed only by Brazil. Argentina is a Republic and has been variously ruled by a President and National Congress or by a military junta. There have been 11 presidents since 1955, of which 6 have been deposed in coups d'etat. Political violence and terrorism are frequent to the point of being traditional, and government alternates between popularly elected leaders and self-appointed ones. Argentina has at times been a federal republic with delegated power on the state and local level, and at times a unitary government with provincial officials holding power at the pleasure of the central government. The population is generally literate, education is compulsory and free, and is available from the primary through the post-doctoral level of training.

Although industrialized, Argentina derives its chief income from agriculture and livestock. The country is equipped with the administrative, commercial, and transport infrastructure typical of a modern industrial state. However, many types of machinery and equipment (including most heavy machinery) employed within the country are not manufactured domestically and must be imported. There is a moderate standard of living with considerable variation between the very poor and the very rich. Labor unions are very active among the working force, which comprises close to a third of the population. Cereals, beef, and wheat are the principal exports and serve to pay for those items that must be imported for industrial use. Per capita GNP is second only to Venezuela in South America and is about 30th in the world, yet Argentina is constantly burdened with inflation which affects domestic policy as well as foreign trade.

Argentina shares a long common border along the Andes with the Republic of Chile, while its northern and northeastern frontiers are shared with the much smaller nations of Paraguay, Bolivia, and Uruguay, as well as with Brazil, a much larger country in population and area. Uruguay can be considered a kind of buffer-zone between Brazil and Argentina, countries which tend to be rivals with one another. While Argentina participates in worldwide trade and requires imports to maintain its economy, its chief interests lie within the continent of South America and in the Antarctic.

Argentina's armed forces are adequate for national defense and the navy has the strategic reach to operate some distance beyond coastal waters,

The nature of government in Argentina is such as to permit fabrication of nuclear weapons without an expression of national consensus on the issue.

Incentives for Acquisitions of Nuclear Weapons

- The desire for a modern, powerful armed force, capable of maintaining Argentina as an important power in South America.
- Belief that the strength of the regime will be enhanced domestically if Argentina enjoys the prestige of being a nuclear power within the international community.
- Rivalry with Brazil. Concern that Brazil, with its larger population, national territory, and greater resources, may one day attempt to dominate its neighbors.
- The determination to maintain an independent policy in world affairs, requiring both international prestige and an impressive military capability.

Disincentives to Proliferation

- Anticipation that foreign nuclear assistance and exports to Argentina would be embargoed.
- Concern that Argentine proliferation will alarm Brazil and Chile, and trigger a nuclear arms race within South America.
- Fear that nuclear weapons may fall into the hands of terrorists or extremists and be used for purposes of extortion.
- Anxiety that the control of nuclear weapons will become the means of achieving power domestically within Argentina.

Technical Capabilities

As a moderately industralized nation, Argentina is fully capable of recruiting the scientists and engineers required for the development of nuclear weapons. While the Argentine financial situation often appears precarious, exports of grain and beef furnish a reliable source of capital for acquiring those materials not available within the country.

In terms of nuclear technology and facilities, Argentina is the most advanced country in Latin America. Argentina enjoys a fairly plentiful supply of natural uranium from which its first nuclear power reactor has been fueled, a natural uranium reactor which is now onstream. Argentina also has three research reactors, a pilot heavy-water plant, and a laboratory-scale reprocessing facility, There are unconfirmed reports that the latter is being expanded. The first power reactor at

Atucha was constructed by the German firms of Siemens, Kraftwerk Union, and Ruhrstahl. A second reactor is being built with Canadian and Italian participation, and is projected to go onstream by 1979. It is hoped that at least six nuclear reactors will be in operation by 1985.

There appears to be no technical or administrative impediment to Argentina's acquiring nuclear weapons. In fact, the chairman of the country's National Atomic Energy Commission has stated publicly that Argentina has the capability to construct weapons, although it is not presently attempting to do so. It is noteworthy that officers or former officers of the armed services have occupied positions on the Commission.

Argentina has been trying to obtain a complete nuclear fuel cycle, including full-scale heavy water and reprocessing facilities. Efforts thus far to import these facilities have been rebuffed by potential suppliers.

Argentina's choice of natural uranium-fueled reactors and the studies and experiments on plutonium appear to be an effort to avoid dependence on foreign sources for enrichment of uranium. It must be assumed that Argentina itself will eventually acquire, with or without foreign assistance, the means to reprocess fuel from its power reactors. In the meantime, Argentina has taken the first step toward becoming a nuclear supplier in its own right by signing an agreement to assist Peru in the development of a research reactor.

Net Assessment

Incentives and disincentives seem to be roughly in balance, but with a slight advantage to the latter for the foreseeable future. The availability of the materials and technology necessary to become a nuclear power is onIy a moderate constraint. The most compelling disincentive is that an Argentine decision to proliferate would almost certainly stimulate a similar action by Brazil, which has the capability to become a more formidable nuclear power, i.e., Brazil could "win" any nuclear arms race on the continent. On the other hand, the prospect of being the first nuclear power in South America, and the second in the Western Hemisphere is a tempting one. From an Argentine perspective it would be a source of prestige, strengthening the regime at home and enhancing status abroad. The preeminence of prestige motivations is perhaps the most noteworthy factor in the Argentine case. The Republic faces no credible external threat to its security.

Circumstances That Might Alter the Relationship Between Incentives and Disincentives

There is small likelihood that public opinion in Argentina would oppose the acquisition of nuclear weapons. In any case, the Government is capable of acting contrary to prevailing public sentiment. The political composition of the government will be a much more important factor. For example, the domestic political pendulum might swing back to a civilian and more liberal regime which would militate against nuclear weapons.

The views of Argentina's weaker neighbors are unlikely to be decisive in any decision regarding nuclear explosives. On the other hand, clear evidence of a Brazilian intent to construct nuclear weapons would greatly increase Argentina's incentive to do likewise. It is noteworthy that neither Argentina or Brazil has ratified the NPT or the Treaty of Tlatelolco which established a Latin American nuclear-free zone. But neither country has the practical option of becoming the only nuclear weapons state in South America. Consequently, they must determine whether sufficient benefits would be gained if both possessed nuclear weapons, and if possession would offset the new tensions and costs these weapons might entail. The likely condemnation of any moves toward proliferation by the rest of Latin America, as exemplified by the attitude of Mexico and the widespread endorsement of the Latin American Nuclear Free Zone, is suggestive of one type of cost.

Pakistan

Background

Pakistan is a country of 65 million people living along the valleys and tributaries of the Indus and Jhalum Rivers and on the foothills and slopes of the Himalayas, It is bounded on the South and East by India, the Northeast by

Indian Kashmir, the North by Afghanistan, the West by Iran, and the South by the Arabian Sea. Pakistan is a Federal Republic led by a president who governs through a prime minister and a cabinet based on a bicameral parliament.

Pakistan is a partly industrialized state capable of shipbuilding and similar work. It is largely dependent on foreign sources for machinery, transport equipment, chemicals, electrical equipment, and petroleum, which it must pay for by the export of the products of cottage industries, some minerals, cotton, fish, and rice. The standard of living within the country ranges from that of hill peoples and subsistence farmers, through a small middle class to a tiny upper class of entrepreneurs and industrialists. While Pakistan can sustain itself at a subsistence level, its industrialization depends on the acquisition of capital and materials from abroad.

Internal political circumstances are exceedingly unstable, characterized by numerous divisions and centrifugal tendencies including outright separatist movements (in Baluchistan and Pushtoonistan) supported from abroad.

The separatist movement in Baluchistan is mirrored within the adjacent Iranian province of Baluchestan, while Pakistan's northern boundary with Afghanistan is subject to Afghani pressure. The loss of East Pakistan in the 1971 war with India, the dispute over possession of Kashmir, and the persistent border tensions over the Rann of Kutch are symptomatic of the pervasive hostility in Pakistan-India relations and of Pakistani weakness in the face of its stronger neighbor.

Pakistani armed forces may not be adequate to deal with the numerous border problems and near insurrections in border areas—to say nothing of any renewed conflict with India. Close relations with Iran and Turkey have assisted Pakistan's economic development but have contributed little toward the nation's security.

Pakistan depends on foreign manufacturers and governmental assistance from abroad for its weapons and military equipment. Since the United States ended military aid, China has supplied much of the newer equipment for Pakistan's armed forces. According to press reports, the most recent Chinese assistance has included some submarines and destroyers.[8]

A number of events in recent years have given impetus to serious Pakistani consideration of the nuclear option. India's successful intervention in the civil war in East Pakistan, with the consequent emergence of an independent Bangladesh, demonstrated the weakness of Islamabad's position. Pakistan's ally, China, was unable to intervene because of the Soviet-Indian alliance, while covert efforts by the Nixon Administration to bolster Pakistan proved futile. Public opinion in the United States tended to support the independence of Bangladesh.

The Prime Minister, Mr. Bhutto, has said that he would prefer to rely on conventional weapons for security but that Pakistan would develop a nuclear capability if it could not acquire sufficient conventional arms.[9] India's detonation of a nuclear device, absorption of Sikkim, and flirtation with authoritarianism have not reassured Pakistan about its own security. The general dearth of criticism from the international community (save for that from China) in response to these events has been a further source of uneasiness and has contributed to Pakistan's sense of isolation. The Canadian decision to withhold assistance to Pakistan's nuclear programs under its new nuclear export policy seemed aimed directly at Pakistan, despite (or because of) Canadian assistance to India's nuclear development eventuating in that country's test of a nuclear device.[10] Islamabad has found Ottawa's requirement that shipments of nuclear materials be restricted to countries willing to ratify the NPT or to accept safeguards on their entire nuclear program unacceptable. Pakistan has adhered closely to past agreements with Canada on safeguards attached to the Canadian-supplied nuclear powerplant at Karachi,

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8 See "Intelligence," *Far Eastern Economic Review*, Vol. 94, No. 51, Dec. 17, 1976, p. 5.

9 See "Bhutto Talks of Going Nuclear," *South China Morning Post* (Hong Kong) Dec. 21, 1974, p. 3.

10 See k"Canada's Nuclear Export Policy: Statement by Secretary of States for External Affairs in the House of Commons," Dec. 22, 1976, *Information* Canadian Embassy, Dec. 28, 1976.

but has declared it will not "accept totally unreasonable conditions as the price for Canada's continued cooperation."

U.S. attempts to tie the sale to Pakistan of conventional weapons to an agreement not to purchase a French fuel reprocessing plant has generated additional resentment.[11] Pakistan has not, however, given up the contract with France for acquisition of the plant, and Paris had declared it would honor the agreement.[12] Whether the deal will, in fact, be implemented remains to be seen. The Soviet Union's decision to supply India with a 6-year supply of heavy water for its nuclear program merely confirms Pakistan's view that nonproliferation is one-sided on the Indian subcontinent. Pakistan has neither ratified or signed the Non-Proliferation Treaty.

Incentives for the Acquisition of Nuclear Weapons

- A history of tension and warfare with India, culminating in the loss of East Pakistan in 1971, which raises the spectre of further armed conflict in the future.
- The Indian-Soviet defense agreement of 1971, that seems aimed at Pakistan as much as at China.
- The inability of China and the unwillingness of the United States to assist Pakistan in an Indian war, as demonstrated in *1971.*
- The urge to acquire some means of unifying the country, countering the process of political fragmentation, and overawing foreign supporters of domestic tribal separatists.
- The goal of becoming the leader of the Moslem world.

Disincentives to the Acquisition of Nuclear Weapons

- The probable alienation of potential sources of international support and arms.
- The magnitude and cost of the effort to acquire nuclear weapons.
- The prospect that such a program would divert technicians and capital away from the vital task of industralization.
- The possibility that proliferation would make any diplomatic settlement with India impossible.

Technical Capabilities

Pakistan has successfully brought two nuclear power reactors onstream with outside assistance. One of those reactors, at Roopur, was lost to Bangladesh in the war with India in 1971. The second reactor has been onstream since 1971. Before the loss of East Pakistan and the detonation of an Indian nuclear device, the chief motive for development of nuclear energy was to modernize Pakistan by exploiting the most advanced energy technology available where accessible. However, other forms of electrical generation, notably hydroelectric, have proven more fruitful.

Pakistan lacks enrichment, fuel fabrication, and fuel reprocessing facilities. It also lacks significant uranium deposits. There are sufficient technicians and engineers to staff a nuclear weapons effort, although that would be to the detriment of other important programs. The principal shortcoming is the lack of the administrative skill needed to bring together the resources, personnel, and money required to embark on a weapons program independent of outside help. It appears that Pakistan could not expect to produce a nuclear device before the early 1980's, if it is dependent on its yet-to-be-acquired fuel reprocessing plant in order to obtain plutonium.

Net Assessment

The technical capability to acquire nuclear weapons at this time is far less than the incentive to do so. It would be possible, with stringent organization of capital, personnel and administration, to establish a promising program for weapons development. But Pakistan must first obtain a fuel reprocessing

[11] See "Pakistan: Bhutto Bows to Nuclear Pressure," *Fur Eastern Economic Review,* Vol. 94, No. 5, Dec. 17, 1976, p. 27.

[12] See "Canada to End Nuclear Power with Taiwan," *Los Angeles Times,* June 19, 1974, p. 2.

facility or otherwise acquire the special nuclear material for weapons. Nevertheless, Pakistan's determination to preserve its security and territorial integrity cannot be ignored as a motivation to overcome what otherwise appear to be important obstacles to the development of nuclear weapons. Consequently, much will depend on Pakistan's perception of the dimension of the Indian threat. The principal disincentive is the cost of a weapons program for Pakistan's economic development effort—both in terms of domestic opportunity costs and possible reductions in foreign assistance.

Circumstances That Might Alter the Relationship Between Incentives and Disincentives

Among the circumstances that could alter the relationship between incentives and disincentives are the following:

- A radical increase or diminution in the perceived threat from India.
- Pressure from Iran and China to forego nuclear weapons development.
- A guarantee by the nuclear powers of the territorial integrity and defense of non-nuclear powers in general, or a guarantee of the security of Pakistan by a nuclear power (preferably the United States).
- The breakup of Pakistan as a national entity (the question becomes moot).

Taiwan

Background

Taiwan is an island with over 16 million inhabitants, governed from Taipei as the Republic of China (ROC). The head of State of the ROC is a president ruling through a premier and cabinet. The principal representative body is the Legislative Yuan, part of whose members hold office for life, the rest being elected. Governmental power may rest in the hands of either the president or the premier, depending on the political and military following of the individuals involved. High government posts are virtually monopolized by the Mainland Chinese minority who fled to the island in the wake of the defeat of the Nationalist regime at the hands of the Communists in 1949.

The ROC still claims to be the legal government of all of China and remains in a formal state of belligerency *vis-a-vis* the People's Republic of China (PRC). The PRC, for its part, lays claim to Taiwan and pledges to "liberate" the island. While the ROC, in the past, has been firmly tied to the United States for defense, this relationship has been greatly weakened with the American failure in Vietnam and with the opening of diplomatic and trade relations between the PRC and the United States.

The ROC'S ground, naval, and air forces are presently adequate to provide a credible deterrent to PRC attack. Over the long term, however, the conventional military balance will probably shift heavily in favor of Peking.

Taiwan is prosperous, with light to medium industry. Its prosperity depends on import-export and entrepot trade, foreign investment in Taiwan, and ROC investment abroad. Outside of Japan, Taiwan enjoys the highest per capita GNP in Asia. Foreign trade excludes any commerce with communist powers, but otherwise extends throughout the world.

The diplomatic emergence of the People's Republic of China, its assumption of U.N. membership in place of the ROC, and the U.S.-Chinese rapprochement have all contributed to the increasing international isolation of the Taipei regime. Those countries courting the People's Republic of China for commercial or diplomatic advantages have shown a willingness to abandon their formal diplomatic relations with Taiwan, although they have tended to maintain their commercial interests in that country.

As a consequence of the above-mentioned factors, Taiwan's long-term security prospects are problematical. Continued erosion of the regime's diplomatic position could lead to increasing international economic pressures. Militarily, ROC forces may be unable to obtain needed assistance from abroad in the event of an attack from the Mainland—although at present the PRC probably lacks the amphibious capability to launch an effective assault.

Because it is dependent on foreign suppliers, the ROC'S nuclear program is vulnerable to disruption. Withholding nuclear technology and material from the ROC could be a result of suspicion that Taipei is seeking nuclear weapons, but may equally come from an unwillingness to offend China (as was the case when Canada cancel led its nuclear program with Taiwan). However, other countries, less concerned about proliferation or hostile to Mainland China, may see some advantage to assisting Taiwan's nuclear program. A country like South Africa, which possesses the technology and is considered a pariah in the international community anyway, might well see some advantage to cooperation with Taiwan.

Taiwan has ratified the Non-proliferation Treaty. If that ratification was in the interest of maintaining good relations with the United States, weakening of those relations could also weaken Taiwan's commitment to the treaty.

Incentives for the Acquisition of Nuclear Weapons

- Anxiety that at some point the PRC will attempt the conquest of Taiwan by force.
- Concern about the credibility of the U.S. defense commitment to Taiwan.
- Belief that nuclear weapons in the hands of the ROC could be used to deter or defeat a PRC attack.
- Hope that Taiwan's capacity to initiate nuclear war would induce the international community to restrain the PRC from the use of force against Taiwan.
- Belief that the possession of even a token, nuclear force would give the ROC Government greater psychological force and political credibility in its claim to be a legitimate and viable alternative to the present regime in Peking.

Disincentives for the Acquisition of Nuclear Weapons

- Fear that acquiring nuclear weapons would alienate the United States and other powers upon whose goodwill Taiwan depends for security and trade.
- Lack of domestic supplies of uranium and other nuclear materials, rendering Taiwan dependent on foreign sources for development of its nuclear power program.
- Nonproliferation pressures resulting from Taiwan's adherence to the NPT and the imposition of IAEA safeguards.
- The risk that possession of nuclear weapons by Taiwan would expose Taiwan to nuclear attack without a commensurate increase in Taiwan's defense capability.
- The burden of acquiring nuclear weapons and delivery means sufficient to act as a deterrent to PRC attack.

Technical Capabilities

While the ROC is not an advanced industrial nation, it possesses all of the basic technology for the development of nuclear weapons. Although it lacks its own means of producing some of the special materials for a nuclear program, the ROC does possess within its shipbuilding, metallurgical, chemical, and electronic industries the capability to develop those means. Scientific, technical, and engineering personnel are numerous now and increasing in number.

The development of nuclear technology has its impetus from an extensive nuclear research program and the introduction of nuclear energy for the generation of electricity. The latter is a result of the increasing demand for electricity and competing demands between the electric power industry and other industries for the domestic supplies of fossil fuels.

The ROC has already acquired one nuclear power reactor that will come onstream during 1978. It also has a fuel-fabrication facility.

The technical barriers to nuclear proliferation include the lack of a domestic uranium supply and reprocessing facilities. Taiwan is dependent on foreign suppliers for nuclear fuel, fuel reprocessing, uranium enrichment, and reactors. In the light of a strong international reaction to published reports that it was planning to build or was building a plutonium reprocessing plant, Taiwan has pledged not to proceed with such an undertaking.

There is no reason to suppose that Taiwan is less capable of mastering nuclear technology than was the PRC, nor may it be supposed that the administrative organization of the Taiwan government is not equal to the task of developing nuclear weapons.

The ROC intends to have six nuclear power reactors onstream by the mid 1980's. These are boiling water reactors fueled with enriched uranium, not appropriate for the efficient production of plutonium. However, Taiwan does have a Canadian-supplied NRX research reactor, of the same type as that used by India to produce plutonium. It is significant that the Government's principal military ordinance, research, and development facility is colocated with the Institute of Nuclear Energy Research.

Taiwan has a proven capability of separating plutonium from spent fuel on a laboratory scale. A small reprocessing laboratory was constructed in Taiwan but is presently disassembled.

It would appear that Taiwan could have a nuclear device in a relatively short time, if the Government were to abrogate the NPT and repudiate its pledge not to reprocess spent fuel. An alternative, but less likely scenario might see Taiwan follow the Israeli model and create the widespread impression that it possesses nuclear weapons—without overtly confirming it. Already the ROC has publicly claimed the technological capability to produce nuclear weapons while pledging not to implement that capability.

Net Assessment

The pressure on Taiwan from the PRC, and the ROC'S relative diplomatic isolation, render Taipei less sensitive than some other governments to antiproliferation views in the international community. The possibility that nuclear weapons would either ensure the ROC'S continued independence, lend strength to any opportunity to reestablish a Nationalist regime on the Mainland, or facilitate an accommodation with the PRC not unfavorable to the ROC all lend incentive to proliferation.

The ROC has adhered to the nuclear nonproliferation treaty. But the risk of alienating Japan and the United States through proliferation may be balanced by the prospect that ROC nuclear weapons might incline the international community to restrain the PRC from acts against Taiwan that would threaten nuclear war. Adherence to the nonproliferation treaty may, therefore, be contingent on the perceived strength of the U.S. commitment to the defense of Taiwan.

Technological considerations do act as restraints. The principal constraint is the dependence on foreign suppliers for reactor components, uranium, and reprocessing. If there is a concerted effort to deny the ROC such materials and technology, then proliferation will be impeded. Because the United States is both the ROC'S principal nuclear supplier and its only major military ally, Washington has very substantial influence over the future course of Taipei's nuclear policy.

Circumstances That Might Alter the Relationship Between Incentives and Disincentives

Among the circumstances that could alter the relationship between incentives and disincentives are the following:

- A sharp change in the pace and/or direction of the movement toward normalization of relations between Washington and Peking.
- A change to a firm and materially substantial commitment by the United States to the continued independence of the ROC.
- Acquiescence, however indirectly, by the ROC to Mainland control.

The major variable in the situation is the course of U.S.– PRC relations. If the normalization of U.S. relations with Peking evolves in such a way that the ROC feels it cannot depend on any continuing relationship with Washington, the result may be desperation in Taipei and a decision to opt for nuclear weapons.

The other striking feature of this case is the strength of the ROC'S incentive to acquire nuclear weapons. Like Israel and South Korea, the ROC faces a serious, clearly defined, external military threat to its existence. Under the circumstances, nuclear weapons could serve as a deterrent and weapon of last resort, Moreover, several major states with interests in the area, e.g., the U. S. S. R., Japan, and the U. S., might see some benefits resulting from an ROC nuclear weapons capability. For the United States, it might permit the disengagement from any remaining security commitments to Taiwan without precipitating a PRC conquest of the Island. This is not to suggest, however, that any of these states would view a nuclear-armed Taiwan as being, on balance, in their best interest.

CONCLUSION

One approaches with caution any attempt to integrate the diverse factors influencing nuclear proliferation into a global assessment of incentives and disincentives to acquire nuclear weapons. However, a review of the Nth country case studies suggests that the principal incentives influencing nations operating at the threshold are the following.

1. The need to counter perceived local and regional threats.
2. The desire to accrue the political status that seems to accompany a weapon capability.
3. The desire to hedge against political and military uncertainties while increasing the capability to exert regional influence.

The principal disincentives operating on the same countries are the following:

1. Concern about adversary responses, including the stimulation of regional nuclear arms races,
2. Possible alienation of the superpowers and suppliers, principally the United States, with resulting loss of nuclear imports and economic development assistance.
3. Diversion of resources from needed industrial development and social welfare programs.

What particularly stands out is the central role of regional conflicts and contests for influence. An effective policy to inhibit proliferation will have to address the almost universal aspiration for security, influence, and prestige, and the disputes these aspirations engender. It will also have to address means of encouraging a response to proliferation on the part of allies, suppliers, adversaries, and the international community as a whole, which will maximize the costs and penalties associated with proliferation. Specific policy options to achieve these purposes were analyzed in chapter III.

Chapter V

The Non-State Adversary

Chapter V

The Non-State Adversary

This chapter discusses potential nuclear non-state adversaries and the civil liberties implications of measures to deter their actions against nuclear facilities or involving nuclear materials. In the context of nuclear proliferation, potential nuclear non-state adversaries encompass individuals or non-governmental groups that might take advantage of the spread of nuclear material, facilities, or weapons to harm or threaten society.

THE NATURE OF NON-STATE ADVERSARIES AND THEIR ACTS

Nuclear non-state adversaries include those who might attempt to steal a nuclear weapon; to steal nuclear material to sell, ransom, or use to make a nuclear explosive or dispersal device; to purchase illegally, or smuggle, nuclear material, or otherwise participate in a nuclear blackmarket; or claim that they possess nuclear devices to extort concessions or cause alarm. The term also includes those who might undertake serious malevolent actions against nuclear facilities. They might threaten or actually attempt to sabotage a nuclear facility or transport vehicle, or seize temporary control of a nuclear facility.

These adversaries are often referred to collectively as criminals and terrorists, although all are criminals in that their actions would violate existing laws. The term criminal however, generally implies a purely profit motive while the term terrorist (in current usage) implies political objectives. The spectrum of potential nuclear non-state adversaries is much broader. It includes profit-minded criminals, political extremists, a dissident faction within a government, violent foes of the manufacture of nuclear arms or of civilian nuclear power programs, disgruntled employees of the nuclear industry, or individual lunatics. The actions that might conceivably be carried out by such individuals or groups range from hoaxes to the construction and detonation of a nuclear explosive device which could kill hundreds or ‘thousands of people and deny the use of large areas of land. Strictly speaking, nuclear adversary actions should not include minor incidents (such as vandalism), although it is useful to study minor incidents for indications of trends in the direction of more serious actions.

The Spectrum of Potential Nuclear Actions

The non-state threat compromises a spectrum of potential actions, with varying degrees of difficulty to complete and varying degrees of consequences.

At the low end of this spectrum are bomb threats, nuclear hoaxes, and token acts of violence not aimed at producing serious casualties or damage. These in general pose little direct danger to public safety and require a minimum of skill, resources, and organization to carry through.

Further up the scale are actions such as low-level sabotage which could result in serious

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damage to a nuclear facility and could endanger onsite personnel, although they would not necessarily pose a threat to public safety.

At the high end of the scale are actions such as theft of weapons material followed by the construction of a nuclear explosive device, or sabotage of a reactor which succeeded in causing a core-melt and breach of containment. The sabotage of a reactor was judged peripheral to the subject of this report: the proliferation of nuclear weapons. Therefore, this report has not assessed the difficulty of reactor sabotage.

Chapter VI assesses the resources required to construct a nuclear explosive device, and concludes that some clever and competent non-national groups could possibly design and construct a crude nuclear explosive having significant nuclear yield.

The effective design of security systems for nuclear facilities requires an understanding of the threat to be defended against. Defined threat levels can be used to gauge, as a first approximation, the difficulty of obtaining weapons material. Until recently, however, threat levels were not defined by the U.S. Nuclear Regulatory Commission (NRC). In January 1976, the NRC began a special review of the safeguards at 15 facilities licensed by it to possess significant amounts of highly enriched uranium or plutonium. In March 1976, the U.S. Energy Research and Development Administration (ERDA) began participating in the reviews. The threat levels defined for this review consisted of:

> "An internal threat of one employee occupying any position, or an external threat comprised of three well-armed (legally obtainable weapons), well-trained individuals, including the possibilities of inside knowledge or assistance of one insider."]

Of the 15 NRC licensed facilities involved in the safeguards reviews, 8 were judged adequate to withstand both the threats defined above.

More recently, NRC has required these facilities to begin upgrading their security to guard against an increased possible threat. This potential threat could involve a conspiracy of two or more insiders acting in collusion with an outside group of several attackers armed with automatic rifles, recoilless rifles, and high explosives. As part of the upgrading, full-field investigations and other security checks will be required for licensee employees who might effectively conspire to steal or divert weapons-grade material. The subject of physical security at nuclear facilities possessing material of weapons grade is discussed in more detail in chapter VIII "Safeguards Technology",

In the section which follows, it will be seen that the nuclear incidents to date have all been low level.

The Record of Nuclear Incidents[2]

Between 1969 and 1975, the AEC and then ERDA recorded 288 threats or incidents of violence in the United States directed at nuclear facilities or buildings or offices that were in some way related to nuclear activities, (This figure does not include nuclear hoaxes, of which there were 38 in roughly the same period. See the section on nuclear hoaxes below). Of these, 240 were bomb threats; 14 were bombings or attempted bombings; 22 were incidents of arson, attempted arson or suspicious fires; and 12 were cases of forced entry or other breaches of security. There was, in addition, one possible case of diversion of a minute quantity of plutonium. A number of incidents were directed against university research facilities or Federal office buildings. There were no casualties. The ERDA list is apparently not complete. Moreover, it seems unlikely that no incidents took place before 1969. A case of low-level reactor sabotage resulting in considerable onsite damage is not contained on the list. In addition, a night watchman was reportedly wounded by an intruder at the Vermont Yankee plant in 1971. This was the only known casualty in an adversary nuclear incident in the United States. Several known thefts of radioactive material

[1] NUREG-O095/ERDA 77-34; Joint ERDA-NRC Task Force on Safeguards (U) Final Report July 1976; Unclassified Version; p. ii.

[2] See appendix 111, volume 11 for details.

(but not radioactive waste or special nuclear material) do not appear on the list. (None of the material was used to endanger the public.)

There are no complete chronologies of incidents involving nuclear facilities or material elsewhere in the world. Those incidents that have been reported in the foreign press consist mainly of bomb threats, hoaxes, vandalism, low-level sabotage, a few thefts of low-enriched uranium, and one verified incident of non-lethal radioactive dispersal of material possibly stolen from a hospital. There have, however, been serious incidents of bombing and sabotage in Europe causing considerable damage to property. Demonstrations against the construction of new nuclear powerplants in West Germany, where antinuclear forces appear to have merged with extremist political movements, have resulted in violent confrontations with the police.

The combination of antinuclear elements with political extremists has led to violence in Europe where further violence and perhaps some escalation seems possible. There is no evidence in these incidents that any group has so far attempted to acquire plutonium, highly enriched uranium, or radioactive waste for use in an explosive or dispersal device.

Most of the nuclear incidents worldwide have been low-level and have not imperiled public safety. More such incidents can be expected as the nuclear industry expands. The record suggests that the nuclear industry will not be immune to the problems of bomb threats, low-level sabotage, and pilferage, which are common to other industries.

Publicity surrounding the incidents was not great, attracting international attention in only a few cases. The perpetrators included disgruntled employees, common thieves, political extremists, foes of nuclear power, and a few lunatics. Their motives included protest, greed, revenge, or desire for attention.

For the most part the perpetrators were individuals; a few consisted of small groups. The low-enriched uranium smuggling ring in India, involving contacts in at least three countries, showed the most organization. (See appendix III, volume II.)

Although all nuclear incidents to date have been of a relatively minor nature, this gives no excuse for complacency in the future. The present record of nuclear incidents was assembled in an era of relatively few nuclear reactors. In the future, nuclear power will be greatly expanded, even in low-growth projections, and plutonium recycle may afford potential non-state adversaries a number of highly visible targets. This fundamental change, coupled with marked trends towards increased violence, makes the past an uncertain predictor of the future.

Moreover, in many developing countries, internal coups, guerrilla wars, insurgent movements, and military regimes are common. One can imagine, for example, how a military coup could involve a struggle for control of a nuclear reactor or, even more serious, a reprocessing plant with its stocks of separated plutonium. Another factor gives cause for concern in the Third World. Developing countries may not have the resources necessary to provide adequate security around their newly acquired nuclear facilities. Thus, as the nuclear industry expands into the Third World, as it is apparently going to do over the next several decades, these facilities may become more attractive targets for insurgent and terrorist groups.

Origins of Increased Concern About the Non-State Adversary

Although only minor nuclear incidents have occurred so far in the United States, public concern about the possibility of nuclear adversary actions, particularly nuclear terrorism, has been increasing in recent years. There appears to be a number of reasons for this. First among these are the rapid growth, actual and projected, of nuclear power plants throughout the world and the projected use of plutonium as a fuel. Increased demands for energy in both the industrialized and developing nations and the impacts of the oil embargo in 1973-1974 spurred the development of nuclear power.

Concurrent with the expansion of nuclear power, a national environmental movement grew in the United States. In their criticisms of nuclear energy, many environmentalists have been giving increasing attention to the possibilities and consequences of deliberate malevolent actions by terrorists and criminals. Moreover, the great increase in violent crime and international terrorism, reported in detail by the mass media, have made malevolent acts seem more commonplace and closer to home. Expectations of violence are probably also increased by regular exposure to violence in fiction, particularly in movies and television. Finally, many of the events of the past 15 years have reduced public confidence in our social, political, and economic institutions, Whereas the citizens of the United States might have once accepted their leaders' statements that strong and sufficient measures were being taken to prevent nuclear adversary actions, the public now tends to be more skeptical of such assurances.

The Growth of International Terrorism[3]

One of the reasons mentioned in the previous section for the growth of public concern about potential nuclear adversary action is the great increase in international terrorism.

Terrorism can be described as the use of actual or threatened violence to gain attention and to create fear and alarm, which in turn will cause people to exaggerate the strength of the terrorists and the importance of their cause. Since groups that use terrorist tactics are typically small and weak, the violence they practice must be deliberately shocking.

Terrorism has become an international phenomenon in recent years. Modern air travel provides terrorists with worldwide mobility, and mass communications provides them with a worldwide audience. New weapons have increased their capacity for violence, while society has become increasingly vulnerable because of growing dependence on complex systems and technology that can be exploited malevolently (e.g., nuclear energy, civil aviation).

During the last few years, small groups of extremists have repeatedly demonstrated that terrorist tactics can create international incidents causing national governments to negotiate before a worldwide audience.

In the presentation of data which follows, international terrorism is defined as terrorism that has clear international consequences. It includes incidents in which terrorists go abroad to strike their targets (as in the Lod Airport massacre), or select victims or targets because of their connections to a foreign state (as in the assassination or kidnapping of a diplomat), or attack international lines of communication and commerce (as in the hijacking of an airliner). It does not include incidents of domestic terrorism.

Since the late 1960's, international terrorism has been on a sharp upward curve, whether one measures such a curve on the basis of the number of terrorist incidents each year or on the basis of the number of casualties inflicted. (See figures V– la and b.)

Figure V–2, taken from an unclassified CIA report "International Terrorism: Diagnosis and Prognosis, " breaks international terrorist incidents down into several categories. (The totals in figure V–1, taken from data collected by the RAND Corporation differ slightly from the totals in figure V–2, because of slightly different reporting criteria.). All told, more than 140 terrorist organizations—including a number of fictional organizations created to shield the identity of the true perpetrators of some particularly shocking or politically sensitive acts—from nearly 50 different countries or disputed territories have thus far engaged in international terrorism. About 1,000 persons have died in international terrorist incidents since 1968; another 2,000 have been injured. If the casualties of domestic political violence are added, the number of deaths may reach 10,000, For comparison, 20,000 persons are murdered every year in the United States.

Some observers have been encouraged by an apparent decline in international terrorism in 1976. However, figures V– la and b show that this apparent decline was not real; international terrorism rose in 1976. The *apparent* decline of international terrorism in 1976 can be explained by the fact that 1976 saw more

[3]See appendix III, volume 11 for details.

Figure V-1 a.

Total Number of Incidents of International Terrorism, 1968-1976

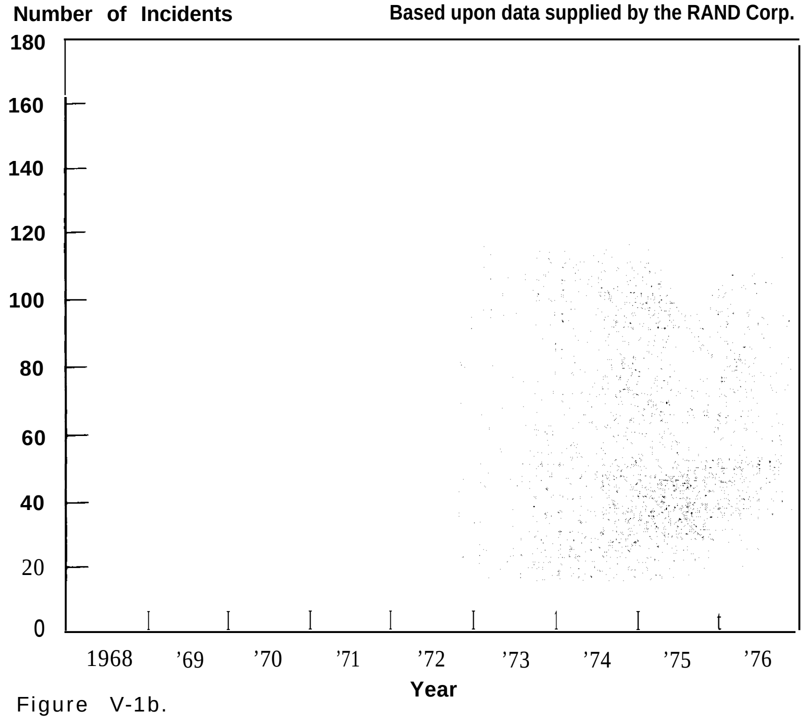


Figure V-1b.

Total Number of Deaths in Incidents of International Terrorism, 1968-1976

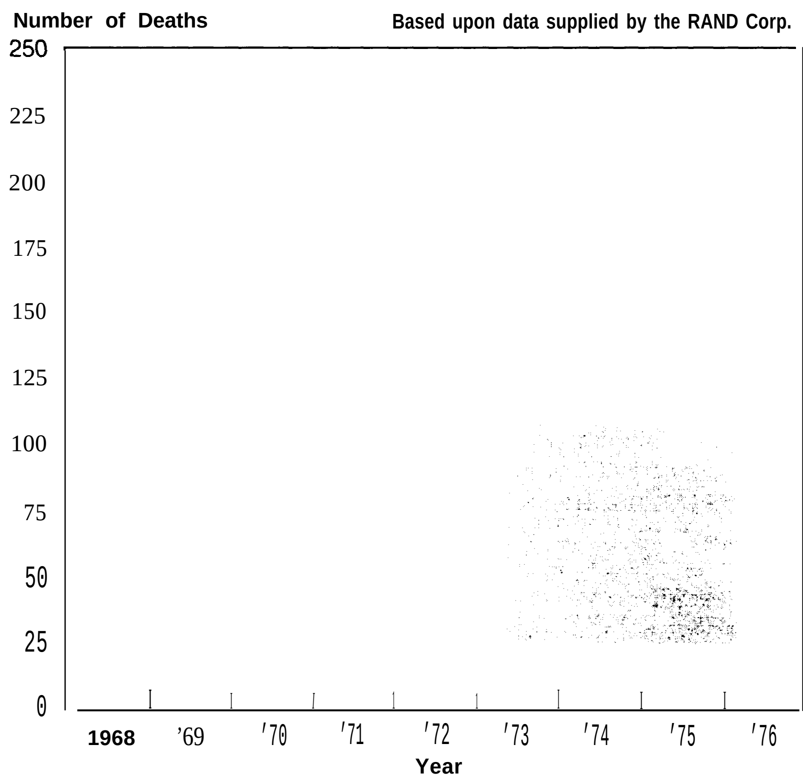
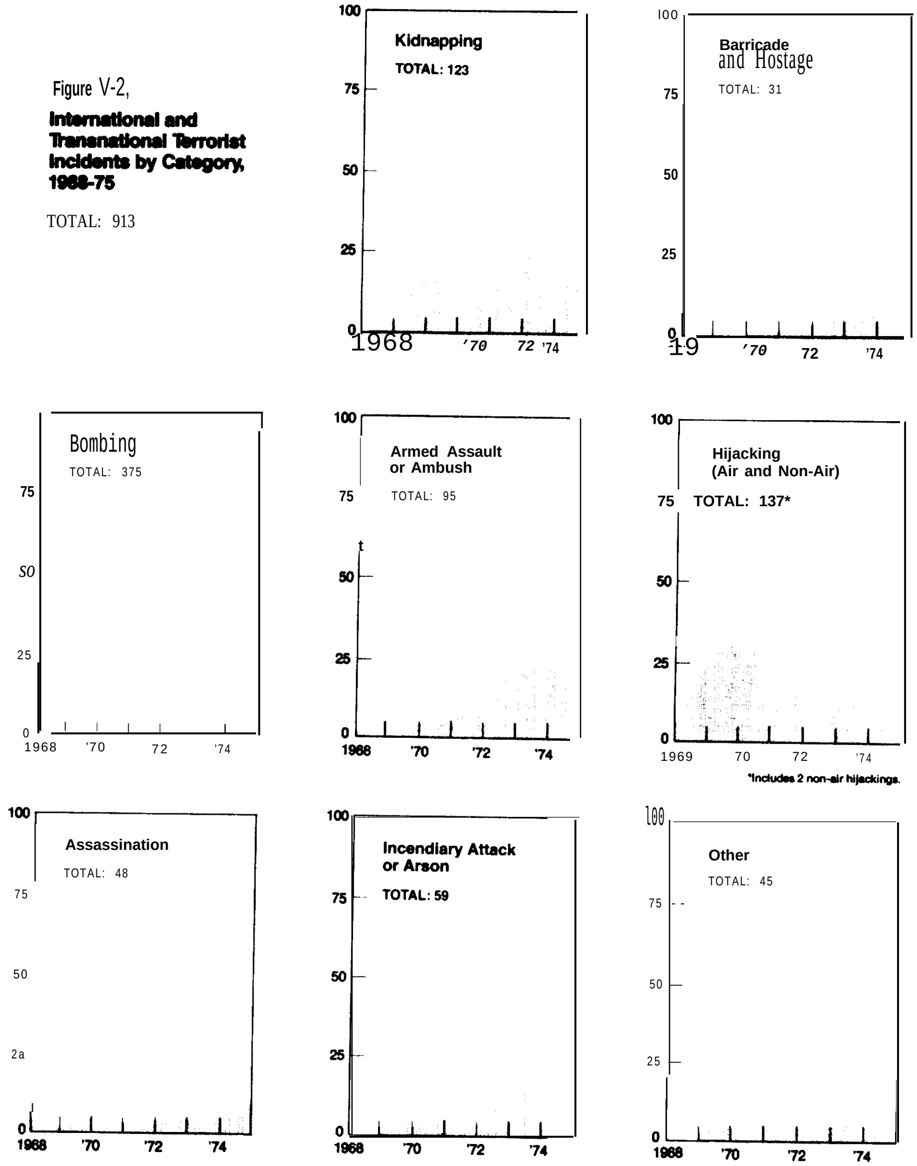


Figure V-2,
International and Transnational Terrorist Incidents by Category, 1968-75

TOTAL: 913



SOURCE: *International and Transnational Terrorism: Diagnosis and Prognosis*, PR 76 10030 Central Intelligence Agency (April 1976).

assassinations and murders and fewer hostage incidents than the preceding year. Hostage incidents may be in the news for days or even weeks; murder is usually in the news for a day or two.

Although any forecasts about terrorism in the future are conjectural, some trends are discernible.

Although few terrorists have reached their stated long-range goals, terrorism has proved useful in getting publicity and occasionally obtaining some political concessions. The record to date might even be considered reasonably positive from a terrorist perspective. Terrorist groups have been notably successful in avoiding capture and escaping punishment.

With the exception of a number of bilateral agreements providing for a greater exchange of intelligence and technical assistance, the international response to terrorism has been relatively weak and ineffective.

Terrorists will remain highly mobile, able to strike targets anywhere in the world. Recent developments in explosives, small arms, and sophisticated man-portable weapons will provide terrorists with an increased capacity for violence. They appear to be getting more knowledgeable in their tactics, their weapons, and their exploitation of the media. They will continue to emulate each other's tactics, especially those that win international publicity. Terrorist groups appear to be strengthening their links with each other, forming alliances, and providing mutual assistance. One result is the emergence of multinational freelance terrorist groups willing to carry out attacks on behalf of causes with which they are sympathetic, or to undertake specific operations or campaigns of terrorism on commission from client groups or governments. Nations or groups unable or unwilling to mount a serious challenge on the battlefield may employ such groups or adopt terrorist tactics as a means of surrogate warfare against their opponents. Moreover, there are signs that some international and domestic terrorist groups are beginning to recruit individuals who are attracted to violence not for political ideals, but for money or the lure of a clandestine lifestyle.

Terrorism can be expected to persist and perhaps increase as a mode of political expression,

Potential Nuclear Terrorism

There is substantial disagreement among experts as to the likelihood of terrorist attempts to acquire a nuclear capability. A nuclear capability would greatly increase their potential destructive power. The detonation of a crude nuclear device in a carefully selected, heavily populated area could kill tens of thousands of people.

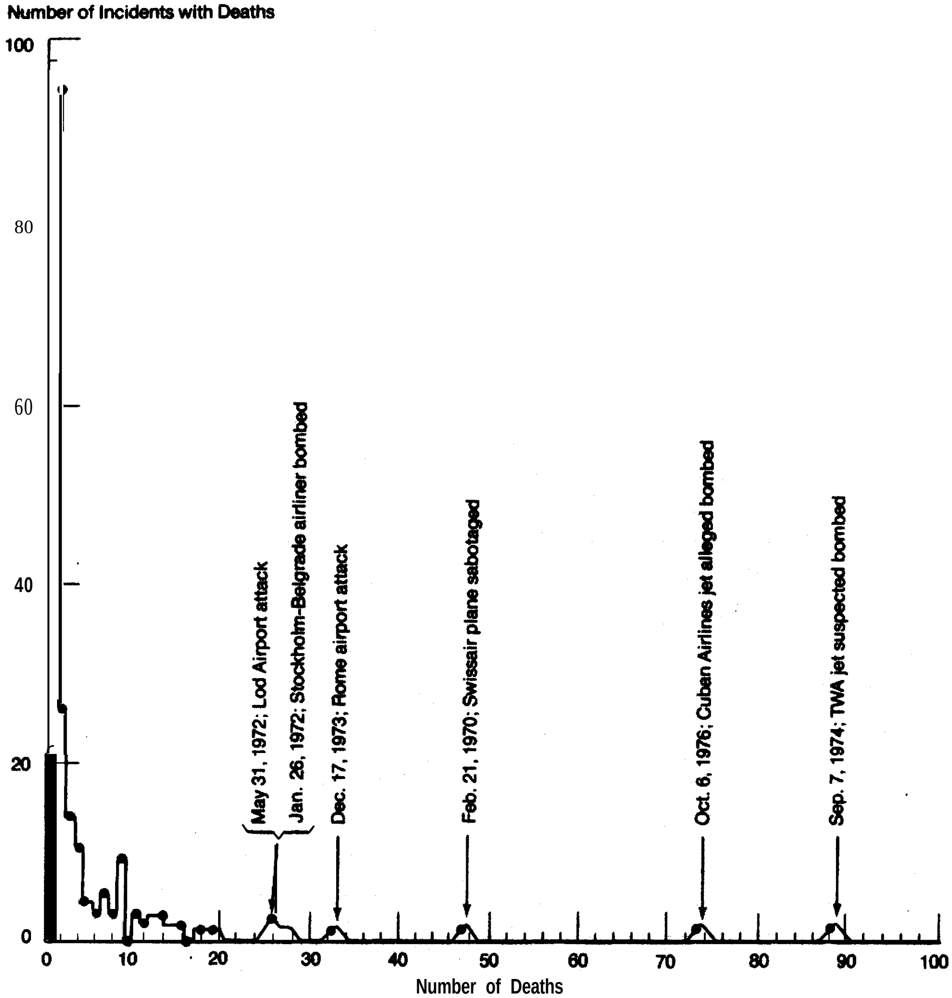
The historical record shows that in no single incident in the past 50 years have terrorists killed more than 150 people, and incidents involving more than 20 deaths are rare. (See figure V–3). This is not because of lack of capability. Terrorist groups could have acquired the means to kill many more people than they have, even by using only conventional explosives.

On the basis of the historical record and the theory of terrorism, it is not clear that causing mass casualties or widespread damage is attractive to a terrorist group. By using terrorist tactics, political extremists have created alarm, attracted worldwide attention to themselves and to their causes, compelled governments to negotiate and often grant concessions, while at the same time forcing governments to spend an unequal amount of resources for protection against terrorist attacks. Terrorists have contributed to the downfall of a few governments, aggravated North-South and East-West relations, kept the Palestinian question at the forefront of international concern, introduced strains in the Western alliance, and adversely affected the quality of life in many open or formerly open societies. They have achieved these results without resorting to mass murder.

Mass murder might actually be counterproductive. It might alienate sympathizers and potential supporters, provoke severe crackdowns that public opinion would demand and support, and threaten the survival of the organization itself. For these reasons, any scheme of nuclear destruction may create disagreement and dissension within the

Figure V-3.

Number of Deaths per Incident of Terrorism Involving Any Deaths 1968-1976 (October 6)



(See appendix III-A for more information on the death incidents.)

Based upon data supplied by the RAND Corp.

organization contemplating it, and expose the operation and the organization to betrayal. For these reasons, a number of experts have argued that mass murder appears unlikely to be contemplated by terrorists groups capable of making elementary political judgments.

However, there is no assurance that terrorists will continue to behave in the future as they have in the past. A desperate group might decide to strike one catastrophic blow,

Moreover, as Roberta Wohlstetter has suggested "... familiar political ends . . . sometimes involve a means like the Red Army terror in Lod Airport, a careless slaughter of innocents that may indeed be an omen of the sort of random killing we see in nuclear destruction. "[4]

In addition, it should be recognized that pure massive destruction would serve the goals of nihilistic groups, should they emerge in the coming years.

[4]Roberta Wohlstetter, Terror on a Grand Scale, Survival, May/June 1976.

The primary attraction for terrorists to go nuclear may not be to cause mass casualties. Almost any nuclear action by terrorists would attract widespread attention. For example, if a terrorist group seized control of a nuclear power reactor or a nuclear weapons storage site, they would create a frightening situation and achieve worldwide publicity by the seizure alone. As another example, it might not be necessary for terrorists to actually design and construct a nuclear explosive device in order to achieve the effect they want. Extortion based on a credible nuclear threat would require less technical skill and risk but would still receive publicity, inspire fear, and, possibly, succeed in obtaining concessions.

In addition, as pointed out in appendix III of volume II, even nuclear explosions need not be equated with mass slaughter. The detonation of a nuclear explosive at any one of a number of important sites at a time when very few people would be about could have a stunning effect, while minimizing the number of deaths.

The whole area of motivations, incentives, demands and negotiations in the area of nuclear blackmail by terrorists (and other non-state adversaries) deserves systematic examination, which it has not received. At present, the published literature contains only speculations about the types of demands terrorists can, cannot, and are most likely to make. Many of these speculations are extremely ingenious, but their main focus is on the terrorist nuclear action itself; few attempt to come to grips with the much harder question of how a terrorist group could exploit the enormous leverage a nuclear device would give to effect a commensurate irreversible political change.

Organized Crime as a Potential Nuclear Non-State Adversary

In this discussion, organized crime means an organization dedicated to illegal activities; its existence transcends any single act; the organization survives its members. Organized crime should be distinguished from individual groups of criminals that organize themselves to carry out specific crimes.

Whether organized crime should be considered a likely nuclear non-state adversary remains a matter of debate. Several studies and commentaries on the subject are summarized in appendix 111 of volume II. L. Douglas DeNike concludes that it is credible that organized crime would engage in nuclear activity:

> "Armed with plutonium or high level waste, organized crime might demand Federal assurances of non-interference with their operations. Punishment for non-cooperation might be the loss of Washington, D. C., as a habitable center. Nuclear thieves could demand large sums of cash, control over policy or special concessions from national governmerits."[5]

Considering the possibility of theft of nuclear material, the MITRE study concludes:

> "They (organized crime) are interested solely in acquiring more money and power for themselves. , . They are involved in almost all the hijacking that goes on in the United States, and have been able to exert considerable control over substantial parts of industry, labor, and government. Their business is often international and they have longstanding and secure links in Europe, the Middle East, Latin America, and the Far East. There is little question that, for a sufficient amount of money, members of organized crime would take a contract to acquire special nuclear material for another party."[6]

Other experts disagree that nuclear extortion or theft would be a likely activity for organized crime. This point of view has been summarized by Brian Jenkins:

> 81 . . . one should be cautious about overestimating the attractiveness of engaging in nuclear extortion or trafficking in fissionable material to the criminal underworld, especially to organized crime. . . organized crime is a conservative, service-oriented industry. It provides gambling, prostitution, and narcotics. The profits from the provision of these services are good and, perhaps more important, steady, . . There is a willing market for such services, and despite the social harm they cause, they may not be perceived by the

[5] L. Douglas DeNike, Radioactive Malevolence, *Bulletin of the Atomic Scientists* (February 1974).

[6] *The Threat to Licensed Nuclea r Facilities,* M TR -7022, 95, The Mitre Corporation, September 1975.

public as a direct threat to individual or collective security. Indeed, the existence of organized crime depends a great deal on tacit public acceptance or at least indifference and therefore it has tended to avoid criminal ventures—for example, in this country kidnappings for huge ransoms—that are likely to arouse public anger. Nuclear blackmailing would bring tremendous heat on the organization and provoke crackdowns that could interrupt the flow of large steady profits from socially more acceptable crimes."[7]

There is, however, one area of consensus within the debate. No one who has commented on the topic seriously believes that organized crime lacks the resources, skills, patience, or force necessary to steal special nuclear material or engage in an illicit international trade of material. The deterrents, if they exist, would possibly lie in fears by the leaders of organized crime that such actions would provoke public outrage and lead to severe responses that would seriously damage organized crime's other profitable enterprises. If organized crime attempted to deter such counter-measures with a nuclear threat, it would mean, in effect, that the leaders of organized crime had decided to challenge the sovereignty of the nations in which their normal activities take place. This would require a fundamental change in the objectives of organized crime, which typically up to now has sought to make money and to acquire political influence to protect its investments and operations but not to directly acquire political authority at the highest levels or provoke political reaction.

At the same time, even those who believe that the risks to organized crime of involvement in nuclear theft or nuclear extortion probably exceed the perceived benefits, appear to find it credible that if a worldwide market for nuclear material develops, and if the price is right, organized crime (perhaps without becoming directly involved in the theft of nuclear material), might act as a fence or broker for the stolen goods. Plutonium or uranium could be stolen or fenced for their monetary value as commodities, that is, as reactor fuel or, in the case of low enriched uranium, as feed for dedicated facilities. (See chapter VII "Diversion From Commercial Power Systems" and "Dedicated Facilities".) There are some indications that theft of low-enriched uranium for reactor fuel may have already happened in India. (See appendix III, volume II.) Thus, as nuclear power spreads worldwide, and especially if plutonium comes into widespread use as a reactor fuel, it is possible that organized crime might become involved in all aspects of black and gray markets in nuclear material as commodities. Such a development would be extremely dangerous. It is difficult to see how such a market could for long resist developing into a market for plutonium as bomb material.

Some observers argue that organized crime would not get involved in a black market in plutonium for bombs (or in assembled nuclear weapons), for the same reasons, discussed above, that they would not be likely to attack nuclear facilities or engage in nuclear extortion. Thus, organized crime might also steer clear of trading in special nuclear material as commodities, if they perceived the commodities market and the bomb market as closely linked. (See also chapter VII "Purchase and Theft" and appendix VII of volume 11.)

Nuclear Hoaxes; Psychotics

A *nuclear hoax* is defined as a threat to *detonate a nuclear explosive* or to *disperse radioactive material*, when the threatener lacks the capacity or the dedication to carry out the threat. No such threat to date has been judged credible, and no perpetrators have had the capability of which they boasted, therefore all have been classed as nuclear hoaxes. There have been 38 nuclear hoaxes between 1970 and 1976. The characteristics of nuclear hoaxes are discussed in some detail in appendix III of volume II.

Hoaxes demonstrate that there are people who are thinking about using nuclear material to cause harm or as the coercive basis of a threat. It is not clear how many hoaxers, if they had access to nuclear material, would choose to mount a real threat rather than a hoax. There continue to be many conventional

[7]Brian Jenkins, "Will Terrorists Go Nuclear ?," Paper #64, California Seminar on Arms Control and Foreign Policy, Santa Monica, October 1975.

bomb hoaxes even though dynamite is easy to come by. However, the interpretation of the available data, both nuclear and non-nuclear, suggests that there are those who would carry out a real nuclear threat if they had the nuclear material and the capability to use it.

It appears, from a study of hoaxes, that psychotics may be more attracted to nuclear threats than politically or criminally motivated persons. Psychotics may also be responsible for many of the low-level nuclear incidents that have occurred so far. Most psychotics would probably not attempt to do anything more serious than cause disruption. On the other hand, lunatics have been the perpetrators of many known schemes of mass murder. Thus, some psychotics would have the will to carry out the most destructive of nuclear adversary actions. In terms of actual capabilities, however, they of all the categories of potential nuclear non-state adversaries are usually the least competent. However, there are some brilliant psychotics who have technical knowledge and skill. If one such also has the will to cause destruction and has access to weapons material he would constitute a formidable adversary.

Assessment of Threat Credibility

It is a vital and potentially difficult problem to distinguish a hoax from a real threat—that is, a threat backed up by capability and determination.

The FBI by Federal statute is the lead investigative agency in all cases where threats are made involving radioactive material. The nuclear aspects of threat assessment have been delegated to ERDA.

Current assessment of a nuclear threat consists of both a technical evaluation of the alleged nuclear device by ERDA and a behavioral evaluation principally by the FBI, of the threat message and the context in which it originated. So far, no perpetrators have backed up their allegations of a nuclear capability by any sort of evidence,

The usual approach has been to rule out the possibility of a credible threat. If the assessment found that the threat was not credible, an assumption was usually made that it was a hoax. Positive criteria for establishing that a threat is in fact a hoax are being developed.

At this time, a great deal of emphasis is placed on evaluating technical aspects of the threat and accounting for the supplies of special nuclear material. However, even if all U.S. special nuclear material could be perfectly accounted for, a foreign source of special nuclear material could be used in a threat mounted in the United States.

The cost of evaluating, investigating, and reacting to nuclear threats is not insignificant. An increasing number of persons are acquiring information and technical expertise in nuclear matters. If a person very knowledgeable about nuclear matters were to initiate a hoax it would be difficult to negate its credibility from a technical and behavioral assessment alone. In such cases, the ability to assess the adversary's dedication to carry out the threat would be critical.

If the time should come when an adversary of verified capability presents a credible threat, then the ability to assess motivation, intent, and dedication will be essential if it is decided to establish communications.

Summary

There are probably groups at large in the world today that possess or could acquire the resources necessary to become nuclear adversaries, if they wanted to. That is, they might be able to sabotage a reactor, steal fissile material, build a dispersal device, or possibly even a crude nuclear explosive device. Presently these include organized crime, certain terrorist groups who might undertake such actions with or without the assistance or complicity of a national government. Arguments arise less in the area of theoretical capabilities, but more in the area of intentions.

The historical record provides no evidence that any criminal or terrorist group has ever made any attempt to acquire fissile nuclear material or radioactive waste material for use in an explosive or dispersal device.

One ought to take little comfort from this fact, however. The lack of intelligence or visible evidence does not mean that the option has not been discussed; that some group might move in this direction without providing clues or warning. It is disquieting to realize that, in the past, most new terrorist groups have not been detected before their first terrorist act.

There is no logical progression that takes one easily from the existing pool of potential nuclear non-state adversaries to actual nuclear non-state adversaries, or from the nuclear incidents that have occurred to nuclear actions of greater consequence. Terrorist groups, as they presently exist, might be among future nuclear non-state adversaries, but their acquisition of a nuclear capability would not be a simple escalation of what has been demonstrated in terrorist actions thus far.

It is also a long conceptual jump from the present activities of organized crime to their acquisition of a nuclear capability.

Some authors of nuclear hoaxes have manifested desires of becoming nuclear non-state adversaries but none have demonstrated the required capabilities, and it is not certain that all hoaxers, even if they had access to nuclear material, would be anything more than hoaxers. In terms of intentions alone, some psychotics are potential nuclear non-state adversaries. In terms of capabilities they, of all the categories of potential nuclear non-state adversaries, are usually the least competent. To acquire a nuclear capability would require a quantum jump in capabilities for the vast majority of psychotics or an environmental change that would make the task much easier to accomplish.

Whether any of the current potential nuclear non-state adversaries, or other as yet undefined adversaries, will decide to actually go nuclear, cannot be answered at this time, Potential adversaries can be identified, their objectives, their capabilities, and the likely modes of operation if they do decide to go nuclear can be described.

There is left a vast area of uncertainty between what can be done and what will be done. The area of uncertainty could be reduced if society had a better understanding of the possible motivations and utilities of nuclear action to potential adversaries; not how society assesses its utility, rather how potential adversaries might. Although a growing body of literature on terrorism exists, much less is known about how they reach their decisions to do or not do something, how they weigh the various factors involved, how they judge risks and benefits. Likewise, in the area of crime little is known how organized crime would address a decision in this area, nor is it known if the issue has ever come up.

The nuclear non-state adversary may not arise from those groups currently identified as potential nuclear non-state adversaries; there may already be, or there may appear in the future, new kinds of adversaries, or special subclasses of existing adversaries, that have not yet been identified who might be more likely to use nuclear means to achieve their objectives. Threats to nuclear facilities or involving the malevolent use of nuclear material may emerge on a different organizational or mental plane. In the past decade, international terrorists have become a significant problem. They are a new entity which has emerged in the past decade, and although they have not yet given any indication of going nuclear, they could transform into entities that might, It is difficult to say now what new entities may emerge in the coming decade.

The origin, level, and nature of the potential nuclear non-state threat may change. Among the current adversaries, new tactics may be invented to effectively exploit the leverage that a nuclear capability would give and achieve a goal commensurate with the threat. If an individual or group successfully carried out a scheme of nuclear extortion or destruction, other individuals or groups would probably imitate the act. Thus, the probability of a second incident occuring, especially after a success, would seem to be greater than the probability of the first. The growing ties among international terrorist groups, referred to earlier in this chapter, increase the possibility of imitation.

The political context may change. Terrorists with the capabilities for acquiring a nuclear explosive may be placed in a desperate situation that will begin to erode the political arguments against nuclear action. The potential profits could become so enormous that organized criminal groups could be attracted to the nuclear industry. A war between two small nuclear powers may occur in which nuclear weapons are used, inviting further use by nations and subnational groups. Plutonium could become widely obtainable if adequate safeguards and physical security are not implemented, giving more entities the material with which to construct nuclear explosives.

Finally, the entire subject of adversary actions involving massive threats or destruction has apparently only started to receive systematic study. The imaginative use of chemicals or biological agents or even conventional explosives as the basis of a massive threat has apparently not caused much concern in the public mind, although such materials may be more easily obtainable than nuclear material and require less skill to cause large loss of life. The origins of the nuclear age may have much to do with this; the word nuclear recalls Hiroshima, not PeachBottom. Nevertheless, although the concentration on potential non-state nuclear violence to the neglect of other forms of potential mass violence may be strictly speaking irrational, it may be intuitively correct. If non-state adversary groups with the will to threaten or carry out large-scale violence do appear, they may choose nuclear means, even if it is somewhat more difficult, because they understand the public fascination and fear, and know that the nuclear threat or act will have the greatest impact.

CIVIL LIBERTIES IMPLICATIONS OF U.S. DOMESTIC SAFEGUARDS

Civil liberties issues have recently moved to a prominent position in the public consideration of nuclear power development. The growth of concern *over* the impact of nuclear power on civil liberties would probably have occurred even without consideration of plutonium reprocessing. As incidents of non-nuclear terrorism have mounted worldwide there has been an increased program to guard nuclear facilities against possible sabotage. Such increased security measures raise some issues of civil liberties impact, but the development of plutonium recycle and other nuclear technologies using material that could, if diverted, be made into nuclear explosives has set off the current debates.

Plutonium reprocessing offers the greatest opportunity for potential non-state adversaries—terrorist groups, profit-oriented criminal organizations, deranged persons, and disaffected employees of nuclear facilities—to obtain special nuclear material. Therefore, this section devotes its major attention to the civil liberties impact of safeguard measures necessary to prevent the theft of plutonium and to effect its recovery if stolen.

To analyze the potential impact of plutonium recycle on civil liberties, this section will:

- Provide a brief framework of civil liberties concepts.
- Describe the most likelv size of a plutonium recyle industry' in the near future.
- Analyze possible safeguard measures for such an industry and discuss their civil liberties implications,
- Present three widely held positions about the acceptability of civil liberties risks in a plutonium-safeguards program.
- Provide observations on the underlying assumptions and relative strengths and weaknesses of these three positions.

Of necessity, this discussion must treat both background issues and policy arguments in compact form; a full treatment of these matters can be found in appendix III of volume II, along with an extensive bibliography.

A Brief Framework of Civil Liberties Concepts

U.S. society regards protection of individual freedom and limitations on the exercise of Government power as fundamental tenets of the Republic. Some civil liberties interests, such as the right of religious belief and exercise, receive very broad, near-absolute status; other civil liberties interests, because their exercise has impact on public health and safety, the rights of others, or national security, have to be defined and applied by balancing competing social interests or conflicting civil liberties claims. The rise of new social and economic settings, new technologies, and complex urban life also require constant adaptation of the civil liberties concepts framed in the 18th century Bill of Rights.

What distinguishes U.S. society from many others, including some other democratic systems, is the belief that protection of civil liberty is so central to moral, political, and legal values that serious limitations on liberty should always be shown to be clearly necessary; that measures having such effects should be kept to the minimum required in a given circumstance; and that U.S. courts will weigh the need for such measures and are empowered to declare unconstitutional any laws or executive actions which transgress basic liberties.

In the context of plutonium recycle safeguards, the two aspects of civil liberties which would be most directly involved are free *expression* and *fair procedure.*

Free expression involves the guarantees of free speech, press, assembly, association, religion, and privacy protected by the First Amendment to the Federal Constitution and its State counterparts. Fair procedure, or due process, involves the standards by which Government investigatory activity should be conducted and the procedures under which Goverment makes formal determinations about individuals, in both administrative proceedings and criminal trials.

While courts play a central role in defining and enforcing constitutional rights in the United States, it is also tradition that the legislatures and executive branches of Federal and State governments are expected to be, and often have been, strong guardians of the citizen's liberty. This means that debates over the civil liberties implications of Government programs such as plutonium recycle are policy matters for elected officials and the public to consider. What is good civil liberties policy, therefore, is not merely a matter of what the courts may have held to be constitutional law in prior-related situations. It is also what elected officials and the American public believe to be the best balance between liberty and other social interests in a particular context. This public responsibility is especially important in situations-of which plutonium recycle is one—where it may be unlikely that the courts will pass judgment in the early phases. (The role of the courts in assessing the civil liberties impacts of nuclear safeguards is discussed in greater detail in appendix III of volume II.)

Potential terrorist threats to obtain and use nuclear, chemical, or biological weapons pose especially knotty problems of civil liberties policy, Since dangers to human life and public safety could be great, safeguards against such activities must be strong and effective if public confidence is to be preserved. Yet safeguard measures which would sweep so widely as to curtail basic liberties for substantial numbers of people or for broad sectors of public life could move our society toward the kind of garrison-state environment that political terrorists hope to force upon democratic nations to undermine the vitality of their social orders. Walking the line between underreaction and overreaction is the goal of democratic societies, and careful examination in advance as how to draw that line is the context in which we must examine both the decision to develop and safeguard a plutonium industry and the likely impact of various safeguard measures on civil liberties.

The Most Likely Size of a Plutonium Recycle Industry in the Near Future

When the consideration of civil liberties and plutonium recycle first arose during

1974-76, critics and supporters based their arguments on projections that envisaged a very large plutonium recycle industry in the next 25 to 50 years. By the year 2020, these early projections indicated that there would be some 60 plutonium fabricating and reprocessing plants and 2,000 reactors in the United States, an extraordinarily large number of shipments per year of special nuclear materials between fabricating plants, reprocessing plants, and storage sites; and a plutonium work force of over 1 million persons.

Official and unofficial projections have been scaled sharply downward during the past year. The following table (figure V-4), drawn from the Generic Environmental Statement on the use of Mixed Oxide Fuel (GESMO), indicates the current projections of components for a light water reactor industry using uranium and plutonium recycle. GESMO estimates that in 2000, 27,000 people would be employed in the fuel cycle and 55,000 people in the nuclear electrical power industry. Of these people, a maximum of 20,000 persons in the fuel cycle would be in positions requiring clearances, 13,000 of which would require full-field investigations.[8]

The size of the employment force needed to transport special nuclear material between fabricating and reprocessing plants has become a matter of uncertainty rather than firm projection. If the decision were made to colocate fabricating and reprocessing plants, this would eliminate the need for shipping pure plutonium offsite. Coprecipitation of plutonium oxide and uranium oxide at the reprocessing plant would also eliminate transportation of pure plutonium.

The size and distribution of a plutonium industry is now seen as much smaller than when the civil liberties impacts were first examined, and several major technological aspects remain either uncertain or are open to choice rather than being technologically determined. How this affects the civil liberties problems will be discussed later,

Safeguard Measures for a Plutonium Industry and Their Civil Liberties Implications

Current Federal law forbids the unauthorized possession of special nuclear material or efforts to obtain it illegally, Extensive personnel and physical security programs are used in military nuclear facilities, and in Government shipments of special nuclear material. The NRC's recent announcement of its intention to instaIl a clearance program for employees of private nuclear reactors has already been noted. There are comparable personnel and physical security programs outside the nuclear industry to safeguard sensitive facilities (gold depositories, intelligence facilities); to screen out dangerous objects (airports scanning for weapons); and safeguard shipments of valuable or dangerous objects (bank currency shipments, nerve gas). This leads some commentators to conclude that plutonium safeguards would differ only in degree and not in kind from protective programs that our society already employs.

However, other commentators point to the extremely high level of harm that would be done if a nuclear diversion and explosion were successful (in numbers of deaths and long-term radiation effects), and to the immense public fear of nuclear explosion that a blackmail threat itself would generate. They conclude that these risks are so great that a plutonium safeguards program would have to be different in kind, not merely degree. It would have to be far more intense, permanent, and put more people outside the plutonium industry under preventive or responsive intelligence than anything presently in force.

There are several important points of agreement between these two views:

—If plutonium recycle is initiated, there would be a genuine need for high-security measures. In other words, this

[8]In March *1977,* the Nuclear Regulatory Commission announced a proposed rule to require 4,000 employees in 63 private nuclear reactors to get a security clearance requiring full-field investigation, and 2,000 employees in such plants to get the equivalent of a "confidential" clearance, requiring a name check against national agency files. This program is aimed primarily at protecting against reactor sabotage.

Figure V-4

The Projected LWR Industry, 1980-2000* with U and Pu Recycle

LWR Industry Components	Number of Facilities		
	1980	1990	2000
LWR'S	71	269	507
Mines**	416	1,856	4,125
Mills	21	56	77
UF6 Conversion Plants	2	4	5
Uranium Enrichment Plants	3	3	5
UO_2 Fuel Fabrication Plants	6	6	7
Reprocessing Plants	1	3	5
MOX Plants	1	3	8
Federal Repositories for Storage	0	2	2
Plutonium Shipments in metric tons**	5 tons	273 tons	1,170 tons
Commercial Burial Grounds	6	6	11

"From Table S-10 of Final GESMO NUREG 0002, Vol. 1 Summary

● gFrom Page XI-35 of Final GESMO NUREG 0002

would not be an instance where responsible critics would allege that there was no need for any strong measures, as they denied the presence of security risks serious enough to justify passage of the Alien or Sedition Laws in the 1790's, the Palmer round-ups of aliens in the 1920's, or the Joseph McCarthy investigations of the 1950's.

—In the general public debates over broad police powers of arrest, search, and seizure, some argue that work should be done on the underlying problems that cause high crime-such as unemployment or racial discrimination—rather than allow police to use intrusive or harsh techniques. In the case of potential threats against plutonium plants, however, there are no real prospects in the foreseeable future of adopting national or international policies to remove the causes of all political terrorism, individual derangement, or criminal conspiracies, thereby obviating the need for high-security measures.

—No complete technological solution is available, or is foreseen, that could entirely eliminate the need for other safeguards measures which could raise civil liberties issues. For example, the machine scanners used in airport searches have made it unnecessary to require pat-down searches of millions of air travelers, thus providing a technological measure of high acceptability to the courts and the public. However, searches to recover plutonium, if diverted, could not presently be accomplished by radiation detection alone, and it would be necessary to use some measures that would have potential for violating civil liberties,

Having noted these areas of general agreement among observers of the safeguards problem, the types of safeguards used in the past in high-security contexts are described and their civil liberties implications discussed. These can be grouped under four headings: employee screening; material production; threat analysis; and recovery measures.

1. **Employee screening** ranges from minimal national agency name checks and questionnaires asking for detailed personal histories to full-field investigations asking neighbors, former employers, and associates about the background, loyalty, character, and lifestyle of applicants for employment. Screening may also entail the use of polygraphs to measure physical and emotional responses to questions about

suitability characteristics (use of drugs, thefts, lying about previous activities) or the use of psychological tests to investigate emotional and mental instability. All of these techniques could be directed at identifying employees who might use their position to steal or sabotage nuclear material. There are serious civil liberties concerns over both the standards of conduct employed in such screening (such as current denials of sensitive employment to homosexuals) and the verification techniques used (polygraphs and psychological tests, which have been attacked both as unreliable and as violations of privacy).

2. **Material protection** involves measures to control access to or misuse of special nuclear material. Some of these-such as mechanical detection of radioactive material, inspection of hand-carried items, and personal identity checks-do not raise serious civil liberties issues. Other techniques, such as visual or audio surveillance of workers on the job or pat-down searches (frisking) of individuals entering or leaving an area do raise civil liberties issues.

3. **Threat analysis** would involve efforts to obtain advance warning of diversion or sabotage attempts, or to guide recovery efforts should a successful diversion take place. Overt intelligence checks of potential assailants usually entail investigative techniques such as background inquiries, checks of law enforcement intelligence files, and physical surveillance. Covert intelligence measures may include electronic surveillance, surreptitious entries, use of informants and undercover agents, mail openings, and similar methods. While overt intelligence techniques may be both necessary and acceptable if limited to genuine potential terrorists, the classic civil liberties danger in such activity is that the investigative net is cast too widely, and covers large numbers of ideological dissidents. The covert intelligence techniques also raise this danger, exacerbated by the covert nature of the privacy-invading methods. Whether covert techniques are used under administrative controls or are subject to either judicial or legislative committee supervision, bears on the degree of potential injury they will inflict.

4. Recoverv measures are potentiallv the most dangerous to civil liberties. At the low end of the spectrum in potential harm are quarantines of the facility, full-scale searches of personnel, and searches of surrounding areas by mechanical (radioactivity) detectors. At the high end of the spectrum, should other measures fail, could be large-scale roundups of suspects, room-by-room physical searches by hand, wholesale evacuation of populations from target areas, censorship of the press, and harsh interrogation of persons strongly believed to be members of the diversion groups or who know the location of stolen material.

With this brief overview of the kinds of measures involved in safeguard programs, the following section discusses the estimate of civil liberties risks and tradeoffs in the context of three main positions about plutonium and civil liberties developed over the past few years.

Three Positions Widely Held in U.S. Society as to the Civil Liberties Risks of Plutonium Recycle

The positions described below have been constructed from an analysis of public statements made by industry representatives, scientific and legal experts, executive-agency officials, members of Congress, public-interest groups, and similar commentators. The sources for their statements can be found in appendix III of volume II.

Position One: A Plutonium Economy Would Require Such Extensive Safeguards and Curtailments of Civil Liberties That Its Creation Would Jeopardize Free Society in the United States.

This position makes a number of key assumptions:

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a. The presence of hundreds of thousands of pounds of plutonium in reprocessing plants or in transit—when 20 pounds would be enough to make a nuclear explosive, and with prevailing conditions of domestic and international terrorism—poses a situation so perilous to public safety that only a far-reaching, zero-risk safeguards program would be sufficient to protect the public. Therefore, that kind of sweeping safeguard program is the one to envisage.

b. The immense potential consequences of a nuclear diversion from inside or an assault from outside would probably lead the courts to uphold sweeping preventive intelligence measures. The courts would be even more likely to decline to interfere if Government took Draconian measures in response to a blackmail threat or nuclear incident. The release of intelligence agencies and security investigators from constitutional limits would not only be harmful in itself but would also be likely to stimulate surveillance and dossier-building in non-nuclear fields.

c. Even if a safeguards program were originally set up with strong civil liberties protection written into legislation or executive orders, public reaction to foreseeable incidents of diversion and blackmail, and certainly to any successful explosion, would lead to the dropping of such limitations and the adoption of a maximum security program. Thus no safeguards program can be expected to stay limited as a plutonium economy continues for any length of time.

d. The growing political movement opposing nuclear power will produce protest demonstrations focused on highly visible targets such as fuel-cycle facilities and transportation. This will require harsh protective responses and produce serious confrontations.

e. Giving industrial security forces and corporate managements a role in collecting data and managing security programs about employees would be harmful to sound employer-employee relations.

f. Given these likely consequences, and the fact that alternative energy sources such as coal or solar power require no such safeguard measures, proponents of plutonium recycle must prove to Congress and the public that no other energy sources or conservation programs can be developed to meet American energy needs, even at higher but not unbearable economic costs.

Based on these assumptions, Position One concludes:

- On civil liberties grounds alone, Congress should reject plutonium recyle.
- The United States should not export plutonium recycle technology. This is partly to diminish the threat of diverted plutonium being smuggled into this country by terrorists, thus creating the need for extensive customs-search procedures. It is also urged in order to avoid having the United States export a technology that would inhibit the evolution of greater civil liberties in developing nations.

Position Two: Safeguards Can Be Adopted For a Plutonium Industry That Would Be Both Effective Against Threats and Acceptable **in Terms of Civil Liberties.**

Position Two proceeds from the following primary assumptions:

a. Operators of military and commercial nuclear facilities have been managing safeguard programs successfully for decades; adapting these to the new scope and requirements of a plutonium economy would therefore represent an expansion of present operations, not a totally new venture.

b. It is unacceptable for a strong society such as the United States to let potential threats from a few terrorists, criminals, or disturbed people deprive the American economy and the public of badly needed energy supply. Nuclear power is economically competitive with other sources, capable of safe use, and environmentally sound. The need to safeguard nuclear power facilities is no more a reason for rejecting nuclear power than potential threats against other vulnerable facilities, such as natural gas facilities, dams, city water reservoirs or subway systems constitute good reason to close them down.

c. Whether the size of a plutonium work force would be 20,000 or 1 million, it is justified to set clearance standards for persons who choose to work in that industry. This deprives no one of her/his rights to pursue gainful employment, even in the nuclear field, as there will be many other nuclear research and operating facilities beside the commercial plutonium industry, The same justification of voluntary choice with advance knowledge is presently seen to justify other personnel security measures in highly sensitive operations outside the nuclear field.

d. The intrusions into personal liberties of workers, community residents, and diversion suspects that would take place if a diversion were detected or a nuclear blackmail threat made—a wesome as those situations are—are really no different than if nerve gas or a highly dangerous bacteriological agent were stolen from a civilian or military site. In all such cases, preliminary investigation by professionals would establish the credibility of the danger, negotiations would be weighed, and a response pursued appropriate to the situation. There is simply no way a democratic society can eliminate the possibility of such episodes.

e. Regarding intelligence-gathering about potential diverters, there is a need for obtaining intelligence about terrorist organizations and other groups whose actual conduct indicates that they might use nuclear means of violence. Legislation and regulations would carefully spell out the operational limits of such intelligence programs, both as to the range of groups on which data would be collected and the methods used to do so.

Based on these assumptions, Position Two reaches the following conclusions:

. After full public participation in a rule-making proceeding addressing both safeguards requirements and civil liberties considerations, the United States should proceed with a plutonium licensing program.

. The United States should also proceed with sales of plutonium recycle facilities abroad, under a safeguards program that would meet both U.S. and IAEA standards.

Position Three: An Acceptable Program of Plutonium Safeguards is Possible But Only If American Society is Willing to Run Some Permanent Risks of Diversion In Order to Keep Civil Liberties Risks at a Low Level.

These assumptions underlie Position Three:

a. To adopt a zero-risk approach to safeguards, or even to speak of holding threats to negligible proportions, is to ensure that the civil liberties costs of such a program will be unbearably high. Once it is assumed that reducing threats to near zero is the objective, managers of a safeguards program would be driven to adopt highly dangerous techniques of personnel security and preventive intelligence.

b. Instead of this standard, there should be adoption of a standard that would trade-off some small risks of diversion against heavy risks to basic civil liberties. Americans should see the creation of a reasonable, efficient, and freedom-respecting network of safeguards as the approach to plutonium security.

c. This would mean deliberately rejecting some widely proposed techniques of personnel screening, employee monitoring, and preventive-intelligence gathering on anti-nuclear groups, not merely because many of these techniques are of doubtful effectiveness but because their civil liberties costs are too high. In balancing slightly greater risks of diversion against very heavy risks to basic freedoms, the decision would have to be made to protect freedoms.

d. A least restrictive alternative test can be applied to each component of a safeguards program. As a recent report to the Nuclear Regulatory Commission put it:

> We think it vital that such a "least restrictive alternative" approach be the keystone of the NRC's approach to the selection and shaping of safeguards measures. In approaching a particular safeguards problem, the Commission should evaluate the impact on civil liberties of each of the ways of solving that problem. The factors to be considered in evaluating the impact of various safeguards measures on civil liberties should include the following: (1) the extent of the intrusion on personal liberties; (2) the frequency and per-

vasiveness of the intrusion on civil liberties (Will it be part of a daily routine or will it only occasionally be employed? Will its effects be temporary and limited or long lasting?); (3) the number and types of individuals affected (employees in nuclear plants, members of suspected terrorist organizations or dissident groups, "innocent" members of the public); (4) the likelihood that a particular safeguards measure will actually be employed; and (5) the likelihood that the same or similar invasions of civil liberties will take place even if the safeguards measure under consideration is not employed.

e. For plutonium recycle to go forward, such a set of fully articulated tradeoffs would have to: be set out as the philosophy of a safeguards program; be tested before the public in a variety of hearings and proceedings; be fully accepted by the commercial firms and Government regulatory agencies most directly concerned; be written explicitly into legislation and implementing regulations; be subjected to firm annual reporting duties and legislative reviews; and have procedures created for both administrative appeals and judicial review.

f. It would be especially important to a proper safeguards program that the Nuclear Regulatory Commission not simply turn over to the discretion of the FBI the conduct of preventive intelligence for plutonium security, or leave the decisionmaking responsibility in a recovery effort or diversion response to ad hoc developments among Federal, State, and local officials. These activities, because they are among the most important for civil liberties, should be defined and supervised by the NRC, possibly with a congressional oversight role.

g. Holding to this line would involve continually reaffirming the bargain in the face of probable low-level and possible high-level incidents. This would mean that the American public would have to hold the line of moderation, refusing to let itself be stampeded by demagogues, and forcing sufficient public supervision to prevent the program being subverted by secret government.

[9] Timothy B. Dyk, Daniel Marcus, and William J. Kolasky, Jr., *Civil Liberties Implications of a Safeguards Program for Special Nuclear Material in the Private Nuclear Power Industry*, a report to the Nuclear Regulatory Commission, October 31, 1975.

Based on these assumptions, Position Three draws the following policy conclusions:

- Congress should go forward with a full-dress review of the need of plutonium recycle to meet America's future energy demands, and of whether this process can be made environmentally and physically safe. If the answer to these inquiries is yes, then Congress should receive from NRC a fully worked out plan for safeguards, which then would be publicly reviewed and implemented.
- Position Three takes no stand on the desirability or civil liberties risks of selling plutonium technology abroad.

Observations and Comments on the Three Positions

The effort to isolate key differences among the three major positions obviously produces some rigidity in stating premises and conclusions. Someone may share one or more premises of a position without reaching the same final conclusion as the advocates of that position. For example, a person may believe that the voluntary nature of employment in a plutonium industry justifies personnel clearances without concluding that it justifies more intrusive techniques, such as polygraph examinations. Also, the differences between Position One (which would forego plutonium recycle because of civil liberties concerns) and the other two positions (which would go forward with plutonium recycle with different steps to solve civil liberties problems) are clearly more marked than the differences between Positions Two and Three.

There is also a sense in which each of the three positions outlined is partially right.

— Position One points correctly to the dangers of so much plutonium being handled in a world of terror and mishap; the public pressure that could be created to use Draconian safeguards measures; and the highly optimistic assumptions as to unbroken national responsibilities and moderation on which both Positions Two and Three rest their faith,

— Position Two reminds us that the year 2020 will come gradually, allowing a plutonium economy to develop slowly; safeguards could therefore be developed step by step, modifying the technology, physical locations, plant design, shipment procedures, and many other elements as it went along.

— Position Three suggests persuasively that it has been a traditional feature of American pragmatism to resist either/or choices, seeking ways to trade off one set of risks against another to preserve both liberty and order.

It is helpful also to examine the effect of some altered assumptions of safeguard approaches on these positions, and some of their weaker points.

— The concerns of Position One about diversion of special nuclear material during transportation would be greatly reduced if collocation of reprocessing and fabrication facilities or coprocessing (without collocation) completely eliminated transportation of weapons material. Similarly, concerns about assaults by outsiders would diminish if facilities containing material usable in weapons were convincingly designed to prevent removal of weapons material even by a large, heavily armed band. Such successful defenses for colocated facilities could reduce or eliminate the need for offsite security measures such as surveillance and dossier-building on members of the public. Finally, if the number of people in the plutonium industry who would be subjected to full background investigations and would be periodically subjected to on-job surveillance were very limited in number (such as several tens of thousands), the number of people affected is less than presently exists in the defense industry or other sensitive private activities. It is not clear, however, what number of employees must be affected in order to reach a point of civil liberties concern; some people would regard 20,000 as an acceptable number for such intensive security measures; others might accept only lower numbers.

— The assurances contained in Position Two would be disputed by many knowledgeable persons. It is not *proven* that the past and present safeguards system has been totally successful, Because of the significant amounts of unaccounted for material accumulated over the last 20 years, the possibility that diversions have already occurred cannot be dismissed. However, none of this material has ever been involved in a weapons threat. (Note that all weapons threats received to date have been hoaxes. See chapter V and appendix III, volume II.) Nor is it clear that Position One is correct in saying that an expanded plutonium industry merely represents a difference in degree, not in type. In cases where a plutonium facility becomes a major or dominant employer in a community, there is less freedom of choice for residents as to whether they accede to the security restrictions or refuse to work at the facility. In small rural communities the company-town syndrome may appear, making it difficult for employees to resist extensive security measures.

— As for Position Three, past experience with security officers makes many persons doubtful about the possibility of containing a security program to least restrictive security procedures, Security personnel are prone to seek tighter measures; professionally, they tend to seek foolproof techniques that threaten infringement of civil liberties. Even with tight internal security and strong perimeter defenses, it is likely that security personnel would want to employ positive intelligence (e.g., surveillance and informers to identify potential attackers or critics). Also, the addition of ombudsmen or public advocates to the system to protect against unwarranted security intrusions is subject to the well-known danger that constant proximity to security processes render them too sensitive to the needs of the security forces. Finally, Position Three may be ignoring the resulting effect of a successful diversion if followed by major threat or actual casualties. It is not clear that the original limited safeguards system contemplated by Position Three would survive the pressures of an outraged public determined to prevent any further incidents.

In trying to decide which one or combination of these views is right and therefore should be used in policymaking, it should be recognized that this is not a problem that can be put to the tests of either logic or empirical investigation. The reality is that each of these positions rests, fundamentally, on sociopolitical judgments as to how the U.S. Government and public opinion have dealt in the past with threats to national security (real or assumed); how Government and commercial security forces would be likely to carry out a safeguards program; how much privacy, dissent, protest, and cultural diversity our civil liberties traditions demand or our society should encourage; and how the American public would probably respond to diversions, blackmail threats, or a nuclear explosion, in terms of its shocked post-incident attitudes toward the scope of safeguards measures.

There is also no good decision guide in the way other industrialized democracies are dealing with the plutonium recycle issue. In Britain, for example, the debate over plutonium and civil liberties is in almost exactly the same stage as in this country. There is support in British Government documents, parliamentary reports, commercial industry materials, and civic-group literature for each of the three positions outlined above.

In conclusion, the choice between the total ban on plutonium advocated by Position One and the acceptance of plutonium recycle by Positions Two and Three (though with different conceptions of how to conduct a safeguards program) is likely to be made on a total package basis by U.S. society, not on the basis of the civil liberties considerations alone. Indeed, the civil liberties aspects really tend to reinforce the existing orientations of each of the main contending parties debating the value and risks of plutonium recycle as an energy source.

The single most important conclusion suggested by this review is that if a plutonium industry as described earlier in figure V-4 were to be pursued in the near future, steady attention would need to be paid by Congress, the executive agencies, public-interest groups, and the courts to the way in which safeguards are defined, administered, monitored, and reviewed. Keeping a plutonium safeguards program consistent with civil liberties would become an important, continuing task of those who cherish American freedom.

Chapter VI

Nuclear Weapons

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Nuclear Weapons

The resources required for the design and construction of nuclear explosives are examined in this chapter. Peaceful nuclear explosives (PNE) are also analyzed to understand their practicality in view of the possibility of weapons tests conducted under a PNE guise. Finally the potential use of nonexplosive nuclear weapons is described under "Radiological Weapons" in this chapter.

NUCLEAR FISSION EXPLOSIVE WEAPONS

A nation that decides to develop nuclear explosive weapens must commit certain resources to the program. The requirements depend on the complexity and quantity of the weapons desired, but a minimal weapons-development program is of particular relevance to proliferation control. This chapter examines the manpower, money, equipment, and time required for such a program. The level of effort required for a non-state adversary to produce a crude nuclear explosive is also considered.

Fissile material is the critical component of a nuclear explosive. Several different materials are considered: U^{233} and U^{235} in varying enrichments, and Pu^{239} with various concentrations of plutonium isotopes, particularly Pu^{240}. Large amounts of all these materials are, or may be, involved in the worldwide nuclear power industry. Two fissile byproducts of nuclear operations, Np^{237} and Pu^{238} are also considered. This chapter analyzes the quantities of various materials required for a practical nuclear explosive and reviews the threshold quantities at which physical security safeguards are required by the Nuclear Regulatory Commission (NRC).

Resources

The minimal weapons program described here is necessarily restricted to designs of relatively low complexity. Devices depending on thermonuclear components have been excluded, and attention has been devoted to those straightforward patterns of assembly that would be the easiest to realize.

A range of minimal efforts exists. At the upper end of this range is a national effort whose aim is to produce a small stockpile of nuclear explosive weapons. An important class of *national* programs to consider is a clandestine effort to produce, *without nuclear testing,* a first weapon which is *very confidently* expected to have a *substantial nuclear yield.*

At the lower end of the minimal range is a small non-national group (for example, a terrorist or criminal group) whose objective is the crude fabrication of a single nuclear explosive device.

In the discussion which follows, it has been assumed that adequate supplies of fissile material have been made available.

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National Program

A minimal *national* program would call for a group of more than a dozen well-trained and very competent persons, having experience in many fields of science and engineering and access to the open technical literature. They would need a staff of technicians, diverse laboratory facilities, and a field-test facility capable of handling experiments with large high-explosive charges. This group would further need the financial and organizational structures to fabricate or purchase on the open market a variety of items required for the assembly mechanism and for the (non-nuclear) test instrumentation.

If these requirements are met, and the program is efficiently and competently carried out, the objective could be attained approximately 2 years after the start of the program at a cost of a few tens of millions of dollars.

This estimate does not include the time and money to obtain the fissile material or to establish a modest scientific, technical, and organizational infrastructure. The estimate also does not include the cost of a delivery system. It should be realized, however, that in many circumstances the delivery system could be quite crude.

Some details of the effort, including composition of the technical group, would depend on whether a gun-assembly weapon or an implosion weapon were built. However, the expenditures of manpower, money, and time would not differ significantly for the two types of weapons. (See the discussion of low-technology design below.)

The success or failure of the effort described above in producing a militarily effective nuclear explosive is far more dependent on the *competence* of the people involved than on the technological problems themselves. In trying to evaluate the potential of a specific nuclear weapons development program, detailed knowledge of the strengths and weaknesses of personnel is more valuable than details of the technological base of the country.

In the context of the *national* effort discussed above, competence involves more than the proper credentials (i.e., university degrees). For the group to be competent, the members must have a degree of creativity and intuition. However, a high degree of inventiveness is not required. Geniuses are not needed. What is needed is a group that has the ability to do absolutely sound work, both theoretically and experimentally, and independently arrive at correct judgments.

The level of technological effort put forth in the minimal *national* program can be called *low technology*. Low technology encompasses the sort of nuclear device designs that would likely be produced for a first use or first test. This requires techniques which allow high confidence without prior nuclear test experience. This could be characterized as 1945 U.S. technology. A discussion of low-technology design is given below.

Non-National Program

At the low end of the minimal range of effort, a small group of people, none of whom have ever had access to the classified literature, could possibly design and build a crude nuclear explosive device. They would not necessarily require a great deal of technological equipment or have to undertake any experiments. Only modest machine-shop facilities that could be contracted for without arousing suspicion would be required. The financial resources for acquisition of necessary equipment on open markets need not exceed a fraction of a million dollars. The group would have to include, at a minimum, a person capable of searching and understanding the technical literature in several fields and a jack-of-all-trades technician. Again, it is assumed that sufficient quantities of fissile material have been provided,

The actual construction of even a crude nuclear explosive would be at least as difficult as the design itself. The small non-national group described above would probably not be able to develop an accurate prediction of the yield of their device. The device could be a total failure, because of either faulty design or faulty construction. Here again, a great deal depends on the competence of the group; if it is deficient, not only is the chance of producing a total failure increased, but the chance that a member of the group might suffer serious or fatal injury would be quite real. However, there is a clear possibility that a clever and competent group could design and construct a device which would produce a significant nuclear yield (i.e., a yield much greater than the yield of an equal mass of high explosive).

Low-Technology Nuclear Explosives

Low-technology devices can be fabricated from any fissile material that has sufficient concentrations of U^{235}, U^{233}, or plutonium. The different critical masses of these materials require different amounts of fissile material for constructing nuclear explosives of basically similar design. Other significant distinctions of these materials are their radioactivity and their inherent neutron background. These two properties affect their handling and fabrication, the variety of assembly schemes available for use, and, to some extent, the yield potentials of low-technology devices.

With respect to radioactivity and handling characteristics, U^{235} clearly offers the least difficulty. U^{233} is considerably more radioactive, and this problem is compounded by a small impurity content of U^{232}, which decays through a long chain to thallium–208 which emits penetrating and intense gamma radiation. Plutonium presents serious handling problems, principally because intense alpha radiation causes it to be very toxic when inhaled as a dust, Reactor-grade plutonium is several times more radioactive than weapons-grade plutonium but the radiation levels encountered with either are practically the same compared to the much lower radiation levels encountered with U^{235}. 1 Radioactivity problems are manageable for all these substances, especially for anyone with reactor-fuel handling capability.

The impact of neutron background requires discussion. The neutron background can come from many sources. There are neutrons present at all times because of cosmic ray activity, but this background is quite small. The major source in fissile material is from spontaneous fission. For one kilogram of U^{235}, spontaneous fission produces approximately one neutron per second. The spontaneous fission rates of weapons-grade plutonium and typical reactor-grade plutonium are 60,000 and 300,000 times higher, Another source of neutrons is the alpha-n reaction. In this case, radioactive decay of the fissile isotope yields alpha particles, some of which then collide with impurities such as boron, carbon, or oxygen to yield neutrons.

The classic problem presented by background neutrons is that of *prenitiation* of the nuclear-fission chain reaction. In order to assemble fissionable material to produce a nuclear explosion, a subcritical mass (or masses) of material must be rapidly moved into a configuration which has a level of supercriticality sufficient to produce a significant nuclear yield before it blows itself apart. Preinitiation in a nuclear explosive is defined as the initiation of the neutron chain reaction before the desired degree of supercriticality has been achieved. Because the nuclear yield depends upon the degree of supercriticality at the time the chain reaction is initiated, preinitiation will result in a lower yield. However, initiation is a statistical process and can be understood using statistical techniques.

Preinitiation, by itself, does not necessarily make an explosive unreliable. Preinitiation does result in a statistical uncertainty in the yield. Another way to state this is that the probable nuclear yield is statistically distributed between predictable upper and lower limits, which are likely to be more than a factor of 10 apart. For a *well-understood design properly constructed*, however, the most probable yield range could be predicted within much closer limits.

In some low technology assembly designs, preinitiation can cause the nuclear yield to be

[1] The material commonly called weapons-grade plutonium contains primarily plutonium–239 and less than 7 percent of the undesirable isotope plutonium–240. Reactor-grade plutonium has a larger percentage of this isotope and is produced in most commercial power reactors under normal operating conditions.

so low that it is effectively zero. However, there are low-technology assembly designs where the lowest yield because of preinitiation is still militarily significant.

It is widely known that there are two basic methods of assembling fissile material in a nuclear explosive. The first method is to assemble two (or more) subcritical masses by the use of gun propellants. This is commonly referred to as a gun-assembled nuclear weapon.

In a gun-type device, the velocities of assembly that can be obtained in practice, although high in everyday terms, are still so small that unless the neutron background is low, all or most of the nuclear yields realized will be virtually zero.

A second method is to compress a subcritical configuration of fissile material into a supercritical mass by use of a high explosive surrounding the material. This assembly is commonly referred to as an implosion weapon and can be used to assemble the fissile material very rapidly. The velocity of assembly is much higher than can be achieved in gun assemblies, Also, because of the material compression, less fissile material is required to reach any given level of supercriticality. The very rapid assembly allows use of fissile material with higher neutron background than can be used in gun-assembled devices. Said another way, for a given level of neutron background in the fissile material, the probability of preinitiation is reduced by use of the faster implosion assembly.

Highly enriched U^{235} or U^{233} or plutonium can be used to produce effective weapons by use of low-technology implosion designs. A low-technology gun-assembled system would give effectively zero nuclear yield if plutonium were used.

It is widely believed that gun assembly is the simpler way to produce a nuclear explosive. Although the gun assembly may be conceptually simpler, the difficulty of actually constructing a nuclear explosive is roughly equivalent whether a gun or implosion assembly is used. The difficulties of the gun assembly are often not appreciated: a large mass of high density must be accelerated to a high speed in a short distance, putting quite unusual requirements on the gun design.

Yields of Low-Technology Nuclear Explosives

Using low-neutron background materials (i. e., U^{235}, U^{233}, and weapons-grade plutonium), it is possible to design low-technology devices to produce yields reliably up to the equivalent of 10 or 20 kilotons of TNT. For high-neutron background materials (e.g., reactor-grade plutonium), low-technology devices will have probable yields lower than those where low-neutron background materials are used. The probable yields could be lower by a factor of 3 to 10 or more (depending on the design); but yields in the kiloton range could be accomplished.

Thus, militarily useful weapons with reliable nuclear yields in the kiloton range can be constructed with reactor-grade plutonium, using low technology.

The Second Stage of a National Program

After the construction of its first nuclear explosive, a country might follow one of several courses in its weapons-development program. It might merely choose to continue making and stockpiling weapons similar to its first, with no nuclear testing or expansion of its program.

Alternatively, the nation might proceed to develop weapons that are militarily more useful than its first low-technology explosive. From purely technical considerations, this second course is entirely possible.

A likely objective of a second-stage national program would be the development of weapons of similar yield to its first low-technology explosive, but with one or more of the following improvements:

(a) markedly smaller physical size;
(b) composed of significantly less fissile material;
(c) narrower range of uncertainty of yield,

Alternatively, a nation might concentrate on producing weapons with significantly higher yield than its first explosive. These objectives could be achieved using reactor-grade plutonium.

The greater complexity of such designs would require greatly expanded resources of manpower, funds, and equipment. A few nuclear tests would be an essential part of the expanded program.

The expanded program could not be clandestine and would require several years to achieve significant advances.

Thresholds of Fissile Material for Setting Physical Security Requirements

Materials containing U^{235}, U^{233}, and plutonium can be used for making fission explosives only if these isotopes are sufficiently concentrated. For each isotope, a minimum concentration of that isotope in U^{238} can be specified, below which the mixture is not usable in a practical nuclear explosive. The minimum concentration for U^{235} has been specified at 20 percent (i.e., one part U^{235} to four parts U^{238}) for many years. There appears to be no reason to change this.

The bare-sphere critical mass of metallic 20 percent U^{235} and 80 percent U^{238} is about 850 kg (i.e., about 1,900 pounds). This critical mass can be reduced by a factor of two or three by surrounding the sphere of fissile material with some substance, such as iron, uranium, or beryllium, in order to reflect neutrons back into the fissile material. However, the size and weight of the combination of reflector and fissile material will not be substantially less than that of the bare sphere, and may even be greater. Finally, the assembly system, whether gun or implosion, adds substantially to the size and weight of a nuclear explosive.

Thus, if any fissile material is mixed with U238 with such low concentration of the fissile isotope that the bare-sphere metallic critical mass is greater than about 850 kg, the material could not be used to construct a nuclear explosive of practical weight.

Detailed calculations show that the above criterion sets the following thresholds for U^{235}, U^{233}, and plutonium mixed with U^{238}:[2]

U^{235} to U^{238}	1:4	(i.e. 20 percent concentration of U^{235})
U^{233} to U^{238}	1:7	(i.e. about 12 percent concentration of U^{233})
Pu^{239} to U^{238}	1:7	(i.e. about 12 percent concentration of Pu^{239})
reactor-grade plutonium to U^{238}	1:6	(i.e. about 14 percent concentration of reactor-grade plutonium)

Below these concentrations, the total weight of the explosive would be so large as to make it impractical.

The United States currently requires physical security on strategic amounts of uranium enriched to 20 percent or more in U^{235}. The 850 kg bare-sphere metallic critical mass criterion provides a basis for consistent safeguard requirements for U^{233} or U^{235} in U^{238}.

For other materials such as plutonium in U^{238}, and for U235, U233, or plutonium mixed with Th^{232}, the criterion is still applicable for safeguards requirements. s In these cases, however, highly concentrated fissile material could be obtained by chemical rather than isotopic separation. Chemical separation is considerably less difficult than isotopic separation, and is likely to remain so despite potential advances in enrichment technology.

The United States currently requires physical protection for 2 kg or more of plutonium, 2 kg or more of U^{233}, and 5 kg or more of U^{235} (contained in uranium enriched to 20 percent or more). There appears to be no compelling technical reasons to change these mass thresholds for physical security. However, consideration has been given to these thresholds only in the context of use of materials for fission explosives, and not in the

[2] Private communication, Robert W. Selden, Lawrence Livermore Laboratory.

[3] Because uranium is not soluble in thorium, a metal alloy is not possible; the criteria thus should be applied to powder mixtures or mixtures of oxides.

context of use in dispersal weapons. (See "Radiological Weapons," end of this chapter.)

Similar safeguards threshold properties should be formulated for other fissile byproducts of peaceful nuclear operations, notably neptunium–237, when and if they become generally accessible. They probably do not constitute a problem at this time. The isotope P^{238}, which is widely used for isotopic power sources, is also a fissile material (comparable to Pu^{229} in this respect). However, it is so intensely radioactive and generates so much heat that it would be entirely impractical for use in a nuclear-fission explosive weapon,

PEACEFUL NUCLEAR EXPLOSIVES

A nation that has clandestinely developed a nuclear weapon may require a test to confirm its design or to collect data for a more sophisticated weapons program. Because bomb tests larger than 10 10 kt are unlikely to escape detection, the nation might be deterred by the spectre of international repercussions—except for one loophole. The nation could claim that the explosion was for peaceful purposes, exactly as India did. Even existing nuclear states might use peaceful nuclear explosions (PNEs) as a cover for weapons tests because the two are technically indistinguishable. Thus, PNEs have been a major obstacle in arms-control negotiations for a comprehensive test ban treaty (CTBT). Such a treaty could in itself deter proliferation by providing an example of self-restraint on the part of the nuclear powers. A double effect of PNEs, therefore, is to detract from disincentives to proliferation and provide a cover for those who do proliferate.

Only recently have such concerns over the abuses of PNEs begun to outweigh the hopes for benefits from them. Beginning in the late 1950's, the United States actively researched and promoted domestic applications of nuclear explosions under its Plowshare Program. Many non-nuclear weapons states grew so interested in the promises of the technology that a PNE provision in the Non-Proliferation Treaty (NPT) became an important incentive for their signature. In return for their agreement to refrain from developing any kind of nuclear explosion, these nations were guaranteed access to any benefits of PNEs on a nondiscriminatory, low-as-possible-cost basis,

A look at some of these possible beneficial applications of nuclear explosions is warranted to understand if they are fulfilling their original promise and if they are worth preserving or promoting, The technology of PNEs is reviewed in appendix II of volume II. In brief, the applications fall into two categories: excavations and contained explosions. The United States abandoned its plans for excavation projects in 1969 because the technology was immature and inflexible, and the radiation release constituted both a health hazard and a violation of the Limited Test Ban Treaty. The U. S. S. R., however, created a reservoir with a nuclear explosion and is seriously interested in using them to make more reservoirs and to excavate mountainous portions of a canal route, The PNE applications mentioned by non-nuclear weapons states have been mainly excavations. Among these are canal projects studied by Egypt and Thailand.

The applications of contained nuclear explosions include several that would help exploit energy and mineral reserves. Examples are stimulation of gas and oil recovery (including oil shale), creation of storage cavities, and fracture of ore bodies to permit mining by leaching. A comprehensive study of contained PNE applications in the United States was completed in 1975 for the Arms Control and Disarmament Agency (ACDA) by the Gulf Universities Research Consortium, Their charge was to project the use of PNE technology up to the year 1990. Their report indicates that some of the proposed projects might be economically attractive, but not in the next decade and not before a great many technical unknowns and adverse environmental effects are resolved. The only application—albeit a limited one—that does not seem to have non-nuclear alternatives is the use by the U.S.S.R. to seal runaway gas-well fires.

Because of these many difficulties, the United States has ceased its former role of promoting PNEs. After having spent $160 million on the Plowshare Program, the United States currently allots about $1 million per year and has shown a willingness to forgo PNEs altogether. The Soviet interest on the other hand has increased as that of the United States has waned, although they appear to have entered a period of questioning now.

Implementation of the PNE provisions of the NPT has been assigned to the International Atomic Energy Agency (IAEA), which seems to see a limited role for itself. It acts as an information clearinghouse and proposes to assist with feasibility studies. (It recently conducted a preliminary review of the Egyptian canal project.) An ad hoc advisory group has been assembled to consider future activities. Very few requests for information have been received by the IAEA, and this apparent lack of interest in PNEs by non-nuclear weapons states perhaps parallels the slow maturation and diminished promise of the technology. Nevertheless, even an NPT nation with no previous plans to use PNEs might legitimately want to keep open the option or resent the discriminatory approach of the NPT, which allows the development of PNEs only to weapons states.

The slow implementation of the PNE services can also provide justification for a nonsigner to stay outside the NPT and even to develop its own "peaceful nuclear explosion. " This veil is quite transparent, however. The nation would have to make its claim credible by manifesting a carefully planned agenda of potential PNE applications. Interestingly, India has only vague plans and has not requested any IAEA assistance. These PNE plans would have to justify the large and sophisticated development program required for a real PNE: An effective PNE must be inexpensive, physically small, and yield minimal amounts of radiation, in contrast to the "low-technology" nuclear weapon described earlier.

A more indirect but nonetheless substantial effect of PNEs on the NPT results from their impact on arms control negotiations. Since the 1968 signing of the NPT, wherein the nuclear weapons states agreed to move towards disarmament, the only test bans that have been negotiated between the United States and the U.S.S.R, are the 1974 Threshold Test Ban Treaty (TTBT) and its associated 1976 Treaty on Underground Explosions for Peaceful Purposes (PNET, still unratified). The PNET places the same upper limit of 150 kilotons on explosions as the TTBT because both sides admitted that no one can verify that PNEs are not being used for weapons development, even with the unique PNET feature of onsite inspections. This limit places very little restraint on weapons testing. The separate status accorded to PNEs will make further reductions more difficult to achieve and will hinder progress toward a comprehensive test ban. The separation was made at the insistence of the U.S.S.R.

In the face of such technological and political ambivalence, the present U.S. course has been to proceed with a low level of research on major uses of PNEs and move slowly and cautiously toward providing PNE services to NPT signees. This course appears neatly to encompass all three major dangers of PNEs: hindering progress toward a CTB, retarding membership in the NPT, and providing excuses for nations to develop their own nuclear bombs.

An alternative course could be to temporarily ban all testing of PNEs pending a less ambiguous demonstration of a beneficial and viable application. Research could continue on non-nuclear aspects of the applications. International opinion is not conducive to a permanent ban at this time, but that could change if the promise of the technology continues to be limited. Even a temporary ban could ease progress toward a CTB,

A step in the opposite direction would be to establish an international service to provide PNEs to all nations regardless of their membership in the NPT. This action would eliminate the excuse for development of an indigenous PNE. The very existence of such a service, however, would tend to condone nuclear explosions in general.

Until international agreement can be reached on some action, PNEs will remain a difficult problem.

RADIOLOGICAL WEAPONS

Radiological weapons are defined to be devices for dispersal of radioactive materials, produced a substantial time before their dispersal (e.g., not in a nuclear explosion) for any of the following purposes:

a. Killing people within a short time (less than a few weeks).
b. Killing people, or causing severe illness, after a long time (weeks to many years).
c. Damaging property through short-term contamination to levels that require evacuation to prevent severe effects on occupants.
d. Damaging property through long-term contamination, to low levels that would deny access to or use of an area if present occupany or use standards for the general population were enforced.

Targets for dispersal could be:

a. High concentrations of people inside buildings; dispersal as aerosol introduced into air-conditioning or ventilation systems.
b. High concentrations of people outside (e.g., crowded urban streets or sports events),
c. Urban areas as a whole, with high-population density, to affect people and property inside and outside buildings.
d. Large urban, suburban, or rural non-agricultural areas, primarily to deny access and require expensive decontamination. The dispersal might even be designed specifically not to produce any significant acute health effects.
e. Agricultural area, primarily to deny access and use.

In principle, any radioactive substance could be used in a radiological weapon. A number of radioactive isotopes are in widespread use outside the nuclear power industry, in hospitals, universities, research institutions, and industrial research and manufacturing facilities. Most of these applications have nothing to do with nuclear power research or applications. For example, cobalt–60 is widely used in treatment facilities in hospitals; strontium–90 and cesium– 137 are used in measuring gauges in several industrial applications; radioactive sources of all kinds, some of them quite strong, are kept in university laboratories. Several incidents of theft of such sources have occurred in the United States and abroad, and at least one incident of deliberate (although not lethal) dispersal has occurred. (See appendix III of volume II.)

Most theoretical attention, however, has focused on the use of plutonium, spent fuel, or waste from spent fuel in radiological weapons. Such materials could be dispersed either by an aerosol generator (perhaps after dissolution), or by the use of attached chemical explosives, depending on the material, the objective, and the target.

Small quantities of nuclear material not subject to physical security safeguards could be dispersed in ways that would cause many prompt and / or delayed deaths and require expensive decontamination. However, there are also many generally available, publicly described, chemical and biological agents that could be as effective, or more so, than radioactive agents as weapons for killing people and / or contaminating property.

No known cases of deliberate dispersal of plutonium, U^{233}, spent fuel, or waste from spent fuel have occurred in the United States, at least since 1969, when the AEC began compiling complete statistics of such nuclear incidents.

The available records from the rest of the world are less complete; one case of spent-fuel waste dispersal *may* have been plotted, but was not executed.

Radiological weapons could be the subject of a hoax as well as the basis of a real threat. Although threats to detonate a nuclear explosive have proved more popular with hoaxers to date than threats to disperse radioactive material, the latter type of hoax is potentially more troublesome. It would be easier to mount a *technically* credible dispersal hoax than a nuclear explosive hoax. However, hoax identification does not rely on technical assessment alone. (See appendix III, volume II.)

In conclusion, a large number of toxic substances, including plutonium and other radioactive isotopes, could conceivably be used by groups or individuals for effectively attacking large numbers of people or causing considerable property damage by denial of use or expensive decontamination. The question of imposing effective physical security safeguards to prevent theft or diversion of nonradioactive toxic substances in widespread use has apparently not been assessed, but appears on the surface to be extraordinarily difficult and perhaps not feasible. It does not appear reasonable to require safeguards for small quantities of nuclear or other radioactive materials in the absence of consideration of safeguards on nonradioactive toxic substances.

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Chapter VII

Sources of Nuclear Material

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Chapter VII

Sources of Nuclear Material

A nation planning the development of nuclear weapons has several options for obtaining fissile material. Diversion from commercial nuclear power facilities has received the greatest attention recently: nuclear material could be obtained through the evasion of safeguards or the use of unsafeguarded facilities, possibly following abrogation of safeguarding agreements. The other routes are the construction of dedicated facilities, such as a small plutonium production reactor or a weapons-grade enrichment plant, and purchase or theft of weapons material or complete weapons. Each of these routes is subject to constraints and each country will weigh the options differently depending on its own resources, capabilities, political situation, and intentions.

DIVERSION FROM COMMERCIAL POWER SYSTEMS

Although none of the nations that have nuclear weapons have obtained them by this means, it is possible that a nation could extract the fissile material needed for nuclear weapons from its commercial nuclear power systems. This section will examine existing reactors and several under development, along with their complete fuel cycles. With this background, the relative difficulty of diversion from each system can be understood and compared. In the past, resistance to diversion has not been a parameter in the design of nuclear power systems. As diversion is increasingly seen as a problem, research is beginning on reducing the vulnerability of existing systems. Some preliminary conceptual work has also been done on reactor systems that are inherently resistant to diversion,

The Fuel Cycle

The flow of nuclear material in a commercial power program—from the mine, through the reactor, to disposal or reuse—is called the nuclear fuel cycle. The nuclear materials of interest for either an explosive or a powerplant are those that release extra neutrons and energy when they fission, or split apart. Such fissile isotopes are not abundant in nature, although some are produced as a byproduct of power production: neutrons striking certain nuclei will convert them, after a short decay chain, to fissile isotopes.

Two general fuel cycles exist, each based on a different element. In the uranium cycle, the isotope U^{238} does not fission easily but does breed a fissile isotope of plutonium, Pu^{239}. A fissile isotope U^{235} is also present in natural uranium. In the thorium cycle, the thorium isotope Th^{232} breeds the fissile isotope, U^{233}. Within each of these fuel cycles, quantities and concentrations of various isotopes, and the procedures for processing them, vary with the particular reactor type.

The two types of nuclear power reactors available on the world market today both use

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the uranium fuel cycle. These are light water reactors (LWRS) developed by the United States and Canadian heavy water reactors (CANDU). Others which have been largely developed and could be deployed in the near future are the high-temperature gas reactor (HTGR), and the advanced gas-cooled reactor (AGR). Most development effort in several advanced countries is focused on the liquid metal fast breeder reactor (LMFBR), but commercialization is not expected for at least 10 years. Development of another breeder reactor, the light water breeder reactor (LWBR) is proceeding at a slower pace.

All these reactors, plus a few others that could become important, are described in detail (along with their fuel cycles) in volume II, appendix V. Because they are of immediate interest, the fuel cycles and diversion potential of LWRS and CANDUS will be summarized in this section. The LMFBR, LWBR, and thorium cycle in general will also be examined briefly in this chapter. Research plans on alternate fuel cycles are briefly summarized. Conceptual studies on inherently nonproliferating reactors are described at the end of this section. Safeguards to prevent and/or detect diversion are discussed under "Safeguards" in chapter VIII.

Light Water Reactors

Technical Description

The common types of light water reactors differ in the coolant they use-either boiling water (as in BWRS) or pressurized water (as in PWRS). They present identical problems for proliferation prevention, and will be considered together here. Key characteristics of these reactors and their fuel cycles are given in figure VII-1.

The first stage in the LWR fuel cycle is the mining of ore, which contains about 1,500 parts-per-million uranium. The milling operation then concentrates the uranium by straightforward chemical processes into yellowcake (U^3O^8). By far the largest percentage of natural uranium (99.3 percent) consists of the isotope U^{238}. Only 0.7 percent is U^{235}, the isotope that will fission in a LWR. Because LWRS are designed to operate with a U^{235} concentration of about 3 percent, natural uranium must be enriched. In preparation for enrichment, yellowcake is converted in a special plant to uranium hexafluoride (UF_6), which is a gas at a sufficiently low temperature to permit easy handling.

Although several enrichment techniques are known, the only full-scale plants built to date use the principle of gaseous diffusion. The separation achieved in one stage of a diffusion plant is small, so a series of stages, called a cascade is required to raise the U^{235} concentration to the desired level of enrichment. A gaseous diffusion plant must be very large to be economical. Commercial plants are built to. serve at least 50 large (i.e., 1000 MW(e)) reactors. Each plant costs several billion dollars and consumes a large amount of electrical power (about 3 percent to 5 percent of the energy produced by its enriched product). Another enrichment technique-gas centrifuge-can achieve a greater separation factor between the isotopes in each stage. It appears to be economical on a smaller scale and requires much less electrical power. This technique has 'not yet progressed beyond the pilot plant stage, but several new commercial plants of this type are in the planning stage.

Other enrichment methods are much further from commercialization. Such new technologies should be watched as they develop, since they may become inexpensive and simple enough to be attractive to many countries.

After enrichment, UF_6 is converted to uranium dioxide ($U0_2$) and fabricated into fuel assemblies. The fuel assemblies are shipped and loaded into the reactor, where they remain for several years. One third of the fuel assemblies are replaced each year in a pressurized water reactor (PWR), and one fourth in a boiling water reactor (BWR). Refueling involves shutting down the reactor, allowing it to cool, removing the reactor head, and transferring the spent fuel underwater to a storage pool. The entire process takes 4 to 6 weeks.

At present, spent fuel is simply stored at the powerplant or in spent-fuel pools at other locations. The intention of the industry is to

Figure VII–1

Power Reactor Characteristics (For Units ≥ 500 MWe)**

	BWR	PWR	AGR	HWR (CANDU)	HTGR USA	SGHWR	FB (US) CORE	FB (US) BLANKET	FB (UK) CORE	FB (UK) BLANKET
Thermal efficiency (%)	34	33	41	29	39	31.5	40	40	41.3	41.3
Average spec. power in fuel (kW/kg heavy metal)	26	39	13.5	24	76	19.8	155	6.0	138	5
Initial core: Irradiation level (MWd/kg heavy metal)	17	22.6		6	54.5	15.5	80	4	—	—
Fresh fuel enr. (% U 235)	2.03	2.26	1.6	Nat.	93.15	1.8				
Spent fuel enr. (% U 235)	0.86	0.74	0.9		50	0.8				
Inventory: kg nat. U/MWe	434	365	620	143	326	520	15[2]	32[2]	13.2[2]	48[2]
kg SW/MWe (0.25 tails assay)	221	209	285		349	245				
kg Pu(E)/MWe							1.8		2.8*	
Pu(E) produced[4] (g/MWe yr)	296	300	120	581		180	70		214	
Replacement loadings: Irradiation level (MWd/kg heavy metal)	27.5	32.6	17.5	7.5	95	22	0	6.6	66	2
Fresh fuel enr. (% U 235)	2.73	3.20	2.3	Nat.	93.15	2.2				
Spent fuel enr. (% U 235)	0.84	0.90	0.87	0.2	30	0.63				
Net consumption: kg nat. U/MWe-yr[1]	165	173	165	168	90	182	1.9[2]			
kg SW/MWe-yr (0.25 tails assay)	125	137	119	—	96	120				
Pu(E) produced[4] (g/MWe yr)	248	260	187	502	(U 233) 250	257	170		214	
Operating time to reach equilibrium (yr)	4	3	4	1	5	4.5	3	3-7[3]	3	3-7

[1]MWe – yr = 8760 MWh. Figures are based on instantaneous credit for spent fuel.
[2]Depleted uranium.
[3]Depends on position.
[4]Allows for reprocessing losses and, where appropriate, for the decay of Pu241.
NOTE: All plutonium figures are expressed in equivalent grams Pu239, i.e. in Pu(E) for use in FBRs, applying the following "worth factor": 239 x .00; 240 x 0.18; 241 x .53; 242 x 0.08.
[1 g Pu(E) corresponds to 0.85 g Pu (fissle)].
*Out-of-pile 1 kg/MWe
**Uranium, Resources, Production and Demand, OECD Nuclear Energy Agency and the International Atomic Energy Agency, December 1975.

reprocess spent fuel to recover unfissioned U^{235} and plutonium that was generated from U^{238}. plutonium can directly replace U^{235} as fissile material in fuel, thus reducing demand for uranium ore and the need for enrichment. If it is found undesirable for economic, political, or safety reasons to reprocess spent fuel, the cycle can terminate at this point. If this is the case, long-term storage facilities or a permanent disposal method for the spent fuel rods must be planned.

If reprocessing does occur, spent-fuel elements are sent to the reprocessing plant in large, heavy shipping casks designed to provide both shielding against intense radiation and cooling to remove decay heat. At the reprocessing plant, the fuel elements are chopped up and the contents dissolved in acid. Solvent extraction is then used to separate plutonium and uranium from the fission products, which are stored for eventual disposal. The plutonium and uranium emerge in separate streams. The uranium is converted to UF_6 for reenrichment, and the plutonium to plutonium dioxide (PuO^2 either for stockpiling or recycling. All operations in the reprocessing plant must be performed by remote control, because of the intense radioactivity of spent fuel and the toxic nature of plutonium.

If the plutonium is to be recycled, the PuO_2 is shipped to a mixed-oxide fuel fabrication plant, where it is combined with UO_2 so that the final mixture will contain the desired fraction of fissile isotopes. A mixed-oxide fuel fabrication plant is more expensive than a uranium fuel fabrication plant, because remote handling is required for plutonium.

Diversion From the LWR Fuel Cycle

Material convertible to weapons grade could be diverted at any point of the LWR cycle, but the difficulty of conversion, and hence the attractiveness of the diverted material varies markedly from point to point. This section will provide an estimate of the amount of material that must be diverted at each stage of the LWR fuel cycle in order to produce one nuclear explosive, give a summary of the operations that must be performed upon the material to convert it to a form that can be directly used in a nuclear weapon (process details are given in volume II, appendix V), and assess the feasibility of (a) a nation and (b) a non-national group performing these operations.

The safeguards that a diverter or thief would have to evade or surmount are described under "Safeguards" in chapter VIII, and are only briefly mentioned in this section. The resources required to construct a nuclear weapon once weapons material has been obtained are discussed in chapter VI.

Yellowcake (i.e., U^3O^8) from a uranium mill, after a few chemical steps, could be enriched to weapons-grade uranium or partially transformed to Pu239 in *national* dedicated facilities, as described in the "Dedicated Facilities" section of this chapter and in volume II, appendix VI.

Approximately 6.5 metric tons of yellowcake would have to be fed to an enrichment plant to yield 30 kilograms of 90 percent U^{235} (enough for one or two explosives). Approximately 75 metric tons of yellowcake would be required to supply enough natural uranium to fuel a dedicated production reactor that would produce 10 kilograms of Pu^{239} per year (enough for one or two explosives). In the latter case, it would not be necessary to refuel the dedicated production reactor more than once every 10 years or so. However, the nation probably would prefer to refuel every year or two in order to obtain weapons material quickly and steadily.

The capital cost of a reactor and reprocessing plant that could produce one or two explosive's worth of plutonium per year, starting with yellowcake, is in the tens of millions of dollars. This effort is within the capabilities of many (perhaps close to 50) nations, but is entirely impractical for a non-state adversary. The cost of a small enrichment facility is more complex to assess; it is discussed under "Dedicated Facilities" in chapter VII. It is also entirely impractical for a non-state adversary.

International Atomic Energy Agency (IAEA) and Euratom safeguards exist for yellowcake (in fact, Euratom safeguards start with uranium ore), but a country in the market for yellowcake to supply a dedicated facility would probably have little difficulty in clandestinely purchasing a sufficient amount. Moreover, many countries have considerable resources of uranium ore, and in these countries a dedicated mine and mill could be used to supply a dedicated facility. (See chapter X.)

An enrichment plant presents a more attractive target to the diverter. Although the design output of commercial enrichment plants is only 3 percent to 4 percent U^{235}, and completely impossible (not merely impractical) to use directly in a nuclear fission explosive, much of the work to raise the enrichment to weapons grade has been accomplished. For 30 kg of 90 percent LWs, nearly 8000 kg of natural uranium hexafluoride feed and 6900 separative work units (SWU) are required, but if 3 percent U^{235} is the feed, only about 1500 kg of uranium hexafluoride and about 2500 SWU are required.

Several options are possible for a nation which elects to divert from its own commercial enrichment plant. The components of the entire plant could be reassembled so that the product would be highly enriched uranium. The change is not difficult for a centrifuge plant, but is complicated and time consuming for a diffusion plant. Nevertheless, the Chinese appear to have followed this route in converting a U.S.S.R. supplied diffusion plant. This change is too drastic to be done covertly if the plant were safeguarded.

If the nation had a large, safeguarded enrichment plant, it might choose to convert one section of the plant to a high-enrichment cascade. Again, this would be difficult to do in a diffusion plant and relatively easy in a centrifuge plant.

An alternate option would be to divert part of the low-enriched uranium product and feed it into a separate, small enrichment plant to boost it to highly enriched uranium. The additional small plant could be either inside the large plant or at another site. Only about 400 centrifuges of European design would be required to produce 30 kg of 90 percent U^{235} per year from 3 percent LWs feed. For comparison, an enrichment plant of near-competitive commercial size to supply ten, 1000 MW(e), LWRS with low-enriched uranium would have a capacity of 1,300,000 SWU per year and contain approximately 200,000 centrifuges of European design. Enrichment plant safeguards are discussed under "Safeguards" in chapter VIII, but it should be noted here that the scenarios sketched in this paragraph are not implausible as long as inspectors are limited to monitoring the perimeter of the facility and unmonitored input and output paths are permitted.

As already discussed, enrichment is not an option for the non-state adversary. However, low-enriched uranium could be an attractive target for embezzlers if a criminal black market in low-enriched uranium developed. The black market could conceivably supply low-enriched uranium merely as a fuel for power reactors (see chapter V "Non-State Adversaries and volume 11, appendix 111 for a discussion of a case of low-enriched uranium smuggling), or more ominously, as feed for a dedicated national enrichment plant designed to produce weapons material.

From the output of the enrichment plant to the loading of the reactor the only target in the LWR fuel cycle (without plutonium recycle) is the low-enriched uranium itself, which must, as discussed above, be boosted to highly enriched uranium in a dedicated enrichment plant to be useable in nuclear weapons.

Because of the long time required for refueling a LWR, national diversion of irradiated fuel could not take place without considerable economic and power penalties, except at a normal discharge and loading operation, or from the spent-fuel storage pool.

Light water reactor fuel (without plutonium recycle) of typical burnup contains about 0.8 percent plutonium, of which about 25 percent is Pu^{240} plus Pu^{242}. With plutonium recycle, high burnup LWR fuel would contain about 1 to 2 percent plutonium of which about 35 percent would be Pu^{240} plus Pu^{242} (Detailed data is given in volume II, appendix V.)

A high Pu^{249} plus Pu^{242} content is widely—but incorrectly—believed to render plutonium unsuitable for militarily effective weapons. A high content of these isotopes is a complication; given a free choice, a weapons designer would *prefer* plutonium with a low Pu^{240} content, but it should be realized that effective nuclear explosives can be made with plutonium of the Pu^{240} content described above. This point is discussed in greater detail in chapter VI.

With a plutonium content of 0.8 percent, approximately 1.4 metric tons of spent fuel in the form of uranium dioxide (UO^2 must be reprocessed (at 100 percent recovery) to obtain 10 kg of plutonium. In a PWR, this is contained in three fuel assemblies. Stated another way, 1 year's fuel discharge from a PWR consists of about 31 metric tons of $U0_2$ containing about 240 kg of plutonium.

As discussed in the "Dedicated Facilities" section of this chapter and in appendix VI, volume II, it is well within the capability of many developing countries to construct their own reprocessing plant to extract plutonium from spent fuel for use in weapons. However, it appears probable that the IAEA will develop the capability to safeguard LWRS and LWR storage pools so that it will be very unlikely that a diversion could take place undetected. Thus, national diversion from a safeguarded LWR or LWR storage pool would probably be overt.

If the operator arranges a series of plausible reactor problems leading to extensive downtime for the year preceding the diversion, low burnup fuel with a low Pu^{240} content will result. For example, at 5000 MW days/metric ton burnup, the plutonium content of the last reload would be about 70 kg, of which only 10 percent would be Pu^{240}.

Theft of spent fuel by non-state adversaries is just barely credible. The theft itself and subsequent transportation of the highly radioactive fuel (which would have to be cooled and shielded in transit) would require a number of armed and highly organized adversaries, some of whom would have to be willing to accept considerable, possibly lethal, radiation exposure. Reprocessing of spent fuel by non-state adversaries is also just barely credible, even if the group were very well financed and possessed practical chemical engineering experience. A crude but technically feasible solvent extraction or ion-exchange system can be imagined, but it would require several months of process time for extracting 10 kg of plutonium, During that time the group would be immobile and vulnerable to an intense search.

From the point of view of both the national diverter and the non-state adversary, a large commercial reprocessing plant is an attractive target. Appendix V of volume 11 discusses the diversion points in a model reprocessing plant. Plutonium nitrate stolen from the nitrate blending area would require only a simple precipitation to be converted into weapons material; plutonium dioxide from the conversion area could be used directly in a nuclear explosive. A national diverter would probably take the further step in either case of conversion to plutonium metal. The safeguarding of a reprocessing plant is discussed under "Safeguards" in chapter VIII, but the point will be noted here that materials accountancy, by itself, has neither the sensitivity nor the promptness to assure timely detection of covert diversion from a large reprocessing plant, either by a nation or by non-state adversary. Other safeguard measures are therefore employed, such as portal monitors which can detect gram amounts of plutonium. (See chapter VIII.)

A model mixed-oxide fuel fabrication plant is diagramed in appendix V of volume II. The output of the model plant consists of fuel rods with a mixture of uranium dioxide and up to 3.5 percent plutonium dioxide. To obtain 10 kg of plutonium, about 300 kg of mixed oxide would have to be diverted or stolen. The logistical problem of removing so much material is a significant deterrent, but the biggest obstacle to the non-state adversary is chemically separating plutonium from uranium. Although conceptually simple, involving dissolution followed by ion exchange, the task would need someone with practical chemical engineering experience and would require perhaps several weeks to several months, depending on the details of the adversary's separation facility. For the national diverter, the chemical separation problem would be minor and could probably be accomplished in one to a few days.

In the portion of the fuel cycle between the output of the reprocessing plant, and the

Figure VII–2.

Summary of the Diversion Points in the LWR Fuel Cycle

FACILITY	MATERIAL	IS THE MATERIAL USEFUL TO THE NATIONAL DIVERTER?	IS THE MATERIAL USEFUL TO THE NON-STATE ADVERSARY?
Mine Mill Conversion Facility	Natural uranium (0.7 percent U^{235} as ore (0.2 percent uranium) U_3O_8 UF_6	YES, but only as feed for a dedicated facility (plutonium production reactor or enrichment plant)	NO (but criminals might engae in black market in these materials)
Enrichment Plant Uranium Fuel Fabrication Plant	low enriched uranium (3 percent U^{235} as UF_6 UO_2	YES, but only as feed for a dedicated enrichment plant	NO (Criminals might engage in black market in these materials)
Transportation to Reactor Temporary Storage at Reactor	UO_2 in fuel assemblies	Nation would eventually have to replace fuel	
Reactor Spent Fuel Storage	Pu —about 0.8 percent in highly radioactive spent fuel	YES; dedicated reprocessing facility required	NO except Yes for large, very well financed, technically competent group with a secure base of operations and a few members willing to risk radiation injury
Reprocessing Plant* Transport to fuel fabrication plant Input area to fuel fabrication plant	Pure $Pu(NO_3)_4$ or pure PuO_2	YES; Nation would probably convert material to metallic plutonium	YES; If $Pu(NO_3)_4$, simple conversion to PuO_2 equmd. It Pu02, material directly usable in explosive
Plutonium Fuel Fabrication Plant	PuO_2 (3 percent to 7 percent) mixed with over 90 percent UO_2	YES, Chemical separation of Pu from mixture only a minor obstacle. Logistics of diverting 100 to 300 kg of material for one explosive troublesome.	Yes, BUT chemical separation a time consuming operation. Logistics of stealing or diverting 100 to 300 kg of material for one explosive cause problems.
Transport to Reactor Temporary Storage at Reactor	About 1 percent Pu as PuO_2 mixed with UO_2 in fuel assemblies	YES, as above. (Nation would eventually have to replace fuel)	Yes, BUT chemical separation a time consuming operation. Logistics of stealing complete fuel assembles present significant obstacle.

"With coprecipitation, however, diversion potential at these pants would be similar to diversion potential at plutonium fuel fabrication plant. i e considerably less for the non-state adversary and somewhat less for the national diverter

SOURCE OTA

mixed-oxide blending area of the mixed-oxide fuel fabrication plant, plutonium would exist in the form of plutonium dioxide. This material is directly useable in the fabrication of nuclear weapons, although a nation would probably convert it to plutonium metal. This portion of the fuel cycle, which includes stockpiled plutonium, presents the most concentrated target for diversion. Although one can conceive of very stringent safeguards against covert diversion even in this exposed portion of the cycle, safeguards, by their nature, cannot prevent a nation from seizing a plutonium stockpile attached to its own reprocessing plant. As discussed in chapter VI, a modest national weapons development program can attain a high degree of confidence in the performance of its weapon without nuclear testing. Once the political decision is taken to seize the stockpile, the nation can have a reliable explosive in a matter of days to weeks, even using reactor-grade plutonium.

Summary of *Diversion Points in the LVVR Fuel Cycle*. —The preceding discussion has described the diversion points in the LWR fuel cycle, specified how much material would have to be stolen or diverted at each point to yield material for one or two explosives, and has evaluated the difficulty of chemical and physical processing necessary to convert the diverted material into weapons material. Figure VII-2 briefly and qualitatively summarizes this discussion.

The Canadian Deuterium Reactor (CANDU)

Technical Description

The Canadian Deuterium Reactor (CANDU) is able to operate with natural uranium because heavy water absorbs fewer neutrons than does ordinary water, leaving more to carry on the chain reaction. This eliminates the need for the entire enrichment process, including UF_6 conversion. The mining and milling processes are the same as for LWRS, but reactor operation is substantially different. The CANDU is designed for ondoad refueling. Instead of shutting down and opening the reactor to change a batch of fuel, a refueling machine opens both ends of one of the many tubes throughout the reactor. These tubes contain several short fuel rods, A fresh rod is inserted in one end and a spent rod removed at the other. The tube is then resealed and repressurized with cooling water.

There are no plans at present to reprocess CANDU spent fuel. More plutonium is produced than in an LWR of the same power level, but it is more dilute because of the greater amount of U^{238}. The fraction of U^{235} in the spent fuel is very low (actually less than in the tails from present enrichment plants), and reprocessing would be less likely to be economical than for the LWR cycle. The spent fuel is now being stored indefinitely, pending development of a final waste disposal method.

Diversion From the CANDU Fuel Cycle

The CANDU fuel cycle presents considerably different opportunities for diversion than does the LWR cycle. Separated fissile material is not exposed anywhere in the CANDU fuel cycle, in contrast to the LWR cycle with plutonium recycle. The enrichment and reprocessing facilities are totally absent. The only diversion points in the CANDU fuel cycle are the reactor itself and the spent fuel storage pool.

As in the case of the LWR, non-state theft of spent fuel from the storage pool followed by reprocessing is just barely credible.

As discussed for the LWR, reprocessing for weapons purposes, spent fuel that has been diverted from a reactor or spent-fuel storage pool is within the capabilities of many nations. The quantity of fuel that must be diverted from a CANDU to yield 10 kg of l%, and the quality of the Pu obtained under various conditions, is discussed below.

CANDU fuel of normal burnup (about 7500 MW days/metric ton) has a plutonium content of about 0.4 percent of which about 25 percent is Pu^{240}. As described in appendix V of volume II, CANDU is refueled continuously and some fuel bundles could be pushed through more rapidly for lower burnup and lower Pu^{240} content. At a burnup of 2500 MW days/metric ton (one-third normal) the plutonium content is about 0.2 percent, of which only 10 percent is Pu^{240}. To obtain 10 kg of plutonium at least 5700 kg of low burn-up uranium-oxide fuel would have to be diverted, or about 260 fuel bundles, For normal burnup fuel about 2800 kg, or 130 bundles, would have to be diverted, For comparison, in the CANDU-600 model, about 12 fuel bundles are normally pushed through the reactor per day.

In contrast to the LWR, production of low pu^{240} plutonium in the CANDU does not involve a significant loss of power output.

Safeguard systems for a CANDU reactor and storage pool can probably be designed and implemented so that repeated covert diversions of fuel assemblies cannot take place undetected during either normal or accelerated refueling. Diversion from the CANDU is therefore also likely to be overt,

Liquid Metal Fast Breeder Reactor (LMFBR)

Technical Description

The LMFBR is expected by the industry in every nuclear supplier nation except Canada to be the successor to the LWR reactor since it would essentially eliminate uranium resources as a constraint. The reactor is somewhat analogous to a PWR, except that it uses liquid sodium at low pressure as a coolant and has no moderator. The fuel is mixed plutonium (10 percent to 20 percent) and U^{238} oxide. Radial and axial blankets of U^{238} surround the core to capture escaping neutrons and breed plutonium, The LMFBR is expected to produce as much as 15 percent more fuel each year than it consumes. This excess (about 250 kg per year) can be used to fuel other reactors or diverted to a weapons program with no impact on the fuel cycle. Refueling is similar to LWRS, with about one-half the core and one-third the blanket replaced each year. No enrichment is required, except possibly for the initial core, because the plutonium that is bred can be used in subsequent cycles. Reprocessing, however, is central to the LMFBR cycle. The bred plutonium cannot be recovered without reprocessing, and the whole point of the LMFBR is that it can breed enough plutonium to refuel itself and to start up new reactors.

Diversion From the LMFBR Cycle

The diversion points in the LMFBR cycle can perhaps be best explained by comparing them to those of LWR cycle with plutonium recycle.

The mining and milling stages can be virtually eliminated, because the depleted uranium contained in the tails from present enrichment plants can be used. Enrichment is superfluous, except possibly for the intial core.

As in the case of LWR recycle, the reprocessing plant, fuel fabrication plant, and fresh-fuel storage area at the reactor, including the transportation links between them, are the points most vulnerable to diversion.

Diversion from the reactor itself is not credible and the material in the spent-fuel storage pool, in transit to the reprocessing plant, and in the input stages of the reprocessing plant is highly unattractive to the diverter because of its fierce radioactivity. However, as in the case of the LWR, handling and reprocessing diverted spent fuel in a small reprocessing plant dedicated to the task is within the capability of many nations.

The input to the fuel fabrication plant would consist of depleted or natural uranium dioxide and pure plutonium dioxide from the output of the LMFBR reprocessing plant, with possibly an additional contribution from a LWR reprocessing plant or stockpile. The uranium dioxide and plutonium dioxide will be mixed at the fabrication plant and compressed into fuel pellets. The ratio of plutonium to uranium in the fresh fuel varies with the exact design proposed, but would be in the range of 1:10 to 1:5. At 1:5, the material would be of only marginal usefulness in a nuclear explosive; at 1:10 the material could not be used directly in a practical nuclear explosive. However, only 55 to 110 kg of fuel would have to be stolen to obtain 10 kg of plutonium. Fresh fuel for the LMFBR would be a factor of 2- to 6-times more concentrated in plutonium than fresh fuel in the LWR cycle with plutonium recycle, depending on the details of both schemes.

Details on LMFBR reprocessing are not firm as yet. In general, diversion opportunities at an LMFBR reprocessing plant would be similar to those at an LWR reprocessing plant, heightened by the fact that the throughput of plutonium per metric ton of fuel input would be greater by a factor of approximately 10.

In general, approximately 5 times as much plutonium would flow through the LMFBR cycle as through the LWR cycle, for the same amount of electricity generated. (LMFBR fuel gives about twice as much electricity per metric ton as does the LWR.)

In addition to the quantitative differences between the two cycles (there is *more* plutonium in the LMFBR cycle and it is *more concentrated),* there is also a potential qualitative difference. A significant amount of the plutonium produced in the blankets will contain less than 5 percent Pu^{240}, i.e., it will be weapons-grade plutonium in a normal fuel cycle. (See' chapter VI.) In the LWR cycle, plutonium of this quality is produced only by operating with frequent, very costly refueling.

Thorium Fuel Cycles

Power-reactor fuel cycles employing thorium have received much less attention than uranium fuel cycles. The thorium fuel cycle uses U^{233} as the fissile isotope and Th^{232} as the fertile isotope. Several reactors have been proposed that might employ thorium. A high-temperature gas-cooled reactor (HTGR) is operating, and a demonstration light-water breeder reactor (LWBR) is presently being constructed.

Thorium fuel cycles that have been studied include:

- High-Temperature Gas Reactor (HTGR);
- Light-Water Breeder Reactor (LWBR);
- Light Water Reactor (LWR);
- Heavy Water Reactor (HWR);
- Molten Salt Breeder Reactor (MSBR); and
- Thorium and mixed thorium/uranium fuel cycles in fast breeder reactors (FBR).

The limited availability of uranium is often cited as a major reason for considering the thorium cycle. However, although it is assumed that thorium is 3- to 5-times more plentiful than uranium throughout the world, the actual quantity of thorium, and the likely concentration of the ores, are in fact uncertain.

In *thermal reactors* the thorium fuel cycle may permit (1) a more efficient use of resources, possibly including the operation of a breeder, which is impossible with the uranium/plutonium cycle. (U^{233} produces, on the average, 2.28 neutrons per thermal neutron capture, versus 2.11 for Pu^{239}. This provides just enough extra margin so that breeding may be possible.); (2) more economic power generation than that from LWRS (uranium cycle) if uranium costs continue to increase (provided thorium costs are low); and (3) a delay in the need for fast breeder reactors (FBR) and a lower eventual demand for them because the demand for uranium would not be as great with thorium fuel cycles supplying some power.

In fast breeder reactors a thorium or mixed-fuel cycle may permit (1) a larger margin of safety in the control of the reactor; and (2) production of a fuel which could be employed for both fast and thermal reactors. (Thermal thorium-based reactors have a breeding ratio near one, so they produce little, if any, excess fuel.)

The thorium fuel cycle has both dangers and inherent safeguards from the proliferation point of view. The fuel that it breeds, U^{233} is an excellent weapons material, with a critical mass approximately one-third that of U^{235}. It is comparable in weapons-material quality to Pu^{239}. However, some protection against diversion is offered by the unavoidable production of U^{232} when U^{233} is produced. U^{232} is the first in a chain of radioactive decays which eventually yields thallium-208, which emits a penetrating 2.6-MeV gamma ray. The fabricated fuel and fuel materials are radioactive and present a definite health hazard a few days after separation. After several years, the radiation dose from kilogram quantities of U^{233} becomes high enough to rapidly deliver a lethal dose to anyone in direct contact.

Anyone diverting U^{233} fuel would have to overcome radiation hazards to obtain and transport the material, and to fabricate a weapon. The radiation also results in two indirect safeguards advantages. First, access to the material is limited by the requirement for remote handling behind radiation shielding. With little likelihood of any hands-on operations, access to the material for diversion purposes is much more difficult. Secondly, the penetrating 2.6-MeV gamma ray enables portal monitors to detect extremely small (milligram) quantities of U^{233}.

However, the radioactivity of U^{233} fuel is primarily a safeguard with respect to non-national adversaries. A national diverter could easily provide the radiation shielding necessary to handle the material. Indeed the country would have to provide the shielding to utilize the thorium fuel cycle in its power reactors,

The radiation hazards of U^{232} unfortunately create problems for safeguard inspectors as well as potential diverters. The necessity for remote handling may limit the accuracy of safeguard 'measurements.

A key feature of the thorium fuel cycle relative to proliferation control is the fact that U^{233} can be denatured. That is, it Can be mixed with the abundant U^{238} in concentrations of about 12 percent or less in order to make it unuseable in a practical nuclear explosive. By contrast, Pu^{239} cannot be denatured, as there are no plutonium isotopes that could be mixed with Pu^{239} that would preclude its use as a nuclear weapons material. (See chapter VI "Nuclear Fission Explosive Weapons".)

The number of gas centrifuges necessary to enrich U^{233} that has been mixed with U^{238} is significantly less than that required to enrich a mixture of U^{235} and U^{238} to the same degree. As a practical matter, however, the enrichment of denatured U233 would be difficult due to the significant radiation danger involved. Contact maintenance would be very hazardous. The costs and technology required for remote maintenance on a gas-centrifuge enrichment facility would be high.

The characteristics of reactors that might use thorium fuel cycles are not well defined because most have only been studied on paper. High-temperature gas reactors are the most advanced of all these concepts, with a small commercial plant (the 330 MW(e) Fort St. Vrain plant) in operation. However, as discussed in the following section, HTGRs expose highly enriched uranium throughout their fuel cycle. An LWBR demonstration plant is now being completed. A very small MSBR has been operated successfully, The others are still design concepts. High capital costs associated with HWRS, due to the use of pressure tubes, large cores, and heavy water, and with LWBRS (including the costly prebreeder), may be a significant disadvantage.

Conclusions on the Thorium Cycle

Thorium cycles look attractive from a nonproliferation point of view, and they are especially resistant to diversion by non-state adversaries. Selected thorium cycles should be further studied to better define their economic, technical, and safeguards promise (e.g., see section on "Alternate Fuel Cycles and Nonproliferating Reactors" below).

High-Temperature, Gas-Cooled Reactor (HTGR)

A small (330 MW(e)) commercial HTGR is now operating near Fort St. Vrain, Colo. West Germany is constructing a 300 MW(e) plant based on a variation of this concept. Both are cooled by helium and moderated by graphite.

The outstanding feature of the HTGR from a proliferation standpoint is its use of highly enriched (93 percent U^{235}) uranium fuel particles. These fissile particles of uranium carbide, with a hard coating of carbon and silicon carbide, are mixed with fertile particles of thorium dioxide in the fuel elements. This fresh fuel would be attractive to a diverter. Separating the uranium from the manufactured fuel should be possible, even for a subnational group, although their process would probably be clumsy and inefficient.

The HTGR must be shut down for refueling, Recycling is required to recover the bred U^{233} and the remaining U^{235}. As discussed in volume II, appendix V, the relative economic merits of various HTGR reprocessing and recycling programs have not been fully evaluated, but they may favor a one-time recycle.

Developers of the HTGR are studying alternate designs that would use lower enriched fuel.

Light-Water Breeder Reactor (LWBR)

Technical Description

The light-water breeder reactor (LWBR) relies extensively upon LWR technology and has the major purpose of producing as much fissile material as it uses. The present concepts are based on the pressurized water reactor (PWR), and maybe implemented by placing a different reactor core and control system in present PWR reactor plants. A demonstration operation in the Shippingport reactor is scheduled for the late 1970's.

The LWBR is a thermal reactor which would convert thorium to U^{233}. Because the breeding (conversion) ratio is near one, prebreeders are required to produce enough U^{233} for the first few breeder cores.

The basic core design utilizes the seed-blanket concept, in which each fuel module contains fissile regions (seeds) and a fertile blanket. A low-water content in the core is required to minimize neutron capture in hydrogen, so a water-to-metal ratio of about one-tenth that of the standard PWR has been proposed. Safety problems are exacerbated by this difference.

To avoid parasitic neutron capture in control rods, control is achieved by axial movement of the fuel modules in relation to each other. Fertile blankets increase the size of the core but capture neutrons that would otherwise be lost to the system.

It is expected that the reactor will be refueled in a manner similar to the LWRS. The reactor will be shut down for a period of up to 30 days, and the pressure vessel head taken off and a portion of the fuel removed.

Diversion From the LWBR Fuel Cycle

For the prebreeder, the first point at which the diversion potential differs from the LWR cycle is at the enrichment plant. Prebreeder fuel will contain 10 percent to 13 percent U^{235}. Although this enrichment is too low to be used directly in a nuclear explosive, it provides excellent feed for a dedicated enrichment plant. About 440 kg of 10 percent U^{235} hexafluoride feed would be required to produce 30 kg of 90 percent U^{235}, and about 180 centrifuges of European design could produce this quantity of highly enriched uranium per year from 10 percent feed.

Fuel modules for the prebreeder will contain uranium dioxide rods and thorium dioxide rods. No chemical separation of the fresh fuel would have to be done to acquire 10 percent LWs.

A total fuel discharge from a 1000 MW(e) prebreeder would contain about 100 kg of plutonium concentrated to about 1 percent in the uranium dioxide rods, about 300 kg of U^{233} concentrated to about 1 percent in the thorium-dioxide rods, and about 800 kg of U^{235} at an enrichment of nearly 8 percent. No isotopic separation would be required to obtain pure plutonium or pure U^{233}. Only chemical reprocessing would be needed to acquire material that could be directly used in nuclear weapons. As for the LWR, this task is within the capability of many nations, but impossible for all but very technically competent and well financed non-state groups.

The above numbers should be regarded with caution. Detailed data have not been published for a commercial-sized plant.

Two separate reprocessing plants might be used to reprocess LWBR prebreeder fuel. The diversion potential for the facility reprocessing the uranium-dioxide rods would be very similar to that for the LWR facility. In the case of the thorium-U^{233} reprocessing plant, a major difference would be the intense and penetrating gamma radiation from U^{232} (as discussed in the previous section), rendering diversion more difficult.

Fuel going back into the prebreeder could either be reenriched uranium dioxide plus thorium dioxide, or, more likely, mixed plutonium dioxide plus thorium dioxide, plus uranium dioxide, In the second case the diversion potential for fuel fabrication and mixed-oxide fuel assemblies would be similar to that for the LWR.

The uranium fuel for the breeder is presently seen as being 90 percent U^{233} and 10 percent U^{235}, A reactor load for a 1000-MW(e) core would contain 2,000 kg of this 100 percent fissile fuel and 93,000 kg of thorium. The fuel would consist of mixed uranium dioxide and thorium dioxide pellets. The mixed pellets would contain about 5 percent uranium dioxide and 95 percent thorium dioxide. Fresh fuel could therefore not be *directly* used in nuclear explosive weapons, but only chemical separation would be required. This chemical separation would be a time-consuming process for the non-state adversary.

Pure fissile uranium would be available at the reprocessing plant.

The LWBR differs from the LMFBR in an important point. The LMFBR produces a distinct surplus of plutonium over what is required to refuel itself. The LWBR, with a breeding ratio of close to one, produces only enough to refuel itself. Thus, fissile material diverted by a nation from the LWBR cycle would have to be replaced from prebreeder output or stockpiles. The most likely penalty a country with an expanding LWBR economy would have to pay for diverting from its breeder cycle is a slowdown of expansion. For a country with a static LWBR system and no prebreeding, replacing the diverted fissile material would present a serious problem.

Comparison of Reactors

The discussion of diversion from the different reactor fuel-cycle systems has shown large differences in the levels and locations of vulnerability. The vast number of variables, varients, and unknowns make an attempt at quantifying these differences premature. Figure VII-3 presents a qualitative evaluation of opportunities presented by the systems discussed above and in volume 11, appendix V. The ranking is on the basis of the usefulness of the fissile material as follows:

A—No significant diversion potential.

B—Highly dilute AND substantially radioactive material. Diversion is barely credible for the non-state adversary,

C—Concentrated material, but contains sufficient radioactive isotopes to require heavily shielded processing.

Highly diluted material, so that large quantities must be diverted.

Not impossible for non-state adversary to steal and convert to weapons material, but difficulty provides a substantial deterrent.

D—As F, but substantial chemical and/or mechanical processing needed. Possible for non-state adversary to convert to weapons material.

or

As F, except material required for continued operation of fuel cycle.

F—Material in concentrated form suitable for straightforward conversion to weapons, with modest radioactivity. Easy for non-state adversary to use as, or convert to, weapons material.

The relative value of the opportunities for diversion as summarized in figure VII-3 depends on the intentions and capabilities of the diverters. Four general categories of proliferators can be envisioned.

Nations Desiring a Major Nuclear Weapons Force

A major nuclear force might be required by an industrialized or emerging country intent on becoming a world or regional power. A large and reliable supply of high-quality fissile material would be needed. Covert diversion from safeguarded facilities would probably be precluded by these criteria and by the incompatibility of this method with the goal of international prestige. Some non-weapons states (such as Germany and Japan) are capable of building their own facilities with the dual purpose of power and fissile material production. India is developing this capability, but few others will if economic power is a requirement (discussed in chapter X). Nations party

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to the Non-Proliferation Treaty (NPT) or subject to safeguards on imported reactors would have to abrogate safeguard agreements after the necessary facilities were in place.

System characteristics that would be especially important for this category of proliferator are:

- a high-production rate of high-quality fissile material;
- immunity to international embargos and sanctions; and
- minimum impact on the fuel cycle.

The specific paths which this type of proliferator could follow to obtain the strategic nuclear materials are at present:

(1) *Enrichment:* A plant with more capacity than needed for domestic LWRS could be built. The excess could be rationalized as being for export if it were necessary to keep the intentions secret during construction. In fact, no LWRS are needed in countries (such as South Africa and Australia) that could become major uranium exporters and prefer to supply enrichment services also. The amount of highly enriched uranium that could be produced without impacting on the fuel cycle would depend on the excess enrichment capacity. A large supply of uranium, either domestic or from a secure source, would be needed to keep reactors and weapon programs supplied. The cost would primarily be the loss of enrichment revenues from the previously exported low-enriched uranium. This would amount to approximately $20,000 per kg highly enriched uranium.

(2) *Reprocessed LWR Fuel:* An entire LWR fuel cycle would probably be required to resist nuclear embargos. The output of one reactor operated to optimize the quality of the plutonium would be sufficient for 30 to 40 weapons per year. The frequent shutdown would result in the loss of one-half to one-third of the power output, which is a high penalty, but after several years a substantial arsenal would be available and the reactor could be returned to normal operation. The plutonium lost to the fuel cycle would have to be replaced by enriched uraniums, but the cost would not be high if the uranium is recycled.

(3) *Reprocessed CANDU* Fuel: A reprocessing plant would have to be built, but this could be done covertly prior to the safeguards abrogation. If plutonium output is maximized, about 40 to 60 weapons could be derived from each 600 MW(e) reactor. Feed would have to be increased considerably, since uranium recycle would be less attractive than for the LWR. Full-power production could be maintained. Even if the feed is not increased, 20 to 30 weapons could be produced annually. Access to heavy water would have to be maintained in either case. About 10 metric tons are required per year for normal operation, more if refueling is accelerated. A small, unsophisticated plant might produce heavy water at about double the normal cost of about $130 per kg. This cost increase could add $1,300,000 or more per year for the quantity required for the operation of the reactor.

Comparison. —The third route is clearly preferred if heavy water is not a problem. The plutonium production rate is high, and vulnerability to international restrictions almost nonexistent. The total cost of the full CANDU cycle should be less, though the reactor is 10 percent more expensive, because a heavy water separation plant is cheaper than an enrichment plant.

Future Developments.—The near-term future reactors (HTGR and AGR) do not present markedly different opportunities. The HTGR uses high-enriched fuel, which means that if a nation has a full fuel-cycle capability it also has another direct route to weapons material. The fresh fuel itself would not be of interest, as then the reactor would have to shut down. The HTGR breeds more fuel than the LWR, and recycle is a virtual requirement. The HTGR has somewhat more potential for diversion than the LWR, but probably less

Figure VII-3.
Reactor Diversion Report Card

	Fabrication and Transport of Fresh Fuel	Reactor, including Fuel Storage at the Reactor	Spent Fuel Transport and Storage	Reprocessing	Reprocessed Fuel-Fabrication (including transport)	Stockpile of Excess SNM
LWR No Re-processing	A	B	B	(A)*	(A)*	(A)*
LWR, Reprocessing, No Pu Recycle	A	B	B	F	A	F
LWR, pu Recycle	c	C (Onsite Fresh MOX) B (Spent Fuel)	B	F	F (if fuel not blended at Repro. Plant) C (if fuel blended at Repro. Plant)	(A)*
LWR, Denatured U-Th	A	A	B	D	A	(A)*
HWR (CANDU), No Reprocessing	A	B	B	(A)*	(A)*	(A)*
Uranium gas cooled Reactors (AGR)	A	B	B	F	A	F
HTGR	D	D (Fresh Fuel) C (Spent Fuel)	c	F	c	(A)*
LMFBR and GCFR	D	D (Fresh Fuel) C (Spent Fuel)	c	F	F	F
LWBR	D	B	B	D (National diverter) F (Non-state diverter)	D (National diverter) F (Non-state diverter)	(A)*
MSBR	A	A	(A)*	F	(A)*	F

See figure VII-2 for a summary discussion of diverson points m the LWR fuel cycle
“Nonexistent

SOURCE: OTA

than the CANDU. The AGR appears less appropriate for proliferation than the LWR. Fresh fuel has a lower enrichment and the spent fuel contain relatively little plutonium. Recycle is not expected, even if the fuel is reprocessed.

Some of the more distant reactors present more difficult problems. The LMFBR and the similar gas cooled fast reactor (GCFR) will both produce copious quantities of high-grade plutonium, and both are relatively easy to make independent of international interference since the cycles are self-supporting except for a supply of depleted uranium. The fuel-cycle impact of diversion is negligible because of the excess of plutonium.

The LWBR is not attractive to this type of proliferator since the entire production of U^{233} is required to continue operation. The prebreeder cycle could be supported, but most of the fissile material produced is U^{233} which is diluted in U^{238}. This cycle would probably be considerably more expensive than the PWR cycle for weapons-material production. The molten salt breeder reactor would be only marginally better in that the breeding ratio is slightly higher, thus producing an excess of U^{233} which would be adequate for producing 4-8 weapons per year.

A qualitative ranking of the resistance to proliferation for all these systems is shown in figure VII-4.

Nations Desiring a Small, Not Necessarily Sophisticated, Nuclear Capability

In this case, covert diversion is a possibility but may not be a necessity. If the facilities are not safeguarded, the important characteristics would be as follows:

- Immunity to international embargos and sanctions—this type of nation is less likely to have full-fuel cycle facilities.
- Minimum impact on the fuel cycle-a substantial power loss would be harder to absorb.
- Initial cost—nuclear reactors are already very expensive, These nations may not be able to afford a more sophisticated one even if it is more vulnerable to diversion.
- Ease of conversion to weapons material —the lesser sophistication of this type of nation makes major processing difficult.
- Production rate and quality of fissile material—this is less important than for the previous case. Little material is needed and the yield of the weapon is much less important than the fact of its existence.

If the facilities are safeguarded, a different set of factors apply.

- High rate of material flow—to make diversion less noticeable.
- Many vulnerable points to make safeguarding difficult.
- Minimum impact on fuel cycle.
- Initial cost.
- Ease of conversion.

The enrichment option of the previous case will be plausible only if techniques other than diffusion become viable. Diffusion is simply too big and expensive for this type of nation. Covert diversion of low-enriched uranium could be improbable since the country might not have the capability of building a small dedicated weapons-grade enrichment plant, even using low-enriched uranium as the feed. Therefore, part of the plant itself would probably have to be modified to yield high-enriched uranium.

The LWR reprocessing route is particularly good for the covert diverter because of the large number of vulnerable points. The impact on the fuel cycle need not be large, because the diverted plutonium can be replaced by slightly more enriched uranium or slightly less power output. It would not be necessary to possess an enrichment plant. If there is no commercial reprocessing, however, spent fuel would have to be diverted to a small dedicated reprocessing plant. It would be difficult to evade safeguards for long, so this path is improbable. The overt diverter would need a

Figure VII4.

Reactor Systems Resistance to Proliferation

(Note that a high rank means the system is least susceptible to diversion.)

Reactor system	Availability	1 . Force	Small Force (unsafeguarded facilities)	Small Force (safeguarded facilities)	Option	Non-Sate Adversaries
Light Water Reactor (enrichment)	Present	5	6	7	1	1
Light Water Reactor (spent fuel)	Present	4	3	1	4	4
Light Water Reactor (reprocessing & recycle)	Present	6	5	8	5	6
CANDU	Present	8	7	2	2	2
High Temperature Gas Reactor	Near Term	7	4	6	6	7
Advanced Gas Reactor	Near Term	3	2	3	3	3
Liquid **Metal** Fast Breeder Reactor	R&D (advanced)	9	9*	9	9	9
Gas Cooled Fast Reactor	R&D	10	10*	10	10	10
Light Water Breeder Reactor	R&D	1	1	4	7	8
Molten Salt Breeder Reactor	R&D (presently inactive)	2	8*	5	8	5

“May not bean Option for cost or technological reasons

SOURCE: OTA

complete fuel cycle—including enrichment—in order to thwart embargos. This might be so expensive as to be impractical.

The CANDU would be excellent for the overt diverter who would simply process the normal spent fuel. The covert diverter would have to smuggle out his own spent fuel. This is not an impossible task, as up to 10 years of spent fuel could be in the pool in the form of thousands of bundles. Accounting for all of them will be a formidable, but not impossible, task.

Comparison. —The overt diverter will prefer the CANDU, again assuming access to heavy water. An LWR with Pu recycle would be better suited to the covert diverter because of the greater number of vulnerable points. The static nature of the source (spent-fuel rods) in the CANDU or LWR without reprocessing tends to make eventual detection of covert diversion quite probable.

Future Developments.—The AGR presents essentially the same opportunity as the LWR. Reprocessing is less important than for the LWR, and could be eliminated. If there is reprocessing but not recycle the overt diverter would have a substantial stockpile at his disposal, just as there would be for the same LWR cycle. The AGR's lower enriched uranium would be slightly easier to procure than that for the LWR in case of embargos, and there would be essentially no impact on the power production since the recovered plutonium is not being used. The HTGR with its high-enriched fresh fuel and required reprocessing presents more opportunities for both overt and covert diverters. The fuel-cycle facilities, however, are expensive and technologically demanding and might never be available for export. This could eliminate overt diversion.

The R & D reactors could again enhance or limit opportunities. The overt diverter would prefer the LMFBR and GCFR for the same reasons as would the major nation, but may not be able to afford them. The LWBR would be quite inappropriate. The MSBR might produce sufficient strategic nuclear materials, but its intricate technology would be difficult to manage. The MSBR concept, however, may be readily adaptable to small sizes, which would make it more attractive. The covert diverter would also prefer fast breeders, possibly by a wide margin, Thermal breeders provide few opportunities.

Nations Desiring the Option of Rapid Development of Nuclear Weapons in the Future Should That Appear Necessary

The important factors are:

- rapid access to strategic nuclear materials
- high production rate of fissile material
- cost

The enrichment option is not particularly interesting because the process is too slow, except possibly for centrifuge designed for fast conversion to high enrichment.

The LWR reprocessing route is very vulnerable, in that a significant stockpile of plutonium can be legitimately maintained. This provides immediate access, and considerably more can be supplied from the batches of spent fuel waiting to be reprocessed, Spent fuel with no commercial reprocessing would require a small reprocessing plant to be built ahead of time and held in readiness. Even then, there would be no stockpile for immediate seizure,

The CANDU would be less appropriate for this proliferate unless an appropriate reprocessing plant already exists for other reactors.

The HTGR could be useful because fresh fuel could be quickly processed even if no other fuel-cycle facilities were available. This would mean loss of the reactor as it could not be refueled, but national emergencies might be seen to override this factor. The fast breeders would provide substantial strategic nuclear materials both in the fresh fuel and in reprocessing plant stockpiles.

The LWBR would provide useful high-enriched fresh fuel as in the HTGR and easily processed spent fuel if needed, The entire core inventory could be made available quickly and would provide a great many weapons. The MSBR contains 2300 kg U^{233} at all times (enough for as many as 460 bombs). This material could be processed immediately because its low-fission product inventory eliminates the need for long-term cooling. The small normal excess of U^{233} could also be stockpiled, and would provide immediate access to about eight weapons for every year's stockpiling.

Non-State Adversaries

The prime requirements are:

- many vulnerable points
- high rate of material flow
- ease of conversion

The only present generation system that offers a significant opportunity is the LWR with reprocessing. Plutonium recycle allows the reprocessing plant, plutonium shipments, mixed-oxide plant, and possibly even the fresh fuel to be targets for attack or diversion,

The AGR is as resistant as the LWR if no reprocessing takes place. The HTGR fresh fuel is a possibility, but considerable work must be done to separate the high-enriched uranium from the thorium. If the high-enriched uranium can be attacked before it is mixed with thorium, the weapon preparation would be easier.

The LWBR can be attacked at the fuel fabrication plant or at the reprocessing plant. The U^{233} is more easily separated from the thorium here than in the HTGR. The MSBR is almost invisible to the non-state adversary. All operations are performed at the plant site, and only a small amount of U^{233} need be exposed. This could easily be denatured in U^{233} before shipping.

Figure VII-4 ranks these systems in order of vulnerability to each of the diverters.

Research Reactors

There are many research reactors operating throughout the world, Appendix V in volume 11 lists the research reactors outside the United States with a power rating of 1 MW(t) or more. Examination of that list shows that there are 18 countries which possess either (a) natural uranium or low-enriched uranium-fueled reactors that will have accumulated 10 kg or more of Pu^{239} by 1984, or (b) reactors fueled with 80 percent to 100 percent U^{235} with a power rating of 5 MW(t) or more (i.e., an annual fueling requirement of 5 or more kg of 80 percent to 100 percent U^{235}), or (c) both of the above.

Examination of a list prepared by ERDA shows that, through December 31, 1976, the United States exported a total of 1,115 kg of plutonium to 38 countries. Eight countries have received more than 5 kg of plutonium from the United States (see list in volume II, appendix V). From January 1, 1968, through December 31, 1976, the United States exported nearly 10,000 kg of uranium enriched to 20 percent or more in U^{235} to 21 countries. Eight countries have received substantial amounts of highly enriched uranium.

The exported plutonium is used largely in critical assemblies, that is, experimental facilities run at zero power. This plutonium is essentially uncontaminated by fission products, and is of very high quality for use in weapons.

Thus, substantial diversion or theft potential exists outside the commercial power industry. India's nuclear explosive was made with plutonium produced in one of the research reactors mentioned above.

Alternate Fuel Cycles and Nonproliferating Reactors

Present commercial and near-commercial fuel cycles have been conceived and developed with essentially no thought given to their implications for proliferation or to the difficulties of safeguarding them. Other possibilities exist, however, that are less vulnerable to diversion.

Alternate Fuel Cycles

ERDA has recently set up a study in the Office of Nuclear Energy Assessments, Division of Nuclear Research and Applications, to investigate and evaluate alternative fuel cycles. The criteria for evaluation of the alternate cycles are: (a) proliferation risk potential, (b) safeguard potential, (c) technical feasibility, (d) economics and resource utilization, (e) commercial feasibility, and (f) introduction date. In evaluating proliferation risk potential, emphasis will be placed on diversion or theft of nuclear material for the purpose of making an explosive weapon. Both domestic and foreign applications will be considered.

The schedule calls for a final report in October 1978, with a developed set of proliferation criteria and an assessment of selected alternate fuel cycles. ERDA is requesting supplemental funds of $4 million from Congress for FY 77, and has budgeted the program at $7 million for FY 78.

The program is currently in the phase of collecting proposals for alternate fuel cycles and issuing some contracts for promising proposals already collected. Some work previously contracted by ERDA has been assembled under the aegis of this project. A screening for the most promising alternates is set for July 1977.

For the results of this program to be most useful, the alternates that are selected for further study ought to be balanced between relatively short-term payoff on technical modifications of existing cycles and radically new approaches. The differences between national capabilities and non-national capabilities should be kept in mind. An alternate such as coprocessing, for example, might put a substantial obstacle in the way of a non-national group but provide much less of a deterrent to national proliferation.

A good deal of emphasis is apparently being given to an effort to develop a quantitative methodology for evaluating proliferation potential, The first phase of this criteria effort is due to be completed in June 1977. Such an effort can be extremely useful in forcing the people involved to think through the problems in detail. However, a set of numerical criteria purporting to quantitatively evaluate proliferation risk should be regarded with skepticism.

The areas that the program is currently looking at can be grouped in the following categories:

(1) Reexamination of the LWR and the LWR fuel cycle
(2) Introduction of the CANDU into the United States
(3) Thorium fuel cycles
(4) The fast-breeder fuel cycle

In the first category, reexamination of the LWR fuel cycle, a variety of concepts are being considered, most of which are aimed at increasing the energy obtainable from LWR fuel without going to plutonium recycle.

Several possibilities exist for modifying the design of the LWR so that spent fuel will have a lower fissile content, approaching that of the CANDU, thus reducing resource-utilization pressures for plutonium recycle. Preliminary estimates indicate that a modified LWR could extract an additional 20 percent of power out of a given amount of uranium, as compared to an additional 30 percent with plutonium recycle and present LWR design. Possible changes include opening up the lattice and decreasing periods between refueling; increasing the initial uranium enrichment; decreasing neutron absorption in the coolant, moderator, and control rods by either geometry changes or material changes, including use of heavy water; or the use of uranium-metal fuel. (Some of the above design changes are incompatible with others.) Many such design variations have been considered in the past, when nonproliferation was not a consideration, and rejected because of technical or economic reasons.

An updated assessment of the use of metal fuel has recently been completed at ORNL. The study indicates that uranium enrichment could be reduced by up to one half (i.e. 1.5 percent instead of 3 percent), and that the fissile content of the spent fuel would indeed be very low, Metallurgical problems have in the past precluded this option; however, recent development work is reported to look extremely promising,

The adoption of a throwaway cycle (i.e., no reprocessing) would make the LWR cycle a less-attractive target for diversion by nations and a much less-attractive target for theft by non-state adversaries. The central international issues would revolve around the disposal of the spent fuel, including questions of transportation safety, disposal sites, long-term storage security, and disposal costs. Pressures to recycle might recur if uranium prices rose high enough.

Other LWR schemes under consideration (but apparently not funded as yet) include several reprocessing variants. In one concept, only uranium would be recycled; plutonium would be either (a) partially decontaminated and stored as highly radioactive plutonium nitrate solution, or (b) purified and stored. Variant (a) would provide some deterrent for the non-state adversary, but neither variant addresses the question of national proliferation. Indeed, variant (b) involves stockpiling plutonium. Plutonium stockpiles are the most vulnerable target for the national diverter and require massive security against the non-state adversary. Coprocessing is also on the list of alternates, and also apparently as yet unfunded. This concept would recycle LWR spent fuel without separation of uranium and plutonium. Instead of pure PuO_2 at the end of the reprocessing/conversion stream, there would be approximately 1 percent PuO_2 in 99 percent $U0_2$. The economics are unclear. Fuel fabrication costs would increase because more fuel would contain toxic plutonium. Reprocessing costs would decrease. Claims have been made for increased fuel utilization.

Coprocessing would present a substantial obstacle to the non-state *diverter*, Plutonium would never appear in highly purified form in the fuel cycle. One thousand kg of mixed-oxide material would have to be stolen to obtain 10 kg of plutonium. The separation of PuO_2 in such a dilute form would present a very time-consuming task to the non-state adversary.

Coprocessing, however, presents a much less-significant hurdle to the *overt national diverter,* A nation could keep a small PuO_2-UO_2 separation plant "on ice" until it made the decision to go for a nuclear explosive; it would then appropriate the mixed-oxide material, and separate it in a matter of days.

The implications of coprocessing for the *covert national diverter* are less clear. In the case discussed above, the equipment for separating uranium and plutonium would be absent, forcing the nation to divert 1000 kg of mixed-oxide material for every contained 10 kg of Pu. This presents serious logistical problems, which, however, possibly could be surmountable, even in a safeguarded plant. In a variant of the above process, where uranium and plutonium are only partially separated (to give about 5 percent PuO_2 and 95 percent UO_2, as the final product) covert national production of tens of kilograms of pure $PU0_2$, undetected by the materials accountancy system, is credible given a commercial-sized plant. Whether or not this material could then be removed from the plant without detection would depend on the efficiency of containment and surveillance safeguards. (See chapter VIII.)

ERDA is at present, actively looking at some of the problems of collocating reprocessing plants, fuel fabrication plants, and possibly plutonium-burning reactors. Generic studies of environmental effects and institutional problems are underway, as are technical studies of a possible nuclear energy center at Hanford. Confining plutonium in fresh fuel to a small number of fixed sites has the potential for reducing the risk of non-state theft. The results of these studies will also be applicable to multinational fuel-cycle centers. (See "International Control of Proliferation", chapter VIII.)

Another LWR option being investigated by ERDA is the tandem fuel cycle. In this scheme, discharged LWR fuel is inserted into a heavy water reactor (HWR) to achieve an additional 33 percent burnup. After discharge from the HWR, the fuel would be stored indefinitely. There are severe technical, economic, and licensability questions to be resolved, as discussed in appendix V of volume 11.

Other concepts to extend the use of spent fuel without recycle include bombarding spent fuel with neutrons from:

- a target bombarded by protons from a high-energy accelerator (the accelerator breeder idea);

- controlled thermonuclear fusion (the spent fuel would be inserted into a blanket in the fusion reactor);
- laser or ion beams on fusion targets; and
- an LMFBR

Using fusion neutrons to produce fissile material (either plutonium or U^{233}) could be economical before self-sustained fusion was achieved, The accelerator-breeder and fusion/fission devices may well have an important role to play in extending resources of fissile materials and possibly in cleaning up nuclear waste. Both devices might have applicability in the international thorium cycle discussed below.

However, such neutron irradiation schemes can clearly be regarded as antioroliferation measures only at an international center. A nation with a device designed to irradiate spent fuel could as easily irradiate clean uranium or thorium. A nation would ship highly radioactive spent fuel to an international irradiation center, where the plutonium or U^{233} content of the spent fuel would be increased by a factor of 2 or more. The spent fuel might then have to be refabricated. Finally, the still radioactive spent fuel, with enhanced plutonium or U^{233} content, is shipped back to the nation for reinsertion into the reactor. After one or more such round trips, the spent fuel is shipped back for disposal. Both this concept and the accelerator breeder are discussed in appendix V of volume II. Many of the metallurgical problems discussed for the tandem fuel cycle would exist for these options, Neutron irradiation of spent fuel appears to be a somewhat contrived antiproliferation measure.

The ERDA studies on introducing the CANDU into the United States appear to be focusing on economics, licensability in the United States and U.S. commercial feasibility. No current U.S. reactor vendors manufacture $CANDU_s$, and presently there is little U.S. utility interest, The proliferation potential of $CANDU_s$ and LWRS was compared in the preceding section, where it was concluded that safeguarding against the national diverter was a harder problem for the CANDU than the LWR without recycle. Thus, purely from a nonproliferation point of view, LWR redesign appears more attractive.

Through another program, ERDA is investigating the problems of commercializing the HTGR. Because the HTGR contains exposed 93 percent U^{235} in its fuel cycle, it has serious proliferation implications. However, the alternates program is investigating the use of less than 20 percent U^{235} in the HTGR cycle. The detailed assessment is underway but not yet completed. Earlier studies indicated that a low-enriched uranium cycle, possibly as low as 6 percent U^{235}, would be technically feasible but at a distinct economic disadvantage to the 93 percent U^{235} cycle. The low U^{235} HTGR would have better fuel utilization than the LWR. Major redesign of the HTGR might yield more favorable results.

The program is apparently planning an extensive investigation into thorium fuel cycles, including work on the recently proposed international thorium cycle. In this system, *national reactors* would operate on a fresh fuel mix of something like 1 part U^{233}, 6 parts U^{238}, and 10 to 60 parts thorium. As discussed in chapter IV, a U^{233}/U^{238} ratio of 1:7 represents a lower limit of concentration, below which the mixture cannot be used in a practical fission explosive. Preliminary calculations suggest that spent fuel from such a reactor would contain only one-fifth to one-tenth as much plutonium as spent fuel from present reactors, for the same amount of power output, Spent fuel would be sent to *international fuel support centers* which would reprocess the spent fuel, extracting the plutonium for burning onsite, possibly in fast breeders with thorium as the fertile element. The U^{233} produced in the fast breeders would be denatured with U^{238} at the center, fabricated into fresh fuel, and shipped to the national reactors. Thus either enrichment (for fresh fuel) or reprocessing (for spent fuel) would be necessary to extract weapons material from fuel in national hands. Both routes are possible for the national diverter, but both require the construction of a dedicated facility.

The national diverter, if discovered, is very vulnerable to fuel-supply cutoff in the international thorium cycle. The international thorium cycle offers a very high degree of protection against the non-state diverter.

A partial list of questions to ask about the denatured thorium cycle includes:

1. What is the concept for starting up thorium cycle reactors? Can startup fuel material be generated without paying the economic penalty that appears to be required for the LWBR?
2. How does the rate of growth of nuclear power affect the attractiveness of the cycle?
3. The thorium concept requires reprocessing, whereas an optimized throw-away LWR U-P_U fuel cycle does not. What are the relative safeguard, economic, and uranium utilization differences for each of these concepts?
4. How much redesign of LWR_s (and HWR_s) is necessary to achieve an optimum thorium fuel-management program?
5. What are problems and costs of production development of the thorium reprocessing (Thorex) process?
6. What is the increased safety/radiation risk of a thorium fuel cycle during
   a) normal operation?
   b) abnormal situation (e.g., sabotage attempt) ?
7. How much development and exploration is required for a large-scale supply of reactor-grade thorium?

The project is also studying coprocessing of fast-reactor fuel for either the U/Pu or the Th/U^{233} cycles. The emphasis would be on metallic fuels for breeding in the core, rather than in the blanket. As pointed out before, coprocessing is a tactic of limited usefulness against national proliferation.

Nonproliferating Reactors

One of the most intriguing concepts that ERDA is studying is being funded at $250,000 for FY 77 by the Division of International Security Affairs. This is the concept of nonproliferating reactors.

Through strict design requirements, this approach attempts to eliminate the diversion paths present in current and projected power-reactor systems and their associated fuel cycles. Several key design criteria are: (a) the system shall contain only a small amount of fissile material at any given time; (b) there shall be no access to the fuel during the lifetime of the reactor; (c) any diversion of fuel will cause the reactor to shut down; (d) the reactor shall be refueled by the addition of fertile (i.e., non-fissile) material only; (e) the reactor shall not operate as a breeder, but as a sustainer, producing just enough fissile material to keep itself running (i.e., the breeding ratio should be essentially one); (f) reprocessing shall be done onsite inside a biological shield.

In addition, the reactor is required to produce economical power and be designed so that accidents have minimum consequences of fsite,

This last requirement suggests that it might be possible to site the reactors fairly close to load centers and use the waste heat locally, thereby markedly increasing overall efficiency. Finally, although the optimum power level for such reactors is not known, preliminary studies suggest that the reactors may be economical on a small scale, i.e., 50 to 250 MW(e).

Preliminary conceptual studies have been done on three reactor systems.

- Gas core reactor ($100,000)
- Suspended particle bed reactor ($40,000)
- Modified molten salt reactor ($100,000 assigned; $20,000 spent)

Conceptual and design studies on a gas core reactor have been carried out for a number of years at Los Alamos Scientific Laboratory (LASL) under NASA funding. Some experimental work has been done for NASA with a zero power assembly. An experimental flowing gas system has started up at LASL recently, and has attained criticality.

The gas core reactor designed for the nonproliferating reactor study is a conservative variant of the 6000°K plasma reactor being designed for NASA use around the year 2000. This particular nonproliferating gas-core design has the following features: $U^{233}F_6$ gaseous fuel; beryllium moderator and graphite neutron reflector; molten thorium-salt breeding blanket; relatively low-operating temperature of approximately 1200 ‘K; power level of 200 MW(t); entire plant-fissile inventory of 100 kg of U^{233} (i.e., this includes the material being reprocessed). Diversion of 4 kg of U^{233} will shut the reactor down, as would adding more thorium in an attempt to increase the breeding ratio.

Preliminary calculations indicate that if the operating temperature of a nonproliferating gas-core design is raised to the 4000°K range (i.e., the magneto-hydrodynamic range), the total inventory of U^{233} may decrease to a few tens of kilograms. Moreover, the quantity of U^{233} that could be diverted without shutting down the reactor would probably also decrease markedly. This sensitivity of fissile inventory to operating temperature should be explored more thoroughly.

Another aspect of the gas core design that merits further investigation is the possibility of using denatured U^{233} fuel.

The suspended particle bed reactor features extremely small coated-fuel particles and a gas-cooled, heavy water moderated, fluidized - bed design. Such high burnup is attained that reprocessing is of no benefit. The reactor is refueled online with fertile material only, but has a high fissile inventory of 3000 kg of U^{233} for a 300 MW(e) system.

The molten salt reactor concepts are based on the use of a circulating fluid fuel with online continuous fuel reprocessing.

A detailed 300 MW(e) molten salt breeder reactor design previously prepared for another purpose was examined to determine the feasibility of redesign for nonproliferation requirements. Potential diversion paths were identified and changes suggested which were qualitative in nature (there was insufficient time to actually redesign the reactor).

The modified molten salt reactor as a nonproliferation reactor has many features which make it attractive. However, it appears that the system would have difficulty meeting the requirement for a breeding ratio of approximately one. It is not known how significant the deviation from one would be. The system inventory is high, on the order of 500 to 1000 kg of U^{233}, which at this time would be judged excessive. Finally, it is not clear that diversion of a significant quantity of U^{233} would cause the reactor to shut down.

For all the nonproliferating reactor designs, enough U^{233} to start the reactor up would have to be supplied from an external source, probably a thorium cycle fast breeder. One thorium cycle breeder could provide enough start-up U^{233} for many nonproliferating reactors. Start-up U^{233} would have to be produced, reprocessed and shipped under guard, In this sense, nonproliferating reactors would not *totally eliminate* diversion possibilities, but the concept does hold forth the promise of enormously limiting diversion and proliferation paths.

Conclusion on Nonproliferating Reactors.— This small program is the first attempt to design reactors specifically with nonproliferation and nondiversion in mind. As such, it deserves continued funding at an expanded scale, a wide hearing, a thorough assessment, and an open-minded comparison with other alternatives.

DEDICATED FACILITIES

All nations now possessing nuclear weapons obtained fissile material from facilities specifically *dedicated* to its production or separation. Therefore, a nation need not undertake a nuclear power program in order to have a nuclear weapons program. In fact, a nation determined to acquire nuclear weapons may be able to do so with lower capital costs, in a shorter period of time, and with less scrutiny from other nations by building facilities specifically dedicated to the production of fissile material by *itself* (or with gray market aid).1

[1]See "purchase and Theft" section, this chapter and appendix VII of volume 11 for a discussion of black and gray markets.

Such a nation would have two basic options:

(1) Construct a plutonium-production reactor plus a reprocessing plant to separate the plutonium from the spent fuel;

(2) Construct an enrichment plant to produce highly-enriched uranium {rem natural uranium.

Variants on the above two options are possible. For example, a nation might feed a dedicated reprocessing plant with spent fuel obtained from an unsafeguarded power or research reactor. This is the route India took, removing fuel from the unsafeguarded Canadian-supplied Cirrus research reactor. Alternatively, a nation might divert low-enriched uranium from a safeguarded facility or buy low-enriched uranium in a black or gray market and boost it to highly enriched uranium in a dedicated enrichment plant. No case of the diversion or purchase-plus-boosting route is known to have occurred.

A major motivation for nations to build dedicated facilities is to have a reliable, possibly secret, and/or legal source of fissile material. As safeguards are improved and extended over all imported nuclear facilities, and as greater restraints are placed on the sale of enrichment and reprocessing plants, more nations may be inclined to develop their own facilities.

The construction of any facility dedicated to the production of weapons material, which of course is not safeguarded, would constitute a violation of the NPT by parties to that treaty. The NPT nation must accept IAEA safeguards on all its peaceful nuclear materials, in all its peaceful nuclear facilities, and must require IAEA safeguards on its nuclear exports to all non-nuclear weapons states. However, nothing in the NPT prohibits the transfer of nuclear material or technology to nonparties to the NPT, even though such nations may have some unsafeguarded facilities. At the present time, the non-NPT nation, even while receiving safeguarded imports from NPT parties, may still indigenously build or obtain unsafeguarded nuclear facilities from another nonparty to the NPT.

In spite of the above fact, even countries not party to the NPT would usually have strong incentives to attempt to keep construction and operation of dedicated facilities secret, at least until they had built up a stockpile of weapons material. A nation that can suddenly demonstrate the capability to explode a nuclear device has a strengthened position. At the same time, a clandestine weapons program avoids the recriminations and international political pressures that the nation might encounter if it pursued the program openly.

Under some conditions, a nation might feel it had little to lose and perhaps some political prestige to gain by the open pursuit of a nuclear weapons option. This section will thus include consideration of dedicated facilities that would be difficult to keep secret.

Weapons Program Levels

The magnitude of the weapons program a nation decides to undertake is a crucial factor in determining what kind of dedicated facility it will choose to build.

A country interested in only a small weapons program would look first at option (a), the plutonium production reactor. As shown in appendix VI of volume II, the rate of plutonium production is proportional to the reactor-power level. For example, a reactor operating at 25 MW will produce between 9 and 10 kg of plutonium per year, enough for one or two explosives. As outlined below, such a reactor can be built and operated at nominal cost, in a relatively short time, with a small number of personnel, and there is at least a fair chance that its existence could be concealed for several years. This size will be referred to as a Level I reactor.

A more ambitious program, one which would yield between 10 and 20 explosives per year, would require a reactor operating at about 400 MW. This is referred to as a Level II reactor. Its construction would require a large investment in capital and involve a large number of engineers and construction workers, Because of the magnitude of the task, there is little chance that the project could be kept secret, either during construction or in operation.

An alternative to a single Level II reactor might be the construction of several Level I reactors that together would yield the same plutonium output as the larger reactor. A nation with a limited technological base might find it easier to build several smaller reactors, each based on the experience gained with the first.

If a nation decided to build an enrichment plant to feed its nuclear weapons program, it would have to allow for 15 to 30 kg of highly enriched uranium for one explosive. The most likely choice of enrichment technique at present (as discussed below) is the gas centrifuge. Because construction of an enrichment dedicated facility would be more expensive and difficult than a Level I reactor it is unlikely to be considered by a nation that wants only one or two weapons per year. One exception might be a nation that has either developed or purchased a centrifuge enrichment plant for a commercial power program. In that case, the components for a dedicated enrichment plant might cost no more than add-ens to the existing plant, The cost for a small dedicated enrichment plant would then be low enough for a Level I weapons program. (See also chapter VII "Diversion From Commercial Power Systems" for a discussion of this route.) Another important exception in the future might result if other enrichment techniques are found that are cheaper and technologically simpler.

Assessment of the likelihood of a nation building any of these dedicated facilities, and of the probability that its efforts can be detected, requires an evaluation of the cost, time, and personnel required,

The numbers vary widely with the types of assumptions made. If one assumes that the dedicated facility will be essentially a scaled-down commercial facility, the cost, time, and personnel estimates are generally quite high. One might more realistically assume that a designer would make considerable simplifications if the facility were built specifically to produce nuclear weapons material. In particular, such plants can be subject to less stringent safety and radiation-protection restrictions.

The estimates of cost, time, and personnel will also depend quite heavily on the particular nation building the facility. Important factors are the available natural resources, the technological and industrial base, the number of trained scientists and engineers, and the cost of labor.

Level I Plutonium Production Reactor[2]

The most likely choice for a Level I production reactor would be one fueled with natural uranium, moderated with graphite, and cooled by air. The uranium might either be mined and milled indigenously, since many nations have at least small uranium reserves (see appendix VI of volume II), or it might be purchased on a gray or black market if commercial purchases would raise suspicions. Graphite and heavy water are the only practical moderators to use with natural uranium. The heavy water is an improbable choice because it is expensive, available from only a few countries, and indicative of its purpose if imported in large quantities. Air is selected as a coolant rather than water because it simplifies the design, construction, and maintenance of the reactor and the fabrication of the fuel elements.

One graphite-moderated, air-cooled, natural-uranium reactor that has operated successfully is now fully described in open literature. It might well serve as a model reactor to guide the construction of a dedicated facility. This reactor is the Brookhaven graphite research reactor (BGRR), described in appendix VI of volume II. The BGRR is a 30 MW reactor which, when operated with natural uranium (from 1948 to 1957) for research purposes produced about 9 kg of

[2]Much of this section originally appeared in: John R. Lamarsh, "On the Construction of the Plutonium Producing Reactors by Smaller and / or Developing Nations," Prepared by CRS, April 30, 1976. See also appendix VI of volume II.

nearly pure Pu^{239} annually (enough for one or two weapons per year). The cost of the BGRR and its related equipment was $16.7 million when built in 1948. It is not necessary to duplicate the BGRR in detail in order to attain the same rate of plutonium production. Simplifications in the BGRR design would permit the building of a plutonium-production reactor that would be cheap and reliable, and that would require the talents of only a small group of conventionally trained engineers.

The design of a simplified BGRR is discussed in detail in appendix VI of volume II with cost estimates for the various components. Costs are based on current U.S. prices, and as such they may have only the roughest applicability to another nation. Moreover, the costs in appendix VI refer to a bare-bones program, with primitive conversion and fuel-fabrication facilities and perhaps some sacrifice of safety and environmental controls. The overall reactor cost estimated with these assumptions is $10 million. Other estimates have been made for a Level I reactor of the same basic type which are considerably higher.

A conservative estimate for the capital cost of a Level I reactor of modified BGRR design producing 9 kg of Pu^{239} per year, is, therefore, in the range of $15 million to $30 million.

The personnel requirements for the design and construction of the facility are modest, as all of the essential design parameters are in open literature. High-level research and development personnel are not required. Only a handful of experienced and competent professional engineers—possibly no more than 10—would suffice to design and oversee the construction of the facility.

The reactor could be ready for production approximately 3 years from the beginning of the project.

Level I Reprocessing Plant[3]

To fabricate nuclear explosives as quickly as possible, the fuel from a dedicated Level I production reactor would be removed after it had been in the reactor for approximately 1 year. The concentration of plutonium would then be about 9 kg in 75 tons of fuel, or about 120 grams per ton. The nation would have to build a reprocessing plant to separate the plutonium from the spent fuel.

A plutonium recovery plant must be designed and operated with care. The raw fuel, when first discharged from the reactor, is highly radioactive. Even if the fuel is allowed to cool for 120 days, during which time the activity decays by a factor of 100 or more, the total radioactivity is still about 45,000 curies per ton or 0.05 curies per gram of fuel. This means that the chemical processing of the fuel must be carried out remotely, in a shielded cell, at least up to the point where the fission products are removed.

It should be noted, however, that the radioactivity of the BGRR fuel is much lower than that of a typical power reactor. The activity of power-reactor fuel after a cooling-off period of 120 days runs between 2 and 3 million curies per ton, a factor of about 50 times higher than BGRR fuel. Considerably more precautions must therefore be taken in reprocessing power-reactor fuel than fuel from a BGRR.

Although the chemical steps required in the process are straight-forward and well-known, design and operation of the plant is complicated by the radioactivity of the spent fuel, the toxicity of plutonium, and the potential criticality of the plutonium fuel. These problems

[3]Much of this section originally appeared in: John R. Lamarsh, "On the Construction of the Plutonium Producing Reactors by Smaller and/or Developing Nations," Prepared by CRS, April 30, 1976. See also appendix VI of volume II.

require remote control, concrete shielding, and careful procedures, but do not constitute major obstacles,

Virtually all reprocessing plants built since the 1950's use the Purex solvent-extraction method. Both the chemical engineering techniques and the designs of actual reprocessing plants are well documented in open literature. For example, the plans for the Barnwell, S. C., reprocessing plant recently constructed by Allied General Nuclear Services (AGNS) have been widely distributed to the public and are available in the NRC Public Document Room. Because AGNS is such a large plant, with a through capacity of 5 tons of fuel per day (1,500 tons of fuel per year), considerable scaling down of this plant would be necessary for the purpose of reprocessing fuel from a Level I reactor.

Plans and specifications for a smaller plant are also available. In the late 1950's, the Phillips Petroleum Company undertook a feasibility study of a small reprocessing plant designed to handle spent fuel from Commonwealth Edison's Dresden-1 plant, then scheduled for operation in 1960. Phillips issued a report on this study in 1961, containing detailed drawings of every component of this plant. Although some chemical/nuclear engineers have expressed skepticism about the workability of the Phillips plant, because of its compact design and high level of automation, it nevertheless can be viewed as an excellent starting point for the design of a clandestine reprocessing facility in a small and/or developing nation.

A number of simplifications, described in appendix VI of volume II, are possible when the plant is designed for the sole purpose of recovering plutonium from BGRR fuel. Several of these simplifications result because the fuel has a lower burnup than fuel from a power reactor as discussed above, and, less shielding and fewer precautions are necessary when reprocessing the production-reactor fuel,

All of the equipment and supplies required to build and operate a plutonium recovery plant are generally available on the world markets. There is no single item that is so exotic as to be obtainable from only a single source,

Estimating the cost of a reprocessing plant is difficult even for commercial operations. The discussion in appendix VI of volume 11 arrives at a figure of less than $25 million, while estimates from other sources range from a few million, to $10 million, to $70 million. The highest cost estimates do not appear to take into account the simplifications possible with relaxation of safety and radiation protection standards and the use of lower burnup fuel. The lowest cost estimates correspond to extremely crude and imperfectly shielded (but technically feasible) solvent extraction or ion-exchange facilities, not suitable for a sustained program but which might be constructed to obtain material for a total of only a few explosives.

In view of this range of assumptions and costs, a reasonable estimate for the cost of a frugally designed reprocessing plant for BGRR fuel, based on the Purex solvent-extraction process, is less than $25 million. If the plant were built to handle higher burnup fuel (for example, spent fuel diverted from a power reactor), the costs would be somewhat higher.

Thus the total capital costs of a Level I reactor and associated reprocessing plant are in the range of several tens of millions of dollars.

Many of the same technical personnel involved in the reactor project could be utilized for the plutonium recovery plant. Such a plan makes good sense because the recovery plant would necessarily be located adjacent to the reactor and would probably be built during the same time frame. The total engineering personnel for the two projects would be in the range of 10 to 20. Top-ranking research and development personnel are not required, as the staff largely follow and/or modify established designs. Nevertheless, the staff must contain competent engineers with applicable practical experience. A reactor and reprocessing plant cannot be built by reading books alone.

Many developing countries with a modest technical infrastructure would have the capability to build and operate the Level I reactor and reprocessing plant described above, The construction of Level II reactors (producing 100 kg of plutonium/year), discussed below, would not be feasible for countries without a fairly high level of industrialization and a considerable nuclear base upon which to build.

Level II Plutonium Production Reactor

It is reasonable to assume that any dedicated plutonium production reactor would be fueled with natural uranium, because if facilities for enriching uranium were available it would be more logical to base a weapons program entirely on enriched uranium rather than reactor-produced plutonium.

In order to produce 100 kg of Pu^{239} per year (enough for 10 to 20 nuclear explosives), a reactor operating at about 400 MW is necessary (a reasonable allowance of 30 percent downtime is made).

Several different choices of moderator and coolant are possible. The moderator for a natural uranium-fueled reactor can be only heavy water or graphite. The coolant can be either ordinary or heavy water, or any one of a number of gases. As discussed in appendix VI of volume II, the most practical choice would probably be a graphite moderated, light-water cooled reactor.

Such a reactor would be similar to the first reactors built at Hanford, Wash., in the Manhattan Project. While a nominal 400 MW Level 11 reactor wouId operate at only about one-fifth the power of an early Hanford reactor, the nuclear designs of the two systems would be very similar. (The designs of the Hanford reactors have recently been declassified.)

One estimate of the total capital costs of a Level 11 reactor with associate reprocessing plant is in the range of $175 million to $350 million. Roughly 50 to 75 engineers would be needed in the design and construction phase of this Level II program, supported by roughly 150 to 200 skilled technicians. The length of time required from the start of the design to the first output of plutonium metal would be 5 to 7 years. As in the Level I reactor, the output would be nearly pure Pu^{239}.

Level I and Level 11 Enrichment Plants

Several methods might be considered for enriching uranium. To date the most successful method is the gaseous diffusion process, which was developed by the Manhattan Project in World War 11. This technique has remained essentially the only source of enriched uranium for military and civilian nuclear programs since that time, both in the United States and abroad. However, gaseous diffusion plants are inherently large structures that utilize a relatively sophisticated technology, much of which remains classified; they require an enormous investment of capital; and they consume large amounts of electric power. Finally, they cannot be concealed. The gaseous-diffusion route to nuclear explosives is not feasible for any but a handful of the largest and most developed countries, and will not be considered further in this report,

Another method for enriching uranium is the Becker nozzle process. Such an enrichment facility is being sold to Brazil by Germany, and a variation of it is being developed in the Union of South Africa. However, this method requires a large number of stages (see discussion of stages in appendix VI of volume 11) and consumes 2–1/2 times as much electric power as gaseous diffusion and about 30 times as much as centrifuges (see below). Although the Becker method has fewer classified critical aspects, it does not appear to be a reasonable choice for any but an advanced nation.

Separation by means of high-speed centrifuges was explored during the Manhattan Project but later abandoned. This technique has reemerged in the last few years and has reached an advanced stage of development, both in this country and abroad. It appears likely that the centrifuge method of enrichment will prove to be cheaper than any other presently developed method of enriching uranium,

An Anglo-German-Dutch enrichment group, Urenco, has successfully demonstrated

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the first cascades of two small centrifuge plants, each with a planned capacity of about 200,000 kg separative work units (SWU) per year at Capenhurst, England, and Almelo, Holland. Urenco has plans to expand one or both plants to a total enrichment capacity of 2 million kg SWU by 1982. A small test facility is in operation at Oak Ridge, Term. One American firm has proposed building a major centrifuge uranium-enrichment plant to provide fuel for nuclear powerplants.

One advantage of the centrifuge method for a dedicated facility is that a small number of units or groups of centrifuges can be placed in operation as soon as they are built and tested. The separative operation need not wait upon the completion of a large facility. Production of weapons-grade uranium can begin at a small level and gradually be increased as additional centrifuges are installed.

The capacity of an enrichment plant necessary to produce 30 kg of highly enriched uranium (enough for one or two explosives) is shown in appendix VI of volume II to be between 6000 and 7000 kg SWU/year, depending on the tails assay. If each centrifuge has a capacity of 5 kg SWU/year this size plant would require 1200 centrifuges. An enrichment plant for a Level II weapons program would have to be about 10 times this size, with a capacity of 60,000 kg SWU/year.

The costs of a Level I or Level II centrifuge plant can only be based on estimates made by those now planning commercial plants. Those figures are not only estimates themselves, but most are for plants considerably larger than a dedicated enrichment plant would be and costs do not scale linearly with size. Urenco, which plans a plant whose capacity is several million kg SWU/year, (i.e., hundreds of thousands of machines), has estimated its capital costs at $165/SWU. A U.S. estimate of capital costs for a 3 million kg SWU/year plant is $300/SWU. Another U.S. estimate for a smaller (300,000 SW U/year) plant is $700/SWU. Finally, Japan expects the cost of a 50,000 kg SWU/year plant to be $3,300 /SWU.

The only one of these estimates to correspond closely to the size of a Level II centrifuge plant is the Japanese estimate. On this basis, one might put the cost per SWU at $2,000-$4,000 and the total plant capital cost at $120-$240 million. Because, as discussed earlier a Level I centrifuge-enrichment plant is likely to be built only as an “add-on” to an existing plant, its costs may run the same per SWU as those of a larger plant. Taking the range of U.S. estimates of capital costs of $300 -$700/SWU, this assumption leads to a cost estimate for a Level I add-on plant of between $2 million and $5 million.

The costs discussed above do not include those for research and development. Centrifuge separation is a difficult technology only recently developed by a few of the most advanced nations. The AEC classified centrifuge technology in 1960, and Urenco also maintains tight security. Although unclassified details of early centrifuge technology are available, considerable development work would be necessary before even a small operable enrichment plant could be built.

Comparison

The centrifuge enrichment route calls for quite different resources and capabilities than does plutonium production reactors. In the latter case not only are complete facility plans readily available, but nuclear reactor and chemical engineers are being trained openly around the world.

For these reasons it is improbable that centrifuge enrichment would be the route taken by a country with a limited industrial and scientific base interested in a Level I facility.

There do not appear to be major differences in personnel requirements between the two types of Level II facilities—plutonium production and centrifuge enrichment-although the centrifuge program might require somewhat more manpower, The centrifuge program might also take longer from inception to metallic-weapons material. The capital and operating costs appear comparable.

Thus, an industrialized country desirous of producing significantly more than one bomb per year might carefully weigh the centrifuge enrichment plant against a large plutonium reactor.

Advanced Isotope Separation Techniques

Several enrichment processes are under development that may allow highly enriched uranium to be produced from natural uranium (or even depleted uranium) in a very small number of stages. Two of the processes, laser isotope separation (LIS) and the ion-cyclotron resonance process (the Dawson process), are under development on contract to ERDA. There are two variants of the LIS process. One, the atomic LIS process, is under development at Lawrence Livermore Laboratory (LLL). The other, the molecular process, is under development at Los Alamos Scientific Laboratory (LASL). The atomic process is also being developed by a private U.S. firm, Jersey Nuclear AVCO Isotopes (JNAI), a subsidiary of Exxon Nuclear and Avco Corporation. Research applicable to LIS is also being conducted in a number of other countries, notably the U. S. S. R., France, and West Germany.

A third process, an advanced form of electromagnetic separation, is under conceptual investigation by a private U.S. firm, Phrasor Technology, Inc., and research may be underway in at least one other country. It is unclear how much actual laboratory research and development has been done.

The three processes, LIS, advanced electromagnetic, and Dawson, share several key features. All promise to extend uranium resources, because low-tails assay should be easily achievable. The present gaseous diffusion facilities produce tails of 0.2 percent to 0.3 percent U^{235}, and operation at lower tails assay would be very expensive.

The advanced processes project a tails assay of 0.05 percent U^{235} or less, and an economical extension of uranium resources of about 30 percent could therefore be achieved from lower tails assay. In addition, tails accumulated over the years from the gaseous-diffusion process could be run through an advanced process to extract residual U^{235}. ERDA has estimated that by 1989, at an average of 0.25 percent U^{235} in accumulated tails, enough extractable U^{235} will be contained in the tails for the lifetime fueling of 40 to 50 reactors, each of 1000 MW(e).

The three processes also hold forth a promise of lower cost enrichment. The goal of the ERDA program is a 50 percent to 75 percent reduction in enrichment costs, but much greater cost reduction may also be possible. If these approaches are economical on the large scale, all would be also economical in small-scale plants, in marked contrast to centrifuge processes and especially to gaseous diffusion processes. The reason for this is that the advanced technologies will probably require very few stages (possibly only one) to go from natural uranium to low-enriched uranium for reactors. The gaseous-diffusion process requires over a thousand stages; the centrifuge process requires the order of ten stages, with many centrifuges per stage.

The LIS processes and the Dawson process are still in the research stage, with solutions to several difficult problems still to be demonstrated. The proprietors of the advanced electromagnetic process claim that they are ready to begin pilot plant development, but they have apparently done little laboratory development. (It should be noted that a version of the electromagnetic process, the calutron, was used during the Manhattan Project to separate U^{235} for the first uranium weapon. The calutron method is described in appendix VI of volume II.)

The EXXON LIS process, although closer to the pilot-plant stage than the corresponding ERDA process (perhaps partially because of its less ambitious cost-reduction goals) also has technical problems to solve.

All three processes have built on a high technology base. LIS development in the United States depends heavily on the electro-optical base developed by the Department of Defense. The electromagnetic process has apparently built upon ion propulsion research in the space program.

All three processes have the potential for exacerbating the nuclear proliferation problem. This is true in general of all enrichment processes which could produce highly enriched uranium from natural uranium in a few steps, because such processes are highly economical on a small scale once research and development have been completed.

This report has looked more closely at laser isotope separation (LIS) than the other two processes, and has had access to classified material, including ERDA-prepared responses to a series of questions and a classified discussion meeting with representatives from LASL and LLL. In order to keep this document unclassified, much of the detailed material supplied by ERDA has been omitted. As a consequence, the detailed state-of-the-art and description and evaluation of remaining technical problems are not presented.

It appears unlikely, based on knowledge of U.S. technology, that LIS could contribute to nuclear proliferation before the 1990's. ERDA plans to reach a decision in 1979 on which of the approaches, atomic LIS, molecular LIS, or Dawson, to fund to the pilot-plant stage. Pilot-plant operation is scheduled for 1984. This schedule depends on the successful solution of a number of difficult technical problems.

Proliferation From Advanced Isotopic Separation Techniques

Like any other enrichment technology, LIS could theoretically contribute to proliferation in the following ways:

1. The indigenous development of a dedicated facility;
2. Misuse of a commercial facility;
   (a) Replication for the purpose of producing weapons material,
   (b) Covert diversion, and
   (c) Seizure.

These routes are considered in turn below.

Once LIS is known to work on the pilot-plant scale, research and development can be expected to intensify in several technically advanced countries. Some of these countries would probably develop LIS 5 to 10 years after a U.S. demonstration. Countries with only a moderate technological base would take longer.

The above discussion presupposed that LIS technology remained tightly and effectively classified. Leaks of essential data or technical details would speed-up development of LIS by other countries by eliminating the need for some basic research. However, the design, construction, and operation of a workable LIS system (even one that was not commercially competitive) from source preparation to isotope extraction would still require a lengthy and expensive development and learning program.

For these reasons, indigenous development of an LIS dedicated facility to produce highly enriched uranium is unlikely to be a feasible route for nations with a low c r moderate technological base.

A greater danger is that LIS technology will be marketed by one or several advanced countries. France and the U.S.S.R, in particular could well succeed in LIS technology at about the same time as the United States (again, it should be noted that the eventual success of LIS is not a certainty). As noted above, several other countries would probably be only 5 or 10 years behind. Because LIS is economical on a small scale, many countries with a small nuclear power program could make a good economic case for wanting an LIS enrichment plant.

The spread, through sale, of commercial LIS technology would teach many purchasing nations a technology that they probably could not have developed for themselves. Replication of the technology in a small facility to produce weapons material would not be easy, but would be possible for more nations than indigenous development, The sale of commercial LIS technology could also result in many nations possessing a declared and safeguarded facility that could be modified, covertly or overtly, to produce weapons material.

It would be the aim of safeguards to detect covert production of weapons material in a commercial LIS facility. It is not possible to assess a nonexistent safeguards system on a nonexistent plant containing a nonexistent process. However, several general statements can be made. The most important obstacle to effective safeguarding of a LIS plant against covert diversion could turn out to be the obstacle that presently might hamper safeguarding of centrifuge enrichment facilities: the fact that inspectors do not have access to the area where the actual enrichment process is going on, but must rely on monitoring inputs and outputs at the perimeter of the facility, with some input and output routes exempt from monitoring (i. e., perimeter monitoring with undeclared paths. See chapters VIII "Safeguards" and VII "Diversion From Commercial Power Systems".) On the other hand, the intrinsic nature of the LIS process, with relatively small pieces of equipment and a low-process inventory, could make LIS plants easier to safeguard against covert diversion than present enrichment facilities. In addition, many LIS plants would be small, and small plants are intrinsically easier to safeguard than large plants because the uncertainties in materials accountancy are smaller in absolute terms of kg of enriched uranium. Therefore, LIS plants may not present uniquely difficult safeguarding problems.

A greater danger than covert diversion is overt divers ion, which international safeguards, by their nature, cannot prevent. Some form of sanctions would be the only effective response to overt diversion. A nation with an enrichment facility is in a strong position to withstand international embargos aimed at LWR fuel, and LIS facilities could provide this immunity to countries that could not consider present enrichment technologies. (See chapters 111 and VIII for a discussion of sanctions.)

The difficulty of modifying a commercial LIS plant designed for 3 percent U^{235} reactor fuel to produce highly enriched U^{235} for weapons would depend on the engineering details of the process. (It should be noted that one need not go to 90 percent enrichment to have useful weapons material: anything above about 50 percent U^{235} would be useful.) There do not appear to be any basic physics reasons to preclude obtaining weapons-grade material in a few stages in either the atomic or molecular LIS processes. Jersey Nuclear Avco Isotopes (JNAI) has stated that their process appears to be unsuitable for the production of highly enriched uranium. Representatives of the Lawrence Livermore Laboratory (LLL) LIS group have stated that they do not agree with the JNAI statement, if it is meant to apply to all possible atomic vapor processes, although, LLL continues, it could be true for the particular JNAI design. The concept of a "tamper-resistant" LIS process, atomic or molecular, is an attractive idea, but a good deal of technological analysis would be necessary to establish how tamper resistant any particular design was. Moreover, too much reliance should not be placed on tamper-resistant LIS designs. Even a very tamper-resistant design would not be an absolute fix; what it would do is drive the nation towards the route of replication with modifications (a research and development program might be necessary to accomplish this) rather than overt seizure.

Some observers have suggested a U.S. moratorium on LIS development, coupled with strenuous U.S. diplomatic effort to obtain agreement from other countries to suspend work on LIS. Others express great doubt that the United States could achieve international agreement to stop the development of LIS or other advanced enrichment technologies, in view of both the pressures in many countries for independent and inexpensive enrichment and the worldwide market for enrichment services expected to develop in the 1990's.

ERDA predicts the worldwide market for enrichment to reach about 130 million SWU per year in the year 2000, based on their projections of 1200 GW(e) for LWRS worldwide by the year 2000. These projections may prove to be too high, nevertheless present and planned U.S. and foreign enrichment stands now at about 60 million SWU per year, all of it the expensive diffusion or centrifuge processes (see figure X-18). The advanced enrichment technologies, promising much less expensive enrichment, are thus extremely attractive to countries wanting both to assure themselves of self-sufficiency at a low cost in meeting their own enrichment needs and to profit from the sale of enrichment services.

Some observers have argued that the United States should develop an advanced enrichment technology and guarantee to sell enrichment services for a low fee or at cost. If this were done, they maintain, the profit incentive for other countries to develop such technologies would be removed, and the incentive for smaller countries to buy an advanced enrichment facility would be much reduced. Thus, these observers argue, U.S. development of these technologies would in fact slow down their spread.

It would be unrealistic to expect, if this happened, that no other countries would develop advanced enrichment technology. A few advanced countries, with large nuclear programs and an avowed interest in LIS or another advanced enrichment technology (notably France and the U.S.S.R.), would almost certainly prefer their own low-cost enrichment facilities, even at the cost of indigenous development, to reliance on U.S. guarantees.

The same argument of desire for independence could be used by countries seeking to purchase an advanced enrichment facility, even if guaranteed services were available from the United States and perhaps a few other suppliers. Whether the independence argument will be plausible, or will be perceived as only a mask for an unstated weapons objective, would depend strongly on how supplier-importer relationships develop over the next decade.

In summary, the sale of LIS and other advanced enrichment technologies presents a greater proliferation danger than indigenous development of the technologies. The present course of formulating suppliers' agreements to end the sale of enrichment facilities is therefore particularly crucial in the case of the advanced technologies. (Chapters III and VIII discuss methods to restrict the spread of enrichment and reprocessing.)

All enrichment technologies capable of producing highly enriched uranium from natural uranium in a few stages should be closely watched by the United States. At the time of the ERDA decision point in 1979, the competing ERDA technologies should be evaluated for proliferation potential, in addition to economical and technical promise. In particular, the ability to safeguard advanced enrichment facilities and the possibility of tamper-resistant processes should receive attention.

In evaluating the proliferation potential of advanced enrichment technologies, the effect that their uranium-conserving properties might have on the economics of the introduction of plutonium recycle and fast breeder reactors should also be considered.

Detection of Dedicated Facilities

This report has not had access to any classified intelligence information. Therefore, only a few general comments on the detection of dedicated facilities can be offered.

Once the political decision has been made, it would take up to 5 years to build a facility dedicated to the production of weapons material and to obtain the material for the first explosive. As discussed in chapter VIII "International Control of Proliferation, " a nation would probably be at an advantage if its weapons program were not detected until after it had assembled its first explosive. Therefore, the question of the detection of dedicated facilities focuses on the probability of detection within a time span of approximately 5 years—between the time a nation begins serious internal discussion of the possibility to a short but significant time before it has the weapons material in hand.

The likelihood of detection of a dedicated facility in a particular country depends on several factors. For example, it will be relatively easy to detect a clandestine nuclear facility in a country which otherwise has a very limited nuclear program. It will be relatively easy to detect a clandestine nuclear facility in a country which appears to have cause to want a nuclear weapons capability, because intelligence analysts will be more alert for early indications of a move towards clandestine nuclear activity. It will also be relatively easy to detect a large Level 11 nuclear facility.

One of the most important intelligence techniques, especially for the first indications of a dedicated facility, is political reporting. The very first indications of a dedicated facility are unlikely to come from technological techniques, such as satellite photography. Visible photography from satellite or aircraft would become an important tool only after an active, coordinated surveillance program has begun.

A sustained effort, probably over a period of several years, coordinating many elements of the intelligence system—political reporting, visible photography, monitoring of the movement of materials and persons, sampling for chemical or isotopic indicators (such as Kr^{85} for a reprocessing plant) would be necessary to build up familiarity with the target of surveillance and thus confidence in conclusions.

It appears unlikely that a Level II facility could long escape detection. Too many people would be involved in its design, construction, and operation. Level I facilities probably would present a detection problem in many countries, especially if the country were not considered one of the five or six most likely Nth countries. Intelligence agencies cannot continually monitor the whole world for dedicated facilities, and must allocate their resources according to priorities of problems and priorities of targets.

PURCHASE AND THEFT

A third potential route to the acquisition of nuclear weapons is the direct purchase or theft of either the fissile material or the weapons themselves. The commodities might be purchased through an illegal nuclear black market, bought or traded from a friendly nation in what is termed a gray market, or even stolen directly from some national nuclear-weapons arsenal. These paths bypass the need for the expensive and demanding technologies required by either the commercial power or dedicated facilities route, Thus, if this type of transaction emerges, the scope of proliferation could be extended to technologically limited nations and non-state adversaries (NSAS) who would otherwise have found the task difficult and risky. The pace of proliferation could be further accelerated by the relative ease of obtaining weapons, a general sense that the nonproliferation regime was crumbling, and a specific concern that one's enemies could be covertly arming. This section describes and evaluates the three elements to this route: black market; gray market; and theft. Appendix VII of volume II provides further detail.

Black Market

The term black market, as used here, means the illicit trade of goods where the commodity does not in general belong legitimately to the seller. The commodities traded in a nuclear black market could be fissile material, weapons designs, or actual weapons. The most probable fissile material is plutonium derived from commercial power cycles, because it can be directly used for weapons fabrication. Only a very small fraction of the plutonium expected to be moving in a worldwide plutonium fuel cycle by the end of this century would have to be diverted to produce many bombs annually. Research-reactor and breeder-experiment fuel are other potential sources. A detailed design of an effective bomb would be an attractive commodity, especially for NSAS, because it would reduce the time and risk necessary to develop an effective weapon. The third black market commodity—weapons—might be stolen from military stockpiles, particularly if proliferation continues and security is lax in the new weapons states.

Participants in black markets can be categorized as buyers, suppliers, and intermediaries. Several potential participants can be identified in each category, and the type of transaction and motivation varies with the participants. Buyers might be nations or subnational groups (terrorists, political or military factions, and criminals). The types of nations most likely to pursue a black market route are those technologically limited but internationally ambitious or those confronted with a sudden dire emergency which precludes the more conventional but time-consuming routes. Demand for illicit weapons or strategic nuclear materials could arise for economic reasons. An approximate price for plutonium if freely traded could be about $9000/lb. ($20/gram).[4] Ten kg for one or two bombs would at that price be $200,000, and a small arsenal of 20 bombs would cost less than $4,000,000. The black market price would probably be several times higher, but even so the total cost could still be much less than that of the construction and operation of dedicated facilities. Subnational groups that consider terror to be a legitimate weapon could be drawn to nuclear weapons as described in chapter V, but might find procurement of the material otherwise too difficult. A military faction might want nuclear arms to facilitate a coup, or to hold in reserve for a national emergency if the civilian government has forsworn their development. Criminal groups, conceivably even individuals, might want to acquire arms for extortion.

Different commodities require different suppliers, Fissile material (plutonium) might be diverted by an employee at a nuclear facility such as a reprocessing plant. Motivation could be money, coercion, or ideology. Alternatively, strategic nuclear materials could be acquired by terrorists or criminal groups staging an armed attack, probably on shipments. Military weapons might also be procured by armed attack, but the tighter security would require even higher motivation on the part of the attackers. Corrupt military elements in a nuclear weapons state might steal their own bombs for profit, especially if security is casual. If intermediaries are involved they would most likely be criminal or international terrorist groups.

One constraint on a nuclear black market is the difficulty of initiating transactions. Most buyers and suppliers are unlikely partners. Contact and trust may be difficult to establish, except possibly between terrorist groups. Suppliers can generally find buyers more easily than vice versa, since potential buyers are relatively obvious. By contrast, a supplier might be the only employee out of 500 at a reprocessing plant with the motivation and the ability to divert plutonium. The supplier, however, runs the greater risk since he enters into the transaction with the illegally obtained commodity.

These transactions are more likely to occur if both the supply and demand are high. The supply of weapons designs and weapons themselves is likely to change only slowly (although access to them may increase faster). The potential supply of fissile material, however, could increase dramatically if large-scale reprocessing and plutonium recycle are initiated. If all the spent fuel from 1,000 LWRS (anticipated by 1995) is reprocessed, then diversion of one-tenth of 1 percent of the annually produced plutonium would be sufficient for about 50 bombs. This supply might be limited by effective safeguards and physical security, which can sharply reduce opportunities for illegal diversion, just as they reduce opportunities for national diversion. Material accounting, containment, and surveillance will reduce employee theft, while physical security should deter and repel armed attack, Physical security is especially important to protect weapons.

Given sufficient supply and demand, a sustained market could emerge from initial intermittent transactions. Thus, the market would be transferred from an amateur to a professional operation. The latter would be more dangerous because it would be continually seeking new suppliers and customers, and because the greater expertise of the operators would inhibit interference. A full-blown market could consist of many individual diversion activities and continuing networks, with criminal organizations providing necessary middleman services. A sustained black market requires a high demand, which would probably come only from less developed countries: more advanced countries would want more and better bombs than a black market could be expected to provide, and NSAS are unlikely to be able to afford more than a few. The major source of supply might be a number of reprocessing plant employees. If each smuggled out just one gram of

[4] Based on previous expectations and discussions with industry representatives. Utilities presently assign zero value to their plutonium in the spent fuel, but if recycle is allowed, the value would depend on the cost of the enrichment which the plutonium replaces, the cost of reprocessing, and the additional cost of mixed-oxide fuel fabrication.

plutonium per day (an amount probably too small for either material accounting or portal monitors to detect) he should realize at least $5,000 per year and maybe several times that. This source could be supplemented by attacks on shipments of plutonium, which could net several million dollars worth of material. A market of several hundred pounds of fissile material worth millions of dollars per year seems credible. Although small by comparison to the drug market, this is large enough to interest criminal groups and to have a major impact on proliferation.

Gray Market

A gray market falls between a black market and normal commercial transactions. The commodity belongs legitimately to the seller and the transaction is legal under the laws of the nations concerned but must be covert because it would be unacceptable if known publicly. The main reasons for secrecy of nuclear transactions would be to avoid alerting an enemy and to avert domestic or international reaction to furthering proliferation, especially if in violation of the NPT. The transaction could involve weapons, fissile material, or technical assistance.

The buyer in a nuclear gray market could only be a government, because purchase by any non-national group would be illegal. The supplier could be another government, a corporation, or an individual. Government-to-government transfer of nuclear arms could occur if a close and valued ally was on the verge of annihilation. Sale or barter of such weapons under more normal conditions is less likely. Fissile material is a more probable commodity, and technical assistance the most likely. The latter could consist of design information for either weapons or plutonium production facilities, or the critical components for either one, A supplier nation might enter into gray market transactions either at the demand of a nation that provides a vital resource (e.g., oil) or by the desire to gain political support (e.g., Pakistan and India both trying to gain favor with Arab nations), Alternatively, some nations may engage in a joint development program to reduce costs and shorten schedules.

Corporations with a large investment or substantial business expectations in another country could be subjected to considerable pressure to assist in a weapons program, particularly the plutonium production aspects. Revelations of corporate bribing of foreign officials gives a certain credence to this speculation, but the difference between a bribe and a contribution to proliferation will not be lost on corporation executives. The impact of exposure could also be much larger, Furthermore, the nations with the most leverage would the ones needing the least assistance. Hence, this type of transaction seems less likely than governmental assistance. If it does emerge, however, the most likely suppliers would be reactor manufacturers, architect-engineers, and consulting companies. These are discussed in appendix IV of volume 11. Companies might be more susceptible to foreign overtures if their domestic nuclear activities are curtailed.

Individuals could contribute to a weapons development program by becoming scientific mercenaries. A sizable pool of scientific manpower conversant with plutonium reprocessing, materials handling, and related fuel-cycle technology already exists. Lack of demand for their skills at home might force a few to seek employment elsewhere, and bitterness over their loss of careers could overcome their ‘scruples about contributing to proliferation. A constraint on this movement would be the desire of most nations to keep their weapons program secret. The nation may not wish to rely on the loyalty of foreigners in this situation, and may be unable to sequester them voluntarily for the long duration of the development program.

It is possible that some examples of gray marketing have already occurred. It was reported in 1975 that West Germany had been covertly involved in South Africa's uranium enrichment development programs This cooperation was denied but some evidence indicates it may have existed. Nuclear mercenaries have **a** precedence in the migration of scientific manpower to the developed countries in the brain drain of the 1950's and 1960's.

[5] *The Observer* (London), Oct. 5, 1975.

Countermeasures to Black and Gray Market

An important step in combatting these transactions is to detect them. Intelligence-gathering operations can serve to identify participants, but the difficulty experienced with cracking the illegal drug market illustrates the problems that will be encountered in penetrating a nuclear black market. Isolated transactions would be even harder to detect unless the participants revealed themselves. If the buyer in either a gray market or black market is a government, then some aspects of its weapons fabrication may emit unique intelligence signals (as for other weapons development programs). This is discussed in the previous section, "Dedicated Facilities." Intelligence activities could also track migrating manpower, but the difficulty of separating the critical cases from the legitimate movements will be great and conflicts with civil liberties may arise. International safeguards should be capable of at least detecting when significant diversion has occurred. With that as a start, then intelligence can more easily track the material and determine the participants.

International safeguards have been directed at national diverters, but the same methods would be effective against black market diverters. Both intelligence and safeguards can be enhanced and reoriented towards this threat. Increased effectiveness in detection would be a potent deterrent to potential participants. The factor that would probably have the greatest impact in controlling a black market in fissile material would be to limit plutonium recycle. The supply that does exist can be made less accessible by enhanced physical security,

The willingness of participants to engage in these transactions depends not only on perceived rewards and risks of detection, but also on the consequences of detection. Possible responses might include sanctions against countries engaged in nuclear gray marketing, police work to capture black marketeers, and control of the activities of potential nuclear mercenaries and corporations abroad.

Theft of Nuclear Weapons

The most direct route to a nuclear weapon is the theft of someone else's. This report does not analyze weapons security in detail. Nevertheless, certain observations can be made. Fewer groups are capable of attacking a nuclear weapons stockpile or transport than could participate in a black market. Only highly motivated, well-organized, and well-armed attackers would have much chance of overcoming effective military security surrounding weapons.

U.S. nuclear weapons consist of bombs, missiles, artillery shells, depth charges, torpedoes, and demolition charges.[6] All are protected against unauthorized use by internal mechanisms. None of these can prevent the weapons from being used simply as a source of high quality fissile material, but the delay would enhance the chances of recovery. Even without rebuilding the weapons, however, the thief would achieve full psychological value of possession.

U.S. weapons are kept in Europe, the Pacific Ocean area on naval vessels, and at home. Storage sites are usually on military installations. The protection provided is more stringent than that required for commercial fissile material, but the need for upgrading is recognized and being addressed by the Department of Defense. Weapons stored abroad might become less secure if the host government suddenly changed hands. Transport for logistical purposes is probably the most vulnerable link, but it is also infrequent.

It is difficult to defend against a determined, effective, comando type of attack. Groups of about 8 to 20 attackers using an imaginative plan and aided by one or more insiders would be especially difficult to resist without rapid reinforcement. On the other hand, it would also be difficult to mount this type of attack

[6] Joint Committee on Atomic Energy, Development, Use and Control of Nuclear Energy for the Common Defense and Security and for Peaceful Purposes, 1976.

without giving some warning to appropriately oriented intelligence activities. Massive attacks such as the Israeli raid on the Entebbe Airport are least likely to be successfully resisted, but neither can they be accomplished anonymously. Consequently, political and military responses, if activated, can be expected to ensure return or destruction of stolen weapons.

Other present nuclear weapons states appear to present about the same barriers to theft as the United States. New nuclear states, however, may be more vulnerable. Some potential Nth countries have experienced turbulent domestic politics, and factions could seize weapons for their own use or for sale on a black market. This threat could be exacerbated if some Nth countries are unconcerned about physical security, or feel it is secondary to the need for immediate operational readiness. Furthermore, such nations will probably not have the sophisticated protective mechanisms built into their weapons.

Conclusions

The emergence of a black market is presently constrained by the lack of supply of fissile material. Widespread plutonium recycle would remove this constraint. Some demand appears to exist, as already evidenced by Libya's attempts to buy a bomb.[7] This demand could increase if more nations feel intense security concerns or if they sense a continuing pattern of proliferation and feel they, too, should have a few nuclear weapons in reserve. The inherent lack of prestige of weapons attained by this route may deter some, but others might feel no compunctions. Thus, if supply is not limited, the outcome is likely to be at least intermittent black market transactions.

Gray market transactions appear at least as likely as those on the black market. The supply of some commodities already exists, the participants are more natural partners, and less risk would be involved. Gray market transactions would be individually negotiated, and so present less danger of spreading. The existence of either black or gray markets would be a serious blow to nonproliferation. They would themselves lower the barriers to weapons, and the feeling that nonproliferation efforts had failed would spur other nations to procure their own weapons.

Theft of weapons is the hardest to evaluate. Largely unpredictable conjunctions of motivation, ability, and opportunity would have to occur. Unless the attack is overwhelming, success will depend to some extent on luck. The military and psychological effectiveness of a stolen weapon would probably be substantially greater than that of a homemade one, particularly for non-state adversaries. Hence, physical security of weapons must be such that the risk of losing them is very low.

[7] Steven J. Rosen, Nuclear *Proliferation* and *the Near-Nuclear Countries,* p. 178, Bullinger Publishing Co., Cambridge, Mass., 1975.

Chapter VIII

Control of Proliferation

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Chapter VIII

Control of Proliferation

The first seven sections of this report described the nations or groups that might want to make weapons and how they might go about it. The materials required for such an enterprise are common, and will become more so as nuclear technology spreads. Many means of control have been developed or proposed to prevent this material from being used for military purposes. There are four general levels on which these efforts can be based. The first is to detect if a diversion has in fact taken place, through the use of safeguards measures. In the United States, the term safeguards generally encompasses physical security, since the threat (non-state adversaries) is the same for both types of protection. On the international level, safeguards and physical security are quite distinct. International safeguards are measures designed to detect and deter diversion and misuse of fissile material by governments authorized to hold such material, while physical security is designed to foil theft, sabotage, and external attacks by unauthorized groups and individuals. From a political and institutional standpoint the two problems are quite different. Supplier and recipient governments have a common interest in physical security, but by definition, national diversion does not involve such a community of interest. Safeguards assume a potentially adverse relationship between inspectors and users of nuclear material. Consequently, safeguards involve the imposition of external controls on the user state by a supplier state or regional or international agency. Primary responsibility for the application of international safeguards has been assumed by the International Atomic Energy Agency (IAEA). Euratom, an agency of the European Community, has regional safeguards responsibilities which are being coordinated with the IAEA. Neither of these agencies has the power to provide or require physical protection, or to pursue and recover stolen material. Nor do they have the authority to detect clandestine weapons facilities or purchase/theft activities. The functions they do perform are described below. Other functions can be performed by intelligence agencies (such as the CIA) as alluded to in the sections on these routes.

In our own government from 1946 to 1974, the important branches were the Atomic Energy Commission (AEC), the Department of State, and the Congressional Joint Committee on Atomic Energy. Two years ago the AEC was split into the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC). The NRC is responsible for safety rules, security safeguards, and accounting safeguards throughout this country.

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The second level is to respond to a detected diversion in such a manner as to force its reversal and deter others from like actions. Neither the IAEA or Euratom have any significant authority in this area, nor has any other international institution. If sanctions are to be applied it must be done by arrangements among nations, as discussed below.

Third, nuclear systems and facilities can be limited to those that minimize opportunities for diversion. This requires cooperation among all suppliers of nuclear equipment. It consists of restricting the export of sensitive facilities (enrichment and reprocessing plants), except possibly for those operated under multinational control. The development of reactors and facilities that are inherently less vulnerable can be emphasized. Suppliers' conferences have been useful in attaining some of these ends. Multinational fuel-cycle facilities may be a promising approach for others. There appears to be very little emphasis yet on low vulnerability systems in any country and no international move to implement them.

The final level is to set a climate in which nations will not want to proliferate. This means decreasing incentives and enhancing disincentives as discussed in chapter IV. It also means weaving a network of treaties, promises, and commitments that is hard to break becuase of the moral, financial, and public appearance factors that act on modern nations. The Non-Proliferation Treaty (NPT) has been a cornerstone in this effort, binding its parties to accept IAEA safeguards on all their nuclear material and on all exports (even to nonparties).

International cooperation is the thread that binds all these objectives. None is perfect or even very effective by itself. Together the total may be greater than the sum of the parts, but only if there is a continual effort to strengthen each element. If successfully and flagrantly breached, the entire system could rapidly collapse.

The first part of this chapter describes the controls the United States places on its domestic nuclear program to protect against theft or diversion of nuclear material. The IAEA procedures for the detection of diversion of nuclear material are also discussed. The second part of this chapter analyzes the institutions and other arrangements designed to control proliferation. Appendices VIII and 1X of volume II provide further detail on safeguards and on the international institutions respectively.

SAFEGUARDS TECHNOLOGY

U.S. Domestic Safeguards

In the United States, safeguards have been defined as "all measures designed to detect, deter, prevent, or respond to the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion; and sabotage of nuclear-facilities."[1]

[1] WASH-1.l 327, P. V-61 (August 1974) Draft (GESMO).

The three subsystems of the U.S. safeguards system are physical protection, material control, and material accounting. These subsystems are discussed in detail in appendix VIII of volume II.

The primary safeguard measures the United States uses to prevent or detect diversion are the physical protection and material control systems. The goal of the physical protection subsystem is to prevent access by force, stealth, or the use of false identity to nuclear material in a facility or shipment. This subsystem should prevent unauthorized removal of nuclear material and prevent sabotage. The physical protection subsystem overlaps the material control subsystem, which is designed to detect any unauthorized or suspicious activity involving nuclear material.

Examples of elements of a physical security system include armed guards, barriers, alarms, locks, portal monitors for detection of smuggled nuclear material, a central command and communication station, search procedures, and liaison with local and State police. Material control encompasses a set of procedures for access to and transfer of nuclear materials. The aim of these procedures is to prevent any two insiders, acting in collusion, from diverting nuclear material from the facility. The effectiveness of these procedures depends on the interpretation of regulations by NRC and the facility operator, and on continued surveillance and testing to ensure that the procedures are in fact being followed.

Material accounting for nuclear material is similar to accounting systems for other valuable materials, involving complete records of movement of the material and the taking of physical inventories. At present, the primary job of the material accounting subsystem is to determine, after some period of time, that the other two subsystems have been effective, or to provide information as to where. and how they may have failed. Highly automated, semicontinuous measurement systems designed to provide prompt information that nuclear material may be missing are under development. (See “Advanced Material Accounting Systems “ in this chapter.)

A history of U.S. safeguards from 1946 to the present is given in appendix VIII of volume II. Until recently, safeguards have not been a matter of high priority to government or the public. Several years ago, safeguards began to attract widespread interest and increased funds were provided. However, a sudden injection of interest and money cannot quickly make up for years of complacency.

In the United States there are three major nuclear programs and three agencies having safeguard responsibilities. The three programs are: military, nuclear power, and nuclear research. The Department of Defense provides safeguards for the nuclear weapons in its possession. The Energy Research and Development Administration (ERDA) operates production facilities for the nuclear military programs and conducts research on nuclear power and other nuclear applications. The Nuclear Regulatory Commission (NRC) is responsible for applying safeguards to both privately owned nuclear facilities and a few ERDA-owned facilities.

NRC Safeguards

This discussion focuses on NRC safeguards. The NRC safeguards can be considered in four classes. The first three are of present concern; the fourth allows time for further study. These problems are:

1. Protection of power reactors against sabotage;
2. Protection of shipments of privately owned weapons-grade material;
3. Protection of existing production facilities that possess and process weapons-grade material against theft or sabotage; and
4. Protection of future fuel facilities that would process large quantities of plutonium-containing fuel or other concentrated weapons-grade material.

The key facilities to be guarded in a domestic nuclear power program are (1) those which a non-state adversary might sabotage, or (2) those from which it might steal or embezzle nuclear material that can be used in a nuclear weapon with little or no processing.

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Protection of Power Reactors Against Sabotage.—The reactor itself must be safeguarded against sabotage, but not, at present, against theft of weapons-grade material. U.S. reactors (with the one exception of the Fort St. Vrain HTGR) do not presently contain onsite material useable in nuclear explosive weapons, except for the plutonium contained in spent-fuel elements. (See discussion in chapter VII of the usefulness of spent fuel to the non-state adversary.)

The subject of reactor sabotage was judged peripheral to the topic of this study—nuclear weapons proliferation. Thus, this report has not assessed safeguards at U.S. reactors.

Shipments of Privately Owned Weapons-Grade Material.—Presently, NRC and ERDA require physical protection for shipments of strategically significant amounts of special nuclear material, i.e., more than 5 kilograms (kg) of highly enriched uranium, or 2 kg of plutonium or U^{233}. Until recently, both ERDA and privately owned materials were transported by private transport companies which met the then-existing security requirements. In 1976, ERDA decided to provide its own transportation system for its nuclear materials, including highly enriched uranium fuels for naval reactors and research reactors and plutonium fuels for the test breeder program. In consequence, all ERDA shipments of significant amounts of nuclear materials between its facilities, private contractors licensed by NRC, and ERDA and private facilities, are now protected by the ERDA system, while the relatively few shipments of privately owned materials are subject to NRC regulations.

ERDA and NRC transportation safeguards are described in appendix VIII of volume II. The important differences between the two systems are: (a) ERDA transport convoys maintain continuous communication with the ERDA control center in Albuquerque over a nationwide dedicated communications network (SECOM). SECOM cannot be used by NRC shipments; (b) ERDA shipments are made in specially designed tractor trailers providing protection to the drivers, resistance to penetration, and wheel locks. The transport vehicle is accompanied by escort vehicles, with which it is in constant communication. NRC requirements are less stringent.

There appear to be no serious legal, economic, or institutional reasons for NRC shippers not to employ the ERDA communications and control system. This, coupled with the use of tractor trailers (similar in performance to ERDA's) and the requirement of an accompanying escort vehicle would significantly upgrade NRC transportation security.

Protection of Existing Facilities That Possess Weapons-Grade Material.—The NRC has licensed 15 privately owned facilities (listed in volume II, appendix VIII) to process strategic quantities of highly enriched uranium or plutonium.

There is at present a controversy over whether or not safeguards at these facilities are adequate. The controversy centers on what level of threat the safeguards should meet: i.e., the debate is about the phzysicul *security* systems.

In the spring of 1976, a joint NRC-ERDA task force investigated the safeguards systems at these facilities. The threat-levels defined for the review consisted of:

- an internal threat of one employee occupying any position, or
- an external threat comprised of three well-armed (legally obtainable weapons), well-trained individuals, including the possibilities of inside knowledge or assistance of one insider.[2]

Nearly half of the licensees were found unable to meet this total threat level and were ordered by NRC to upgrade their physical security. A number of critics, notably the National Resources Defense Council (NRDC), have claimed that the above threat level is far too low. NRDC quotes a memorandum from Carl Builder, then Director of NRC's Division of Safeguards, expressing concern that some current licensees could not meet the lowest threat being considered for the safeguards supplement of the *Generic Environmental Statement on Mixed-Oxide Fuels* (GESMO), which was, like the threat level postulated above, three outsiders and one insider, NRDC further

[2]NUREG-0095/ERDA 77-34: Joint ERDA-NRC Task Force on Safeguards (U) Final Report, July 1976, [Unclassified Version].

refers to several studies done for NRC which spoke of maximum credible threats or credible threats in the range of 12 to 15 or 6 to 8 persons, with 2 or 3 insiders.

The National Resources Defense Council petitioned NRC to dispatch Federal marshals as an emergency procedure to ensure security at the facilities. This petition was denied by the NRC commissioners. On January 21, 1977, the commissioners stated their intention to conduct a public rulemaking "to consider upgraded interimsafeguards requirements and proposed longer term upgrading actions."

In late February 1977, NRC decided that security at these facilities should be upgraded to meet a threat of two or more insiders acting in collusion with an outside group of several adversaries armed with automatic rifles, recoilless rifles, and high explosives. Guard forces were ordered increased and required to be armed with semiautomatic rifles. Full-field background investigations were required for licensed employees who might effectively conspire to steal or divert weapons material.

This report has not assessed NRC safeguards at the facilities in question, but several general observations can be made. Of all of the attributes of the potential adversary, numbers has received the most attention. This may be because the number of possible assailants is the easiest attribute to deal with in designing a security system. The estimated number of attackers is also often considered to directly determine the required number of guards. Guards are an expensive component of security systems, Guards at Government facilities must be paid for by Government; at licensed facilities by private industry. A requirement to maintain a large guard force could shut down some facilities not able to pay the costs and remain profitable.

Appendix III of volume II summarizes a number of studies of threat size and describes the data bases of the studies.

Current research at the RAND Corporation is investigating a number of (non-nuclear) adversary actions which have been selected as analagous to potential nuclear theft or sabotage, This work shows that groups of 3 to 6 are common, that larger groups do appear, and that a group size of 12 does appear to be somewhat of an upper boundary, although there are a few cases in modern industrialized societies in which larger groups have been involved. More importantly, the RAND researchers argue that one must be extremely cautious in interpreting historical data regarding the number of attackers. The number of attackers taking part in a mission are, for the most part, what the perpetrators perceived to be necessary to accomplish the mission, and in most cases what turned out to be sufficient. In other words, the adversaries came with as many as they needed to do the job, and no more. The fact that most came with a handful of persons, 3 to 6, does not represent an upper limit on their capacity to mobilize people. The upper limit would appear to be higher.

Although the historical data are useful as a guide, an estimate of the number of attackers is inescapably a matter of judgment. Without speaking in terms of a maximum threat, the RAND studies suggest a range of anywhere from 7 or 8 to about 15 as a *prudent* estimate,

Again, although it is judgmental, military men and law enforcement officials argue that more than this number might be counterproductive. It is no coincidence that after 5,000 years of military history, the smallest operational unit of almost all armies is a squad composed of 9 to 13 men, Although an attacking force could be composed of several squads, it should be recognized that to assemble even 10 or 12 attackers would stretch to the limit the capacity of most known violent political extremist groups in this country. Moreover, although no one has attempted to determine precisely how many persons must be in conspiracy to commit a serious crime before it is no longer a secret, the probability of discovery must increase rapidly in the higher ranges. The fear of leaks appears to be a principal consideration and constraint in assembling the personnel for a task-force crime.

The number of attackers is not the only parameter to consider in determining the adequacy of physical security. Another factor to consider is armament. Here the potential adversaries seem to have the edge. Civilian guard forces are armed with pistols, shotguns, and in some cases, semiautomatic rifles. (The recent NRC upgrading calls for guards armed with semiautomatic rifles. Guards at ERDA facilities may be armed with automatic weapons and at some facilities may also have armored cars.) NRC officials concede that attackers may be armed with automatic weapons, hand grenades, and possibly even antitank weapons.

Another, and a most important parameter, is tactics. Armed robbers seldom assault their target. They employ stealth, deception, diversion, and other techniques to gain access. Often they are inside or close upon the guards before displaying arms and revealing their intentions. Deception often proves to be successful where assault would probably fail.

A fourth set of parameters involves the size and location of the facilities themselves, and the amount, form, and location of the nuclear material they possess. The number of guards, indeed the adequacy of the physical security system as a whole, is a judgment that can only be made by an examination of each specific site. The approach to be taken should be to design an entire physical security system to protect a specific facility against all conceivable actions—burglary, armed robbery, embezzlement, sabotage, armed assault, standoff attacks—rather than to pick a number of attackers and let an equation determine the number of guards. Once this is done, a team composed of physical security experts and nuclear technology experts should jointly assess the system probing for weaknesses and trying to design successful attacks on the system (i.e., black-hatting evaluation should take place).

This is the approach being taken by ERDA and NRC in their safeguards research programs, discussed in more detail in the section on “Domestic Safeguards Research and Development” later in this chapter. The safeguards system concepts now being developed aim to integrate safeguards and physical security into the design of new facilities, and hold the promise of making them more easily defensible against both outside attack and inside embezzlement. The point to emphasize here is that physical security can and should eventually be upgraded in more basic, varied, and imaginative ways than by simply increasing the numbers of guards and the power of their armament.

For example, it should be recognized that there could be an alternative to relying on onsite guard forces to overcome armed adversary attack. A crucial question, which deserves serious review, is the extent to which safeguard systems can be designed to delay attacking adversaries sufficiently so that the burden of engagement and arrest falls on offsite response forces instead of on onsite guards.

The preceding discussion on numbers of attackers and guards leads to another issue involving guards at nuclear facilities. At present, unless they are deputized by a Government agency, guards at nuclear facilities have only limited civilian-arrest powers. Moreover, the powers of such guards, particularly with respect to the use of deadly force and permissible behavior in hot pursuit, vary from State to State (some licensees have facilities in more than one State). Guards who overstep State laws, even to protect special nuclear material, can face lawsuits, Although unauthorized possession of special nuclear material is a Federal crime (Sec. 42 U.S.C. 2271 (b) and 2272), it is not clear if this crime, by itself, is a dangerous felony. The use of deadly force is justified only to prevent a dangerous felony.

The entire subject of the powers and status of guard forces at privately owned nuclear facilities should be reexamined. The subject of a Federal security force to protect weapons material should be reopened, particularly in view of the increased threat levels licensees are being required to meet.

In addition, there are indications that safeguard threats to private nuclear facilities are coming to be regarded as threats to national security, without being explicitly defined as such. Should sabotage of a nuclear power reactor or detonation of a nuclear explosive by terrorists be regarded as having national security significance? Would sabotage of a large dam or of a liquid-natural-gas tanker, which would cause comparable damage, be a threat to national security? So far, these questions have not been explicitly considered.

One measure that apparently hinges on the question of national security significance is the requirement of clearances for employees of nuclear facilities. NRC and ERDA have maintained in the past that only a few key employees of private nuclear facilities would (or should) be cleared. The purpose of this clearance would be to provide added assurance that managers and guards would not engage in conspiracies to steal nuclear material or sabotage nuclear facilities. The legal basis for such a clearance requirement is an amendment to an appropriation bill (Public Law 93-377), which authorized the Atomic Energy Commission (AEC) to require clearance for licensee personnel if deemed necessary for national security. In light of this wording, NRC seems to have implicitly decided that safeguarding nuclear facilities is essential to national security: that is, it seems possible that the enabling statute which authorizes security clearance for national security reasons might not provide the authorization necessary to clear nuclear employees who may not be involved in national security.

By the year 2000, according to the Draft Societal Impact Chapter of GESMO, the number of people employed in mixed-oxide fuel cycle facilities and requiring security clearances would be in the range of 13,000 to 20,000. In addition, NRC has recently announced a proposed rule to require that 6,000 employees of 63 nuclear reactors be cleared. This program is aimed at protecting against reactor sabotage. This represents a substantially larger number of employees than those “few hundred” thought to be affected when the appropriation bill mentioned above authorized the AEC to implement a clearance program for private licensees.

The question of national security significance needs to be clarified. Moreover, if protection of nuclear facilities against domestic threats is defined as necessary for national security, the policy of using private guard forces becomes extremely questionable.

Protection of Future Fuel-Cycle Facilities. —The preceding discussion of physical security at nuclear facilities has highlighted certain tasks that must precede effective evaluation and implementation of safeguards. These tasks include the determination of a reasonable estimate of the size of a potential attacking force, the inclusion of other attacker attributes in the design of physical security systems for a specific facility, the clarification and standardization of guard powers, and the decision on whether theft from, or sabotage of, a nuclear facility constitutes a threat to national security.

These tasks are important for both existing and future facilities if plutonium reprocessing goes forward.

It is not clear at this time if or when NRC will license plutonium processing facilities. The only such plant which could start operations within the next few years is the Allied-General spent-fuel reprocessing plant, which has been built at Barnwell, S.C. Other facilities to produce plutonium oxide or to fabricate plutonium for breeder reactors exist only on paper and are 5 to 10 years from completion. In the meantime, the ERDA safeguards R&D program is working to develop substantially improved safeguard techniques to meet the problems posed by large-scale plutonium processing and fabrication facilities. Several techniques are discussed below under the heading “Domestic Safeguards Research and Development.”

Domestic Safeguards Research and Development

Both NRC and ERDA have safeguards R&D programs. ERDA has the responsibility for developing safeguards for the new energy systems it develops, and also to ensure that the safeguards for its military and research programs will meet future safeguard goals. On the other hand, the Energy Reorganization Act of 1974 assigned NRC the responsibility for confirmatory research. This has been interpreted so far to mean that ERDA would support the bulk of hardware research, technology development, and demonstration and testing of safeguards systems in actual facilities, while NRC has put emphasis on systems studies, on the development of analytical techniques, and on programs to help it to (1) define safeguard requirements for the facilities that it regulates, and (2) assess not only compliance of these licensees but also the effectiveness of its role in protecting and advancing the interests of the U.S. public.

The most important subjects for study, which both NRC and ERDA are emphasizing, are the methods of assessing and evaluating safeguard systems and subsystems, and of how to make cost-benefit analyses. Both tasks, especially the latter, are very difficult when the threats are hypothetical, the systems remain untested because there have been no significant incidents so far, and the consequences range from zero to catastrophic.

Appendix VIII of volume II describes the principal elements of U.S. domestic safeguards research. The following section discusses and, to the extent possible at this time, evaluates several specific technical safeguards concepts of particular prominence.

Massive Spiking

Massive spiking is the addition of lethal amounts of radioactive material to fresh reactor fuel. The purpose of massive spiking is to protect fresh fuel containing highly enriched uranium or plutonium against theft by nonstate adversaries. The idea has a long history and several studies have recently been done, the most complete of which was a part of the 1975 NRC Special Safeguards Study. It considered several possible methods to achieve massive spiking, and also the possible attachments of intensely radioactive cobalt-60 rods to fresh-fuel assemblies.

The NRC study concluded that massive spiking of fresh fuel would not constitute an insuperable obstacle to an adversary who was competent (1) to separate plutonium from uranium in mixed-oxide form, and (2) to design and fabricate an effective terrorist nuclear explosive.

On the other hand, such spiking would increase the cost of fuel fabrication and transportation by a large factor, expose nuclear facility employees to increased radiation, and substantially increase the risk to the public due to accidents or acts of sabotage.

Attaching cobalt-60 sources to fresh fuel in shipment would place one more obstacle in the way of the diverter, but not an insurmountable one. It would increase transportation costs but more importantly create problems both in loading and unloading and in the risk of accidental exposure.

Massive spiking is not cost-effective when compared to massive containment and stringent physical security for domestic safeguards use. It would not be useful at all in restraint of national proliferation.

Light Spiking

Light spiking is the addition of low levels of radioactive material to fissile material to afford easy detection. This concept was also investigated in the NRC Special Safeguards Study. All three fissile isotopes—U^{235}, U^{233}, and plutonium-are naturally radioactive. The important question is how difficult it would be for an adversary to shield significant amounts of any of these isotopes and pass radiation monitors without being detected.

The NRC study concluded that: (1) gram amounts of highly enriched uranium in easily carried shielded containers can probably be removed without detection; (2) portal monitors equipped with both gamma-ray and neutron detectors should detect attempts to remove as little as one to several grams of plutonium in portable shielded containers; (3) existing portal monitors should effectively detect small quantities of U^{233} because of the highly penetrating (2.6 MeV) gamma-rays associated with unavoidable trace impurities of U^{232}.

The study recommended that the subject of low-level spiking for highly enriched uranium be investigated further, and that an experimental program be undertaken to design and test gamma-ray and neutron portal monitors for plutonium of various isotopic compositions.

Evidently, no further studies or experiments were conducted by NRC or ERDA. It would therefore be useful if: (1) ERDA institutes a design, test, and evaluation program for portal monitors in actual production facility environments (radiation backgrounds directly affect monitor sensitivity), and (2) NRC or ERDA initiate a study to assess costs and benefits which might derive from low-level spiking of highly enriched uranium. It should be noted that the large amounts of highly enriched uranium in military and naval programs are presently the most attractive targets for an adversary who wants material to use in a nuclear explosive.

Spiking is unlikely to be used except for domestic safeguards, but the subject of radiation monitors for surveillance of nuclear facilities is of considerable interest to the IAEA.

Denaturing of Plutonium

The concept of denaturing Pu^{239} with Pu^{240} or some other isotope of plutonium also has a long history. It has long been believed that a high content of Pu^{240}, because of its **high** spontaneous fission rate, renders plutonium unsuitable for use in a nuclear weapon. This is not true. A high content of Pu^{240} is a complication. Given a free choice, a designer would prefer low Pu^{240} material, but all plutonium isotopes can be used directly in nuclear explosives. (See chapter VI.)

Storage and Transport of Plutonium in Dilute Mixed-Oxide Form

Plutonium oxide stored and transported in a mixture containing large amounts of uranium oxide (i.e., dilute mixed-oxide form) would present a significant (but not insurmountable) obstacle to the non-state adversary. This technique would be a much less-effective deterrent against national proliferation than against the non-state adversary. The dilute mixed-oxide material might be produced in the following ways:

(a) Plutonium would not be separated at all from uranium at the reprocessing plant (coprecipitation)

(b) Plutonium would be incompletely separated from uranium at the reprocessing plant (partial coprecipitation)

In alternate (a), the concentration of plutonium in uranium would be approximately 1 percent. The machinery for separating plutonium and uranium would not exist, so plutonium could never appear in concentrated form in the fuel cycle. However, the increased costs of both a larger nitrate-to-oxide conversion facility, and a larger plutonium-uranium mixed-oxide fuel fabrication facility, plus the necessity for over-enriching additional uranium, could more than outweigh savings in the solvent extraction process and in eliminating conversion of recovered uranium to UF_6. If so, this option would not be economically attractive compared to (b) with more stringent safeguards. ERDA plans to consider option (a), at least in the preliminary stages of its Alternate Fuel Cycle Study. (See chapter VII "Diversion From Commercial Power Systems.")

Alternate (b) appears to provide significant improvement in safeguards without undue economic penalties. In effect, it moves one processing step from the fuel-fabrication plant to the reprocessing plant.

The major contribution of scheme (b) is elimination of transport of concentrated plutonium. A potential non-state embezzler or national diverter could still tinker with the separation system at the reprocessing plant to produce pure plutonium. Materials accounting in a large plant could not provide timely detection of the removal of 10 kg of pure plutonium, thus the physical security and material control subsystems (or the containment and surveillance systems in the case of IAEA safeguards) would be crucial.

As far **as** this report has determined, the only study of the deterrent effect of diluting plutonium with uranium was done as part of the NRC Special Safeguards Study. The study investigated the effort required by a non-state adversary group to separate plutonium from uranium. It concluded that an ion-exchange operation, operated in a 10 kg batch mode with 5-percent-plutonium content, would require $5,000 in chemical costs alone. The time per batch was not explicitly stated, but analysis of what is presented suggests 40 to 80 hours processing time per batch, or 30 to 60 days of round-the-clock operation to obtain 10 kg of plutonium. The process as described is clearly not a laboratory operation; it is a small pilot-plant operation, and as such requires the supervision of someone with *practical* experience in chemical engineering or larger-than-laboratory scale chemistry. The time required for the operation, during which the adversaries are immobile, significantly enhances their chances of being discovered.

It is not clear whether any additional work on this subject has been done. It would be valuable to have a clearer idea of the actual time-delay granted by this technique. Although a month or two may be too long, at least several weeks sounds extremely plausible. It would also be useful to examine what new search and recovery techniques could take advantage of the fact that the adversaries would be carrying on a pilot-plant scale chemical operation.

The following proposal for collocating reprocessing and fuel fabrication facilities is closely related (in its potential effect on safeguards) to the above proposal for diluting plutonium oxide with large amounts of uranium oxide,

Collocation of Reprocessing Plant and Fuel Fabrication Plant

If reprocessing plants were sited adjacent to fuel fabrication plants, the transportation of plutonium in concentrated form would be eliminated. However, although the NRC Nuclear Energy Site Survey-1975 (NUREG-001) concluded that ". . . . collocation might have a beneficial effect on safeguards effectiveness; however transportation safeguards considerations do not preclude dispersed siting," all the advantages and disadvantages of collocation have not yet been assessed in any systematic way. This question cannot be separated from the previous question—that of complete or partial coprecipitation of plutonium oxide and uranium oxide at the reprocessing plant. If some form of coprecipitation is used, then the added advantage of collocation would seem to be small.

Advanced Material Accounting Systems

There are unavoidable limitations on material accountancy because of statistical measurement errors. These errors will translate into an inability to detect diversion of significant quantities of weapons material in future large commercial facilities unless the sensitivity of material accountancy can be significantly improved.

No substantial and economical improvement in the sensitivity of materials accountancy can be expected unless real-time material control can be achieved. Two such systems are being developed: DYMAC at Los Alamos Scientific Laboratories (LASL) and RETIMAC by NRC. (See appendix VIII of volume II for a description of these systems.) These two R&D programs have the same goal: to provide continuous or nearly continuous measurements of all materials being stored, transferred, or processed.

The LASL safeguards group is developing instrumentation and online computer systems for DYMAC. This system is being implemented at LASL in three phases. In phase 1, the present LASL plutonium processing facility is being used as a test bed for component development and operator training, Phase II is the design and installation of a DYMAC system for the new plutonium processing facility (TA-55) presently under construction at LASL. This is a small facility with a typical throughput of tens of kilograms per month of plutonium. It does not handle spent fuel. Installation of DYMAC/TA-55 is scheduled for June 1978. Phase III is a program to evaluate the performance of DYMAC at the TA-55 facility.

Operation of DYMAC/TA-55 in the new LASL plutonium processing facility is intended to investigate:

- the reliability and operational feasibility of online nondestructive analysis instrumentation in a production environment,
- the timeliness and sensitivity to missing nuclear material that can be achieved,
- the accuracy and efficiency of data collection that can be achieved,

- the operation of common data base management, and
- the capability for production control, quality assurance, and financial management.

Another task is to design on paper and evaluate the cost effectiveness of such systems for future commercial facilities. The most useful of these studies has been done by LASL and Sandia as part of a project to develop an integrated safeguards system for a mixed-oxide fuel fabrication facility. The report gave estimates of costs and sensitivities for the real-time measurement and analysis system.

LASL and Sandia based their designs on a mixed uranium-plutonium oxide fuel fabrication plant planned by Westinghouse for construction at Anderson, S.C. (Throughput 8000 kg/year of plutonium.) They contacted Westinghouse for assistance in defining plant parameters and providing cost estimates. Although this is a paper study, plant data are realistic and the online measurement and computer systems are conventional or state-of-the-art.

The report states that capital safeguards costs for this system are less than 5 percent of the total plant cost and the total safeguards staff (excluding guards) is about 8 percent of the total staff of 300. At a false-alarm rate of 0.1 percent, a single theft of the order of 0.1 to ().2 kg of plutonium could be detected with a 50 percent probability. With a 16 percent false-alarm rate, a dribble theft of approximately 1 kg over 1 month could be detected with an 85 percent probability of detection. These results should be compared with present NRC requirements for a fuel fabrication facility which are: a 50 percent probability of detection of removal of 0.5 percent of throughput with a material balance every 2 months and a false-alarm rate of 2.5 percent. For the case above, this corresponds to a 50-50 chance of diverting 7 kg of plutonium in 2 months, without being detected by the materials accounting system. (Note that this does *not* mean a 50-50 chance of diverting 42 kg of plutonium per year.)

Although considerable development work and in-plant demonstration is required before the effectiveness and costs of real-time material control can be reliably assessed, the studies indicate that improvements made using DYMAC will be greater for fuel fabrication facilities than for spent-fuel reprocessing plants. DYMAC is batch-oriented, as is the operation of a fuel fabrication plant, whereas a reprocessing plant is a continuous operation.

The R&D Office of the NRC has been supporting work at Lawrence Livermmre Laboratory (LLL) on systems studies of material control and accounting techniques, which include automated online measurements systems for nuclear production facilities (RETIMAC). These are purely software studies, and are not advanced enough to give sensitivities or costs.

One thing that is clear is that even real-time, online materials accountancy systems cannot do the entire safeguards job. Physical security, containment, and surveillance will still have crucial roles to play in any effective safeguards system.

Research on Physical Security Systems

Work on physical security systems for new facilities is being performed by Sandia Laboratories under contract to ERDA, The approach is to design for specific nuclear facilities, either existing ones such as the Allied General reprocessing facility, or specific engineered designs such as the Westinghouse fuel fabrication plant proposed for construction at Anderson, S.C.

On the assumption that credible threat characteristics may change in the future, the researchers postulate a spectrum of internal and external threats, and various combinations of the two. Combinations of barriers, alarms, and guards are chosen to provide multiple impediments to an intruder, or to authorized insiders attempting to perform unauthorized acts. A spectrum of divisionary scenarios, including emergency situations, are considered. The physical protection design is coordinated with the Los Alamos design of fully automated online nuclear material measurement and control of all nuclear materials in the facility. Capital and operating costs for a given system configuration are determined with assistance from the designers of the particular facility. (Compare with the preceding section on "Materials Accountancy,")

Sandia and Brookhaven have developed computer-based models to assess the comparative effectiveness of alternative combinations of safeguards elements to protect nuclear materials against postulated overt attacks on the facility with or without the aid of one or two insiders. Sandia is also in the process of developing models for assessing the safeguards systems against covert diversion attempts by a trusted employee or by several employees in collusion. This is based on the National Bureau of Standards analytical method called "Diversion Path Analysis. " The overt-attack model is presently in use. The covert-diversion model is still in the early developmental stage. The assessment experts emphasize that their analytical tools give qualitative rather than quantitative assessments of effectiveness.

ERDA safeguards system designers believe that the strategy and performance of both adversary and defender personnel are very difficult to predict in any satisfactory manner. Hence, special attention is paid to physical barriers and devices which will delay the adversary, whatever his skill and dedication, without requiring heroic behavior by the onsite guard force. Another aim is to design a safeguards system that will be adaptable to changing design threats with economically acceptable modifications in plant equipment or changes in the size of the guard force.

The most effective safeguards system will be one in which the various safeguard elements are balanced against each other and are integrated into the design of the facility. At this time, it appears to be at least as important to develop a methodology for evaluating the effectiveness of a safeguards system as it does to work on the development of equipment and computerized controls. In order for safeguards assessments to give useful results, reliable input data on the individual elements of the safeguards system is necessary. It is also important, therefore, to continue the experimental program to provide better information on the penetration resistance of barriers, reliability of alarms, and efficacy and safety of techniques, such as foams and reactive sensors that delay and confuse the adversary.

The object of designing a safeguards system to delay attacking adversaries has been described by de Montmollin and Walton:

> "The effect on the design against forcible theft is heavy reliance on passive barriers, the restriction of material accessibility, and protected defensive positions for guards. It is not necessary for the safeguards system to capture or kill adversaries; it is only necessary that control of the material be maintained. The system should be designed to withstand a protracted siege, and the sequence of actions necessary for an adversary to gain ultimate control of the materials should be attacked at many points. Delay should be exploited, and the uncertainty of success as perceived by the adversary should be enhanced wherever possible. Increased delay of the adversaries will correspondingly increase their probability of failure. Given sufficient delay, police support will be ultimately decisive; first, by sealing off the general area to maintain contact as adversaries attempt to break out, and eventually to overcome them. The mission of the safeguards systems must be to provide decisive delay rather than to overcome adversaries in a direct, armed confrontation."[3]

Interaction of U.S. Research and IAEA Requirements and Research

The ERDA safeguards systems development, and complementary NRC work on developing methodologies for safeguards systems assessments, hold forth a good deal of promise for both U.S. and international safeguards. ERDA is aiming for a 1980–82 demonstration of a integrated safeguards system for IAEA safeguards. A discussion of IAEA research programs, and US. and foreign research related to IAEA needs is given in appendix VIII of volume II.

Long-Term Safeguards Effectiveness

A subject which is of concern to some in NRC and ERDA, and which is receiving some preliminary attention, is the question of how

[3] J.M. de Montmollin and R.B. Walton, *The Design Of* Integrated *Safeguards System for Nuclear Facilities,* Nuclear Materials Management Vol V, No. III, p 317 (Fall 1976).

safeguards effectiveness can be maintained during long periods of quiet. The safeguards system, as described early in this chapter, is designed to deter, detect, prevent, and respond. A safeguards system will effectively deter only if it is perceived as being able to very effectively detect, prevent, and respond. Functions must be exercised to remain effective, and if the object is to never give the safeguards system, and the people who run it, real exercise, then sufficiently challenging substitutes must be designed to maintain the quality of the safeguards system and attract good people to run it.

Physical Security Outside the United States

Primary responsibility for the application of international safeguards has been assumed by the International Atomic Energy Agency (IAEA). Euratom, an agency of the European community, has regional safeguards responsibilities which are being coordinated with IAEA. Neither of these agencies has the power to provide or require physical protection, or to pursue and recover stolen material; nor do they have the authority to detect clandestine weapons facilities or purchase/theft activities. As stressed in the introduction, international safeguards are aimed at detection of diversion by a nation from its own facilities. Physical security of the facilities is the responsibility of the nation.

IAEA does advise on physical security, and has published a discussion of physical security procedures in an IAEA manual, INFCIRC/225. In a brief discussion in the IAEA Bulletin of possible future IAEA actions on physical security, IAEA envisages its role as advising, organizing training courses and conferences, and acting as a clearinghouse for information.

The United States has also tried to encourage greater physical security on nuclear facilities worldwide, as it recognizes that nuclear material obtained in one nation may well be used in another nation, In a Presidential message dated May 1975, it is stated that the United States has adopted a policy of no longer issuing licenses for the export or retransfer of more than 5 kg of highly enriched uranium, or 2 kg of plutonium or U^{233}*, unless the government of the recipient country "has an established system of physical security measures acceptable to the United States." This report is unaware of any detailed standards of acceptability beyond a statement that they should be "comparable to those imposed domestically. "

To implement this policy, physical-security review teams were dispatched by ERDA to 18 countries in 1975–76. Visits to an additional 21 nations were planned for 1976, ERDA stated that by the end of 1976, "the United States will have made reviews of the physical-security measures of all major recipients of strategic quantities of U.S. nuclear materials and intends to cover all nations with whom it has Agreements for Cooperation, as well as other nations that might receive trigger quantities through the U.S.–IAEA Agreement. " This report has not assessed physical security in other countries, nor has it been able to assess the ERDA review of foreign physical security, because ERDA has classified its review citing the following reasons: ". . states continue to keep their specific physical-security measures classified and/or under proprietary restrictions. The results of the US. visits are therefore classified, at the request of the nations involved, and the United States cannot divulge results of the review. Furthermore, the laws and regulations of the various recipient nations as well as the factors peculiar to each recipient nation make it difficult to present even general observations." (Some additional material is presented in volume 11, appendix VIII.)

IAEA Safeguards

The Statute of IAEA states that the objective of Agency safeguards is to assure, so far as it is able, that the nuclear assistance provided by it, or at its request, or under its supervision or control, is not used in such a way as to further any military purpose. As a result, IAEA safeguards differ in one vital respect from those of U.S. domestic safeguards. Domestic

*These respective amounts of highly enriched uranium, plutonium, and U^{233} are sometimes called "trigger quantities" because they are the amounts that will set safeguards into effect.

safeguards are concerned with the non-state adversary. International safeguards (i.e., IAEA and Euratom safeguards) focus on the detection of national diversion.

The word safeguards is generally understood to be a collective term comprising those measures designed to guard against the diversion of nuclear material from uses permitted by law or treaty, and to give timely indication of possible diversion or credible assurance that no diversion has occurred. The difference in objectives between U.S. domestic safeguards and international safeguards is reflected in the different measures encompassed in the word "safeguards." As discussed in the preceding section, U.S. domestic safeguards include physical security, material control, and material accounting. For IAEA, the use of materials accountancy is considered to be the safeguards measure of fundamental importance, with containment and surveillance at present considered only as complementary measures. The following definitions for these three measures have been derived from the IAEA Safeguards Technical Manual.

Material Accountancy .—Those safeguard measures which provide the essential knowledge on the identity, composition, quantity, and location of nuclear material. The basic source of data for the Agency's accountancy system is the facility operator's measurement system, records, and reports, and the State's system of accountancy for, and control of, all nuclear material subject to safeguards. For each material-balance area within a State, the facility operator must record, and the State report, the initial inventories of nuclear material and subsequent inventory changes to IAEA. Periodically, the operator's book inventory is compared with a physical inventory taken by the operator and independently verified by an Agency inspector.

Containment.—A safeguards measure which uses physical barriers to restrict or control access to, or movement of, nuclear material. Examples include process tanks and piping, transport casks, building walls, and fences.

Plant operators use containment primarily to provide physical protection of nuclear material, for reasons of health, safety, and/or operational necessity. If safeguards requirements are included in the earliest planning phases, containment can significantly enhance the effectiveness of safeguards. Failure to do so may result in an inherently unsafeguardable nuclear facility.

Surveillance. —A safeguards measure which uses instrument or human observation to detect access to, or confirm movement of, nuclear material.

Surveillance devices and instruments are used 1) during the absence of an inspector to indicate that access to or movement of nuclear material has not compromised the integrity of prior measurements made by the IAEA, and 2) to provide the inspector with a continuity of knowledge of specific inventories and material flows at key points in the fuel cycle. Surveillance devices include cameras, television, seals, and radiation monitors.

The Evolving Role of Containment and Surveillance in IAEA Safeguards

Nuclear material accountancy has continued to be the safeguards measure of fundamental importance in the implementation of IAEA safeguards procedures. The role of containment and surveillance, however, has evolved at a relatively rapid pace within the last few years and is now assuming greater significance. It is now generally accepted that there are unavoidable limitations on material accountancy because of measurement errors. For nuclear facilities with very large throughputs, cumulative measurement errors on nuclear material will introduce uncertainties in the material balance which exceed by several times the IAEA's own limits on significant quantities of diverted plutonium or uranium which it must detect. The dictum "what one cannot measure one must watch" underscores the urgent necessity for fully operational, reliable, tamper-resistant surveillance equipment.

In addition, renewed emphasis is being placed on the NPT objective of timely detection. Material accountancy, with its dependence on independent verification of physical inventories and material flows, is confronted, as above, with an exceedingly difficult problem. For manpower as well as economic reasons connected with facility downtime, physical inventories may be limited to one per year in some facilities, and possibly not more frequently than four per year in the largest facilities. Under the IAEA's own requirements for timely detection, the deterent value of a material balance may be seriously degraded. New surveillance equipment which is just now being designed may be able to meet many of the Agency's requirements for timeliness and holds forth the promise of eventually being able to provide IAEA headquarters in Vienna with real-time surveillance.

Initially, self-monitoring surveillance devices will require frequent communication between the facility operator and/or the host government and IAEA headquarters in Vienna. Within a period of 3 to 5 years, however, certain of the Agency's surveillance devices may be able to provide encrypted real-time status reports, first to IAEA regional safeguards offices and finally to the Vienna headquarters. This capability will place exceptionally stringent requirements on the long-term reliability of equipment and on the necessity for a very low false-alarm rate. The consequences of even a small number of false alarms would be so counterproductive that it seems probable that, like the space program, IAEA's equipment will be designed to meet a zero defects requirement and will be correspondingly expensive.

There have been substantial increases in money and manpower, both in the United States and within the IAEA, to develop surveillance equipment. In order to implement the increases in funding which Congress authorized under the Gifts-in-Kind Program to strengthen IAEA safeguards, ERDA has established an International Safeguards Project Office at Brookhaven National Laboratory. The draft program plan for Technical Assistance to IAEA Safeguards, Task E, Assistance for Containment and Surveillance, includes 22 separate projects. For FY 77, approximately $990,000 has been allocated to fund these projects. Funding by the United States, which is scheduled to continue over a period of 5 years, the increased support within the IAEA for surveillance equipment, and the greater willingness on the part of the nuclear suppliers to support improved measures for physical security and safeguards research in general, all should provide the Agency with reliable and effective surveillance equipment within the next few years.

Effectiveness of IAEA Safeguards for Power Reactors

On December 21, 1975, the IAEA had 43 nuclear power stations under safeguards, 10 of which were onload* refueled reactors of the CANDU or Magnox type. Most of the remainder were light water reactors (LWRS). (See annex L to appendix IX of volume II.) The Agency has fully developed model Facility Attachments and Safeguards Implementation Procedures (SIPS) for both classes of power reactors, including an analysis of potential diversion paths and possible means of countering diversion strategies. Evaluating the effectiveness of the Agency's safeguards on power reactors is rendered difficult because information about critical IAEA procedures and policies are either not available outside the Agency or are classified by the Agency as Safeguards Confidential. For example, no information is available on the Agency's site-specific diversion analyses, the allocation of its inspection effort, the reliability and performance of its surveillance and nondestructive analysis (NDA) equipment (much of which is in the early stages of development), the effectiveness of the different State Systems of Accounting and Control and, in a few instances, the inclusion of special conditions in the Safeguards Agreements with those states that restrict the nationality of acceptable inspectors or the normal use of safeguards equipment and procedures. It is hoped that in at least some of these areas the Director General's proposed Special Safeguards Implementation Report to the Board of Governors will remedy these shortcomings. This report is believed due in September 1977, after several delays totalling over a year in extent.

*I.e., reactors that are refueled without being shut down. See chapter VII "Diversion from Commercial Power Systems," and appendix V of volume II.

Of all the types of nuclear facilities on which the IAEA must apply safeguards, the light-water power reactor (LWR) presents the fewest problems. Safeguards on these facilities are based on an item accountability of fuel elements, a procedure which in principle is free of measurement error. Light-water reactor fuel is relatively large in size and involves a relatively small number of fuel elements in either the core or storage pond. The reactor is usually refueled only once a year; the remainder of the time the reactor vessel is closed and may be sealed by the Agency. The fresh fuel, containing low-enriched uranium, is expensive to fabricate, and tight fuel specifications at the fabrication plant mean that the amount and enrichment of the uranium in the fuel is known within the narrowest limit of any point in the fuel cycle. The intense radioactivity of the spent fuel severely limits the diversion possibilities. Even under INFCIRC/153 (the document issued in 1971 to govern NPT safeguards arrangements), the Agency is permitted adequate inspection effort for effective safeguards for this type of facility. Finally, secure surveillance equipment (such as cameras) is available, although a fair amount of development and testing remains to be done in order to assemble a fully reliable system. Nondestructive analysis techniques required to minimize the threats of fuel substitution have been demonstrated, but have not been routinely applied.

The Agency has the knowledge both in principle and in practice to provide effective safeguards on LWRS and implementation is proceeding.

The safeguarding of ordoad refueled reactors, such as the CANDU, is substantially more difficult. Nuclear fuel for such reactors is small in size, while the number of fuel elements in the core and in either the fresh or spent-fuel storage is very large. The onload refueling feature and the possible use of unsafeguarded natural uranium in the fuel greatly expand both possible diversion scenarios and the IAEA's task of devising and implementing effective countermeasures. Since 1968, the IAEA, Canada, and the United States have been engaged in joint R&D programs specifically directed at surveillance and containment problems of CANDU reactors. More recently, the Canadians significantly increased the level of effort of their R&D programs.

Sufficient information is not available at this point to evaluate the effectiveness of the new surveillance instrumentation in combination with the traditional review of the power stations records and reports. If the IAEA concludes at the end of its testing that credible and effective safeguards procedures for onload reactors cannot be achieved, it may request, and the States probably will grant it, the right to station inspectors at such facilities on a continuous basis. Such a move would greatly increase IAEA costs and workload.

IAEA Safeguards for Enrichment Plants
(Comparison of Domestic and International Safeguarding Problems)

To date, the IAEA has not safeguarded any type of enrichment facility, including pilot plants. However, it may have to undertake such a task in the near future as a result of its recent agreements with both Euratom and Japan. The proposed safeguards procedures for enrichment plants, contained in the IAEA Safeguards Technical Manual, are currently being revised and have not yet been officially released or published. Enrichment plants are not specifically covered in either of the two IAEA books of regulations (INFCIRC/66/Rev.2 or INFCIRC/153), except for one provision in the latter which states that a small plant producing uranium enriched to less than 5 percent in U^{235} need not be subject to continuous inspection.

In view of this lack of experience, and the preliminary nature of plans for safeguarding enrichment plants, only a very limited assessment of IAEA safeguard procedures can be made at this time. However, a few general statements about the difficulties in safeguarding enrichment plants and a few crucial points can be made.

An enrichment plant is the only nuclear facility besides a reprocessing plant that is capable of generating separated weapons material. However, a significant difference exists in that a reprocessing plant is designed to routinely handle material suitable for use in weapons (i.e., separated plutonium) either directly or after a simple chemical step. A commercial enrichment plant normally produces only 3 percent to 4 percent enriched uranium, which is impossible to use in nuclear-fission weapons without further enrichment. Therefore, the output of an enrichment plant is of use to the non-state adversary only if a criminal black market in low-enriched uranium develops. Portions of an enrichment plant can be reconfigured to produce highly enriched uranium. This is a credible scheme for a national diverter, but a scenario in which management and workers of a US. enrichment plant conspire to produce highly enriched uranium is not credible. Moreover, such a proceeding could not be kept secret from NRC inspectors who have the right of unlimited and unannounced access.

The case is different for IAEA inspection of enrichment plants. At present, IAEA inspectors are not permitted access to the cascade area of an enrichment plant (i.e., the portion of the enrichment plant where the actual enrichment takes place). Inspection techniques that are presently proposed for enrichment plants treat the cascade area as a black box with a number of inputs (e.g., people, uranium feed, and new equipment) and a number of outputs (e.g., people, low-enriched uranium, and old equipment). If a reconfiguration of a portion of the plant to produce a small highly enriched uranium loop occurred, IAEA would have to deduce its existence from input and output measurements. In the first place, materials accountancy in a large plant is not accurate enough to provide assurance that a significant diversion has not taken place. More important, new equipment is an undeclared path; IAEA is not permitted to monitor new equipment going into the plant. This path could be a route for clandestine feed for a small highly enriched uranium production loop.

For input-output monitoring to be effective, *all* streams need to be monitored. Physical inventory and surveillance methods need to complement continuous input-output monitoring. Other complementary inspection techniques would include enrichment monitoring (particularly checking tails enrichment) and the use of the isotope ratio technique to check the ratio of U^{235} and U^{234} in the product and tails.

These inspection techniques are still in the developmental stage and have not been applied in an integrated way to an enrichment plant.

Allowing inspectors access to the cascade area upon demand would greatly enhance the effectiveness and credibility of the inspection. Inspection accessibility to the cascade area would certainly not *ensure* that the plumbing changes required for a highly enriched uranium loop would be detected in the maze of cascade area piping. However, it would most likely act as a significant deterrent to any country wishing to conduct a covert operation. In addition, undeclared feed, product, or tails takeoff would also have a higher probability of detection.

There are two reasons given for restricting inspector access. The first, and probably the reason preceived as the most important, is that of protecting commercial secrets. The second is to prevent the dissemination of enrichment plant technology via the inspectors, i.e., to make nuclear proliferation less likely. This reason creates an interesting situation where, in the name of nonproliferation, inspectors are denied access to an area to which, in the cause of nonproliferation, they should have access.

IAEA Safeguards for Reprocessing Plants—Comparison With Domestic Safeguards

The eventual effective safeguarding of a large reprocessing plant presents the greatest technological uncertainty of all safeguarding problems facing the IAEA, because of the complexity of the operation, the inaccessibility of large sections of the plant due to high radiation levels and difficult analytical problems.

Although the IAEA has somewhat more experience safeguarding reprocessing plants than enrichment plants, it has not undertaken the routine application of safeguards to any commercial reprocessing plant on a long-term basis. It has conducted safeguard experiments and exercises at the Nuclear Fuel Services Plant, West Valley, N.Y. (plutonium throughput of 300 kg/year), and at the

Eurochemic plant in Mel, Belgium (plutonium throughput 500 kg/year). Operation of both these facilities has been suspended indefinitely. Currently, IAEA has experimental safeguard projects at the two Italian pilot plants at Sallugia and Itrex (plutonium throughput 64 kg/year). The proposed Safeguards Technical Manual procedures for spent-fuel reprocessing have been drafted but have not yet been published. The safeguarding of reprocessing plants is treated in a very general way in INFCIRC/66/Rev. 2. INFCIRC/153, paragraph 80(b) states that for any facility involving more than 5 kg of plutonium, the Agency may expend at least 1.5 man years of inspection effort. This insures almost continuous inspection, even for very small reprocessing plants.

Table 6 in appendix V of volume II lists existing and planned reprocessing facilities worldwide. It can be seen that there is only one commercial facility in operation, and that most of the facilities to be subject to IAEA safeguards in the next 5 years or so have design capacities of no more than 2,500 kg of plutonium throughput per year. However, the Allied General (AGNS) plant at Barnwell, S. C., has a design capacity of 15,000 kg of plutonium throughput per year, and cost studies indicate that plants of this size or larger are the most economical. Therefore, this discussion will be referenced to a plant with plutonium throughput of 15,000 kg per year.

NRC requirements call for a 50 percent chance of detection by the materials accountancy system of a diversion of 1 percent of the throughput, with a materials balance taken every 6 months. This means that a diverter would run a 50 percent chance of being caught by the materials accountancy system if he diverted 75 kg of plutonium in 6 months from the reference plant. One might argue that 50 percent is too high a risk for the diverter; in that case he could content himself with 10 kg in 6 months with only a 5 percent chance of detection by the materials accountancy system. (The numbers are slightly different for the IAEA.)

For the IAEA, the expected accuracy of material balance is lower; the allowable false-alarm rate, although not yet set, may be lower; and the frequency of inventory is higher. These differences will not qualitatively change the conclusion of this analysis. Looking at the situation from the operator's point of view, he can be 95 percent confident of detecting a diversion of over 120 kg from the reference plant within a 6 month period. That is, if the materials accountancy system does not call a theft, all the operator can say is that he is 95 percent certain that a theft, if it did occur, was less than 120 kg.

Moreover, as one industry reviewer noted: "The conclusions regarding the probability of 'calling' a discrepancy fail to take cognizance of efforts to resolve the discrepancy prior to 'calling.' Since the 'calling' would undoubtedly entail added cost and inconvenience to the operator, there would be significant effort to resolve the discrepancy with the possibility of introducing an unsuspected bias."

The above discussion reveals that the detection of diversion from a large reprocessing plant by the present materials accounting systems is not very sensitive to quantities of the order of tens of kilograms, nor, more important, is the detection timely. That is, detection would occur weeks or months after the diversion.

Both NRC and IAEA therefore require a variety of surveillance and containment systems. These, coupled with physical security systems and personnel (for domestic safeguards) and resident IAEA inspectors (for IAEA safeguards), would make diversion (a) more difficult, and (b) enhance the probability of timely detection. The development, installation, and prosecution of such systems is one of the most important safeguarding tasks to be accomplished.

An important distinction should be made between the non-state diverter and the national diverter.

Although a better understanding of the likely behavior of the white-collar embezzler-adversary and advances in the state-of-the-art in evaluating safeguards systems against covert insider actions are necessary, a national safeguards and physical security system can probably be designed which, if competently implemented, would make it very difficult for a non-national diverter to covertly remove kilogram quantities of plutonium from a reprocessing plant. For example, portal monitors are presently capable of detecting gram quantities of plutonium through a moderate amount of shielding.

The safeguarding problem is more difficult in the case of the national diverter. Although resident inspectors may be able to independently verify materials balances to the accuracies discussed above through promising techniques such as isotopic correlation, diversion from the process stream undetected by the materials accounting system of the order of tens of kilograms per year would still be possible. It would be very difficult for IAEA inspectors, who have no physical security function, to detect covert removal of this material by a nation from its own reprocessing plant. In effect, the inspectors would have to rely on a prompt-reporting, tamper-indicating leak-proof perimeter containment and surveillance system. Such systems have yet to be demonstrated, but are in the early conceptual design stage.

Future of Safeguards on Enrichment and Reprocessing Plants

In contrast to IAEA's limited experience in safeguarding enrichment and reprocessing plants, Euratom has had some experience in safeguarding small enrichment facilities. After many delays, the IAEA-Euratom Safeguards Agreement is now expected to come into force within the next few months. The staffs of the two organizations have worked together for many years in anticipation of this event, but differences in safeguards approaches and the IAEA requirement to *independently* verify that diversion has not taken place will present many problems. For example, it seems certain that IAEA inspectors will be denied access to the Almelo centrifuge cascade during their inspections.

The potential diversion scenarios directly related to measurement errors in the throughput of large plants will place a heavy burden on the use of surveillance and containment as supplementary safeguard measures. In general, the United States has taken the major role in the development of unattended, tamper-resistant surveillance devices for both enrichment and reprocessing plants. Unfortunately, integrated systems tests have not been undertaken in either case.

A major U.S.-IAEA effort to test installed safeguards surveillance equipment at a reprocessing plant (General Electric Company's Midwest Fuel Recovery Plant in Morris, 111.) was frustrated by a G.E. decision not to place the facility into operation. In the absence of a suitable U.S. enrichment facility, strong but unsuccessful efforts were made to persuade Urenco management to test U.S. enrichment plant surveillance equipment at Almelo. The United States is now considering a comprehensive perimeter safeguards system test at the Centrifuge Test Facility at Oak Ridge, Term.

IAEA and Euratom will not be immediately confronted with the safeguarding of very large enrichment or reprocessing plants. Given adequate manpower and technical and financial support, the safeguards systems should be able to evolve and improve as the size of facilities under safeguards increases. It is not possible to conclude at this time that this effort will be successful. There are a number of unresolved technical and political problems, any one of which might preclude credible safeguards against covert national diversion for these types of plants.

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International Atomic Energy Agency

The IAEA was formed under the auspices of the United Nations in 1957 to promote atomic energy for the benefit of mankind without contributing to any military purposes. Its safeguards functions arose from the latter constraint, The agency is authorized to establish and administer safeguards on fissionable and other materials, services, equipment, facilities, and information, but only with the consent of the safeguarded nation.

The statute establishing the agency granted explicitly limited powers. No authority to recover diverted material or to conduct intelligence activities was included, and the agency's role in combatting non-state adversaries by physical security is advisory only, Thus police powers were not conferred upon the IAEA, and none have been granted since.

Initially, safeguarding activities concerned only research and test reactors of less than 100 MW thermal. Procedures were outlined in Information Circular 26 (INFCIRC/26), approved in 1961. This document is reproduced in annex D to appendix IX of volume II. It is interesting chiefly because of its role in setting the pattern for subsequent activities. In particular, the Agency's interest was to develop a facility-specific safeguards system that would evolve with experience and technological developments. Two items later caused difficulty: only first generation fissile material was safeguarded (i.e., plutonium produced in a safeguarded reactor was not covered), and the safeguards agreements had an explicitly limited duration. Both these weaknesses offered a legal route for the acquisition of safeguarded fissile material.

The next major step occurred in 1964, as the emergence of large power reactors became imminent. IN FCIRC/66 was approved to describe the necessary safeguards system. It was later revised to include enrichment and reprocessing plants. INFCIRC/66 is still in effect for nations which have not ratified the NPT. The concepts embodied in INFCIRC/26 are apparent in its successor. The general intent is still to safeguard specific facilities. The desirability of safeguarding derived special nuclear material is recognized, but not to the degree of the original statute which allowed, ". . . access at all times to all places and data. . ." The concern of some states over the intrusions safeguards might inflict on normal operations was addressed by a number of clauses restricting activities. Protection of commercial secrets is explicitly handled, but in a manner that has since been a source of concern in evaluating the effectiveness of the Agency. The inclusion of features which would enhance safeguards as a facility design parameter was not required, an omission which has substantially increased the difficulty of effectively applying safeguards. Most U.S. bilateral safeguards agreements have been transferred to the IAEA under these procedures. The IAEA had agreements with 20 states as of December 31, 1975, for this type of safeguarding arrangement. These are shown in annex F to appendix IX of volume II.

The NPT caused a major shift in the Agency's operation when it came into force in 1970. The salient feature is the shift from facility-specific arrangements to a full-fuel cycle system based on the flow of material at certain strategic points. Article III of the NPT (the safeguards article) is reproduced in appendix IX of volume II. In essence, it requires the non-nuclear weapons states to accept IAEA safeguards in verifying that no diversion had taken place. These safeguards were to be applied to all special fissionable material under control of the member state or transferred to another nonweapons state. Article III further stipulated that these safeguards were to be applied in a manner that would not interfere with the economic operation of the subject facilities. The NPT considerably strengthened the role of the IAEA by assigning it the responsibility for implementing NPT safeguards, and mandating acceptance of these safeguards on all nuclear activities by the non-nuclear weapons states. Another significant feature was the ban on the development of any nuclear explosive, thus removing the PNE loophole described in chapter VI

"Peaceful Nuclear Explosive s," This strengthening, however, came at the cost of losing unlimited access for inspection.

INFCIRC/153 was issued in 1971 to govern the NPT safeguards arrangements. The key sections of this document are reproduced in annex I of appendix IX of volume II. The emphasis is on the timely detection of material diversion, and the chief reliance is placed on material accountability with containment and surveillance as supplements. The material accountability is to be provided by the state with verification by IAEA inspectors. This verification is to be done by independent measurements and observations. The section on design information was considerably expanded over that in INFCIRC/66. In order for the Agency to determine the system needed for monitoring the material flow, it is required that sufficient information be presented. This involves the establishment of material balance areas, and timing and procedures for taking physical inventories. This section leads to the important observation that IAEA can refuse to safeguard a facility if it feels it cannot do so effectively. Since an NPT member cannot legally have an unsafeguarded activity, this gives the Agency considerable leverage. There is still a strong emphasis on minimizing the safeguards intrusion, which led to the material balance area concept. The inspectors' limited access however, is compensated for in part by the new requirements of accounting and the redundancy that is inherent in the safeguards of the full fuel cycle.

The present membership of 110 nations is shown in figure VIII-1. The Department of Safeguards and Inspections (DSI) is one of five major departments reporting to the Director General as shown in figure VIII-2. DSI has been the fastest growing department for 10 years, and its total manpower is scheduled to increase from 138 in 1976 to 161 in 1977. Budget information is presented in figure VIII-3. At present, DSI accounts for 18.6 percent of the total IAEA budget. The 34 industrialized states bear 95 percent of the safeguards cost.

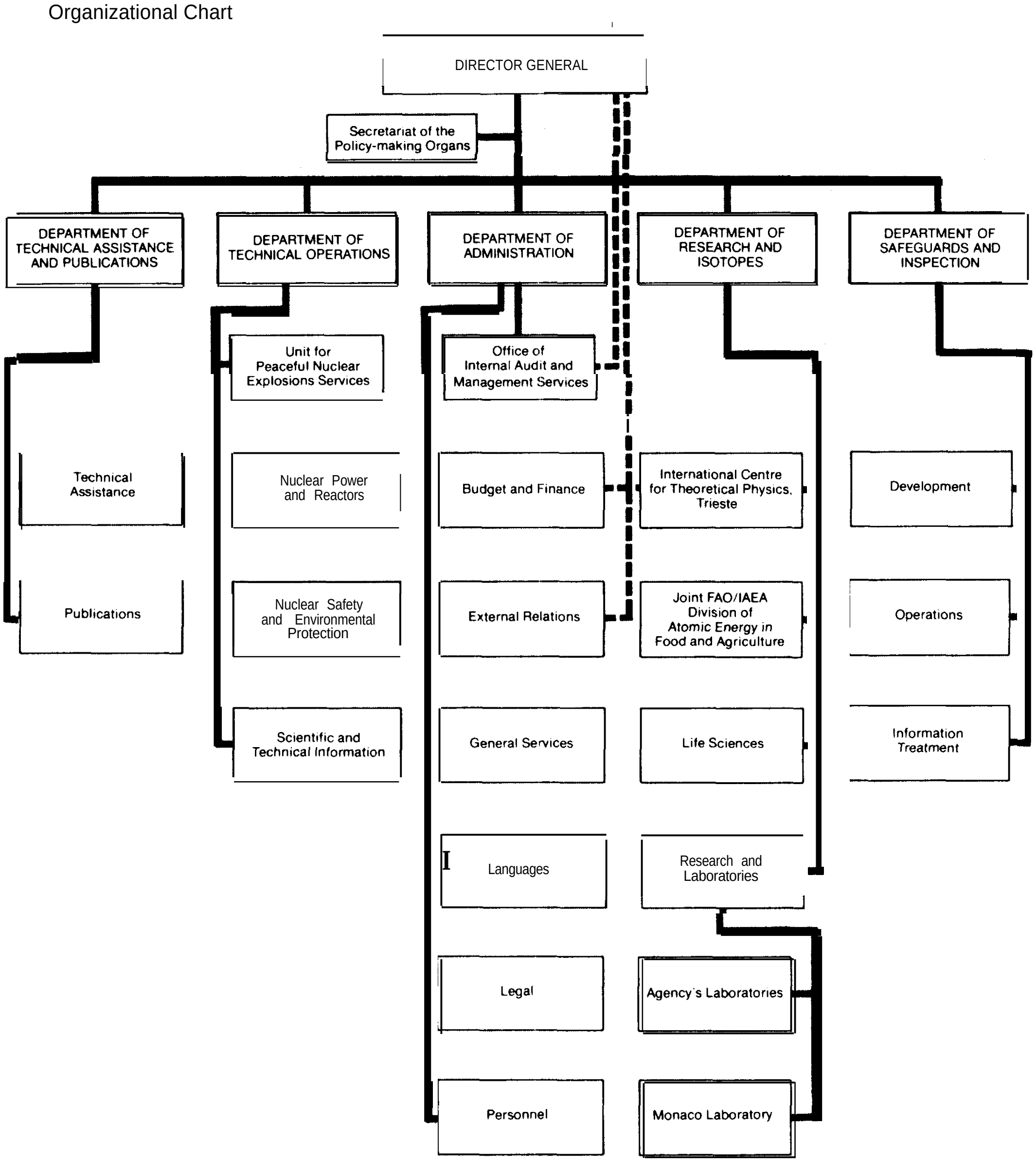
A key factor in the effectiveness of the IAEA's safeguards is the quality of the inspectors. Political pressure can be brought to bear on the hiring and retention of inspectors, and long-term contracts are not available to encourage career decisions. Even the best inspectors must grapple with morale problems when away from home for long periods, and face difficult and sometimes dangerous working conditions. Every effort must be made to ensure a high level of professional competence by providing equitable salaries, promotion opportunities, training programs, and a general understanding that the inspector role is a critical element and a matter of vital importance to the peace and security of the world.

A Safeguards Technical Manual (STM) is now being prepared to form the basis of the procedures and techniques of the safeguards system. Two parts have now been released (as described in appendix IX of volume II) and offer insight into the expectations and intentions of the Agency. Potential diverters and the means to diversion are candidly defined. The function of safeguards to these threats is then developed. The technical requirements of the system are described in the safeguards section above.

Each safeguarded facility will be the subject of a Safeguards Implementation Practices (SIP) document. These will be classified confidential because they are facility specific and contain the Agency analysis of the diversion possibilities and the means to detect them. One of the more important functions of SIPS is formalizing the Agency's analysis of the limitations currently experienced in its safeguarding activities, and identifying improvements which should be made. Both these documents reveal an understanding of the necessary adversary nature of international safeguards.

Noncompliance can take many forms, ranging from simple inadequacies of accounting to outright diversion, encompassing large unexplained losses, and denial of access to critical strategic points. The response would begin with an inspectors' report within DSI. This would be followed by a report from the Chief of the Regional Section to the Inspector General and Director General stating that the inspectors had been unable to verify that a diversion had not taken place. The Inspector

Figure VIII-1.
Organizational Chart



SOURCE=IAEA

General and Director General would be faced with a necessity to evaluate both the quantitative and qualitative information. Many technical as well as subjective factors would have to be weighed. These would include the effectiveness of the state system of accounting, previous history, the magnitude of the suspected diversion, throughput of the facility, the precision and accuracy of the measurements by both the facility operator and the IAEA, the availability and reliability of the containment and surveillance devices, the magnitude of the inspection effort, the performance of inspectors themselves, and, perhaps, questions of a political nature.

If still unresolved, the matter would be brought to the attention of the Board of Governors. Both the Agency and the Board are required to afford the state every reasonable opportunity to provide whatever necessary

Figure Vlll -2

IAEA Member Nations
June 22, 1976

Afghanistan
Albania*
Algeria*
Argentina*
Australia
Austria
Bangladesh*
Belgium
Bolivia
Brazil*
Bulgaria
Burma*
Belorussian Soviet Socialist Republic*
Cambodia (Khmer Republic)
Cameroon
Canada
Chile*
Colombia
Costa Rica
Cuba*
Cyprus
Czechoslovak Socialist Republic
Denmark
Dominican Republic
Ecuador
Egypt, Arab Republic of
El Savador
Ethiopia
Finland
France*
Gabon
German Democratic Republic
Germany, Federal Republic of
Ghana
Greece
Guatemala
Haiti
Holy See (Vatican City)
Hungary
Iceland
India’
Indonesia
Iran
[rag
Ireland
Israel*
Italy
Ivory Coast
Jamaica
Japan
Jordan
Kenya
Korea, Democratic People’s Republic of*
Korea, Republic of
Kuwait
Lebanon
Liberia
Libyan Arab Republic
Liechtenstein*
Luxembourg
Madagascar
Malaysia
Mali
Mauritius
Mexico
Monaco*
Mongolia
Morocco
Netherlands
New Zealand
Niger*
Nigeria
Norway
Pakistan’
Panama
Paraguay
Peru
Philippines
Poland
Portugal*
Qatar*
Romania
Saudi Arabia*
Senegal
Sierra Leone
Singapore
South Africa*
Spain’
Sri Lanka
Sudan
Sweden
Switzerland
Syrian Arab Republic
Thailand
Tunisia
Turkey
Uganda*
Ukranian Soviet Socialist Republic”
Union of Soviet Sociatist Republics
United Arab Emirates*
United Kingdom of Great Britian and Northern Ireland
United Republic of Tanzania*
United States of America
Uruguary
Venezuela
Vietnam
Y@slavia
Zaire, Republic of
Zambia*

“Member natıons that are not party to NPT.
In addition, Taiwan ıs party to NPT but ıs not an IAEA member

SOURCE: IAEA

Figure VIII -3.
Safeguards Costs in Relation to Total Agency Expenditure Under the Agency's Budget 1971-76

Year	Safeguards (us $ 000)	Total Budget (us $ 000)	Safeguards Costs in percent of Regular Budget
1971	1636	14010	11 .1°/o
1972	2035	16532	12.3°/0
1973	2564	19881	12.9%
1974	3441	25064	13.7%
1975	4802	29675	16.2%
1976	6443	34702	18.60/0

See Working Papers Appendix IX.

reassurance is required. If the Board of Governors is unable to resolve a question of nondiversion brought to its attention by the Director General, it is instructed by statute to report the noncompliance to all members, to the Security Council, and to the General Assembly of the United Nations. Under statute, the Board may also "direct curtailment or suspension of assistance being provided by the Agency or by a member and call for the return of materials and equipment made available to the recipient member or group of members." As a final act, the Agency may suspend the membership of the state or states from the exercise of the privileges and rights of the membership. There has not yet been occasion to exercise or test the interpretation of these powers, none of which are likely, in themselves, to give pause to Nth countries. If, however, the phrase "or by a member" is interpreted to include the supplier states, the return of this material and equipment at the "demand" of the supplier states should considerably strengthen the Agency's position. The immensely more difficult problem of the actual application of sanctions would have to be the responsibility of the individual member states and more particularly of the supplier states acting individually or in concert. As has already been noted, the Agency cannot prevent diversion nor does it have the power to recover diverted material. It has no police powers.

In general, the Board of Governors operates by consensus. Votes are taken only when a state feels that its vital interests are at stake. Decisions of the Board as well as the action of the General Conference have been unique in their absence of the political discord which has characterized the deliberations of many other international organizations. In spite of this record, it is difficult to predict what the actions of the Board of Governors would be if it were confronted with a report from the Director General stating that he could not verify that there had been no diversion of nuclear material in a specific state. Although it should not be the case, the response of the Board to such an announcement might be conditioned by the identity of the state and whether or not it was a member of the Board.

Under some conditions of political pressures, the Board might find a majority vote on noncompliance very difficult to obtain, Nevertheless, the response to a proven case of diversion is so crucial to both the future effectiveness of safeguards and the willingness of would-be proliferators to test them that a majority of members of the agency are likely to insist that the Board take the actions authorized by statute. The truly difficult decisions will come when the evidence of diversion is somewhat ambiguous.

There are several political and institutional factors which may be expected to have a marked impact on the IAEA's ability to effectively carry out its safeguards responsibilities over the next few years. In the safeguards area the question of the attitude of member states is probably the most crucial factor. In spite of increased recognition of the need for effective and credible safeguards, there remains an urgent need to enlarge the perceptions of industrial and developing states to the dangers which proliferation presents to all. A cooperative attitude by most member states will establish a pattern of behavior difficult for other nations to flout. This in turn will strengthen the effectiveness of the technical safeguards and provide reasonable assurance that the diversion of nuclear materials for weapons purposes can be detected. Failing this, and confronted with inadequate funding and overriding concerns for either national sovereignty or the protection of industrial secrets, the success of the Agency's safeguards activities will be placed in serious doubt.

The most pressing near-term problem of an Institutional nature, directly affecting the operations of the Agency as a whole and its safeguards efforts in particular, is the matter of the retirement or imminent contract expiration of many key management people at the highest Agency levels. The Director General is 66 years old. If he is to be succeeded in an orderly manner, the nomination must be submitted to the Board of Governors in June 1977. Many of the members of the Director General's immediate staff are his contemporaries and are also approaching mandatory retirement. Of immediate concern is the fact that the contract covering the services of Dr. Rometsch, the Inspector General, must be renegotiated or a replacement recruited by September 1977. The Agency has recently circulated a request for nominations for the position of Director, Division of Operations, Department of Safeguards and Inspections. As a result of the proposed reorganization of DSI, Directors will have to be nominated for the new Division of Operations and the Division of Information. Finally, the Head of the Section for Methods and Techniques, Division of Development, is also approaching mandatory retirement and a replacement for this position will be required. The staffing of these positions will have a marked and long-range effect on the Agency, as well as on the performance and morale of DSI.

The reorganization of DSI (noted above) was planned to meet the major increase in safeguards activities resulting from the implementation of the IAEA-Euratom and Japanese Safeguards Agreements, and application of Agency Safeguards under the United States and United Kingdom offers. This substantial increase in the operational activities of DSI will place new and exacting demands on the Department and on the management of the two operations divisions. At the level of Inspector General there will be an even greater need for strong leadership and effective, imaginative management to meet this challenge.

It is too early to evaluate the impact of the very large increases the U.S. Congress has authorized to strengthen and support IAEA safeguards. In FY 1975, approximately $200,000 was made available in gifts-in-kind through the Foreign Assistance Act, In FY 1977 a total of approximately $1.6 million will be available through the Foreign Assistance Act of 1977 for similar gifts-in-kind. It was the recommendation of President Ford that approximately $5 million should be made available to the IAEA over the next 5 years. The effective use of this money will require a careful and realistic assessment of the Agency's needs.

If the United States does not actively strive to broaden this type of support among all of the nuclear supplier states and the Soviet Union, there is danger that the United States will find itself carrying a disproportionately large part of the burden. The report of a German decision to contribute approximately $300,000 in similar support for IAEA is heartening and should be encouraged.

The IAEA can also be assisted in political and technical ways as well as economic. Political support can be indicated by full backing in arguments, such as the present dispute with Euratom over the IAEA's oversight role, or by manifestations of faith in the Agency's ability to competently fulfill its functions. Technical assistance has been provided for many years by the United States and other nations. This has consisted of instrumentation and security hardware development, safeguards application, training of inspectors, and assistance in data management systems development.

Euratom

The European Atomic Energy Community, created by the Treaty of Rome in 1957 along with the European Economic Community, was the first multinational safeguards system. The original members, *Belgium*, West Germany, France, Italy, Luxembourg, and The Netherlands were later joined by the United Kingdom, Denmark, and Ireland. All Euratom nations except France have since then ratified the NPT.

Euratom inspection rights are broader than those of the IAEA, and are in fact exercised by the inspectors. This includes ". . access to all places and data and all persons who by reason of their occupation deal with material, equipment, or installations subject to the safeguards. . ." The Commission may also require that all fissile material not immediately needed be stored by the Commission. Commercial sensitivity does not restrict the Euratom inspectors. The safeguards approach is similar to that of IAEA in that verification of material accountancy is the key element. In general, reports are required monthly to indicate both inventory changes and the final inventory.

Euratom at present has about 60 inspectors for 400 safeguarded facilities. It is Euratorn practice that the inspectors specialize in certain types of installations and are responsible for these installations wherever they may be found within the European community. The inspector proposes the inspection methods to be used for specific facilities, examines the records and reports of the facility, reviews the differences between the operator's declarations and his findings, and makes the first recommendation on the admissibility of losses and wastes reported by the facility operator. The final decision on this latter matter is made at the level of the Directorate. Responses available are stronger than the IAEA's, including temporary administration of the facility and sanctions by member states.

The non-nuclear weapons states are fulfilling their NPT responsibilities by an agreement between Euratom and IAEA which incorporates the essentials of INFCIRC/153. Euratom will continue its own inspections which will be verified by IAEA. Several significant differences remain to be resolved and the agreement is not yet in force, although considerable cooperation does already exist. One complication introduced by Euratom is the perception of it by other nations as essentially a self-inspection operation, since it is small and cohesive.

The Role of Sanctions in Nonproliferation Strategy

Sanctions already play a role in the nonproliferation regime. Article XII of the IAEA Statute provides that, in the event of a violation of safeguards, the Board of Governors is empowered to suspend nuclear assistance provided the offending country by the Agency or a member state. The Board may also require the return of materials or equipment previously provided and suspend any noncomplying member from continued participation in the Agency. Similarly, under bilateral American Agreements for Cooperation, noncompliance gives Washington the right ". . .to suspend or terminate this Agreement and to require the return of any materials, equipment, and devices. " The Symington Amendment to the Foreign Assistance Act provides for a cutoff of American economic or military assistance to any state exporting or importing unsafeguarded reprocessing or enrichment capabilities.

The purpose of sanctions is three-fold: to dissuade potential proliferators, to prevent the erosion of safeguards effectiveness which would follow a successful violation, and to reinforce international political norms against proliferation.

Sanctions might be triggered by a variety of events, including violations of safeguards agreements; violations of bilateral Agreements for Cooperation; sudden withdrawal from the NPT; nuclear gray marketing; and movement, though not in violation of any legal obligation, towards a nuclear weapon capability. However, the specific context within which these events occur could influence the feasibility and/or desirability of invoking sanctions. Under some conditions (e.g., where other foreign policy interests are involved) there may be compelling reasons not to threaten or apply sanctions. Consequently, any sanctions strategy should permit some degree of flexibility.

This can be accomplished by a strategy of combining two postures: one threatening automatic imposition of sanctions where a clear violation of a legal obligation is involved; a second designed to create a strong presumption that sanctions might be imposed even following more ambiguous violations. Failure to respond strongly following violation of a legal obligation would have serious adverse effects upon nonproliferation efforts. In this case, the risks of inaction are likely to outweigh those of action. On the other hand, the presumptive sanctions posture acknowledges that in some cases the costs and risks of taking action may be too high and that flexibility may be desirable.

The historical record concerning the threat or imposition of sanctions is not one to insure confidence. Major targets of international economic sanctions have included Mussolini's Italy, China, Cuba, and Rhodesia. In none of these instances did sanctions achieve the desired results. Canada's recent termination of nuclear assistance to India did not greatly slow India's nuclear program. But to extrapolate from past ineffectiveness into the future may be inappropriate. Instead, detailed assessment of the degree of existing leverage over specific Nth countries is needed. Within the framework of automatic and presumptive sanctions, a broad set of levers might be utilized. These include manipulation of nuclear assistance, economic and military assistance, U.S. influence over the lending policies of international financial institutions, trade, investment, and security guarantees. Ultimately it may include the threat and/or use of military force.

Different Nth countries are more vulnerable to some sanctions than to others; deterrent impact varies from case to case. At the same time, nearly all prospective near-term proliferators would be vulnerable to one or more of these levers. Recent American pressure upon South Korea to forgo acquisition of a reprocessing plant illustrates that sanctions can be effective, at least in a situation where the target state is highly vulnerable. Whether the threat of sanctions will be as effective under less optimal conditions (e.g., Pakistan and Brazil) remains to be seen.

Multinational Fuel Cycle Facilities

Multinational control of enrichment and reprocessing facilities has been proposed in order to reduce the opportunities for diversion by proliferators. In addition to the obviously greater difficulty one member would have in diverting strategic nuclear materials from a multinational facility as compared to diverting from a plant under his sole control, multinational fuel cycle facilities (MFCF) would have other advantages. They would generally be bigger than plants serving a single nation and therefore offer economies of scale. Fewer large plants are also cheaper to safeguard and protect. The expertise of an advanced member nation could benefit the operability of the plant, while participation by the less advanced nations will serve to mollify their sense of discrimination under the NPT.

Opposing these are several notable disadvantages. The primary one is that MFCFS threaten to spread the very disease they are designed to control, both by weakening the arguments against all reprocessing and by disseminating the technology so that nations could later build their own facilities. In addition, multinational reprocessing plants would still make plutonium accessible. This would necessitate possibly discriminatory burdens of heavy safeguarding of mixed-oxide fuels sent to potential Nth countries, or fuel-cycle schemes which send only enriched uranium to them and reserve the mixed oxide for existing weapons states.

Several important issues will have to be resolved before the concept will become practical. The details of the control of each facility will have to be spelled out in some detail before nations will feel secure in forgoing their option to build domestic plants. Too much control by individual members, however, will interfere with commercial operation when it conflicts with national objectives. Accessing the technology will have to be controlled, possibly by members renouncing the right to build their own facilities. The IAEA role in technical assistance and safeguarding will also have to be resolved.

Multinational fuel cycle facilities have precedents for both enrichment and reprocessing plants. Two enrichment plants and one reprocessing plant have been built in Europe by different groups of governments and private companies. The primary motivation was economic, and the partners were mostly advanced countries which are not generally considered prime proliferation threats. Nevertheless, the examples demonstrate that the concept is feasible at least under some conditions.

Alternatives to MFCFS are national facilities and abstinence, at least on the part of the target nations. A concensus appears to be developing among supplier nations that national control is undesirable. Abstinence can only be secured by guaranteeing substitutes for the services these facilities would have provided. This appears relatively straightforward for enrichment. A clear commitment by the United States to construct the necessary enrichment capacity could eliminate the need for other national facilities. Reprocessing is more difficult, as present or planned capacity cannot handle the spent fuel being produced. The spent fuel is simply being stored, and therefore demand for some sort of disposal is growing. In addition, as the technology of reprocessing is simpler than that of enrichment many nations could bypass export bans by building their own facilities. Some means of relieving potential proliferators of their spent fuel is therefore both necessary and desirable. This could be done by storing the spent fuel in nuclear weapons countries or in MFCFS designed only for fuel storage. The latter approach would have the advantage of beginning the MFCF concept for reprocessing without a full commitment to it, and the relative simplicity of the approach would ensure a greater chance of success.

The IAEA is presently conducting a major study of MFCFS. The first report on institutional and legal aspects has been issued, and others are expected in 1977. Preliminary indications are that the concept will be found beneficial in most respects.

The main impetus behind the concept is concern over proliferation. Even if the economics and fuel-cycle convenience prove useful, however, MFCFS will be contributors, not barriers, to proliferation unless access to the technology, and therefore to the plutonium, is controlled. Hence, implementation must be approached with caution. Spent-fuel storage facilities are one way to jointly test the concept and relieve the pressure for reprocessing.

The Suppliers' Conference

The First Suppliers' Agreement

On August 22, 1974, Australia, Denmark, Canada, the Federal Republic of Germany, Finland, The Netherlands, Norway, the Soviet Union, the United Kingdom, and the United States filed identical memoranda with the Director General of the International Atomic Energy Agency concerning "procedures in relation to exports of (a) source or special fissionable material, and (b) equipment and material designed or prepared for the processing, use, or production of special fissionable material. " As stated by all these states, except the Federal Republic of Germany and The Netherlands which had at the time not yet ratified the Non-Proliferation Treaty, these memoranda were intended to coordinate the fulfillment of "commitments under Article III paragraph 2 of the Treaty on the Non-Proliferation of Nuclear Weapons not to provide such items to any non-nuclear-weapon state for peaceful purposes, unless the source or special fissionable material is subject to safeguards under an agreement with the International Atomic Energy Agency." The documents relating to this agreement were distributed by the IAEA in INFCIRC/209, a copy of which is provided as annex S to appendix IX of volume II.

The agreed procedures and so-called Trigger List was the result of several years of negotiation, and represented the first major agreement on uniform regulation of nuclear exports by actual and potential nuclear suppliers. It had great significance for several reasons. It was an attempt to strictly and uniformly enforce the obligations of Article III, paragraph 2, of the Non-Proliferation Treaty. It was intended to reduce the likelihood that states would be tempted to cut corners on safeguard requirements, because of competition in the sale of nuclear equipment and fuel-cycle services. In addition, and very important in the light of subsequent events, it established the principle that nuclear supplier nations should consult and agree among themselves on procedures to regulate the international market for nuclear materials and equipment in the interest of nonproliferation. Notably absent from the list of actual participants or potential suppliers, as from the list of parties to the NPT, were France, India, and the People's Republic of China. By 1974, however, French policy had changed to one of respect for the agreed-upon Trigger List, and in all other matters related to nuclear exports began to act as if she were a party to the NPT.

The 1976 Agreement

Within a year of the delivery of these memoranda a second series of supplier negotiations were underway, This round, convened largely at the initiative of the United States, was a response to 1) the Indian nuclear test of May 1974, 2) mounting evidence that the pricing actions of the Organization of Oil Exporting Countries were stimulating Third World and other non-nuclear states to initiate or accelerate their nuclear power programs, and 3) recent contracts or continuing negotiations on the part of France and West Germany for the supply of enrichment or reprocessing facilities to Third World states. The initial participants in these discussions, conducted in London under the veil of official secrecy, were Canada, the Federal Republic of Germany, France, Japan, the Soviet Union, the United Kingdom, and the United States.

Two major issues were discussed in the series of meetings which led to a new agreement in late 1975. The first was if, and under what conditions, technology and equipment for enrichment and reprocessing, the most sensitive parts of the nuclear fuel cycle from a weapons proliferation perspective, should be transferred to non-nuclear states. The United States, with support from several other participants, was reported to argue in favor of both a prohibition on such transfer and a commitment to reprocessing in multinational facilities. France had already signed contracts to sell small reprocessing plants to Pakistan and South Korea, and West Germany had agreed to sell technology and facilities for the full fuel cycle to Brazil. They successfully resisted the prohibition proposed by others. The second issue was whether transfers should be made to states unwilling to submit all nonmilitary nuclear facilities to IAEA safeguards, or whether total industry safeguards should become a condition of sales.

On January 27, 1976, the seven participants in the negotiations exchanged letters endorsing a uniform code for conducting international nuclear sales. The major provisions of the agreement require that before nuclear materials, equipment, or technology are transferred the recipient state must:

1. pledge not to use the transferred materials, equipment, or technology in the manufacture of nuclear explosives;
2. accept, with no provision for termination, international safeguards on all transferred materials and facilities employing transferred equipment or technology, including any facility that replicates or otherwise employs transferred technology;
3. provide adequate physical security for transferred nuclear facilities and materials to prevent theft and sabotage;
4. agree not to retransfer the materials, equipment, or technology to third countries unless they too accept the constraints on use, replication, security, and transfer, and unless the original supplier nation concurs in the transactions;
5. employ "restraint" regarding the possible export of "sensitive" items (relating to fuel enrichment, spent fuel reprocessing, and heavy water production); and
6. encourage the concept of multilateral regional facilities for reprocessing and enrichment.

There is of course a problem in trying to impose such constraints on the diffusion of technology. Technical advances made by the recipient country may alter the initial technology to the point where it can reasonably be claimed to be different technology. Such ambiguities are handled by specifying an arbitrary time period—reported to be 20 years—within which all related technology will be unambiguously considered as transferred technology and after which differing interpretations may be possible. The basic obligation, however, is not limited in time. A copy of the U.S. Arms Control and Disarmament Agency news release of February 23, 1976, a discussion of these provisions is found in appendix volume II.

Evaluation of the 1976 Agreement

It is important to recognize what this suppliers' agreement does and does not do. It does not ban transfers to nonparties of the NPT or to states that refuse to place all nuclear facilities under IAEA safeguards.[4] It also does not ban the export of reprocessing and enrichment facilities and equipment, but it attempts to render such exports benign through the imposition of safeguards and government pledges.

It requires IAEA safeguards be applied, and a no-explosives-use pledge be associated both to facilities that are actually exported and to facilities the recipient may build based on the same technology. This is a significant strengthening of the provisions previously applied to Trigger-List equipment. The retransfer provision not only precludes states acquiring technology with fewer constraints by retransfer, but also gives the exporter a veto over what countries may receive retransfers. In this way any countries thought to be particularly high risk, can be prevented from obtaining help via an intermediary. The provisions also explicitly recognize the importance of physical security protection of nuclear materials and facilities, and will strengthen the IAEA role as advisor on physical security matters to interested states.

Beyond the agreement's provisions themselves, its very existence and the process of negotiation that produced it have some significant implications. The most important benefit is perhaps the strengthening of the international norm prescribing the acquisition of nuclear weapons by non-nuclear states. The importance that nuclear supplier states attach to the prevention of proliferation is indicated and symbolized by their agreement on uniform standards. Agreement is made despite the rather considerable opportunities and incentives for each state to compete for sales in a rather tight and lucrative export market by demanding less stringent anti-proliferation requirements than other vendors. In addition, the process of negotiation and the publicity associated with it were instrumental in causing the issues of nuclear proliferation and nuclear exports to be raised to the highest political levels within the governments of all participants. Considerable pressure could therefore be brought to bear on France and West Germany to adopt a policy more closely in line with other major exporters.

While producing only partial (although still quite significant) changes before major agreement was achieved in January 1976, subsequent statements by both governments indicate continued movement closer to the American position and away from insistence of their right to export sensitive facilities. Progress is evidenced by a French decision to avoid any future export agreements involving reprocessing technology and facilities. President Giscard has also announced the formation of a cabinet-level committee to coordinate and supervise French nuclear exports. President Ford announced a toughening of U.S. export criteria in line with the London agreements, calling for a 3-year moratorium on the export of reprocessing and enrichment technologies. In the meantime, Canada has gone further than other suppliers by declaring that its nuclear exports would be confined to countries that have ratified the NPT or that accept full fuel-cycle safeguards. Finally, the existence of the supply negotiations aided the application of American pressure on South Korea and Pakistan to abandon their plans to build reprocessing plants, and increased the political cost for other states that might be contemplating acquiring reprocessing facilities. As of this writing (May 1977), the French-Pakistan deal may be canceled and implementation of the West German-Brazilian agreement is in some doubt.

On the negative side is the fact that the negotiations have involved only actual and potential nuclear suppliers. Having conducted the negotiations in official secrecy and totally outside the IAEA context, the parties have left themselves open to several criticisms by potential purchasing states. The first is that the suppliers are in violation of their obligations under Article IV, paragraph 2 of the NPT "to facilitate. . . the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy," and to "cooperate in contributing. . . .to the further development of the application of nuclear energy for peaceful

[4] Ratification of the NPT or acceptance of international safeguards on all nuclear facilities has now been adopted unilaterally by Canada as a condition for the supply of reactors or uranium. Canada has also called on other suppliers to adopt comparable conditions of export.

purposes, especially in the territories of non-nuclear-weapons states party to the Treaty, with due consideration for the needs of the developing areas of the World.” The second possible criticism is that through the suppliers’ agreement a group of industrialized states have formed a nuclear cartel and are conspiring to promote the continued dependency of developing countries prevented from acquiring industrial capability, the importance of which for building modern industrial economies is demonstrated by the suppliers’ own pursuit of such capability.

If such interpretations gain favor among potential recipients states, the suppliers’ agreement could contribute to a weakening of the sense of bargain on which the acceptability of the NPT to many non-nuclear states rests. It could also weaken the American argument in international forums that cartelization is an inappropriate mechanism for organizing commodity markets. In addition, it could become a symbolic issue of contention in the context of North-South negotiations over the distribution of the world’s resources, wealth, technological capabilities, and power.

Current and Future Issues

As of November 1976, Belgium, Czechoslovakia, East Germany, Italy, The Netherlands, Poland, Sweden, and Switzerland were reported to have adopted the suppliers’ guidelines and joined the suppliers’ discussions. This raises the number of participants to 15 and omits only Argentina, India, and South Africa of those states potentially able to enter the nuclear equipment or services export market in the foreseeable future. By adding three members of the Soviet bloc in addition to Russia, the suppliers’ conference has become a joint East-West enterprise-a fact of considerable political significance. There is still no indication that the IAEA will become involved, even to the extent of serving as a communications medium to other states as it did in the case of the 1974 Trigger List agreement, Possible items for future agendas **of** the suppliers’ group include reopening the question of reprocessing and enrichment exports, establishing uniform nonproliferation provisions in Agreements for Cooperation and contracts leading to the supply of enrichment or reprocessing services, and multinational fuel reprocessing or spent-fuel storage facilities.

The Non-Proliferation Treaty (NPT)

The NPT evolved from the concern over the increasing access to nuclear material from commercial powerplants that emerged in the late 1960’s. The intent was to restrict this access by safeguards and gain a formal commitment by the non-weapons states to remain weaponless. These considerable intrusions into national sovereignty were obtained by guaranteeing access to peaceful nuclear technology and obligating the weapons states to pursue disarmament. The treaty, which went into effect in 1970, is reproduced in appendix IX of volume II.

The status of nations relative to the NPT is noted in figure VIII-2. The great number of signers is encouraging, but included in the almost 50 nonsignatories are Argentina, Brazil, Chile, Peoples Republic of China, France, India, Israel, North Korea, Pakistan, Portugal, Saudia Arabia, South Africa, Spain, and North Vietnam. That lack of participation is a serious weakness of the NPT. The membership could be expanded if participation were made more attractive, possibly by offering members preferential treatment in the export of nuclear technology or security assurances.

The asymmetry between the nuclear and non-nuclear states has caused some discomfort. The non-nuclear states surrendered considerably more sovereignty than did the weapons states, in that the major obligation of the latter was only to pursue negotiations towards arms control. Most states are apparently willing to accept the separate status accorded the present nuclear weapons states, provided that their access to imports is not impaired and that the arms control negotiations are conducted in good faith. Of particular interest are the views of the non-nucIear, nonaligned states of Africa, Asia, and Latin America. These nations have been opposed to the imposition of stricter new controls and limitations on their nuclear imports in light of the nuclear powers' refusal to accept such constraints and controls for themselves as regarding nonweapon aspects of nuclear energy.[5] In their viewpoint, controls regarding the peaceful utilization of nuclear energy should be applied equitably to both nuclear and non-nuclear energy.

The major concern of these nations, however, was focused upon the large political issues rather than upon technical matters. Led by Mexico, Nigeria, Romania, and Yugoslavia, a number of specific demands for action by the superpowers were presented:

- an end to underground nuclear tests;
- a substantial reduction in nuclear arsenals;
- a pledge not to use or threaten to use nuclear weapons against non-nuclear parties to the Treaty;
- concrete measures of substantial aid to the developing countries in the peaceful uses of nuclear energy;
- creation of a special international regime for conducting peaceful nuclear explosions; and
- an undertaking to respect all nuclear-free zones.[6]

Some movement towards meeting these demands will have to be visible for these nations to feel that the NPT is a partnership and not just a constraint on them. The bitter reaction of the nonweapons states during the 1975 NPT Review Conference and the threat of Yugoslavia to withdraw from the Treaty because, in its view, the United States and the Soviet Union in particular had not fulfilled their solemn obligations under Article 6, are clear evidence that the non-nuclear weapons states do not take lightly their understanding of the balance of obligations undertaken by all parties to the NPT.

The NPT by itself clearly does not solve the proliferation problem. As noted above, some of the key countries have not signed the treaty, and hence, are not legally bound from developing their own weapons. Further, any member can, upon justification of extraordinary circumstances, withdraw with only 3 months notice. Members can also legally make all preparations except final assembly of weapons. Hence, a fully armed nuclear state can spring forth, leaving a rather surprised world little time to formulate a response.

Despite these weaknesses, the NPT was a momentous achievement and remains a significant deterrent. There are strong reasons why a nation could find it very difficult to abrogate the NPT, even though it is technically easy to do so. Few nations can afford to flaunt international public opinion so flagrantly, especially if their justification is not convincing. This would be construed as reneging on a commitment to nonproliferation, as well as a violation of an international consensus, and could provoke a strong international response. Nor would most nations take lightly the possible unraveling of the fabric of nonproliferation,

The NPT is useful, at least in the short-term, in slowing down or deterring proliferation, but it should not be viewed as an end in itself. It has been observed that even if the NPT were suitably strengthened and extended by the accession of states not now party to it, it would not be a perpetual assurance that nuclear wars would be prevented.[7] That lack of assurance is attributable to the dynamic nature of competing interests, goals, and objectives. The fate and effectiveness of the NPT will depend upon the actions undertaken by the nuclear weapons parties to fulfill their obligations to the non-nuclear parties, as well as upon the preference or benefits the non-nuclear parties to the treaty accrue as compared to the treatment received by non-nuclear states not party to the treaty. In the long term it is important to recognize that the NPT is merely a part, although a central part, of a more extensive strategy aimed at inhibiting proliferation.[8]

[5] William Epstein, "Retrospective on the NPT Review Conference: Proposals for the Future," Congressional Record, p. S. 19558 (Nov. 10, 1975).

[6] Ibid.

[7] John Maddox, "Prospects for Nuclear Proliferation," *Adelphi* Papers, No. 113, p. 1 (London: The Institute for Strategic Studies, 1975).

[8] Ibid., p. 2.

Conclusion and Prognosis

The basic purpose of the control mechanisms discussed above is to supplement eroding technological barriers to proliferation with institutional and political constraints. These include the Non-Proliferation Treaty, IAEA safeguards, Euratom safeguards, the Suppliers' Conference, various bilateral and other export controls, and unilateral or multilateral sanctions. The achievements to date have been considerable. Thev include:

(1) an improved but still inadequate comprehension of the nature of the problem and the requirements for a solution;

(2) the creation of a broadly endorsed international norm against further proliferation;

(3) the bridging of the East-West gap in international politics with regard to this issue;

(4) the voluntary relinquishment by non-nuclear weapons states of certain sovereign prerogatives in the interest of nonproliferation (e.g., forswearing the right to obtain nuclear weapons, permission for international civil servants to inspect national nuclear facilities, acceptance of controls and restrictions on nuclear imports);

(5) the creation of at least rudimentary institutions for a coordinated international approach to the problem;

(6) the establishment of national governmental machinery to implement bilateral agreements;

(7) identification and utilization of a variety of policy instruments designed to contain proliferation (e.g., security guarantees, international safeguards, nuclear-free zones, etc.);

(8) the elevation of proliferation to near the top of supplier/state agendas and to the attention of the highest level of governmental authority; and

(9) the agreement on a broad *quid pro quo* between nuclear weapons states and non weapons states involving the reciprocal obligations delineated in the NPT.

Although still inadequate, these achievements can provide the basis for the development of a truly effective nonproliferation regime. Whether that promise will be actualized depends largely on two master variables: technological change and political will,

Assuming that the pace and configuration of technological advance (e.g., new enrichment techniques or fast breeder reactors) can be managed or accommodated and that the political will is present, what does the future agenda regarding nonproliferation look like? In broad terms the task will be to:

(1) achieve a clearer understanding of the issue in all its complexity, particularly the linkage between its technological and nontechnological dimensions;

(2) identify priorities for action in terms of importance, urgency, feasibility, and time required for implementation;

(3) reinforce the international norm against proliferation;

(4) strengthen the IAEA by improving its capabilities (e.g., budget) and expanding its responsibilities (e.g., regarding international fuel repositories);

(5) improve international safeguards and export controls by expanding their scope, standardizing their requirements, etc.;

(6) develop institutional innovations (e.g., multinational fuel-cycle facilities);

(7) redefine or clarify the bargain between nuclear weapons states and non-nuclear weapons states underlying the NPT to place the nonproliferation regime on a firmer international political foundation (i.e., bridge the gap between industrialized and less developed countries on this issue);

(8) develop comprehensive sanctions along with an enforcement capability in support of the nonproliferation regime; and

(9) improve coordination between bilateral and multilateral nonproliferation controls.

Chapter IX

Comparison of Routes to Nuclear Material

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Chapter IX

Comparison of Routes to Nuclear Material

The previous two chapters described three routes for obtaining the fissionable nuclear material suitable for weapons, and the restraints on those routes. The route that would be selected by a particular nation or non-state adversary will depend on many individual factors:

1) Technological Capability: If its ability is high, a nation can consider any route. A low capability limits the proliferator to purchase or theft.

2) Availability of Nuclear Facilities: The ability of a proliferator to divert nuclear material depends on the type of facility it owns or can readily acquire.

3) Urgency of Need: If the proliferator must have the weapons on a short time-scale, it may have to openly abrogate safeguards on its own nuclear facilities or obtain weapons by purchase or theft.

4) Critical Resources: If a nation has large quantities of uranium, it would be less vulnerable to sanctions if caught diverting and less liable to be detected if it constructs a dedicated facility.

5) Political Relationships: Acceptance of safeguards or vulnerability to sanctions will force a nation to travel a route with the least chance of detection. On the other hand, alliance with a more advanced nation may provide an Nth country with the technology or resources for a dedicated facility.

6) Perceptions of Controls: If a nation perceives safeguards to be effective, it will be less likely to attempt diversion.

The interaction of all these factors with the Nth country's objectives will determine the optimal path.

One categorization of objectives, as identified in chapter VII, under "Diversion From Commercial Power Systems, " is as follows:

a) Nations desiring a major weapons force.
b) Nations satisfied with a smaller, perhaps less-sophisticated force.

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c) Nations wishing the option of rapid development of nuclear weapons in the future.
d) Non-state adversaries limited to a few crude devices.

A major weapons program might be defined as one that produces at least 10 high quality weapons per year. Only a nation with a relatively sophisticated technological base can realistically consider such a program. That nation would not select a route as unreliable or intermittent as an illegal nuclear market. It could pursue either of the other two routes, but would probably be unable to keep its intentions secret for long. The diversion of sufficient quantities of nuclear material from a commercial nuclear power program would necessitate open abrogation of safeguards, unless the nation already had an unsafeguarded facility. Sanctions such as nuclear embargoes might effectively hamper a nation from continuing along this route unless it had its own uranium reserves and a natural uranium or fast breeder reactor. Construction of a plutonium production reactor dedicated to production of weapons material might have more appeal, in that it would be legal for a nation that is not a party to the NPT, and its production capabilities can be kept secret even if the existence of the facility could not.

The nation that wants a small number of unsophisticated weapons might procure the material from any of the three routes. If it needed the weapons quickly it could purchase the required goods on a black or gray market, if available, or might consider overt diversion from a reprocessing or enrichment plant. If its needs are not urgent, a country might be able to obtain the nuclear materials secretly. If it owned a reprocessing plant it could attempt to covertly divert sufficient material. The country might be unwilling to risk detection if it perceived safeguards to be effective. In that case it might construct a plutonium production reactor, especially if uranium were available. The reactor would be on such a small scale that it might easily escape detection. A final alternative, for a country that possessed a centrifuge enrichment plant would be to rework a portion of it into a high enrichment loop or to build a small “add on” to the existing plant.

The nation wishing only an option for future nuclear weapons development might build or acquire commercial nuclear power reactors. A reprocessing plant would be essential for it to extract the weapons material from spent reactor fuel. If it could not obtain such a facility, it might build one of its own to hold in reserve. A small reprocessing plant for weapons is far easier to design and build than a commercial plant.

The non-state adversary can obtain nuclear material either by black market transactions or by armed attack on shipments or stockpiles of plutonium from commercial power program. The non-state adversary would probably not be able to use material from other points in the fuel cycle because construction of the facilities required to convert the material to weapons grade would be most likely beyond the group’s capabilities.

This brief analysis indicates that all three routes are plausible under some conditions. The least predictable is purchase/theft. If such a route comes into existence, it could satisfy three of the four categories of proliferators. It might also serve the major force nation wanting a few bombs in hand to forestall the preemptive attack that might occur if its intentions became known before its program was complete. Hence, a high priority must be given to controlling this type of transaction. Diversion from commercial power systems can be largely controlled if Nth countries do not have their own reprocessing or enrichment plants. A reprocessing plant in particular provides instant access to any nation willing to abrogate its safeguards agreement and many opportunities for covert diversion by those that are not. The dedicated facility route is the least subject to control. Many nations are capable of this route because of ready access to sufficiently detailed plans and the availability of the modest resource requirements. One of its few disadvantages is that its cost which, while lower than that of a commercial power system, does not produce an economic return. More attention should be directed to possible means of detecting the efforts of nations who have embarked upon a dedicated facility route, and international responses prepared to deter them.

Control—including the manipulation of incentives and disincentives to proliferation —have been discussed in previous sections of this study (see chapter IV). Figure IX-1 summarizes the relationship between the routes available to the would-be proliferator and the major controls most appropriate to each route. Figure IX-2 describes three hypothetical Nth countries. Those national characteristics that would govern the choice of a preferred route and the controls most likely to be effective in each case are identified.

Figure IX-1 Control

Route	Detection	Deterrence	Limit Opportunities	Political Climate Conducive to Nonproliferation
(Covert Diversion	Safeguards	Sandions Political pressure curses, spells & incantations	Export control Spent fuel return Technological measures (e.g., nonproliferation readers) Multinational Fuel Cycle Facilities Guaranteed fuel supply International management of the fuel cycle	Weaken incentives Strengthen security of Nth countries (e.g., Securuty guarantees, military assistance, etc.) Reduce prestige of nuclear weapons (e.g., arms control) Resolve intenational disputes strengthen potitical disincentives Icrease the political posts strengthen domesic anti-proliferation forces
Overt Diversion	Not needed	Sanctions Poitical pressure curses, spells & incantations	(except G.F.S.)	Strengthen NPT Improve ber Enhance rol in internatio Link aid a Expand l
Dedicated Facilities	Intelligence	sanctions Political pressure Curses, spells& incantations	Secrecy for new developments Exports controls	r new developments Nuclear Free . Global and regional arrangements (e.g., MNFCFS)
Purchase/Th	Safeguards & Intelligence	International coordination of police	Physical security protection (e.g., PAL) Tecnological measures (e.g., coprecipitation)	Moderate grievances

SOURCE: OTA

Figure IX-2

Country Case Study I

Salient Characteristics

1) Technological capability: Large, economically strong country with moderate to high technology.
2) Nuclear facilities: LWRs on stream providing high fraction of total power supply. No reprocessing or enrichment facilities.
3) Urgency of need for weapons: No specific, critical need, so an orderly sustained program is feasible.
4) Critical resources: Significant deposits of uranium and other materials used in nuclear fuel cycle.
5) Political relationships: Relatively independent—no patron, but also no immediately threatening rival. Not a party to the NPT, but safeguards agreements on imported reactors.
6) Perception of control: Safeguards believed to be effective and international response to illegal diversion expected to be strong.

Objective

This nation would probably not be satisfied with less than a major weapons force: perhaps 50-100 deliverable weapons.

Route

The dedicated facility route — a large plutonium production reactor and reprocessing plant — would probably be the most probable. Covert diversion is very unlikely, and overt diversion would necessitate the construction of the full commercial fuel cycle, which would be more expensive than the dedicated facilities. The international response to the legal construction of dedicated facilities is likely to be less severe than to covert or overt diversion, even if the tatter is technically legal.

Controls

Control over the acquisition of nuclear weapons by such a country will be difficult. There are no obvious, effective levers should it decide to build dedicated facilities. Influencing incentives and disincentives and gaining a nonproliferation commitment by the nation maybe the best hope. Export controls and sanctions may have some utility particularly if the country is still dependent on some nuclear imports (e.g., reactor fuel), but it would be difficult to maintain supplies units in the face of legal proliferation,

Country Case Study II

Salient Characteristics

1) Technological capability: Small country with low to moderate technology.
2) Nuclear facilities: Two LWRS on stream and several more expected. High economic dependence on availability of nuclear power. No reprocessing or enrichment facilities.
3) Urgency of need for weapons: Looming security threat implies urgent, but not frantic, program.
4) Critical resources: Small, noncommercial deposits of uranium. High dependency on imports for many resources,
5) Political relationships: Party to the NPT: patron of uncertain reliability.
6) Perception of control: Safeguards effective, and international response could be overwhelming.

(cue study II contlnued)

Objective

A small force of about 10 weapons and an unsophisticated delivery system would suffice.

Route

Secrecy and cost would be overriding considerations. The purchase/theft route would be most desirable. If this is not available, a small dedicated facility would be the next choice. Covert diversion of spent fuel would be possible, but quite difficult and would still require the construction of a reprocessing facility.

Controls

incentives and disincentives provide the most effective means of control. Improved physical security for materials and weapons can limit puchase/theft opportunities. Enhanced safeguards and intelligence work can improve the chances of detection. The threat of sanctions can at least limit the nation to routes most likely to be kept secret. Tecnological measures, international management of the fuel cycle, or multinational fuel cycle facilities can limit opportunities for diversion.

Country Case Study III

Salient Characteristics

1) Technological capability: Medium size country with moderate technology.
2) Nuclear facilities: Several LWRs on stream and more under construction which will constitute a high fraction of total power supply. Centrifuge enrichment plant and small reprocessing facility.
3) Urgency of need for weapons: Sudden crisis introduces very urgent need.
4) Critical resources: Small commercial deposits of uranium. High dependency on imports.
5) Political relationships: Party to the NPT patron of uncertain reliability.
6) Perception of control: Safeguards effective. Subject to considerable non-nuclear international influence.

Objective

The primary goal would be to obtain several weapons quickly and more later. Sophistication of weapons and delivery systems is not a major consideration.

Route

Since speed is the prime requirement, overt diversion would be most attractive. Purchase/theft also offers a quick route but is unlikely to provide weapons in the required quantity. Plutonium stockpiles from the reprocessing plant would be rapidly assembled into crude weapons. The enrichment plant would allow independence from international nuclear embargoes in the long term.

Controls

Little can be done to deter a country in such a situation. Any plausible sanctions would appear less dangerous and further removed than the immediate threat, and the means are aleady at hand to procure the fissile material. The most effective controls would have been to previously defuse the political situation, provide credible security guarantees, and prevent the acquisition of sensitive facilities.

SOURCE: OTA

Chapter X

The International Nuclear Industry

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Chapter X

The International Nuclear Industry

The concern over proliferation has emerged largely as a consequence of the growth of the peaceful use of nuclear energy. Measures to control proliferation will therefore interact with several aspects of the nuclear industry: the real or perceived need for nuclear power to fill future energy demand, the means by which this need will be fulfilled, and the economic interests of nuclear corporations and their parent countries. This chapter begins by discussing the need for nuclear energy and its appropriateness for advanced and developing nations. It then presents a plausible projection of the growth of nuclear power worldwide by the year 2000. This projection leads to an estimate of the spread of facilities and movement of materials created by the nuclear industry. Finally, the value to the United States of nuclear exports is estimated. All these subjects are treated in greater detail in appendix IV, volume II.

THE NEED FOR NUCLEAR POWER

The extent to which various nations may rely on nuclear power will depend on their total energy demand and the alternatives available to meet that demand. One difficulty in assessing the energy demand of a nation is that the relationship between a nation's economy and its energy use is still not well understood. Obviously, energy consumption is in someway connected to a nation's standard of living as measured by the accessibility of goods and services: Highly industrialized countries use much more energy per capita than the less developed countries (LDCS). Nevertheless, different nations accomplish similar functions with very different requirements for energy. The per capita energy consumption for a variety of nations is related to the per capita gross national product in figure X-1. This comparison between nations is only a rough one, because both energy and economics are measured differently by different nations. For instance, the numbers do not include noncommercial energy such as firewood, which can amount to half an LDC'S total energy consumption. Nevertheless, it does indicate that the United States might maintain economic growth with substantially less than historic energy growth. This possibility is less apparent for other industrialized nations and quite improbable for the LDCS.

The explanation for these differences lies partially with the patterns of historical development of natural resources. The United States was endowed with vast supplies of energy resources and showed an increasing casualness towards them as its primary energy dependence shifted from fire-wood to coal to oil and gas. This shift, depicted in figure X-2, was engendered chiefly by the low

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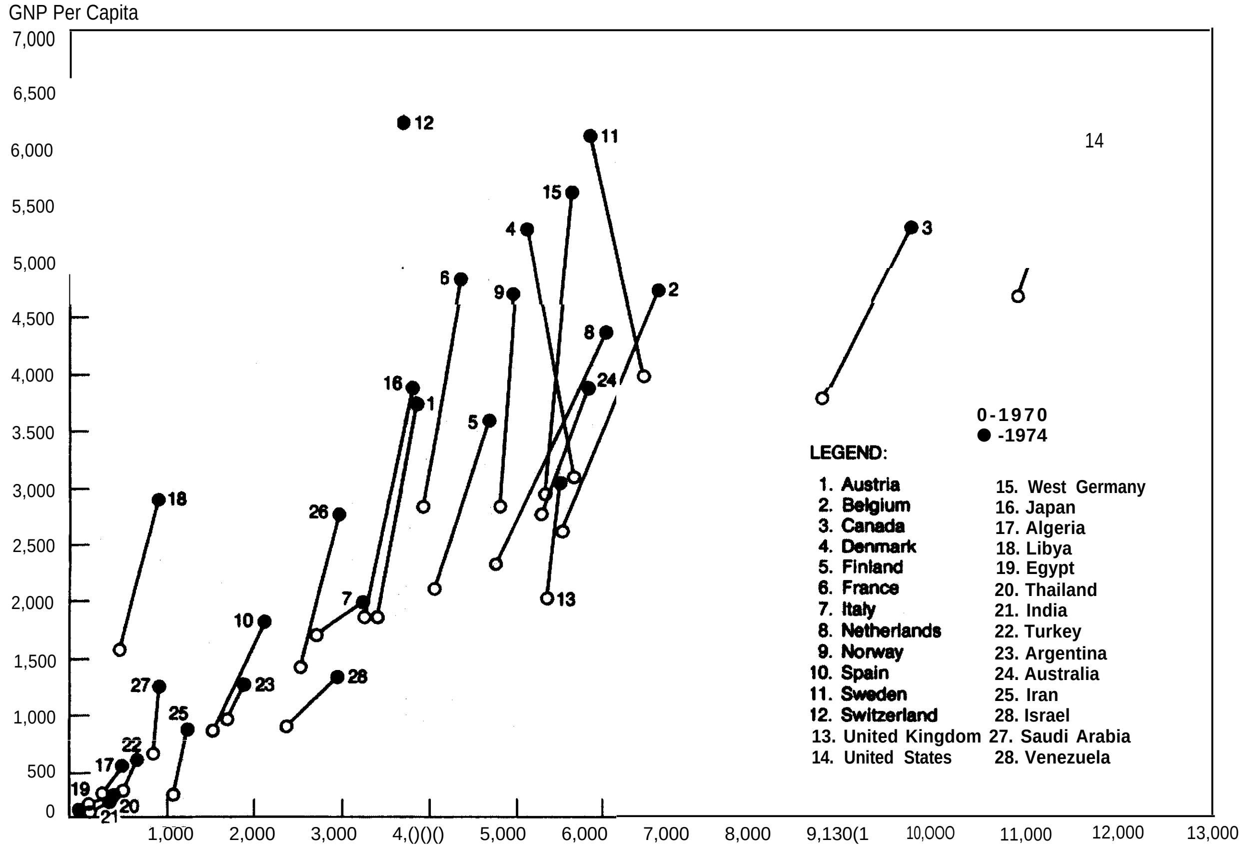
Figure X-l.

Relation of GNP and Energy Consumption



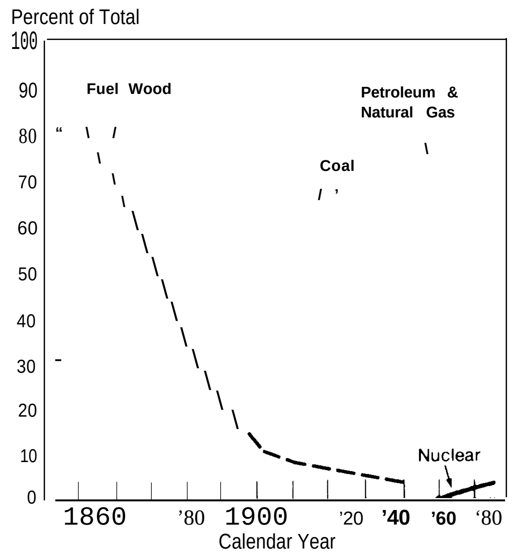
SOURCE World Almanac and Book of Facts, Washington Star, 1973 and 1976, and 'World Energy Supplies 19501974," United Natlons, 1976.

cost and convenience of resource extraction and use. Other nations, constrained by limited resources and high costs, have developed more frugal patterns of use. Most other nations have also been shifting towards increasing use of oil and gas as energy sources, Even though few industrialized nations outside of the United States have substantial reserves of cheap oil and gas, most have been relying increasingly on imports of these fuels rather than on coal. Most LDCS do not have significant reserves of either oil or coal (part of the reason for their lack of industrialization) and are still in the early stages of a shift from noncommercial fuels to imported oil, at least for use in industries and cities where the traditional sources are impractical. In most cases, foreign exchange considerations have led governments to impose high fuel taxes to minimize consumption. A graph of the worldwide use of commercial energy resources, shown in figure X-3, illustrates the rapid rise in oil consumption since 1945. Figure X-4 details this trend for several groups of nations.

Even if the energy consumption growth rate can be reduced, these patterns of energy use will have to change. In particular, the use of oil is not a long-term solution. The United States has been increasing its purchases of this fuel on the world market because of increasing consumption and declining domestic production. It now appears likely that U.S. production will continue to decline, and by the year 2000 it will certainly be much lower than it is now. Some OPEC members could produce at a substantially higher rate than at present, but they generally will not find it to their advantage to do so. Even at present rates of production, oil-rich lands such as Saudi Arabia

Figure X-2.

U.S. Energy Consumption Patterns



SOURCE ERDA 76-1, "A National Plan for Energy Research, Development and Demonstration Creating Energy Choices for the Future."

could find their production declining in about 20 years. Thus oil prices are very likely to become much higher than they are now. Figure X-5 shows estimates of the proved world reserves and estimated ultimate recoverable oil resources. The latter figure is especially subject to error, but the important points are that there is a limit which could easily be much lower and that most of the very cheap oil has already been discovered. The U.S. Geological Survey, for instance, has recently sharply lowered its estimates of U.S. resources. At present consumption rates, the estimate of ultimate recoverable oil in figure X-5 will last 83 years. If consumption increases at 3 percent per year, it will last only 40 years.

A partial return to coal is therefore inevitable despite a considerable aversion to its use. Major problems center on the inconvenience and expense of extracting and using it in an environmentally acceptable way. World coal reserves are shown if figure X-6. The known recoverable reserves provide an energy resource not much greater than that of the estimated total recoverable oil. The addition of the estimated recoverable reserves of coal raises the energy value to over five times that of oil, and improved mining techniques could recover much more. Production in Europe is not expected to change significantly over the next 10 years and the cost of extraction there is high[1]. Large amounts could be exported by the United States, Australia, South Africa, Canada, and the U. S. S. R., but in the United States at least there would be considerable opposition to the domestic environmental damage incurred for exports. Among the LDCS only India and South Korea have substantial coal production.

Nuclear energy has been widely considered to be the only viable alternative. Unlike coal, it is not readily suitable for, uses other than producing electricity. This is not felt to be a disadvantage by its promoters. Electricity is the most convenient form of energy, and is expected by many to become the dominant mode of consumption. It can be generated from a variety of sources simultaneously and used efficiently. Most countries have seen their electricity consumption grow faster than their overall energy use, and they expect this trend to continue. The biggest drawback to electricity is its expense. The equipment to generate it is costly and the fuel to produce it is used inefficiently: because of the thermodynamic processes involved in a steam-electric plant, about two units of fuel are lost as low-grade heat for every one that is converted to power.

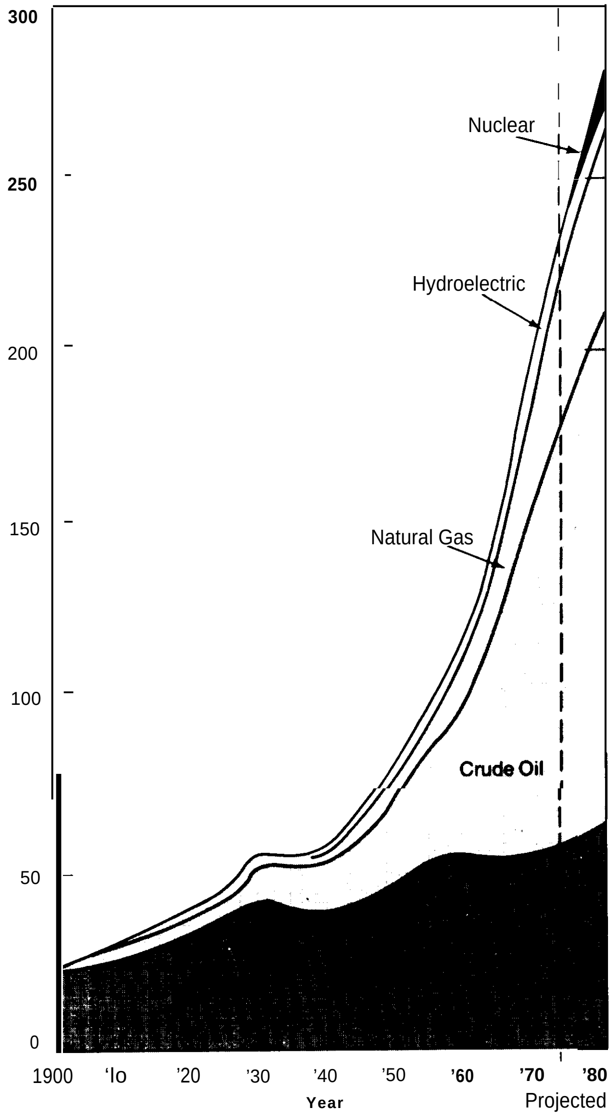
The major uses of electricity are to produce heat and light, perform work (operate machines), operate electronic equipment, and perform certain tasks (such as electrolysis) which depend on the unique nature of electricity y. When tasks such as low-temperature space heating can be performed as well by the combustion of fossil fuels, electricity can seem very expensive and inefficient. As oil and gas are depleted in the future, the only choice may be between electricity and the direct use of coal with all the difficulties it entails. Even though technology may produce more attractive direct-use options such as

[1]*World Energy Outlook*, Organization for Economic Cooperation and Development, Paris, 1977.

Figure X-3.

Changing Use of Energy Resources in the Twentieth Century

Annual Energy Production and Consumption (Quadrillion Btu 's)



SOURCE Survey of Energy Resources World Energy Conference 1974

solar energy or synthetic fuels, significant growth in electricity consumption is probable.

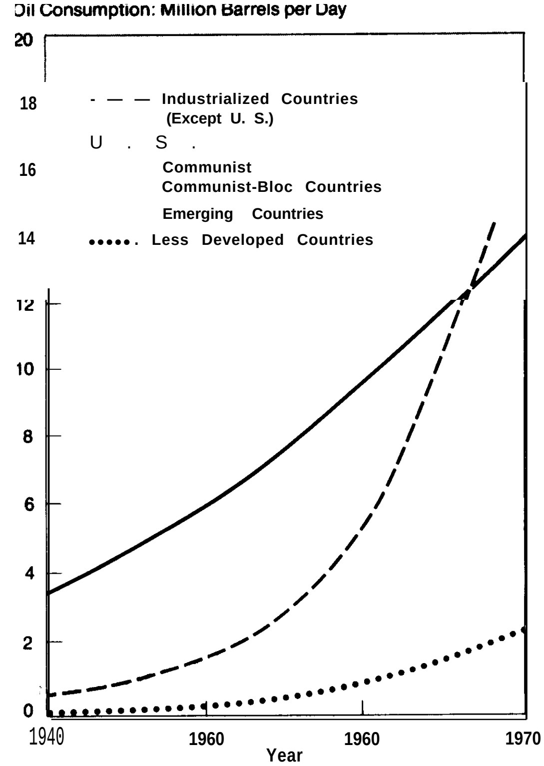
Electricity can be generated from water power (hydroelectricity), steam-turbine plants (fossil fuel, nuclear, solar, or geothermal), photovoltaics or open-cycle engines (gas turbines or diesels). The trend has been to increase the size of plants and to centralize generation in a relatively few sites thereby allowing the use of equipment that can achieve higher efficiency and economies of scale, and easing management by the utility. It also necessitates the transmission of power over long distances and makes each plant a substantial fraction of the entire grid capacity, Nuclear power marks the culmination of this process (except possibly for hydroelectric plants which are even larger, generally require remote siting and are not well suited for other purposes).

Although eventual fossil-fuel resource depletion is one of the major elements behind the desire for nuclear power, the present generation of reactors use uranium so inefficiently that this nuclear-resource base is comparable to that of oil. Nevertheless, the advent

Figure X-4.

Oil Consumption for Selected Groups of Nations

Oil Consumption: Million Barrels per Day



SOURCE: "Survey of Energy Resources," World Energy Conference, 1974.

Figure X -5

World Estimated Ultimate Crude Oil Recovery, January 1, 1975*

(Billions of barrels of oil)

	Discovered ultimate recovery	Undiscovered Potential-Resources Expected	Range	Total Remaining"	Energy Value Quads (10^{15} Btu)
Russia & China et al.	136	300	70-700	436	2529
United States	49	85	50-150	134	777
Canada	11	70	40-110	81	470
Total N. America	59	155	100-250	213	1235
Middle East	549	150	75-280	699	4054
Other foreign:					
Greater N. Sea	23	45	20-80	68	394
Other W. Europe	2	12	7-17	14	81
North Africa	42	33	15-60	75	435
Gulf of Guinea	32	30	15-50	62	360
Other Africa	—	8	3-15	8	46
Northwestern S. America	29	32	20-50	61	354
Other Latin America		50	23-95	69	400
Southeast Asia	19	32	18-50	58	336
Other Far East	9	58	20-120	67	389
Antarctica	—	20	5-50	20	116
Total other Foreign	182	320	300-500	502	2912
Total worldwide	821	925	600-1,400	1,746	10127

'Joint Committee on Atomic Energy "Project Interdependence" 1976
"'As of January 1, 1973

of breeders would transform this uranium *into* an effectively inexhaustible energy source. Another major factor in the desire for nuclear power is the promise of relatively cheap energy. This claim is considerably harder to substantiate. Capital costs have risen dramatically over the past several years and the price of uranium has risen faster than that of petroleum. Even with these higher costs, however, most countries will still find electricity generated from nuclear power cheaper than that from imported oil.

Assumptions that high electric growth rates must be maintained and that nuclear power is the only way to fulfill that demand are not universally accepted. Alternatives proposed to reduce the need for nuclear power are:

- Electricity from other sources: The use of coal could be greatly expanded. Plants fueled with imported coal could be cheaper than nuclear plants in some cases, and much cheaper than those fired by imported oil in many others. New sources could be emphasized as they become available, including wind power, solar electric, and combustion of trash. Cogeneration could be implemented (a steam turbine is coupled with industrial-process steam boilers or district-heating plants in such a way that additional heat energy is nearly 100 percent converted to electricity y).

- Non-Electric Replacements: Fossil fuels and new energy sources used directly as heat sources would in some cases be more efficient than electricity produced from either nuclear energy or these fuels themselves.

Figure X-6.
Solid Fossil Fuel Resources by Continents, and Nations with Major Resources*

Country or Continent	Recoverable Reserves	Energy Value Quads (10^{15} BTU)	Estimated Undiscovered Recoverable Reserves	Total Estimated Resources
USSR	136,600	2,456	273,200	5,713,600
China, RR. of	60,000	2,090	300,000	1,000,000
Rest of Asia	17,549	655	49,479	106,053
United states	181,781	5,095	383,562	2,924,503
Canada	5,537	131	9,034	106,777
Latin America	2,803	68	9,201	32,828
Europe	126,775	2,495	319,807	607,521
Africa	15,628	382	30,291	58,844
Oceania	24,518	485	74,689	199,654
World Total	591,191	13,857	1,402,273	10,753,680

"Survey of Energy Resource, " World Energy Conference, 1974

. Conservation of Electricity: Strict measures (such as increased insulation and use of heat pumps) could free enough existing generation capacity so that new plants would not be needed for a period. Alternatively, a nation could reject the energy-intensive, high-consumption society now generally accepted as a goal.

The desirability and feasibility of these alternatives have to be weighed against those factors both favoring and opposing nuclear power. Factors that suggest nuclear energy be considered are:

1. Lack of cheap alternatives. Even oil-rich nations may opt for nuclear energy if it appears to be cheaper than the world price of their own oil;
2. Expectation of continued fuel price escalation. A nuclear powerplant that is only marginally economical now may become very attractive in a decade, because nuclear power economics are much less sensitive to fuel prices than are fossil plants;
3. A large and growing electricity demand;
4. A desire to diversify the energy supply;
5. The need to guarantee a fuel supply by storage or rapid procurement, both of which are impractical for fossil plants because of the cost and quantity of the fuel;
6. A desire for the prestige which comes from demonstrating the ability to handle high technology;
7. The hope that nuclear power will help provide a shortcut to technological advancement;
8. The feeling that there will be no alternatives to nuclear power in a few decades and that massive deployment will then be impossible without a long learning period.

The absence of one or more of these factors will reduce the desirability of nuclear power. In addition, there are several arguments against a nation choosing nuclear power:

1. The high initial cost for nations with a capital shortage (especially LDCS). Even when the purchase is financed by an exporting nation, only a limited amount of credit is available and the ability to borrow for other purposes will be reduced. This problem has evidently not yet been overwhelming for the LDCS, who seem to prefer the more expensive heavy water reactors;
2. An increased dependence on nuclear supplies for critical parts and material. The range of suppliers is narrower than

that for most other transactions, and this may strike some as neo-colonialism;

3. Absence of technological depth and experience to handle nuclear plants. imported reactors have generally lower capacity factors, which may indicate that the risk of accidents could be higher;

4. Increased vulnerability to non-state adversaries or to enemies in case of war. Sabotage of a nuclear powerplant could cripple a nation's power supply and cause substantial damage;

5. The problem of nuclear waste disposal. If a nation reprocesses its own spent fuel, other nations may be unwilling to accept the wastes. A small waste-disposal program could be relatively expensive and seems unjustified except for nuclear weapons states, who in any case have to dispose of large quantities from weapons programs. Note that a program for the return of spent fuel to supplier countries automatically solves the problem.

6. A power system so small that the nuclear plant would be too large a fraction (more than 10-15 percent) of the overall capacity. A single plant larger than this diminishes total system reliability because a sudden outage would have too great an impact. Development of a nuclear plant that is economical on a smaller scale would greatly enhance its appropriateness for an LDC;

7. Industrial demand insufficient to permit operation of the plant at full capacity around the clock:

8. Lack of a suitably sophisticated work force, such that operation of facilities would place undue demands on the supply of skilled manpower. Note that the work force dedicated to reactor operation need not be very large.

Whether the above factors tip the scale in favor of nuclear power is a judgment that each individual nation must make for itself. The decision by a nation to take its first step toward a nuclear power program may be a momentous one. A miscalculation in the decisionmaking process can be a very expensive mistake. The LDCS in particular must be careful since they will be relatively more damaged should nuclear power turn out to be inappropriate. Since most of the potential Nth countries identified in chapter IV are in this group, proliferation concerns might best be served if supplier nations make a special effort to find appropriate alternative energy sources for them. At present, little energy research is directed at the needs of LDCS. Energy-producing devices could be developed at relatively low R&D expenditures to especially suit the problems of LDCS, which are: difficulty in financing high capital cost projects; shortages of highly skilled manpower; and an abundance of unskilled labor. Examples might be waste digesters to produce methane gas and efficient ovens for producing charcoal (the present method loses 80 percent of the energy, and firewood is becoming critically scarce in many parts of the world). This approach might be reminiscent of colonialism for some LDCS unless such devices are also implemented in the advanced nations, but the latter may also find them useful.

PROJECTIONS

Many estimates of worldwide energy and nuclear growth have been made. These have generally been based on exponential extrapolations of historical growth curves. Until *1973,* this method proved reasonably accurate. The real price of energy had been declining, and consumption was increasing faster than the general economy. The sudden quadrupling of oil prices starting in 1973, followed by the rapid escalation of other fuel costs, produced a surge of interest in nuclear energy. Since then, much of this new interest has waned. The latest nuclear projection by the Organization for Economic Cooperation and Development (OECD) is in fact lower than that of 1973. The primary reason for this decline is economic. Nuclear capital and fuel costs have soared along with oil, and

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Figure X-7
World Nuclear Capacity*
(1000 **Megawatts)**

	1975	1960	1$85	1990	2000
U.S. Rerference Case	39	67	145	250	510
Other Nations	29	100	230	425	1030
Total	68	167	375	675	1540
IAEA/OECD (lower bound)	69	179	479	875	2005

"Edward J. Hanrahan, et al., "World Requirements and Supply of Uranium," presented at the Atomic Industrial Forum Conference, Geneva, Switzerland, Sept. 14, 1976.

economic growth projections are substantially lower, partly because of the higher cost of energy. Thus, the first reaction to the oil price rise was to continue the previous patterns of consumption by turning to new sources, while the later trend was to adjust to new high energy costs by consuming less.

The previous section considered the various factors influencing an individual nation to choose or reject nuclear power. An accurate projection of the nuclear growth in each country would require an exhaustive and complex analysis of both the total electrical power demand and the various alternatives to meet this demand, No projection has yet been based on such an analysis. Several less complete projections are described in appendix IV of volume II.

Even if such a projection had been done, it probably could not adequately treat unpredictable developments such as the cohesiveness of the OPEC cartel. The best projections remain largely guesses based on estimates of the major parameters. Nevertheless, planners need a framework for their discussions, and proliferation control must be based on an understanding of the expected material flow and availability of facilities. They must rely on the less complete studies that have been done.

Projections of nuclear energy growth have been made in recent years by the IAEA and the OECD. The most recent official forecast is a 1976 ERDA modification of an IAEA study. The results are shown in figure X-7 and compared with the 1975 IAEA/OECD study from which it was derived.

Figure X-8 shows the distribution of the 1975 IAEA/OECD projection. Significant points to be drawn from figures X-7 and X-8 are that the United States is reducing estimates of its own nuclear growth more than most other countries and now anticipates a growth rate lower than others. These are largely because of forecasts of a reduced economic growth rate and substantial opportunities for conservation in the United States.

Figure X-8.
Nuclear Power Growth Estimate
(1000 Megawatts)*

	1975	1980	1985	1990	2000
Australia				1	6
Austria	—	0.7	3	6	14
Belgium	1,7	3.5	9.5	16.5	30
Canada	2.5	7,2	18.4	41	115
Denmark	—	—	1.8	4.9	11.4
Finland	—	1.5	3.9	4.9	13
France	2.3	20.4	56	90	170
Germany	3,2	19.1	44.6	77	134
Greece	—	—	0.6	1.2	4
Ireland	—	—	0.7	2	6
Italy	0.6	1,4	26.4	62	140
Japan	6.6	17	49	84	157
Luxembourg	—	—	1.2	1.2	1.2
Netherlands	0.5	0.5	3.5	7.5	16
New Zealand	—	—	—	1.2	3
Norway	—	—	—	1.8	4
Portugal	—	—	1.4	3.3	8
Spain	1.1	8.7	23.7	42	80
Sweden	3.2	7.4	11.3	16.3	24
Switzerland	1	3.8	8	8	12
Turkey	—	—	0.6	2.2	16
United Kingdom	4.8	11.1	15.4	31	115
United States	40.1	82.2	205	386	1,000
OECD,					
High Estimate	68	185	484	890	2,080
Low Estimate	68	171	437	774	1,685
African region[1]		—	3.1	6.9	29
American region[2]	0.3	3.6	14,4	35	147
Asian region[3]	0.7	5	28.2	72	224
Total Emerging & LDC's	**1.0**	**8.6**	**45.7**	**113.9**	**400**
TOTAL (High Estimates)	**69**	**194**	**530**	**1,004**	**2,480**
Low Estimate	**69**	**179**	**479**	**875**	**2,005**

[1]Algeria, Egypt, Iraq, Kuwait, Morocco, Saudi Arabia, South Africa, Tunisia.

[2]Argentina, Brazil, Chile, Colombia, Cuba, Mexico, Jamaica, Peru, Uruguay, Venezuela.

[3]Bangladesh, Hong Kong, India, Indonesia, Iran, Israel, Korea, Malaysia, Pakistan, Philippines, Singapore, Taiwan, Thailand.

*From "Uranium Resources, Production and Demand," Joint OECD and IAEA Report, Paris, December, 1975.

The most recent projections of total electrical power demand for individual LDCS was a 1974 Market Survey by the IAEA. The results of this IAEA study for those LDCS and emerging nations also listed in the OECD report are shown in figure X-9. This figure has been overtaken by recent events as shown by the comparison with more recent OECD figures, but it does give an idea of which nations will be considering nuclear power and what their alternatives are.

The developing nations heavily committed to nuclear (i.e., planning to install more than 10,000 MW by the year 2000) are Brazil, Mexico, Argentina, Egypt, India, Iran, Taiwan, South Korea, Pakistan, Philippines, and Singapore. These are either emerging nations with expectations of becoming major industrial powers by 2000 or industrializing LDCS with especially poor resources. Exceptions may be South Korea with its large coal deposits and Egypt with potential oil reserves. All have nuclear projects underway. A major effort with far-reaching ramifications would be required to convince these nations to eliminate their planned use of nuclear energy altogether. Only those nations with a lower anticipated dependence on nuclear power, as listed in figure X-9, might accept a total substitution of alternatives should that prove desirable. Many already have a start in nuclear technology however, as detailed in appendix IV of volume II, and some are planning on a very high eventual nuclear fraction of their total power capacity.

Even allowing for a reduction in projections, nuclear energy is expected to be a major energy source for the world. The 1,540,000 MW of nuclear capacity in the year 2000 (figure X-7) would produce a total of about 100-Quads (101s Btu) per-year of thermal energy, nearly twice the present rate of coal consumption shown in figure X-3. Producing this much nuclear capacity will be difficult and may well not be achieved. If the world economy continues to grow however, finding alternatives may be even harder.

THE MOVEMENT OF NUCLEAR MATERIALS AND EQUIPMENT

The previous section summarized projections of the growth of nuclear power expected in the future. The impact this growth might have on proliferation depends largely on the characteristics of the international nuclear industry. The capabilities of reactor-supplier nations are particularly important in estimating the success of any unilateral or multilateral proliferation-control measures. The spread of those facilities that are most sensitive to proliferation+nrichment and reprocessing plants—is also critical. Such plants not only give their operators the means to produce weapons material but also reduce their vulnerability to international sanctions. (These and other facilities less critical to proliferation control are discussed in appendix IV of volume II). Finally, the location and adequacy of the supply of uranium fuel itself affects fuel supply strategies, such as guaranteed fuel, and determines when measures that might increase proliferation problems—such as recycling plutonium or relying on the breeder reactor—are really needed. The worldwide distribution of reactors and their supporting facilities is depicted in figure X-10.

Reactors

The nations and enterprises that presently manufacture reactors are listed in figure X-11. The export market has been restricted to the United States, Germany, France, and the U. S. S. R., for light water reactors (LWRS) and to Canada for heavy water reactors (HWRS). Italy and Great Britain also have the spare capacity to export if they can find a market. Japan and Sweden will continue to import, as their manufacturing capability is less than domestic demand.

The general pattern of growth has been for a nation to import its first few reactors and then develop its own manufacturing capability, possibly under a licensing agreement. India is now in the middle of this process, building a capability for producing heavy

Figure X-9.

Projected Distribution of Installed Electric Capacities in Developing Nations by Plant Type*

(1000 Megawatts)

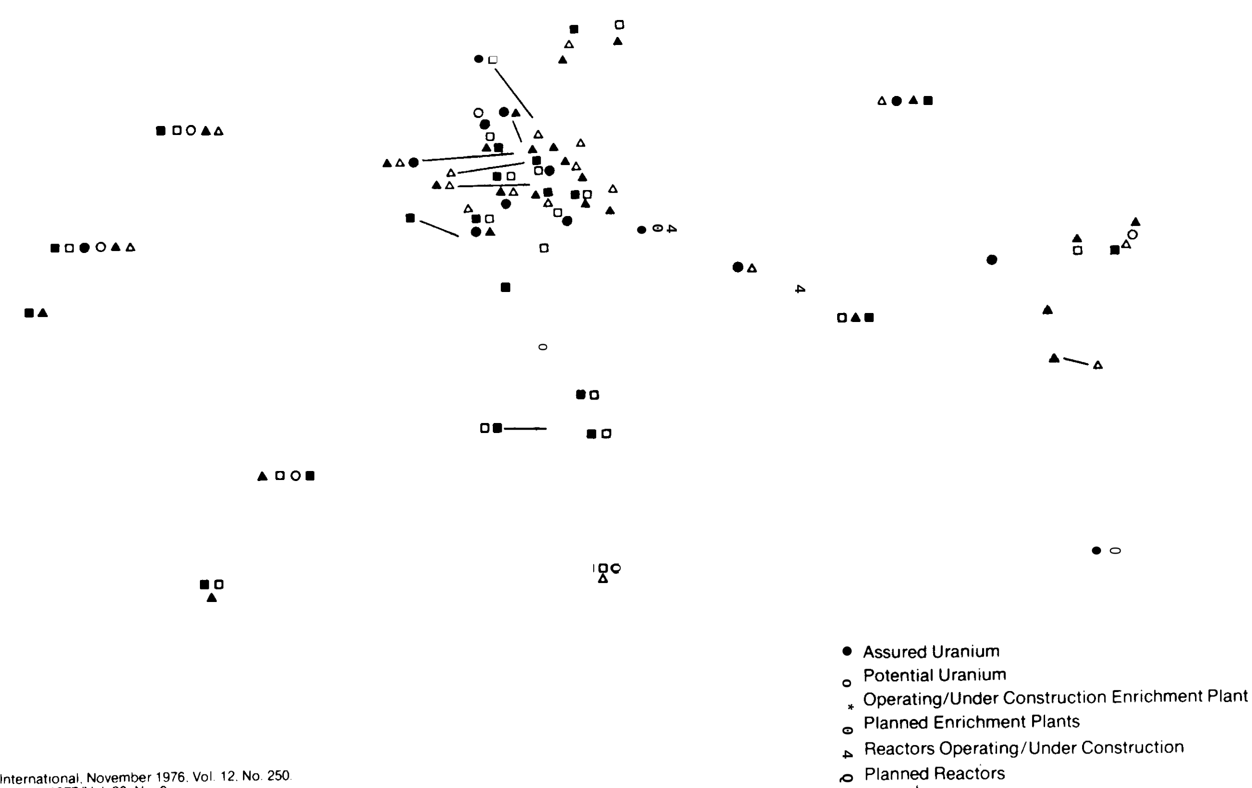
	1980				1990				2000			
	Conv.	Nuclear	Hydro	Total	Conv.	Nuclear	Hydro	Total	Conv.	Nuclear	Hydro	Total
American Region												
Brazil	3.1	0.6	22.0	25.7	3.1	11.4	49.2	63.7	3.1	46.9	52.3	102.3
Mexico	8.6	0.7	6.9	16.2	9.1	21,6	8.6	39.3	9.4	68.0	10.6	88.0
Argentina	5.4	1.5	4.0	10.9	4.9	8.1	8.5	21.5	3.9	18.1	15.8	37.8
Venezuela	6.4	-	1.2	7.6	6.4	4.4	3.4	14.2	6.4	8.4	9.8	24.6
Colombia	3.4	-	2.6	6.0	3.4	1.7	6.5	11.6	3.4	5.3	12.5	21.2
Peru	1.6	-	1.8	3.4	1.6	1.3	3.6	6.5	1.6	3.0	7.0	11.6
Chile	1.1	-	1.6	2.7	1.1	1.7	2.4	5.2	1.1	3.7	4.9	9.7
Cuba	2.5	-		2.5	2.6	2.1	-	4.7	2.6	5.5	-	8.1
Jamaica	1.0	-		1.0	1.0	1.8	-	2.8	1.2	5.8	-	7.0
Uruguay	1.0		0.3	1.3	1.1	1.1	0.5	2.7	1.1	3.1	0.6	4.8
Region Total	34.1	2.8	40.4	77.3	34.3	55.2	82.7	172.2	33.8	167.8	113.5	315.1
African Region												
Egypt	2.8	-	2.4	5.2	2.6	5.0	2.4	10.0	2.5	12.6	2.4	17.5
Israel	3.8	-		3.8	3.8	3.9	-	7.7	5.0	7.4	-	12.4
Kuwait	1.3	-		1.3	1.3	1.3	-	2.6	2.2	3.2	-	5.4
Iraq	1.1	-		1.1	1.1	1.1	-	2.2	1.8	2.6	-	4.4
Morocco	0.3	-	0.6	0.9	0.3	0.4	1.0	1.7	0.3	1.6	1.3	3.2
Algeria	0.4	-	0.4	0.8	0.4	0.5	0.8	1.7	0.4	1.8	1.3	3.5
Nigeria	0.8	-	0.1	0.9	1.1	0.5	0.3	1.9	0.8	2.6	1.0	4.4
Tunisia	0.4	-	0.1	0.5	0.8	0.2	0.2	1.2	0.8	1.6	0.2	2.6
Saudi Arabia	0.4	-		0.4	0.8	0.2	-	1.0	0.8	1.4	-	2.2
Region Total	11.3	0	3.6	14.9	12.2	13.1	4.7	30.0	14.6	34.8	6.2	55.6
Asian Region												
India	25.5	4.2	22.3	52.0	26.0	31.4	43.0	100.4	27.0	130.0	60.0	217.0
Iran	6.3	-	3.0	9.3	6.4	10.0	8.0	24.4	6.5	28.0	10.0	44.5
Taiwan	6.1	2.9	(a)	9.0	10.0	10.3	(a)	20.3	14.9	22.4	(a)	37.3
Korea	4.7	1.2	0.7	6.6	4.7	9.8	2.3	16.8	4.7	24.5	2.3	31.5
Thailand	3.0	-	1.3	4.3	3.1	3.7	2.2	9.0	3.1	9.6	4.3	17.0
Pakistan	3.5	0.1	2.9	6.5	3.2	4.9	4.8	12.9	3.3	15.9	7.3	26.5
Philippines (Luzon)	2.7	-	1.0	3.7	2.8	4.8	2.0	9.6	3.9	12.0	2.8	18.7
Hong Kong	3.5	-		3.5	3.6	3.2	-	6.8	4.9	7.3		12.2
Singapore	1.8	-		1.8	1.8	4.3	-	6.1	1.8	14.9		16.7
Malaysia (Peninsular	1.0	-	0.6	1.6	1.3	1.3	1.4	4.5	1.3	5.0	2.3	8.6
Indonesia (Java)	0.8	-	0.7	1.5	0.8	1.7	1.8	4.3	1.1	5.7	3.0	9.8
Bangladesh	1.1	-	0.1	1.2	1.1	4.0	0.5	5.6	1.1	9.7	0.8	11.6
Rsgion Total	60.0	8.4	32.6	101.0	64.8	89.9	66.0	220.7	73.6	285	92.8	451.4
Sub-Total	105.4	11,2	76.6	193.2	111.3	158.2	153.4	422.9	122	487.6	212.5	822.1
Percentage	54.6	5.8	39.6	100	26.3	37.4	36.3	100	14.8	59.3	25.8	100

(a) Not available

"Derived from IAEA Market Survey for Nuclear Power in Developing Countries, 1974.

Figure X–10.

Worldwide Distribution of Reactors and Their Supporting Facilities



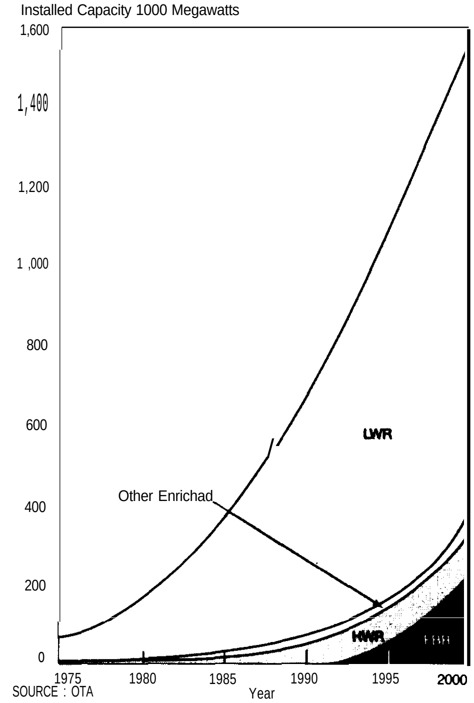
SOURCE: Nuclear Engineering International, November 1976, Vol. 12, No. 250.
Nuclear News, Mid-February 1977/Vol. 20, No. 3.

Figure X–11.
Principal Suppliers of Reactors

HWR	
Atomic Energy of Canada Ltd.	Canada
Kraftwerk Union	Federal Republic of Germany
Canadian General Electric	Canada
LWR	
Kraftwerk Union AG	FRG
Framatronne	France
Atomenergoexport	USSR
ASEA-Atom	Sweden
General Co.	USA
Westinhouse Co.	USA
Toshiba	Japan
Hitachi	Japan
Combustion Engineering	USA
Babcock and Wilcox	USA
Ansaldo Meccanico'co Nuclear SpA	Italy
Mitsubishi Heavy Industries	Japan
Gas Colled	
General Atomic	USA
Nuclear Power Co.	United Kingdom

SOURCE: OTA

Figure x-12.
World Nuclear Capacity Projection



SOURCE : OTA

water reactors derived from its Canadian imports despite total withdrawal of Canada's assistance. Few other nuclear importers, however, will be tempted into the business of reactor manufacturing. The necessary infrastructure is too expensive and demanding to be worthwhile even to provide domestic needs. Entering the reactor export business would be even harder because of the stiff competition and difficulty in demonstrating a reliable product to a new customer.

The growth of various types of reactors most likely to be installed worldwide through the year 2000 are shown in figure X-12. This figure indicates the continued predominance of LWRS, the increasing popularity of HWRS and the entrance of breeders near the year 2000.

Uranium

Those nations with economically recoverable resources of uranium are listed in figure X-13. Interestingly, few of the Western reactor suppliers will be major exporters of natural uranium. Despite their large reserves, Canada and Australia may have restrictive policies limiting their uranium exports. The United States has substantial reserves, but even these may not be enough for domestic needs. The other nations on the list can be expected to export uranium.

Although economically recoverable resources seem to be concentrated in a few countries, most other countries do have some deposits and more may be discovered as exploration is accelerated. Some may find it politically advantageous, even if not economical, to mine and mill uranium to ensure a fuel supply for domestic plants.

The figures presented in figure X-13 do not represent an estimate of ultimately recoverable resources. They have been collected largely

Figure X -13.
Uranium Reserves and Resources •
Data Available November 1.1976

Cost Range	Reasonably Assured Resources (1000 Metric Tins)	Estimated Additional Resources (1000 Metric Tins)	Total (1000 Metric Tons)
Algeria	28		28
Argentina	20.6	39	59.6
Australia	243	80	323
Brazil	10.4	8.8	19.2
Canada	172	605	777
Central African Republic	8	8	16
Denmark (Greenland)	6	10	16
Finland	1.9	—	‘ 1.9
France	55	40	95
Gabon	20	10	30
Germany	1	4	5
India	29.2	23.3	52.5
Italy	1.2	1	2.2
Japan	7.7	—	7.7
Korea	2.4		2.4
Mexico	6		6
Niger	50	30	80
Portugal	6.9	—	6.9
South Africa	462	74	536
Spain	103.5	106.8	210.3
Sweden	300	—	300
Turkey	31	0.4	3.5
United Kingdom	1.8	4	5.8
United States	493	812	1305
Yugoslavia	6.5	15.2	21.7
Zaire	1.8	1.7	3.5
Total (rounded)	2041.0	1873.2	3914.2

‘Nuclear Engineering international, November 1976

for purposes of short-and mid-term planning. Two factors could result in a considerable expansion of the figures. The first is confirmation of more speculative deposits not included here. In the United States, 1,430,000 metric tons have been estimated by ERDA as possible or speculative, and as vast areas of the world have yet to be prospected no estimate at all has been made for them. It is conceivable, although far from definite, that several times the total in figure X-13 eventually will be identified as recoverable. The second factor would be the use of higher cost ores. Nuclear power is relatively insensitive to the price of the fuel, so this possibility cannot be precluded as cheaper deposits are consumed. It is well known that enormous quantities of uranium, far exceeding any projected demand, exist in very low-grade forms such as shales, granite, and sea water, but tapping these resources is not feasible under present techniques. Much less is known about middle-grade ores since the abundance of high-grade ores has limited the interest in them. Middle-grade ores may in fact be virtually nonexistent, as is exhibited by some materials, or they may present a resource base mid-range between the high- and low-grade resources. Much exploratory work remains to further define both these factors,

The adequacy of worldwide reserves of uranium for the projected growth of nuclear

Figure X – 14.

Reactor Characteristics for 1000 MWe Plants[1*]

	BWR	PWR	STD HTGR	CANDU (THOR)	CANDU
Thermal efficiency, %	34	33	39	30	30
Initial core (and blanket*) average					
Irradiation Level, MWD_{th}/MTU	17000	22600	54500	18500	6900
Fresh Fuel Assay, Wt% U^{235}	2.03	2.28	93.15	93.15	0.711
Spent Fuel Assay, Wt% U^{235}	0.88	0.74	~60	~60	0.31
Fissile Pu recovered, kg/MTU[2]	4.8	5.8		—	1.7
Feed Required, ST U_3O_8					
at 0.2% tails	.494	.422	.367	.520	.199
at 0.3% tails	.581	.498	.458	.646	.199
*Feed Required, ST ThO_2[3]		—	42.5	160	
Separative Work Required, 1000 SWU[3]					
at 0.2% tails	239	222	388	519	
at 0.3% tails	185	174	311	441	
Replacement Loadings (Annual rate at steady state; 75% capacity factor)					
Irradiation Level, MWD_{th}/MTU	27500	32600	95000	27000	9600
Fresh Fuel Assay, Wt% U^{235}	2.73	3.21	93.15	83.15	0.711
Spent Fuel Assay, Wt% U^{235}	0.84	0.90	30		0.15
Fissile Pu Recovered, kg/MTU[2]	5.9	7.0			2.3
Feed Required, ST U_3O_8[3]					
at 0.2% tails	0.144	0.154	0.065	0.020	0.125
at 0.3% tails	0.179	0.191	0.106	0.024	0.125
*Feed Required, ST ThO_2[3]	—		8.7	41.5	—
Separative Work Required, 1000 SWU					
at 0.2% tails	105	117	85	19	
at 0.3% tails	84	94	73	16	
Replacement Loadings (Annual rate with Pu recycle[5], 75% capacity factor)					
Fissile Pu Recycled, kg.	.163	.167			
Fissile Pu Recovered, kg/MTU[2,6]	8.1	9.5			
Feed Required, ST U_3O_8/MWe[3,4]					
at 0.2% tails	0.121	0.128			
at 0.3% tails	0.148	0.158			
Separative Work Required, 1000 SWU[3]					
at 0.2% tails	82	93			
at 0.3% tails	66	75			
Lifetime[7] Commitment Required, 30-year life, ST U_3O_8/30 (Replacement requirement) + Initial Core and Blanket					
Without Pu recycle					
at 0.2% tails	4460	4810			3580
at 0.3% tails	5500	5660			3580
With Pu recycle					
at 0.2% tails	3460	3500			
at 0.3% tails	4210	4310			
With Thorium and U^{233} recycle					
at 0.2% tails			2580	1350	
at 0.3% tails			3200	1870	

1 MW_{th} is thermal megawatts; MWe is net electrical megawatts; MWD_{th} is thermal megawattdays; MTU is metric tonnes (thousand of kilograms) of uranium; and ST U_3O_8 is short tons of U_3O_8 yellowcake from an ore processing mill. One SW is equivalent to one kg of separative work.

2 After losses..

3 For replacement loadings, the required feed and separative work are net, in that they allow for the use of uranium recovered from spent fuel. Allowance is made for fabrication and reprocessing losses.

4 Includes natural uranium to be spiked with plutonium; 0.0067 ST U_3O_8/MWe for BWR and 0.0067 for PWR.

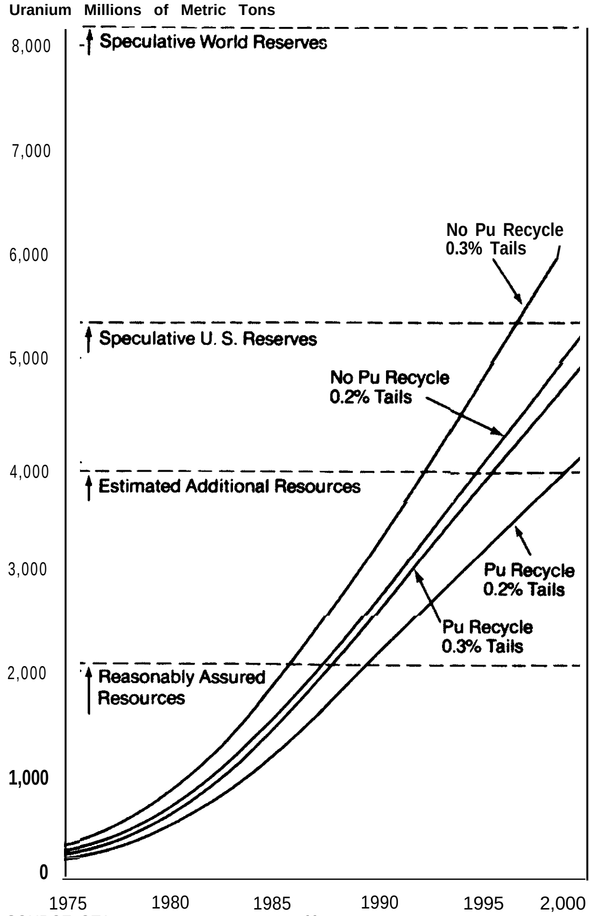
5 Plutonium available for recycle ratchets up each pass because not all of the plutonium charged is burned. Therefore, more plutonium is recovered from mixed-oxide fuel than from standard uranium fuel, and this increment increases with each cycle (5-6 years par cycle) requiring several passes to reach steady state. The data shown represent conditions for the 1960's when most reactors will be discharging fuel which has only seen one recycle pass.

6 Average for all fuel discharged with full recycle of self-generated plutonium. For mixed-oxide fuel (natural U spiked with self-generated plutonium) the spent fuel from BWRS contains 5.11 kg Pu per MTU and from PWRS, 18.7.

7 Lifetime commitments assume operations at 40% Capacity Factor (CF for the first year, 65% CF for the next two years, followed by 12 years at 75% CF. Thereafter, CF drops 2 points per year, reaching 35% in the last (30th) year.

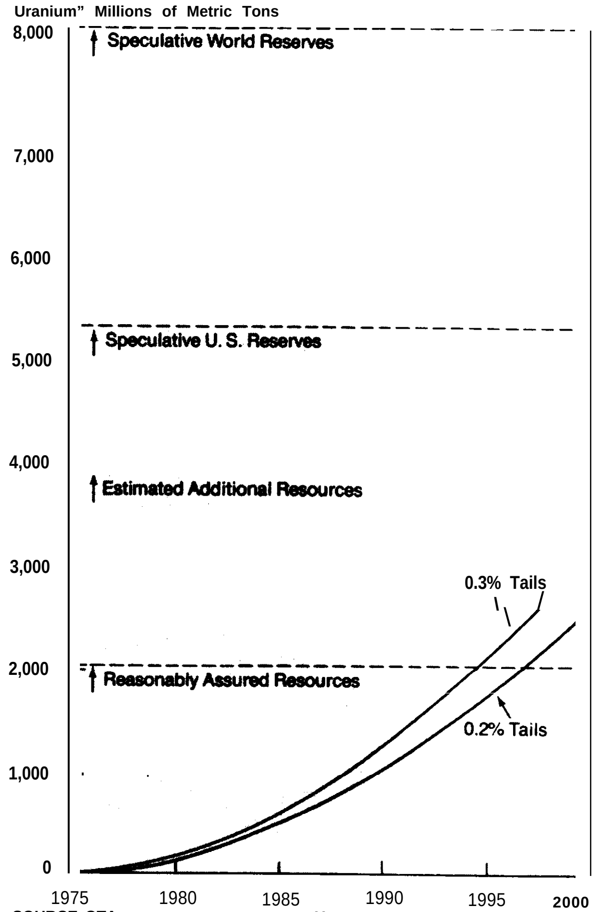
● ERDA-1, "The Report of the Liquid Metal Fast Breeder Reactor Program Review Group," January 1975.

Figure X-15.
Cumulative Lifetime Uranium Commitments



SOURCE OTA

Figure X-1 6.
Cumulative Consumption of Uranium



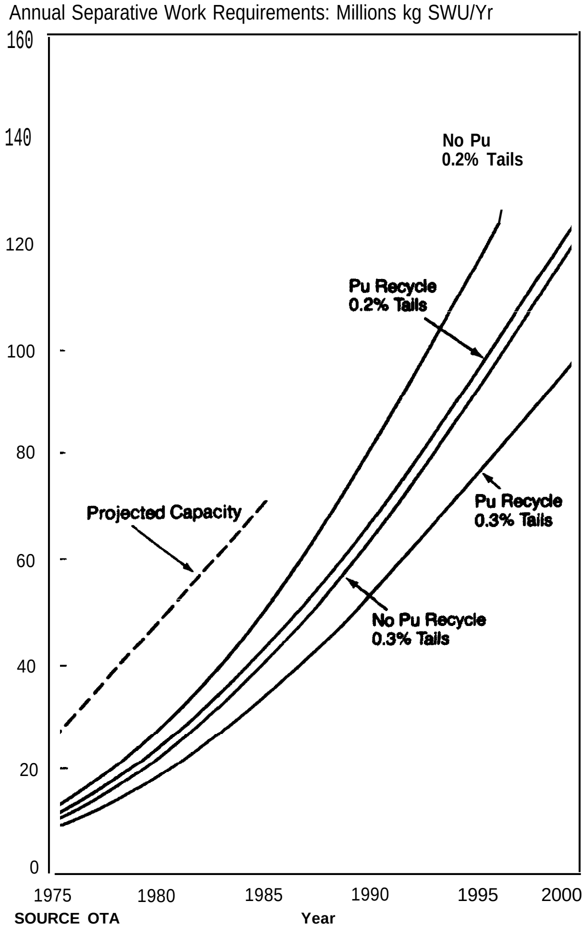
SOURCE OTA

plants depends upon a variety of complex factors. One is the efficiency with which various reactor types use this resource. The abundant LWRS use more than HWRS, and breeders could operate for decades on the uranium that has already been mined. The utilization of uranium also depends upon the operation of the enrichment plants required for LWRS (See chapter VII and appendix V of volume II for technical details of all aspects of the nuclear fuel cycle). If the demand for enrichment services is high, a plant can be operated in a mode that provides a more enriched product but also requires more uranium feed. If more efficient enrichment techniques (such as the laser isotope separation) are developed, they might be able to recover some of the useful fuel now left in the tails.

Another factor influencing the adequacy of uranium reserves is the fuel burnup of a reactor: The fuel would be more completely burned if the LWRS operated at full power for the expected 80 percent of the year rather than at the current average of 60 percent of the year. (A realistic goal might be 70 percent.) At the lower percentage of full-power operation the fuel could be left in the reactor several months longer. However, reactors continue to be refueled at regularly scheduled yearly intervals because it is most economical to time the refueling with the required annual shutdown for maintenance. This leaves a substantial amount of unburned enriched uranium in the spent fuel which could be recovered, along with the generated plutonium, by reprocessing. This step would undoubtedly be advan -

Figure X-1 7.

World Annual Separative Work Requirement



SOURCE OTA

tageous from an energy resource conservation viewpoint but it is far from certain that recycling will become widespread.

The amount of uranium that will be needed by each of the presently available reactors over their lifetimes are shown in figure X-14. These figures can be translated into the demand that will be placed upon uranium resources by the growth of nuclear powerplants. The projected installed capacity as a function of time is plotted on figure X-12. The required cumulative lifetime commitments (allotting to a reactor at the start of operation the entire supply of fuel it will use in its lifetime) for this projection are shown in figure X-15 for enrichment tails of 0.2 percent and 0.3 percent, with and without plutonium recycle. The actual day-by-day cumulative consumption is shown in figure X-16. Both figures show the reserves of-figure X-13, the 1,430,000 metric tons of U.S. possible or speculative reserves, and an estimate of the equivalent world reserves based on the same ratio of speculative to reserves figures as in the United States. This latter figure is purely empirical and is included only to give an idea of the possible magnitude of world reserves. The lifetime commitments reach the estimated total resource base of figure X-13 in 1999 with Pu recycle and in 1995 without it, assuming ample enrichment capacity. If the more speculative reserves are confirmed, uranium may not be a constraint on reactor construction until well into the next century, even without recycling. If, however, even the present estimates turn out to be optimistic, a serious shortage could develop in the 1990's. Actual consumption would not be limited until well after the year 2000, with or without recycle. Thus, nuclear growth could continue past the 1,000 reactors that will commit the estimated base, but this expansion could only be pursued if there were considerable confidence that a fuel supply would emerge to allow the reactors to complete their normal expected lifetimes, This supply might come from new ore discoveries, breeders, laser enrichment of tails, or new recovery techniques for tapping the vast reserves of low-grade, presently uneconomical, ore such as the Chattanooga shales or sea water.

Enrichment

Enrichment plants are essential for LWRS, which must use fuel with a higher concentration of the uranium isotope U^{235} than occurs naturally, The adequacy of enrichment facilities in meeting present and future demands of LWRS will affect the motivations of various nations, either to build their own enrichment plants or to purchase a reactor type such as the HWR that does not require enriched uranium. Global enrichment capacity is plotted against requirements in figure X-17. The U.S.S.R. has been credited with 7 million separative work units (SWUS), but it is not known if that much actually will be available. It is apparent that new capacity

Figure X -18.
Enrichment Plants*

Nation	Type	Location	Capacity Million SWU	Operation Date
U.S. ... ..., ...	Diffusion	Oak Ridge, Term.	4.73	
	Diffusion	Paducah, Ky.	7.31	
	Diffusion	Portsmouth, Ohio	5.19	
			17.23	
	Diffusion	Improvements and Uprating	**10.5**	**1975-85**
	Diffusion	Portsmouth, Ohio (add on)	**8.75**	**1985**
	Centrifuge (Proposed)		**1.6** to **9.0**	**1982-1989**
USSR .. .., ..., ...	Diffusion	Siberia	**7-1o**	—
United Kingdom	Diffusion-	Capenhurst	0.4-0.6	—
	Centrifuge	Capenhurst	**0.2**	**1977**
	Centrifuge (Proposed)**	Capenhurst	**1.6**	**1982**
Netherlands	Centrifuge	Almelo	**0.2**	**1977**
France .. .., ...	Diffusion	Tricastin	**10-8**	**1978-1981**
	Diffusion	Tricastin	**9-1o**	**1985**
Japan . . . ., .. .	**Centrifuge (Proposed)**		**2**	**1988**
Brazil	Jet (Proposed)		**2**	**1989**
South Africa	Jet (Proposed)		5	—

"**Nuclear** Engineering International, **November 1976**
'"**Expansion could beat** Almelo or in **Germany Instead**

will be needed by the 1990's, especially if reprocessing is delayed (plutonium 'can substitute for enriched uranium). Because the construction time for new plants is about 8 years, plants should start in the early 1980's if growth projections are to be met, The enrichment facilities in operation are listed in figure X-18.

The United States has been the major supplier of enrichment services, even to other reactor suppliers, although its dominance is now declining. All large-scale operating plants are the gaseous diffusion type, and most of these are in the United States, The next series of large plants will probably be the centrifuge type, which promises to be more economical, Both are very high-technology processes based on proprietary or classified information. Thus, although centrifuge plants can be built on a small scale and more economically than diffusion plants, not many countries beyond these listed in figure X-18 are likely to undertake commercial enrichment. The nations most likely to enter the enrichment market are Australia and West Germany. If new techniques under development (such as jet-nozzle or laser isotope separation) prove practical, this picture may change drastically. Both Brazil and South Africa are currently developing enrichment plants based on the jet-nozzle technique—Brazil to supply its domestic needs and South Africa to enter the export market. Another new feature that may contribute to the spread of enrichment technology is the participation by some nations (such as Iran) in an enrichment consortium such as Coredif.

Figure X -19.

World Reprocessing Plants*

Location	operator		Type of Plant	Capacity te/y	Date operational	status
US.						
Barnwell S.C.	AGNS		Commercial, oxide	1500	1979-82	Depending on GESMO decisions
U.K.						
Windscale	BNFL	1	Nat. U metal	1500-2500	1964	Operating near full capacity Head end improvement programme in hand
			Oxide head end	300	1972 to 1973	Operated but shut down for investigation of incident and subsequent modification
			Refurbished oxide head end	400	1977-78	Will feed into nat. U separation plant depending on availability of capacity
		2	New commercial oxide plant	1000	1984	For expected domestic requirements part of United Reprocessor's plan
		3	New commercial oxide plant "overseas"	1000	1987	Awaiting decision on public acceptability of overseas contracts
France						
La Hague	CEA	1	Nat. U metal	800	1968	Main plant for reprocessing EdF nat. U fuel but due to be changed over to oxide
			Oxide head end	150 to 800	1976	Phased build up feeding into existing separation plant
		2	New commercial oxide plant	1000	1985	Detailed design just starting
Marcoule	CEA		Nat. U metal fuel	900-1200	1958	Early military plant. Will take over commercial nat. U from La Hague
Germany						
Karlsruhe WAK	KEWA		Pilot scale oxide	40	1970	Operating with fuel of increasing burnup
	PWK/KEWA		Commercial oxide plant	1500	1984	Design specification being prepared. Site to be selected.
Japan						
Tokai Mura	PNC		Demonstration scale oxide	200	1976	Non-active commissioning
—	PNC		Commercial oxide plant	1000	late 1980s	Projected if site can be found
Belgium						
Mol	Eurochemic		Multi-purpose semi-commercial international plant	60	1966	Shut down. Future in doubt. Has been used for reprocessing development
Italy						
Saluggia Eurex 1	CNEN		Pilot scale oxide	10	1969	Current shut down for modification
India						
Trombay	IAEC		Pilot scale nat. U oxide	60	1965	

Note Several other pilot and laboratory scale plants have been and are being operated fordeveloprrrent of reprocessing technology. Commercial reprocessing of research reactor fuel has also been undertaken in several plants around the world, Fast reactor oxide fuel will be reprocessed m pilot scale plants in France and the U.K. and a plant for mixed thorium uranium oxides was built m Italy but has not been operated.

"Nuclear Engineering International, February 1976.

Reprocessing

Reprocessing is considerably less mature than other stages of the fuel cycle. Interest in reprocessing has been limited, both because it is not essential to any reactor now marketed and because its costs have escalated very rapidly as the difficulties of handling plutonium and highly irradiated fuel have become more apparent. If breeder reactors enter the market they will require reprocessing plants. A major argument for building reprocessing capabilities now is to gain experience and to produce plutonium stockpiles for the initial breeder cores. Additional advantages of reprocessing are its contribution to resource conservation and the role it is expected to eventually play in permanent waste disposal.

Despite these advantages, reprocessing has become the focus of much of the opposition to nuclear power. The reason is that reprocessing potentially exposes plutonium with all the resulting implications for health, safety, and proliferation.

At present the only operating reprocessing plant for LWR fuel is a small commercial facility in France that has been running since May 1976. The weapons countries all operate large noncommercial reprocessing plants, and several countries reprocess spent fuel from other types of reactors. The older magnox reactor in Great Britian requires reprocessing for its magnesium-clad fuel. The facilities for LWR fuel that are expected to begin operating in the next few years are listed in figure X-19. Several others have been shut down because of obsolescence. If all spent fuel were to be reprocessed, considerably more capacity than is currently planned would be required. The planned and required capacity is shown in figure X-20. The alternative is simply to increase the temporary pool storage for spent fuel (at some expense), or to devise quasi-permanent storage for it, if processing is to be deferred indefinitely.

Commercial reprocessing plants are expensive and technologically demanding facilities, A minimum size plant might be designed to handle 500 tons of spent fuel per year, equivalent to the discharge of about 25000 MW of installed capacity. Very few nations will have such a large capacity in this century. Hence international reprocessing centers may become economically advantageous.

Even though reprocessing facilities make sense only if serving a large number of reactors and are not essential to LWRS or HWRS, Brazil and Pakistan have signed contracts to import them.

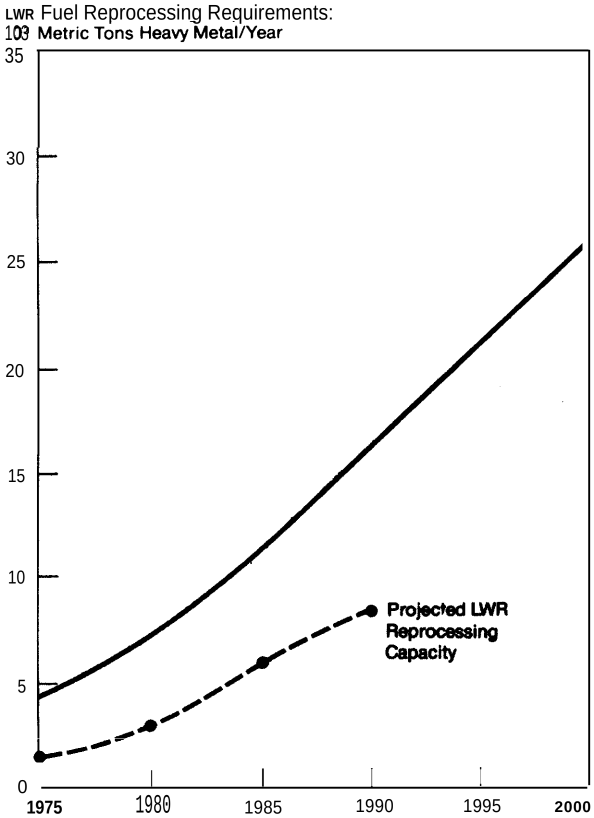
U.S. NUCLEAR EXPORTS

The United States has been the leader in the development of nuclear energy for both domestic use and export. The LWR was developed in the United States, and is now the major reactor of all supplier nations except Canada and the United Kingdom. Most imported reactors have been purchased from the United States and American enrichment plants will be fueling most of the world's LWRS for at least the next decade. The benefits of these exports were not seriously questioned for many years. Not only was nuclear energy seen as a benefit to mankind in general, but nuclear exports were expected to generate sizable profits while maintaining America's technological advantages. There is considerably more controversy now over nuclear power in general and exports in particular, but American companies have simultaneously found them increasingly important to fill spare capacity.

The chief U.S. exports have been reactors and their associated equipment. Engineering and construction services have also been important. The only fuel-cycle service of note so far has been enrichment. The United States has refused to transfer the sensitive technologies of enrichment and reprocessing.

The U.S. share of the reactor export market has been dropping markedly, as indicated by figure X-21. In the future the United States will be selling less to the other industrialized nations, as so many have gone into business

Figure X-20.
World Annual LWR Fuel Reprocessing Potential Requirements



SOURCE OTA

for themselves, and more to the developing countries. The U.S. share of the latter market is likely to be 35 to 40 percent in the early 1980's, but drop to 25 to 30 percent by the late 1980's. This market share amounts to 13,000 to 17,000 MW capacity and an export value of $5 to $7 billion by 1990. The U.S. share of the European market will decline to 5 percent by 1990. Combined with sales to Japan, these exports could total 30,000-35,000 MW, but this would amount to only $5 to $7 billion since the advanced nations supply more of the plant themselves. Total revenue from reactor sales should be $10 to $14 billion.

The reactor export market is a very competitive one, especially because most suppliers are capable of producing more reactors than they can use domestically. The success of any single exporter will depend upon a variety of factors:

1) Governmental export policies: Some other suppliers have added enrichment or reprocessing technology as inducements for their reactor sales, but all recently seem to be agreeing to withhold these technologies as the United States has done. Canada has taken the lead in restricting its exports to signatories of the NPT or its equivalent (full fuel cycle safeguards).

2) Adequacy of enrichment services: In 1974, the United States stopped accepting further orders for enrichment services because its capacity was fully booked. As a result, the U.S. reputation as a reliable supplier of enrichment was damaged. If the United States fails to expand its enrichment capacity or imposes high charges for the services, nations may be more reluctant to purchase American reactors.

3) Financial assistance: Most reactors are sold under advantageous credit terms. Changes in one nation's policy will affect all exporters.

4) Industrial capacity: Although most suppliers now have excess capacity, Canada may soon be booked up because of the strong interest expressed by LDCS in the CANDU reactor.

5) Quality of reactor exports: The United States is still respected as a reliable supplier of proven products that are subject to strict standards of design, construction, and safety, It may, however, have to adapt its reactors to the developing-nation market by such innovations as smaller reactors.

6) International political influence: A given supplier will be helped if its government has a special relationship with an importing nation, and is willing to use that influence.

As these various factors change they may alter the above projections. Barring major policy changes, however, U.S. reactor exports are expected to be about $1 billion per year.

Figure X-21.
Suppliers of Exported Reactors
(Megawatts)

NATION	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86
United States	150	:	—	237	1	958	660	900	656	—	1565	809	—	4035	6164	4745	3675	2542	4764	907	907	—	1
West Germany	—	1	—	—	1	—	—	—	—	477	319	—	—	692	920	—	1200	1200	997	1245	1245	—	1
Canada	—	1	—	—	1	—	—	—	125	202	—	—	—	—	—	—	600	—	629	—	—	—	1
France	—	1	—	—	1	—	—	—	480	—	—	1650	—	—	—	—	1835	—	3822	1822	—	—	1
USSR	—	1	—	—	1	—	—	—	—	—	—	—	—	420	420	—	—	—	—	—	—	—	1
Sweden	—	1	—	—	1	—	—	—	—	—	—	—	—	—	660	—	660	—	—	—	—	—	1
United Kingdom	—	1	159	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1

*Derived from Nuclear News, Mid-February 1977/Vol. 20/Nov. 3

This sum is a small but significant part of total exports ($100 billion in 1975 with a trade surplus of $11.5 billion) and could have a large impact on the balance of trade.

As noted earlier in this chapter, the sale of enrichment services is another large contributor to the revenues obtained from nuclear-related exports. American capacity is currently committed through 1985, and no orders have as yet been taken beyond that date. Roughly one-third of this capacity (about 70-million separative work units (SWU)) has been ordered by foreign customers for delivery in the 1977 to 1985 period. Assuming an average charge of $80 per SWU, the revenue expected from this source will be about $6 billion. Because of the many uncertainties surrounding the development of new enrichment facilities in the United States and elsewhere, it is difficult to estimate the potential export value of this service above that which is already committed.

The export of fuel fabrication services presents a smaller revenue source to the United States than does the sale of powerplants or enrichment services. This process does not require a large capital investment and is not highly technical; in the future, many countries can be expected to market fuel-fabrication services, producing strong competition in this area, In addition, U.S. industry may be hampered by the uncertainty over long-term permission to export fuel services and by the existence of government-supported activities in other countries. The cumulative value of the export of fuel-fabrication services can be expected to be on the order of $1.5 billion through 1985.

The future of spent-fuel reprocessing in the United States is still very uncertain. Even if the decision is soon made to go ahead with reprocessing and plutonium recycle, it would be many years before a commercial industry developed sufficient capacity to provide reprocessing services to foreign customers.

Glossary

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Glossary

Breeder—A nuclear reactor that produces more fissile nuclei than it consumes. The fissile nuclei are produced by the capture of neutrons in fertile material. (See definitions below.) The resource constraint for breeder reactors is thus fertile material, which is far more abundant in nature than fissile material. These reactors have not yet reached commercialization. Fast breeders do not contain a moderator (see definition below) to slow neutrons down; i.e., fast neutrons are used. Thermal breeders do contain a moderator; i.e., slow neutrons are used.

Centrifuge—A rotating vessel that can be used for enrichment of uranium. The heavier isotopes of the UF_6 gas tend to concentrate at the walls of the rotating centrifuge.

Chain Reaction—A series of nuclear fissions, each one stimulated by a neutron emitted in a Previous fission. A chain reaction occurs when at least one of the two or more neutrons released in a fission initiates another fission.

Critical Mass—The minimum amount of fissile material required to sustain a chain reaction. The exact mass varies with many factors such as the particular fissile isotope present, its concentration and chemical form and the geometrical arrangement of the material.

Dedicated Facility—A facility built indigenously (possibly clandestinely) in order to produce fissile material for nuclear weapons. It might be a plutonium production reactor, a uranium enrichment plant or a reprocessing plant.

Denaturing—A technique to render fissile nuclear material unsuitable for explosive weapons by mixing in other isotopes of the same element.

Diffusion—A technique for enrichment of uranium based on the fact that the lighter isotopes of a gas will diffuse through a porous barrier more rapidly than the heavier isotopes.

Diversion—The removal of material from some point in the commercial nuclear fuel cycle to use in nuclear weapons.

Enrichment—The process of increasing the concentration of one isotope of a given element.

Fast Neutron—A fast-moving, neutral subatomic particle. Neutrons are emitted when a nucleus, such as uranium-235, fissions.

Fertile Isotope—An isotope not itself fissile but that is converted into a fissile isotope, either directly or after a short decay process following absorption of a neutron. Example: U^{238} can capture a neutron to give U^{239}. U^{239} then decays to Np^{239} which in turn decays to fissile Pu239.

Fissile Isotope—An isotope that will split, or fission, into two (or more) lighter elements plus extra neutrons when it is struck by a neutron,

Fission—The splitting of a nucleus usually into two or more lighter elements. The total mass of the resulting particles is less than that of the original atom, the difference being converted into energy.

Fresh Fuel—Nuclear fuel ready for insertion into a power reactor.

Fuel Cycle—The set of chemical and physical operations needed to prepare nuclear material for use in reactors and to dispose of or recycle the material after its removal from the reactor. Existing fuel cycles begin with uranium as the natural resource and create plutonium as a byproduct, Some future fuel cycles may rely on thorium and produce the fissile isotope uranium-233.

Fuel Fabrication Plant—A facility where the nuclear material (e.g., enriched or natural uranium) is fabricated into fuel elements to be inserted into a reactor.

Gun-Type Nuclear Weapon—A device in which gun propellants are used to move

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two **or more subcritical masses of fissile material together to produce an explosion.**

Implosion-Type Nuclear Weapon—A device in which high explosives surrounding a subcritical configuration of fissile material compress it into a condition of supercriticality to produce an explosion.

Isotopes-Atoms of the same chemical element whose nuclei contain different numbers of neutrons and hence have different masses, even though chemically identical. Isotopes are specified by their atomic mass number, that is, the total number of protons plus neutrons, and a symbol denoting the chemical element, e.g., U^{235} for uranium-235.

Mixed-Oxide Fuel—Nuclear reactor fuel composed of plutonium and uranium in oxide form. The plutonium replaces some of the fissile uranium, thus reducing the need for uranium ore and enrichment. This is the form of the fuel that would be used in plutonium recycle.

Moderator—A component (usually water, heavy water, or graphite) of some nuclear reactors that slows neutrons, thereby increasing their chances of being absorbed by a fissile nucleus.

Multinational Fuel-Cycle Facilities (MFCF)-A concept for joint national ownership and management of certain steps of the nuclear fuel cycle-especially those steps that are particularly vulnerable to national diversion. Multinational reprocessing plants and spent-fuel storage facilities are currently under study.

Nth Country—A nation judged to have high potential of becoming a nuclear-weapons state—because of its technical and economic ability and its political motivations.

Neutron—Neutral particles which, together with protons, comprise the nucleus of an atom.

Non-State Adversary—Any individual or group that wishes to use destructive force to further its own goals.

Nuclear Fission Weapons—Devices that derive their explosive force from the energy released when a large number of nuclei fission in a very short period of time.

Plutonium-239 (Pu^{239})-A fissile isotope created as a result of capture of a neutron by U^{238}. It is excellent material for nuclear weapons.

Plutonium-240 (Pu^{240})—A fissile isotope whose presence complicates the construction of nuclear explosives because of its high rate of spontaneous fission. It is produced in reactors when a Pu^{239} atom absorbs a neutron instead of fissioning.

Protons—Positively charged particles which, together with neutrons, comprise the nucleus of an atom.

Reactor—A facility that contains a controlled nuclear fission chain reaction. It may be used to generate electrical power, to conduct research, or exclusively to produce plutonium for nuclear explosives.

Reactor-Grade Plutonium—Plutonium that contains more than 7 percent of the isotope plutonium-240. It is created in most power reactors under normal operating conditions, although the liquid metal fast breeder reactor does produce weapons-grade plutonium in one portion of the reactor.

Recycle—The reuse of unburned uranium and plutonium in fresh fuel after separation from fission products in spent fuel at a reprocessing plant.

Reprocessing-Chemical treatment of spent reactor fuel to separate the plutonium and uranium from the fission products and (under present plans) from each other.

Safeguards-Sets of regulations, procedures, and equipment designed to prevent and detect the diversion of nuclear materials from authorized channels.

Special Nuclear Material (SNM)-Plutonium, or uranium enriched in U^{235} or U^{233}.

Spent Fuel—Fuel elements that have been removed from the reactor because they contain too little fissile material and too high a

concentration of radioactive fission products. They are both physically and radioactively hot.

Strategic Special Nuclear **Material** (SSNM)-Plutonium, U^{233}, or uranium enriched to 20 percent or more in U^{235}.

Spiking—A technique to deter theft of nuclear fuel by the addition of radioactive substances.

Thermal neutrons—Low energy, or slow moving neutrons.

Thorium-232 (Th^{232})-A fetile, naturally occurring isotope from which the fissile isotope uranium-233 can be bred.

Uranium-233 (U^{233})-A fissile isotope bred by fertile thorium-232. It is similar in weapons quality to plutonium-239.

Uranium-235 (U^{235})-The only naturally occurring fissile isotope. Natural uranium has 0.7 percent of U^{235}; light water reactors use about 3 percent and weapons materials normally consist of 90 percent of this isotope.

Uranium-238 (U^{238})—A fertile isotope from which Pu239 can be bred. It comprises 99.3 percent of natural uranium.

Weapons-Grade Plutonium—Plutonium that contains less than 7 percent of plutonium-240, an isotope that complicates the design of nuclear weapons.

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