NUREG/CR-2846
BNL/NUREG-51567

Alternative Nuclear Fuel Cycle Arrangements for Proliferation Resistance

An Overview of Regulatory Factors

Date Published: August 1982

John N. O'Brien, Editor

Technical Support Organization
Brookhaven National Laboratory
Upton, New York 11973
Operated by
Associated Universities, Inc.
or the
U. S. Department of Energy

Prepared for:
Division of Facility Operations
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555
NRC FIN NO. A-3221

Available as NUREG/CR-2846 for $12.00 from
GPO Sales Program
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

and

National Technical Information Service
U.S. Department of Commerce
Springfield, VA 22151

Printed in the United States of America
August 1982

ACKNOWLEDGMENT

To acknowledge every individual who assisted in this project would be impossible because of its size, duration, and breadth. However, certain individuals and organizations played a significant role in its completion.

Angelo C. Giarratana, Richard C. Robinson Jr., and Harry S. Tovmassian, all of the Nuclear Regulatory Commission, had cognizance over this project at different times and contributed significantly to it. Their help and assistance proved invaluable at many times and they are gratefully acknowledged for their help and support.

The Word Processing Group and Composition Group of the Photography and Graphic Arts Division at Brookhaven National Laboratory deserve special mention for their diligence and professionalism which resulted in a high quality manuscript and an outstanding type composition product done entirely at Brookhaven.

Members of the Technical Support Organization for Nuclear Safeguards who assisted in writing sections of this anthology are cited as authors and deserve recognition. In addition, John H. Cusack, the group's leader, worked long and hard with me to assemble and proof the entire book.

Many contacts provided invaluable information on the various topics covered in this anthology. In particular, Warren H. Donnelly of the Congressional Research Service provided important support for many of the reports presented in this anthology.

John N. O'Brien
Upton, N.Y.
July 16, 1982

FOREWORD

In 1977 President Carter announced that the U.S. would seek alternatives to the development of advanced nuclear fuel cycles involving separated nuclear weapons grade materials. This policy was in response to growing concern that nations with nuclear fuel cycles utilizing weapons grade material would be able to expeditiously develop crude nuclear explosive devices any time such a device appeared desirable.

The legitimate U.S. interest in arresting the potential for additional nations obtaining nuclear weapons had to be balanced against the sovereign right of nations to choose their own energy sources according to their best interests. It was proposed that alternative nuclear fuel cycles which do not involve weapons grade materials might be developed and used in non-nuclear weapons states to minimize their potential for manufacturing nuclear weapons.

President Carter proposed the International Nuclear Fuel Cycle Evaluation (INFCE) to analyze various alternative fuel cycles which could minimize the risk of nuclear weapons proliferation. At the same time the Department of Energy (DOE) initiated the Non-Proliferation Alternative Systems Assessment Program (NASAP) to support the U.S. contribution to INFCE as well as to assess the domestic implications of alternative nuclear fuel cycles.

In 1978 the Comptroller General, in a letter to the Joint Economic Committee of the U.S. Congress, called attention to the fact that the Nuclear Regulatory Commission (NRC) was not sufficiently involved in the assessment of alternative nuclear fuel cycles. While the NASAP program plan noted that considerable interaction with NRC would be required to obtain a consensus on the licensability and to identify generic environmental and safety problems, no DOE/NRC agreements for such interaction existed.

In response to GAO contentions, NRC initiated a study of alternative fuel cycles with particular emphasis on how NRC jurisdiction and interests might be affected by their use. Part of this study examined safeguards issues associated with alternative fuel cycles with particular emphasis on the development of legal and technical information which bore on the issue of selecting an alternative fuel cycle. The original effort was to include examination of institutional and jurisdictional issues as well as those that were technical in nature. Specifically, NRC wished to examine problems related to multinational fuel cycle facilities, potential effects on the US/IAEA agreement, development of an algorithm for ranking potential fuel cycles as to their desirability, and potential licensing of candidate fuel cycles.

This anthology represents the products of this study which has been conducted between 1979 and 1981. As such, some material is dated. Various areas have been examined with the concept of keeping NRC participation in alternative fuel cycles research at a level appropriate for interagency consultation and decision making.

Since technical issues associated with alternative nuclear fuel cycles were covered intensively in studies directly associated with INFCE and NASAP, most of the efforts presented here are institutional and legal in nature. These analyses are directed toward informing NRC of the character of its involvement in the selection and licensing of various nuclear fuel cycles.

TABLE OF CONTENTS

Page

Chapter One - The Role of NRC in International Cooperation and Commerce ... 1

Institutional Problems Associated with a Domestically Sited Multinational Fuel Cycle Facility - John N. O'Brien ... 2

Institutional Issues Associated with Spent Fuel Storage Under Domestic and International Auspices - John N. O'Brien ... 23

Institutional Problems Associated with a Domestically Sited Multinational Enrichment Facility - John N. O'Brien ... 71

Impacts of Alternative Nuclear Fuel Cycles on the US/IAEA Safeguards Agreement - John N. O'Brien ... 79

Survey of Recent Reports and Trends - John N. O'Brien ... 113

International Nuclear Power Program Development - Kun Mo Chung ... 129

Chapter Two - NRC Licensing of Nuclear Technology ... 143

Safeguards Licensing Problems Which Could Restrain Implementation of NASAP Fuel Cycles - Jerry J. Cadwell ... 144

Export Licensing Problems Associated with Alternative Nuclear Fuel Cycles - John N. O'Brien ... 185

An Analysis of the "Timely Warning" Requirement of NNPA - John N. O'Brien ... 211

Chapter Three - Legal Concerns Arising from Advanced Nuclear Fuel Cycles ... 229

Detection of Special Nuclear Materials at Portal Monitors and Location of Contraband Nuclear Materials: Legal and Technical Problems - John N. O'Brien ... 230

The Possible Legal Consequences of Protective Radioactive Spiking of Nuclear Fuel - Jerry J. Cadwell ... 269

Chapter Four - Ranking Nuclear Fuel Cycles ... 291

A Suggested Ranking for Selected Alternative Fuel Cycles - Jerry J. Cadwell ... 292

A Suggested Ranking for Seven Selected Fuel Cycles - B. Keisch ... 313

Chapter Five ... 341

Technical Safeguards Issues for Alternative Fuel Cycles - E.V. Weinstock and B. Keisch ... 342

Index ... 449

INTRODUCTION

The concept of a "fuel cycle" can be defined with varying degrees of breadth. Any energy producing fuel cycle involves the mining and preparation of material either for construction of the facility, and/or to fuel energy production. Such activities are very amenable to analysis particularly with regard to physical or "technical" factors influencing economies of scale. A broader definition of fuel cycle includes characterization of institutional and administrative arrangements of importance in weighing various options. By including consideration of these arrangements, a more comprehensive examination of options is certainly possible.

In this anthology a "fuel cycle" includes institutional and administrative factors, as well as material flows, hardware, and facilities. Multinational endeavors, in addition to domestic auspices, are considered. While current trends in fuel cycle discussions are taken into account, a full range of international cooperation is contemplated to aid in broad-based consideration of options which may be viable in the future. In addition, issues which were not viewed to be adequately addressed in available literature are examined.

The aim of the research presented here is to illuminate some of the various arrangements contemplated for nuclear energy in the future. Because the general perception of energy self-sufficiency and nuclear non-proliferation differ from nation to nation and from time to time, executive branch policy was not used to automatically eliminate fuel cycle arrangements which were identified as potentially viable although not in consonance with current U.S. policy. As a result, emphasis was put on multinational arrangements on the basis of statutory pronouncements (NNPA) and international negotiations (e.g., international spent fuel storage). Particular attention was given to matters of NRC jurisdication in an effort to maintain a current basis for NRC participation in selecting appropriate nuclear fuel cycle arrangements according to changing conditions and demands.

Chapter One

The Role of NRC in International Cooperation and Commerce

This chapter examines the role of NRC in the conclusion of fuel cycle arrangements being considered by DOE. These include U.S. participation in international cooperation for spent fuel storage, enrichment, and an International Nuclear Fuel Authority (INFA). This chapter also examines the impact of alternative nuclear fuels on the US/International Atomic Energy Agency (IAEA) safeguards agreement. In addition, this chapter surveys recent Government Accounting Office (GAO) and international discussions on nuclear energy policy and non-proliferation.

The purpose of these reports is to apprise NRC of relevant and practical concerns stemming from the adoption of institutional fuel cycle arrangements presently under consideration. Various reports have been published elsewhere dealing with the topical areas discussed here. However, the object of the reports in this chapter is to take a more detailed look at the actual institutional arrangements then has been done to date.

Institutional Problems Associated With A Domestically Sited Multinational Fuel Cycle Facility

John N. O'Brien
NUREG/CR-1028
February 1980

TABLE OF CONTENTS

Page

I. Introduction 5
  A. Purpose of the Report 5
  B. Scope of the Report 5
II. Background 6
  A. Statement of the Problem
  B. Legislation Relevant to Multinational Undertakings 6
  C. The Nature of the Potential Multinational Agreements for International Cooperation in Nuclear Energy Developments 10
III. The Multinational Fuel Cycle Facility 10
  A. The Functions of INFA 11
  B. The Structure of INFA 11
  C. The International Nuclear Fuel Authority as Contemplated in the Nuclear Non-Proliferation Act 12
IV. Potential Problems Related to Domestic Authority Over INFA 16
  A. Jurisdictional Issues 16
  B. Licensing 20
  C. Regulatory Compliance 21
  D. IAEA Participation 22

ABSTRACT

This report sets out to identify the problems which the Nuclear Regulatory Commission (NRC) may face during the establishment and operation of a domestically sited multinational fuel cycle facility. The concept chosen is that of an international nuclear fuel authority (INFA) as contemplated in the Nuclear Non-proliferation Act of 1978 (NNPA).

The general objective of such a plan is to encourage nonweapons states

to forego development of sensitive nuclear technologies and thereby the production of weapons-usable materials. Recognition that the policy of denying sensitive technologies to nonweapons states will not stand up in the face of diversified suppliers and technological advancement, generally, has made a multinational approach more acceptable from a U.S. standpoint.

The relevant sections of NNPA as well as other acts of Congress are reviewed and summarized. The concept of INFA, as it might be used to establish an international spent-fuel storage facility associated with a fuel fabrication and shipment area, is described in detail. Congressional debates and policy statements which would be used to support such an entity are cited. INFA would be controlled by a multinational ruling body and operated by a management tier. INFA would contract to buy low-enriched uranium for subsequent fabrication into fuel assemblies. The multinational ruling body, alone, could impose a fuel cut off on a nation using the non-proliferation objectives laid out in NNPA and the Nuclear Non-Proliferation Treaty as criteria.

The general concepts of treaties and agreements in international law are examined as they apply to establishment of INFA.

The jursidictional character of INFA is examined as it relates to the issues of sovereign immunity, tort and financial liability and taxation, power to contract and institute legal proceedings, and financing and ownership. NRC licensing of the facility is examined in the contexts of the setting of technical standards for modification of operation, siting, export licensing, physical security, and environmental impacts. Regulatory compliance and IAEA participation are examined.

The report concludes that INFA could be established if the impetus for meeting non-proliferation objectives were sufficient to cause the U.S. to partially give up its national sovereignty as a supplier. The recognition that nonweapons states are planning to construct indigenous sensitive nuclear facilities and that the existence of a multinational organization to provide fuel assurances would mitigate these plans would probably provide this impetus. In that event, U.S. and international law provide the institutional framework necessary for concluding such an agreement.

I. INTRODUCTION

A. The Purpose of this Report

This report sets out to examine the institutional and legal problems associated with establishing a multinational fuel cycle facility in the U.S. The concept of multinationalization of the nuclear fuel cycle is a response to increasing concern over the desire of nations possessing small nuclear energy programs to develop indigenous fuel cycle facilities which can be used to make sensitive materials available to both national governments and subnational groups desiring nuclear explosive capability.

The specific measure examined in this report is the projected establishment of a multinationally controlled fuel cycle facility within the U.S. Such a facility, while subject to some form of multinational control, must also be subject to domestic laws protecting the health and safety of the American public.

B. Scope of the Inquiry

The concept of multinationalization of portions of the nuclear fuel cycle can be very broadly interpreted. Although it is recognized that many factors may encourage location of a multinational facility outside the U.S., this report is limited to an examination of the problems associated with a domestically located multinational fuel cycle facility. Suggestions for multinational control have ranged up to complete multinational ownership of all nuclear energy related activities throughout the fuel cycle;[1] this report, however, considers only the receipt and storage of spent fuel and the purchase of low-enriched uranium for resale to members as described in the Nuclear Non-Proliferation Act of 1978 (NNPA).[2]

Enrichment facilities which are operating, under construction, or planned are considered sufficient at least for the reactors now planned or operating.[3] It is evident from the diversity of potential suppliers of enrichment services that, barring major cartelization, enrichment services and uranium supplies for light-water reactors should not be difficult to obtain. On the other hand, the technologies required to operate or construct enrichment facilities are not available to most nations. It is, therefore, unlikely that any nation, other than those already doing so, could supply its own enriched fuel without massive expenditures for research and development as well as construction of an enrichment facility.

Reprocessing technologies are far better understood and, thus, a nation with a small nuclear energy program might seek to recycle the fissile material left in its spent fuel. Such a facility could also alleviate problems associated with overstock of spent fuel assemblies by processing them into more readily storable forms.

This report considers the establishment of a multinational organization having the authority to receive and store foreign spent fuel and to supply new fuel and reactor technology to nations which are members. This arrangement is contemplated in Title I of the NNPA called an International Nuclear Fuel Authority (INFA). The principal objectives of INFA are to assure foreign nations that their supplies of new reactor fuel are reliable and to remove spent fuel from those nations in order to deter reprocessing and separation of plutonium. INFA is characterized here as a multinational organization which can purchase low-enriched uranium for fabrication into new fuel to be sold to members and which oversees a spent fuel storage facility where members can deposit their spent fuel assemblies in exchange for energy credits against new fuel purchases. As a condition of membership, nonweapons states agree not to reprocess spent fuel or enrich new fuel indigenously.

REFERENCES

1. For an excellent discussion of a comprehensive fuel cycle/reactor internationalization concept, see *Evaluation of an Integrated International Nuclear Fuel Authority*, John H. Barton, ed., Stanford University Institute for Energy Studies, 1978.
2. Pub. L. No. 95-242.
3. This conclusion is reached in the preparation of the Nonproliferation Alternative Systems Assessment Program's final reports.

II. BACKGROUND

A. Statement of the Problem

Present U.S. policy to defer indefinitely the development of a commercial breeder reactor and the reprocessing of spent fuel for recycle was intended, at least secondarily, to influence the rest of the international nuclear community to do the same. This objective was based on the belief that the possession of sensitive facilities and/or materials by nations now lacking nuclear weapons capability should be discouraged in the interests of non-proliferation. The existence of sensitive materials and facilities in less industrialized countries is considered undesirable because their economic and strategic policies may not have matured to the point where they are considered relatively stable or because they have open policies toward reprocessing for the very purpose of moving toward nuclear weapons capability.

It is widely believed that, because reprocessing facilities are not economically justifiable on a small scale and are marginally economic on a commercial scale, countries with small nuclear energy programs would profit by joining together in reprocessing. A second assumption is that a nation's concern over uncertain energy supplies may be mitigated by partial control over a reliable fuel supply entity. This aspect of international policy is generally referred to as "fuel assurance."[1]

The U.S. has made many pronouncements concerning the multinationalization of certain fuel cycle activities. Institutional issues have been discussed in several reports and, in general, the political acceptability of any nuclear energy-related multinational scheme hinges, to a great extent, on the nature of fuel assurances.[2] It is becoming increasingly clear that a bilateral commercial agreement between the U.S. and a foreign nation is no longer sufficient to assure foreign nation that they will receive uninterrupted supplies of nuclear fuel in exchange for foregoing the construction and operation of sensitive fuel cycle facilities.

B. Legislation Relevant to Multinational Undertakings

1. The Nuclear Non-Proliferation Act of 1978 - Pub. L. No. 95-242. The Nuclear Non-Proliferation Act of 1978 pays a great deal of attention to providing adequate nuclear fuel supplies to U.S. nuclear trading partners. The entirety of Title I of the Act addresses initiatives intended to foster trust in the U.S. as a reliable fuel supplier.

Section 101 declares, as national policy, that the U.S. will assure fuel supplies to those countries subscribing to U.S. non-proliferation measures. It also mandates that exports of fuel to those nations must be approved by NRC "on a timely basis," usually meaning in time to avoid any major complications or misunderstandings.

Section 102 directs the U.S. to expand its enrichment capabilities, presumably to assure that fuel commitments made by the U.S. to foreign trading partners can be realistically fulfilled. This section also contains language indicating that export licensing proceedings and the conclusion of Subsequent Arrangements must be completed "with minimum time delay."

Section 103 requires the President to undertake a study to determine the need for increased enrichment capacity. This study is to take into account foreign as well as domestic fuel needs.

Section 104 is the most relevant to the creation of a multinational fuel cycle facility. It requires the President to institute prompt discussions with both supplier and recipient nations to develop international approaches to worldwide nuclear fuel assurances. These discussions are to consider, among other things, the establishment of an International Nuclear Fuel Authority (INFA) which would operate between supplier and recipient nations to ensure reasonable fuel supplies. INFA is to operate under conditions dictating that nonnuclear weapons states permit IAEA safeguards on all peaceful nuclear activities, that they not manufacture or otherwise acquire nuclear explosive devices, that they not establish any new enrichment or reprocessing facilities not already in place, and that they place all existing sensitive facilities under "international auspices and inspection."

Section 104 also dictates that discussions should be initiated to establish feasible and environmentally sound approaches, under international auspices and subject to international inspection, to siting, development, and management of all fuel cycle facilities. It is mandated that establishment of repositories for spent fuel under international auspices involving inspection and institutional arrangements should be considered in these discussions; and that nations placing spent fuel in such repositories should receive "appropriate compensation" for the energy content of such spent fuel. Development of sanctions for violation or abrogation of the agreement is also called for.

The President is directed to prepare a proposal for initial fuel assurances and for the creation of a stockpile of low-enriched uranium sufficient to support 100,000 MWe in light water reactors. This stockpile is to be available to assure nations adhering to U.S. non-proliferation policy of adequate fuel on a timely basis in the event of a shortfall in supply or a problem not related to non-proliferation.

Lastly, Section 104 mandates that no binding agreement for performance of the goals stated above can be made final without the approval of Congress by concurrent resolution. Of course, if a treaty is involved, congressional participation is mandated by the U.S. Constitution.

2. The International Security and Arms Export Control Act of 1976-Pub. L. No. 94-329. This Act amended the Foreign Assistance Act of 1961 by adding new Section 669 which specifies that no funds under this Act (and certain others) may be used for economic assistance, grants for military training and education, or military credits to any foreign country which (1) delivers sensitive equipment, materials, or technology to any other country, or (2) receives sensitive equipment, materials, or technology from another country unless both countries agree, in advance, to place all such items under international auspices and management when available and unless the recipient country agrees to place all nuclear facilities under IAEA safeguards. This Act indicates that Congress does not equate IAEA safeguards with international auspices and management. The questions of the exact meaning of international auspices and management and when they are to take effect are the subject of present debate; no clear concensus has been reached.*

3. The International Security Assistance Act of 1977 - Pub. L. No. 95-92. This Act, passed one year later, further amends the Foreign Assistance Act of 1961 by revising the amendment made the prior year. Section 669, added previously, was changed to address only enrichment technology and a new Section 670 was added to cover reprocessing. Several peripherally important provisions were also added.

As to enrichment, the conditions stipulated in the old Section 669 were retained intact. Essentially what was added was that the President can

---

*This debate is discussed in detail later in this chapter.

override a cutoff decision if he finds that it will have serious adverse effects on vital U.S. interests and that assurances have been provided that no acquisition or development of nuclear explosives is related to the enrichment facility.

New Section 670 flatly prohibits transfers of reprocessing facilities on any grounds and adds that detonation of any nuclear explosive device by a nonweapons state is also grounds for an economic cutoff. Notably, no conditions are given under which a transfer of reprocessing technology is allowed.

This Act also directs the President to study several possible impacts of international transfer of technology in order to determine whether current U.S. policy should be altered.

4. The Public Works Appropriation Act for FY 78 - Pub. L. No. 95-108. This Act made funds available for study of how the Barnwell Nuclear Fuel Plant could be used to support non-proliferation objectives and to contribute to International Nuclear Fuel Cycle Evaluation (INFCE)-related activities, provided that nuclear fuel will not be reprocessed there.

5. The Export-Import Bank Act Extention of 1978 - Pub. L. No. 95-143. This Act provides that the Export/Import Bank cannot approve a loan or financial guarantee for any export involving nuclear power, enrichment, reprocessing, research, or heavy water facilities until the proposal has been before Congress for a 25-day period.

It also establishes a system for the Secretary of State to report certain undesirable foreign nuclear actions to the Bank after which the Bank may not approve any future financial transactions with the country involved. Presidential override of such a decision is provided for in the Act. The actions triggering such a situation include the abrogation, violation, or termination of IAEA safeguards or an Agreement for Cooperation and the explosion of a nuclear device by a nonweapons state.

6. The Department of Energy Act of 1978 - Pub. L. No. 95-238. This Act has several provisions relevant to international fuel assurance problems. It authorized $20 million for research for international spent fuel disposition and $13 million for research activities at the Barnwell Nuclear Fuels Plant related to alternative fuel cycles. An additional one million dollars was appropriated to determine if Barnwell could be used to promote U.S. non-proliferation objectives.

The Act also authorized $20 million to be spent undertaking studies, in cooperation with other nations, on the general feasibility of expanding the capacity of spent-fuel stores. These funds cannot be spent on repurchase, transport, or storage of any foreign spent fuel unless the President determines that there is an emergency situation and that such expenditure is in the interest of national security. In this event, the President must notify Congress of his decision with a detailed explanation and justification; Congress then has 30 days before the transaction is made to vote disapproval.

7. Senate Endorsement of the President's Nuclear Initiatives S.R.-40. This Senate Resolution endorsed actions to curb the spread of sensitive facilities, to foster acceptance of international nuclear safeguards, to explore international fuel services, to seek agreement on sanctions against nations acquiring nuclear explosives, and to strengthen IAEA safeguards.

C. The Nature of the Potential Multinational Agreements for International Cooperation in Nuclear Energy Development

The nature of an international agreement is potentially very broad. Although the term "treaty" normally refers to an international agreement which requires approval of a two-thirds majority of the Senate, an executive agreement can be employed to achieve the same ends. International executive agreements generally fall into the following three categories: (1) agreements or understandings entered into pursuant to or in accordance with specific legislation, (2) those not given effect without subsequent congressional approval, and (3) those made by the Executive solely on the basis of Constitutional powers.

An executive agreement to the formation of the INFA would most probably be of the second type. This is because NNPA specifically stipulates in Sec. 104(f) that no binding international agreement may be negotiated until it is approved by concurrent resolution of Congress. This section recognizes that such an undertaking could be concluded by the Executive in absence of further congressional guidance and seeks to mitigate that possibility. This route is more likely than negotiations for an actual treaty because of the commonly accepted notion that a concurrent resolution of Congress is more easily attained than a two-thirds majority of the Senate.

REFERENCES

1. See generally, Thomas Neff and Henry Jacoby, "Nuclear Fuel Assurance: Origins, Trends, and Policy Issues," Massachusetts Institute of Technology Energy Laboratory, Report No. MIT-EL-79-003, February 1979.
2. Myron B. Kratzer and E.F. Wonder, "Institutional Arrangements for the Reduction of Proliferation Risks," International Energy Associates, Ltd., in preparation.

III. THE MULTINATIONAL FUEL CYCLE FACILITY

As with any relatively new area of international law and policy, the range of potential institutional arrangements to establish INFA is very broad and experience with various types is relatively limited. Institutional arrangements for international nuclear commerce are coming under increasing scrutiny as concerns over proliferation points increasingly to their necessity.

The compilation and selection of appropriate international institutional arrangements are beyond the scope of this report. Instead, this report sets out to examine the problems which might be faced, primarily by the NRC, although to a lesser extent by other related domestic agencies, in the establishment and operation of a domestically located INFA.

To simplify this examination of potential NRC problems, a high degree of involvement by the U.S. is assumed for purposes of this report. However, extensive U.S. participation may not be provided for in the agreement which ultimately creates and governs INFA. To make membership more attractive to those nations considering indigenous sensitive facilities, major concession may be required on the part of the U.S. Government, and it is likely that the U.S. will concede some of its sovereign authority over the affairs of INFA.

A. The Functions of INFA

The major thrust of most current non-proliferation measures is to curb the development of reprocessing capabilities in nonweapons states. Many nations with small nuclear energy programs are currently experiencing or can foresee a shortage of storage space for their spent fuel. The fact that spent fuel contains recoverable fissile material makes recycling appear to be a desirable option. A still stronger incentive is the possibility of interrupted energy supplies due to supplier nations' political disposition and the unilateral and multinational changes in market conditions which may result.

It can be expected that member nations will demand sufficient control over INFA to assure that continued operation to their benefit will not be unilaterally curtailed by the host nation — in this case the U.S. As a minimum condition, INFA will have to be able to supply fuel to the power reactors and receive the spent fuel of member nations regardless of U.S. policy changes. At a minimum, therefore, INFA, as contemplated here, will receive foreign spent fuel for storage and ship new fuel to foreign power reactors.

B. Structure of INFA

INFA will have to be controlled by a multinational body, at least to the extent that member nations will feel reasonably assured of uninterrupted fuel supplies. The particular structure of the controlling body has been discussed in several other studies and need not be extensively covered here.[1]

Most discussions of this concept contemplate a two-tiered structure with the multinational controlling body making policy decisions and a lower tier making operational decisions and performing operations. The extent to which the operational tier is under host-nation authority is variable.

Under some schemes the operational tier of INFA is wholly national with the facility under international safeguards. At the other extreme the entire operation of the facility is under multinational control and staffed by foreign nationals from member nations.[2]

C. The International Nuclear Fuel Authority as Contemplated in the Nuclear Nonproliferation Act

Present U.S. policy in international nuclear commerce is, for the most part, dictated by the provision of the Nuclear Nonproliferation Act of 1978 (NNPA). At this time, the application of NNPA to the more complex issues surrounding the furtherance of non-proliferation objectives and worldwide development of nuclear energy is still taking form.

The NNPA offers insights into the institutional objectives of Congress in establishing a multinational fuel cycle facility. The provisions of the act itself give a broad indication of how U.S. policy in this area should develop. The legislative history of these provisions relating to the establishment of what Congress considered INFA to be gives further insights into what Congress, which must approve any such arrangement,[3] might deem acceptable.

1. Congressional Intent. It is acknowledged in congressional discussions before passage of the Act that in order to ask countries to forego reprocessing and use of plutonium fuel the U.S. must provide some incentives:

> we are, in fact, asking other nations to deter voluntarily commercial reprocessing and the premature use of plutonium around the world. This is important because plutonium carries with it the spector of nuclear holocaust either at the hands of terrorists should they obtain this material or as a result of nations' misappropriating nuclear materials from their peaceful nuclear programs.
>
> In addition, the administration will be renegotiating all the agreements of cooperation in order to incorporate more stringent non-proliferation conditions on our nuclear exports. Our policy cannot succeed, however, if it is based solely on denials and controls. We need to offer other nations adequate incentives — there needs to be the carrot with the stick, and big carrots, big incentives — to get other nations to abide by non-proliferation restraints. One of these is to offer them reasonable alternatives to reprocessing, such as the opportunity to return spent fuel to the United States.
>
> We provide in this bill quite a number of incentives to get nations to refrain from reprocessing. INFA, the International Nuclear Fuel Authority, is one, whereby nations will be able to buy their fuels from apolitical, guaranteed international sources. Along with that, we are trying to reduce the time needed for the licensing processing, so that purchases of fresh fuel supplies from the United States will be attractive, again as an alternative to reprocessing. So we are not without incentives in this bill.[4]

It was stressed that fuel assurances from a reliable entity are of prime importance:

> Of perhaps equal importance as an inducement against proliferation is the granting of nuclear fuel assurances to those nations which have no abundant-indigenous energy resources. No nation, the United States or any other nation, wants to be dependent on others, if possible, for its nuclear fuel supply. But there is some evidence from discussion with other nations that fuel assurances if decoupled from the political winds of the moment or attitudes of the moment of a given supplier nation would be looked upon as an attractive alternative to the construction or importation of reprocessing

> facilities for the purpose of separating plutonium as an independent source of fuel.
>
> In other words, Mr. President [President of the Senate], I believe it highly advisable to consider an International Nuclear Fuel Authority to which supplier nations could sell fuel and from which user nations could buy fuel—and most importantly, on a reliable apolitical basis; in other words, a more guaranteed supply than these user nations now feel they have.
>
> The obvious benefit is that those nations buying from such an assured fuel supply would no longer need the assurance previously sought by owning their own reprocessing plant, which, of course, would carry with it the potential side effect of plutonium production and with that the possibility of nuclear weapon production.[5]

Congress also expressed a willingness to work toward interim solutions, recognizing that establishment of INFA was not imminent, by authorizing the President to establish a stockpile of fuel to be used pursuant to international contracts with those nations adhering to U.S. non-proliferation policies.[6]

It was also made clear that Congress contemplated a full fuel cycle authority.

> INFA would deal with both the front and the back end of the fuel cycle. It could run repositories for the storage of spent nuclear reactor fuel and would provide for nations placing spent fuel in such repositories to receive appropriate compensation for the energy content of the spent fuel, if recovery of the energy content is deemed necessary or desirable.[7]
>
> Accordingly, this bill, S.897, contains a set of provisions for starting the U.S. along the path of international cooperation toward the establishment of fuel assurances through such an organization. An international nuclear fuel authority, INFA as we refer to it, which would deal with all aspects of the fuel cycle, including provision for the storage of spent fuel in facilities under international auspices. As an initial step, provision is made, subject to congressional review, for the President to indeed go ahead and set aside an amount of low-enriched nuclear fuel.[8]

The act was amended at one point to reflect Congress's concern that the discussions surrounding establishment of INFA might be unduly restrained by the non-proliferation objectives of the overall act:

> The President is authorized to broaden the INFA discussions to include fuel fabrication, enrichment services, reprocessing, and other nuclear fuel cycles services.... The INFA discussions...should be balanced and not prejudicial to existing technology unless clearly superior technologies are forthcoming....[9]
>
> [The Act also] provides latitude for enrichment and reprocessing facilities if they are established and operated on an internationally acceptable and agreed-upon basis, such as regional fuel cycle centers.[10]

Congress indicated its view that the U.S. should not induce membership by offering U.S. fuel free of charge:

> I would add one thing to that: it was my view when we put in this International Nuclear Fuel Authority provision that this was not a giveaway of our resources in this country. I saw this stockpile and this bank as being a pool into which we would sell our nuclear fuel and other nations perhaps, following our lead, would do the same thing.[11]

There is sentiment to be found in Congress that domestic siting of INFA may be acceptable and even desirable:

> I say it is more dangerous to have it [INFA] in some remote area, easily accessible to some terrorist or some irresponsible chief of state and his forces, than to have it right here.
>
> Second, the U.S. must demonstrate to others that we are willing to accept our fair share of the burden of solving the problem of providing secure storage for spent fuel produced in non-nuclear-weapon states if we are to convince them that we want to make certain that they take a share of it and we are left only with a fair share of it.
>
> Last,... I simply say that, under certain circumstances, assistance to another country with regard to spent fuel can provide a significant incentive to accept effective non-proliferation controls by providing additional time for the development of secure nuclear cycle facilities, especially international storage.[12]

2. The Structure of INFA as Related to Congressional Intent. The low-enriched uranium stockpile which NNPA seeks to establish is not meant to be allocated directly to an international or multinational entity. Instead, it is to be used as a guaranteed interim reserve to assure U.S. nuclear trading partners adhering to effective non-proliferation policies of fresh reactor fuel in the event of an unforeseen interruption of U.S. supply policies.[13] The stated purpose of establishing INFA is to provide a nonweapons state with a desirable alternative to indigenous reprocessing or enrichment facilities which, the Act clearly states, can only be achieved through adequate assurances of fuel supplies and waste management.[14]

Thus, what is contemplated here is an international organization, residing in the U.S., which can contract to buy and sell nuclear fuel in the form of low-enriched uranium for member nations (or even nonmember nations) with the understanding that the organization will enjoy adequate sovereignty to permit interruption of fuel supplies by the political actions of one or several nations acting in minority and independently. In plain language, the host nation (the U.S.) and supplier nations must not have the legal power to cut off fuel supplies to participants for reasons other than those previously agreed upon.

Congressional discussions have indicated that INFA must have the capacity to store spent fuel for other nations and must guarantee that the nation sending its spent fuel receive compensation for the energy value of the spent fuel (presumably calculated as if reprocessing had occurred).

While the act specifically allows discussions and negotiations concerning INFA to include sensitive technologies, it is assumed in this case that reprocessing will not occur initially and that enrichment services will be contracted from existing national and multinational sources. The institutional concepts including spent fuel storage and enrichment will appear later in this Chapter.

In the proposed concept, the international organization would, for the most part, represent a marketplace where consumers and suppliers could conduct business in a suitably nonpolitical environment. This necessarily requires the U.S. to give up some sovereignty in dictating the conditions of international nuclear commerce. INFA would most likely be an international organization as contemplated in the International Organizations Immunities Act.[15] The initial agreement would concern storage of spent fuel and contractual arrangements for sale of fresh fuel directly to and from INFA. In effect, an embargo against a particular nation could arise only from a decision by the multinational controlling body, since supplier nations could no longer unilaterally dictate where their fuel is to be sold or not sold except by prior agreement. This seems to indicate that U.S. export licensing procedure would treat INFA as it does any foreign nation. Once a license to "export" fuel or components is granted to INFA, the U.S. may lose its right to direct specifically to what nation the fuel goes. This would be true for any supplier selling to INFA.

It is assumed that nations will be willing to send their spent fuel to such an organization if they are guaranteed the benefits of reprocessing (equivalent energy content) without establishing indigenous reprocessing capability.

The only facilities associated with INFA which would fall under NRC scrutiny would be the spent-fuel storage facility, the fuel shipment and spent-fuel receipt areas, and the facilities needed to fabricate the particular fuel assemblies required for specific reactors in member nations. There is a question of the limits of authority NRC could have in these places, however, because of the inviolability of the premises. IAEA safeguards would be applied to all aspects of the facilities, and it is assumed that continuing NRC authority could be negotiated in areas of physical security as well as public health and safety.

REFERENCES

1. See "Regional Nuclear Fuel Cycle Centers," 1977 Report of the IAEA Study Project, Vienna, 1977, ISBN92-0-159177-2; Chayes and Lewis, *International Arrangements for Nuclear Fuel Reprocessing*, (Ballinger, Cambridge, 1977); Jacoby and Neff, "Nuclear Fuel Assurance: Origins, Trends, and Policy Issues," M.I.T. Energy Laboratory, Report No. MIT-EL-79-003, February 1979.
2. Id.
3. Nuclear Nonproliferation Act of 1978, Pub. L. No. 95-242, Sec. 104(F)(1).
4. 124 Cong. Rec. S 1,325 (daily ed. Feb. 7, 1978) (remarks of Sen. Glenn).
5. 124 Cong. Rec. S 1,064 (daily ed. Feb. 2, 1978) (remarks of Sen. Glenn).
6. 124 Cong. Rec. S 1,318 (daily ed. Feb. 7, 1978) (letter to Sen. Hollings from Sen. Glenn).
7. Id.
8. 124 Cong. Rec. S 1,064 (dail ed. Feb. 2, 1978) (remarks of Sen. Glenn).
9. 124 Cong. Rec. S 1,098 (daily ed. Feb. 2, 1978) (remarks of Sen. Church).
10. Id.
11. 124 Cong. Rec. S 1317 (daily ed. Feb. 7, 1978) (remarks of Sen. Glenn).
12. 124 Cong. Rec. S 1326 (daily ed. Feb. 7, 1978) (remarks of Sen. Percy).
13. Nuclear Non-Proliferation Act of 1977 - Report together with additional

views to accompany S.897 - Reported by the Committee on Government Affairs, the Committee on Foreign Relations, October 3, 1977, Senate Report No. 95-467, p. 7.

14. Id.
15. 22 USC 288a.

IV. POTENTIAL PROBLEMS RELATED TO DOMESTIC AUTHORITY OVER INFA

The issues surrounding construction and operation of a domestically sited INFA can be grouped into four general categories. These are the problems related to jurisdictional issues, licensing, regulatory compliance, and IAEA participation. The broad areas of sensitive technology transfer and optional institutional arrangements are not within the scope of this report and are examined elsewhere.[1]

The specific issues associated with each category are discussed below so that application to the candidate arrangement may follow.

A. Jurisdictional Issues

INFA must have the power to perform legal and financial transactions. Jurisdictional issues are concerned with the legal stature which INFA may have relative to the host nation and the rest of the world. While many multinational and international organizations exist, they are very divergent in purpose and constitution. The elements of the jurisdictional character of the INFA are its privileges and immunities, tort and financial liability, power to contract, taxation, and tax liability, and financing and ownership.

1. The Concept of Sovereign Immunity*. Sovereign immunity is a concept which allows that, under certain circumstances, a foreign state entity, institution, or nation is exempt from local jurisdiction in the courts of the host nation. By treaty and custom, more particular doctrines of diplomatic immunity exist. Sovereign immunity, as a general rule, acts to limit the ability of national courts to inquire into the legality of actions by foreign sovereigns and organizations.

There are, currently, two competing concepts of sovereign immunity which developed as concern heightened over the repercussion of the personal actions of foreign nationals. These two concepts are the absolute theory and the restrictive theory. Under the absolute theory of sovereign immunity, a sovereign cannot be made a respondent in the courts of another sovereign under any circumstances. Under the restrictive theory of sovereign immunity, the sovereign is immune with regard to sovereign or public

---

*For a more detailed discussion of sovereign immunity the reader is referred to pp. 43-46 in this Chapter.

acts of the state, but not with regard to private acts. With the exception of the Soviet Bloc countries, the restrictive theory has been almost universally adopted.

The distinction between "private" and "public" acts is not always easy to draw. In international law, the distinction lies within the objective and nature of the action. Of course, such things as traffic accidents and larceny are considered private actions. Problems of distinction arise with regard to such matters as the financial transactions of foreign entities. Generally, if the action in question involves entities which are managed and exploited by a nation mainly for commercial or industrial purposes, its actions are considered to be private. The leading case in international law addresses the distinction between public and private acts denied sovereign immunity to a foreign sovereign stating that when a state acts "in the sphere of its civil personality and performs acts of essentially private nature which might have been done by any individual," it is a private action.[2] This language is meant to draw the distinction between administrative contracts concluded by the national state in the exercise of public power and contracts concluded by it in its private capacity.

When the contractual method for reaching an agreement is in the form described by the rules and procedures of private law, it is considered a private action for which there is no grant of sovereign immunity. On the other hand, when an international agreement is reached in exercise of public power and for the satisfaction of a public interest, it is a public act and, therefore, not subject to suit.

The level of sovereign immunity to be enjoyed by INFA is of great importance. On the one hand, the attractiveness of membership in INFA will largely depend on the difficulty under international law which the U.S. faces in unilaterally modifying or terminating operation of the facility. On the other hand, the U.S. has a legitimate interest in the safety, environmental effects, security, and other related impacts of the facility as it operates on U.S. territory. Absolute immunity would dictate that no violation of those legitimate interests is sufficient justification for the U.S. to unilaterally impose a change in the activity of INFA. Clearly, a large release of toxic or radioactive material would be legitimate grounds for a temporary shutdown of operations at the facility, but the U.S. might be restrained from legally compelling such a shutdown on a unilateral basis if absolute immunity is designed into the institutional arrangement.

This can be expected to be a major point in negotiations since it seems reasonable that the members of INFA would allow temporary shutdown in emergency situations, but would object to any blanket U.S. authority for such an action.

The Foreign Sovereign Immunities Act of 1976[3] addresses these points. This act delimits the sovereign immunity of "foreign states" including "agency or instrumentality of a foreign state." If the international instrument which establishes INFA is mainly commercial in nature, it will enjoy only the sovereign immunity granted by this Act. Generally, any "commercial activity" associated with operation of INFA would not enjoy immunity.

The Act also delimits immunity from attachment and execution on foreign property. Primarily commercial activity of a foreign state will not enjoy immunity from attachment and execution on property. In other words, if the institutional structure of the INFA control and operation is commercially oriented, seizure of the property arising under a law suit filed in a U.S. court is certainly possible.[4] This may not be acceptable to member nations since the nature of a seizure of the facility by the U.S. could be interpreted as legal under domestic and international law regardless of international concensus.

If the international legal instrument used to create INFA specifies that, and the President designates that, it is an "international organization," the International Organization Immunities Act[5] grants a somewhat different set of immunities to INFA although the distinction between the two types of immunities is unclear. This act gives international organizations the power to contract, acquire, and dispose of real and personal property, and to institute legal proceedings. It also grants the same immunities available to foreign governments which indicates that actions are presumed to be "public acts." This immunity can be waived by an international organization for the purpose of any proceeding or contract.

The act also grants immunity to international organizations from search and confiscation and expressly makes the archives of the organization "inviolable."[6] In terms of customs, duties, internal revenue taxes, registration of foreign agents, and treatment of official communications, all privileges and immunities for an international organization are the same as for governments.[7] The act also exempts such organizations from federal property taxes.[8]

The International Organization Immunities Act also grants privileges and immunities to those duly notified to and accepted by the Secretary of State as representatives, officers, or employees, designated by the Secretary of State as prospective representatives, officers, or employees, and members of the family, suit, or servant to those above.[9] It is pointed out, however, that the act does not grant "diplomatic" status and only allows those privileges and immunities specifically set forth in the act.[10] Those specific privileges and immunities essentially grant immunity from suit and legal process relating to acts performed in an official capacity falling within the functions of the position held.

2. Tort and Financial Liability. The type of immunity from liability which employees of INFA or INFA itself would enjoy is not clear. It is assumed that the President and Congress would agree to designate INFA as an "international organization."

In terms of tortious liability, the Foreign Sovereign Immunities Act dictates that any occurrence falling outside the scope of official actions would be subject to suit in a U.S. court as would any action which causes

> "personal injury or death, or damage to or loss of property, occurring in the U.S. and caused by the tortious act or omission of that foreign state or of any official or employee of that foreign state while acting within the scope of his office or employment...except [in the performance of a discretionary function...."[11]

The International Organization Immunities Act states that:

> (a) Persons designated by foreign governments to serve as their representatives in or to international organizations and the officers and employees of such organizations, and members of the immediate families of such representatives, officers, and employees residing with them, other than nationals of the U.S., shall, insofar as concerns laws regulating entry into and departure from the U.S., alien registration and fingerprinting and the registration of foreign agents, be entitled to the same privileges, exemptions and immunities as are accorded under similar circumstances to officers and employees, respectively, of foreign governments, and members of their families.
>
> (b) Representatives of foreign governments in or to international organizations and officers and employees of such organizations shall be immune from suit and legal process relating to acts performed by them in their official capacity and falling within their functions as such representatives, officers, or employees except insofar as such immunity may be waived by the foreign government or international organization concerned.[12]

It is interesting to note that U.S. citizens working on the staff of INFA would not be immune from any suit brought against them in the U.S.

In terms of financial liability, the same standard applies except that "property of those organizations designated by the President as being entitled to enjoy the privileges, exemptions, and immunities provided by the International Organizations Immunities Act" shall not be subject to attachment.[13]

In effect, the Foreign Sovereign Immunities Act grants no immunity to foreign sovereigns from suits arising from personal, private, or tortious actions but specifically singles out the property of an International Organization as being immune from attachment in a liability suit.

Since the type of fuel cycle facility contemplated in this report carries with it few of the potentials for catastrophic accidents that a power reactor has, it is assumed that liability insurance could be secured from a standard commercial source as is done in most industrial ventures.

3. Power To Contract and Power To Institute Legal Proceedings. The International Organizations Immunities Act specifically grants organizations designated under the act the powers:

> (i) to contract
> (ii) to acquire and dispose of real and personal property
> (iii) to institute legal proceedings[14]

This provision, in effect, grants INFA the powers necessary to conduct business.

The Act also exempts international organizations from property taxes imposed by the federal government:

> International organizations shall be exempt from all property taxes imposed by, or under the authority of, any Act of Congress, including such acts as are applicable solely to the District of Columbia or the Territories.[15]

In the absence of a provision to the contrary in the agreement forming the international organization, states are free to enact legislation concerning property taxation. In New York, the United Nations enjoys an exemption in the New York Real Property Taxation Law. This is something which can be expected to be resolved during multilateral negotiations. It may happen that states desiring such a facility will exempt it from local property tax in order to attract the presumably large influx of revenue which it may be expected to bring with it.

4. Financing and Ownership. Unless the facility in question is owned by the multinational organization, the premises would probably not be inviolable and would simply be subject to law governing national enterprises. It is important to bear in mind that the inviolability of the premises is of prime importance in making the INFA attractive to member nations.

Financing may be available through several of the Development Banks or possibly through the Export/Import Bank. Describing the actual mode of financing is beyond the scope of this report; it is important to note, however, that the attractiveness of membership in INFA will depend, to a great extent, on multinational ownership and, therefore, control. This practically negates the desirability of a national facility in the U.S. controlled by a multinational body.

B. Licensing

INFA will be subject to some degree of domestic authority. It can be assumed that some assurances of the safety and security of the facility will be sought by the U.S. Government and that the NRC licensing process — or at least part of it — may be the method for obtaining those assurances. Environmental impact and general siting concerns may also be addressed in the licensing context. Other licensing elements which are considered are export licensing and physical security.

1. General Facility Licensing. The inviolability of the premises owned by INFA will weigh less against NRC licensing than it will against compliance with the conditions of the "license." The U.S. has a legitimate interest in protecting the health and safety of the American public and would consider that interest in a licensing proceeding. Since the INFA could be formed only by an executive agreement with congressional approval, it is assumed that a judgment as to the inimicality to the common defense and security would not be left solely to NRC. Instead, the licensing proceeding would probably deal with setting technical standards for safe operation, siting, environmental impact, material balance accounting, and physical security.

Since NRC would not have the power to unilaterally modify or limit operation of the facility once operating, it is probable that technical standards signaling problems of sufficient concern to cease or modify operations would be agreed upon in advance. These technical standards would be negotiated at the licensing proceeding to ensure the safety of the public.

Siting decisions would be arrived at in the licensing proceeding. The fact that the facility would not incorporate a reactor implies that the danger of a large scale accident is mitigated. (It is assumed that the consequence of a possible criticality accident would be minor compared to an accident at a power reactor.) Siting may be a problem from the standpoint of transportation (both international and domestic) of spent and new fuel. A coastal site may be desirable from that standpoint since it affords direct access to international transportation corridors. Siting may also be decided in advance during international negotiations leaving NRC with only a veto power over the chosen site.

2. Export Licensing. In terms of export licensing, NRC would be empowered only to export to the INFA and not to certain members. In effect, the U.S. would lose its control over the destination of new fuel or the source of spent fuel. This, of course, is the major purpose of INFA — the apolitical application of fuel assurances. The particular application of the export licensing process as outlined in the Nuclear Non-Proliferation Act of 1978 to INFA is beyond the scope of this report and is the subject of another report in Chapter Two.

3. Material Control and Accounting (MCA). The U.S. would clearly want to approve the material control and accounting schemes developed for INFA operations. The INFA accounting scheme would probably be the "state system" which IAEA would verify. NRC will most likely not have the authority to interact directly with MCA once it has approved it, relegating this duty to the IAEA. The insulation this provides is of prime importance in the perception of guaranteed fuel supplies.

4. Physical Security. Physical security is an area where ongoing U.S. responsibility is likely. At a minimum, off-site response capabilities must be arranged for and judged adequate to ensure the safety of the public. Because of the nature of the inviolability of the premises involved, it is doubtful that on-site U.S. security would be employed; there would probably be a licensed contract guard force subject to the same scrutiny that accompanies present NRC licensing procedures. Because of the sensitivity of the facility premises and the various scenarios possible, a comprehensive agreement concerning the response of off site security personnel to on-site contingencies should be negotiated.

5. Environmental Impact. There is little doubt that participation in the establishment of INFA would be a major federal action significantly affecting the environment and, therefore, necessitating the preparation of an environmental impact statement. The lead agency in the preparation of the environmental impact statement may be NRC or DOE.

C. Regulatory Compliance

It must be recognized that the U.S. Government will not have sole power to shutdown or otherwise act to interfere with continued operation of the INFA, except in situations agreed upon in advance with other member nations. Still, the U.S. will want to monitor some conditions at the facility that are considered domestically important. The regulatory framework as it is laid out provides a mode for monitoring those conditions.

It is assumed that the U.S. may want to monitor off-site releases and waste streams. It is expected that the Environmental Protection Agency will take some responsibility, especially to the extent that nonradiological hazards are concerned.

Regulatory compliance may well be limited to compliance with technical standards previously agreed upon. If monitoring revealed a violation of those technical standards, the U.S. could demand a modification of procedure or operation to alleviate the problem. A mechanism for enforcing such a demand should be arranged in advance.

D. IAEA Participation

Since IAEA will apply safeguards to INFA, the relationship between the U.S., INFA, and the IAEA must be established. The nature of the involvement will be dictated primarily by the relationship of the U.S. and INFA. INFA would, most likely, be looked upon as a "state" and safeguarded by the IAEA in a manner consistent with that concept. The U.S. would be on a parity with other members except when host-nation interests are directly involved. As such, the IAEA may not report directly to the U.S., but rather through its normal reporting mechanisms.

REFERENCES

1. See Regional Nuclear Fuel Cycle Centers, 1977 Report of the IAEA Study Project, Vienna, 1977, ISBN92-0-159177-2; Chayes and Lewis, *International Arrangements for Nuclear Fuel Reprocessing*, (Ballinger, Cambridge, 1977); Jacoby and Neff, "Nuclear Fuel Assurance: Origins, Trends, and Policy Issues," M.I.T. Energy Laboratory, Report No. MIT-EL-79-003, February 1979.
2. *State of Rumania v. Trutta*, 26 Am. J. Int'l. L. Supp. 629 (1932).
3. Publ. L. No. 94-583, 28 USC 1602.
4. 28 USC 1609.
5. 22 USC 288a-f.
6. 22 USC 288a(c).
7. 22 USC 288a(d).
8. 22 USC 288c.
9. 22 USC 288d(a).
10. 22 USC 288e(c).
11. 28 USC 1605(5)(A).
12. 22 USC 288d(a)(b).
13. 28 USC 1611(a).
14. 22 USC 288a(a).
15. 22 USC 288c.

Institutional Issues Associated With Spent Fuel Storage Under Domestic And International Auspices

John N. O'Brien

NUREG/CR-2216, BNL-NUREG-51413
March 1981

TABLE OF CONTENTS

Page
I. Introduction 25
  A. Statement of the Problem 25
  B. Purpose of this Report 26
  C. Scope of Study 27
II. AFR Storage Facility Under Domestic Auspices 27
  A. Functions, Operation, and Safeguards 27
  B. Jurisdictions 29
  C. Costs, Pricing and Liability 33
  D. Existing Regulation 35
  E. Pending Legislation 38
III. AFR Storage Facility Under International Auspices 40
  A. Function of an International AFR Storage Facility ... 40
  B. Sovereign Immunity 43
  C. Characteristics of International Organizations 46
  D. Potential Institutional Alternatives for International Auspices 57

ABSTRACT

This report examines the various institutional issues associated with the establishment of away-from-reactor (AFR) spent fuel storage. Technical factors contributing to the problem of spent fuel congestion are briefly reviewed and differing projections of capacity shortfalls are discussed.

Section II analyzes the institutional considerations pertinent to the establishment of a domestically constructed and operated AFR facility. This section discusses facility characteristics, federal agency jurisdictions, the state/federal interface, and financial arrangements.

Section III discusses the problems associated with establishment of an AFR storage facility under international auspices. This section discusses international auspices, appropriate compensation for energy content, and sovereign immunity. A comprehensive description of the organization and structure of international organizations is presented. Recommendations are made for the organization and structure of an international AFR.

I. INTRODUCTION

A. Statement of the Problem

Light Water Reactors (LWRs) operate on low enriched uranium (LEU) which is uranium in which the content of the U^{235} isotope has been "enriched" from the natural concentration of about 0.7% to 3 to 4%. It is then pressed into small pellets which are put into long stainless steel tubes called fuel rods. These fuel rods are put into "bundles" which typically contain 64 fuel rods in Boiling Water Reactors (BWR) and 264 rods in Pressurized Water Reactors (PWR). The number of fuel bundles in the reactor core is typically 190 in PWRs and 760 in BWRs. A typical electric power reactor contains about 100 metric tonnes (MT) of uranium fuel, about one-third of which is replaced yearly. The fuel that is replaced by fresh fuel is called spent fuel and is stored on racks under water in a storage pool at the reactor site.[1]

Only about 1 or 2% of the potential energy in a fuel bundle has been used when it is replaced by new fuel. In the past it was assumed that spent fuel would be sent to a "reprocessing" facility where the unused part of the fuel would be recovered and recycled back into power reactors. Spent fuel was viewed as sufficiently valuable that it could be sold or transferred to a commercial reprocessing facility where it would be recycled at a profit. All plans for nuclear energy production from fuel fabrication to waste disposal took this projection into account.[2]

United States policy changed in 1977 to oppose any type of reprocessing and to promote storage of spent fuel. This policy change was spurred by the recognition that "weapons-grade" material could be extracted during reprocessing, making any nation with a reprocessing facility a potential producer of nuclear explosives. In order to persuade other nations to forgo reprocessing, the United States indefinitely deferred domestic commercialization of reprocessing for purposes of electrical production.

As a direct result of this policy change, spent fuel at reactor sites has been accumulating, because, in absence of reprocessing, there is no place to ship the fuel. Because of the early and universal assumption that reprocessing would naturally follow nuclear reactor development, reactors were built without sufficient storage space for the spent fuel generated during the operating life time of the facility. Therefore, during the lifetime of power reactors now operating, spent fuel will have to be shipped and stored somewhere or the reactors will be forced to shut down.

There are differing projections of when reactors will run out of storage space. Various measures can be taken to increase the storage capacity of spent fuel pools at reactors including reracking, which improves capacity by a factor of over 1.5, and use of neutron-absorbing material, which more than doubles storage capacity. Another option is to "transship" spent fuel from an older to a newer reactor in order to take advantage of unused storage space. A reactor should normally leave enough space in its fuel storage pool to deposit the entire core load. This space, called the full core reserve (FCR), can be used to store spent fuel with no significant decrease in safety. The last solution available is to transfer spent fuel to away-from-reactor (AFR) storage.[3]

Physical alteration of spent fuel bundles may also increase storage capacity by as much as four times,[4] but these methods, which include canning, compacting, or repacking spent fuel bundles, are not fully developed.

A prediction of the time remaining until it is necessary to stop reactor operation must take into account many factors, including:

- The extent of utility rerack efforts
- The number of reactors operating
- The amount of transshipment that occurs
- The length of time each reactor can run on a given quantity of fuel
- Whether FCR is maintained.[5]

The estimates on when AFR capacity will be necessary for continued reactor operations vary widely. For example, DOE estimated that 560 MT of AFR storage capacity will be needed in 1983 with a cumulative total of 3,860 MT storage needed by 1988.[6] However, a recent GAO report takes direct issue with these figures predicting a need for only 152 MT capacity by 1983 and 1,433 MT by 1988.[7] GAO's report, based on a survey of 57 nuclear energy reactor operators, takes into account increased capacity at only those utilities with definite plans to increase capacity, indicating that even its own estimates may be overstated.

An additional factor may arise if the United States, to promote its non-proliferation policy, decides to accept some foreign spent fuel. DOE has anticipated the upper limits of foreign spent fuel acquisition to be from 905 to 5,270 MT by 1992.[8] There is, however, enormous uncertainty in these figures because of the complexity of the foreign affairs accompanying such transactions and the substantial domestic opposition to storing foreign nuclear wastes.[9]

In this report it is assumed that an AFR facility will be built or an existing facility used to accommodate excess spent fuel at some point in the future. Accompanying the construction and/or operation of such a facility, a number of institutional issues will have to be settled. These issues will be largely independent of the actual time frame involved. It is clear that a continuing policy to defer reprocessing will, in time, preclude storage of spent fuel at reactor sites and result in a need for long-term AFR storage. It is also reasonable to assume that, in the event that domestic reprocessing occurs, there will still be a need for interim storage of excess spent fuel before reprocessing.

B. Purpose of the Report

The purpose of this report is to identify and examine the institutional problems which would impede the construction and/or operation of an AFR spent fuel storage facility. Arrangements for AFR storage can vary considerably and different arrangements carry different institutional implications. For instance, the AFR storage facility may be either domestic or multinational. It may be a commercial or a government operation. It may be licensed by NRC or operated solely by DOE without licensing. It may be subject to IAEA safeguards. This report will detail problems of this nature and examine various options.

C. Scope of Study

The scope of this study does not include analysis of various technical methods for spent fuel storage. Nor does it include evaluation of the validity of projections for AFR storage need or the various factors associated with those projections. This study is limited to an examination of nontechnical, institutional issues assuming that an AFR storage facility will be needed in the foreseeable future.

II. AFR STORAGE FACILITY UNDER DOMESTIC AUSPICES

A. Functions, Operation, and Safeguards

It can be assumed that operation of existing nuclear power reactors is dependent upon the future availability of some alternative to at-reactor spent fuel storage presently in place. Even if reprocessing of commercially generated spent fuel takes place in the U.S., the large backlog of spent fuel and limited reprocessing throughput capacity presently available dictate that interim storage will still be necessary.

1. Facility Characteristics and Existing Facilities. A typical water basin AFR storage facility would be required to 1) receive, handle, decontaminate, and reship spent fuel casks; 2) remove irradiated fuel from casks; 3) place the spent fuel in a storage basin; and 4) cool and control the quality of water. An interim storage facility must also be designed for removing spent fuel from storage, loading it into shipping casks, decontaminating the loaded casks, and shipping the loaded casks.[10]

An alternative to water basin storage which has received wide attention is forced-air dry storage of spent fuel which has cooled in water basin storage for at least three to four years.[11]

There are at present three facilities constructed for storage of spent fuel. All three are privately owned, but only two are currently licensed to receive fuel. The General Electric (GE) Morris Plant in Morris, Illinois, had an initial storage capacity of 90 MT projected to increase to 750 MT. At present, about 300 MT of spent fuel are stored there and GE has contracts to accept additional spent fuel from its customers. The Nuclear Fuel Services (NFS) West Valley Plant in West Valley, New York is now storing 170 MT of spent fuel, but NFS no longer accepts spent fuel and has no plans to do so in the future. The Allied General Barnwell Plant in Barnwell, South Carolina, is a completed commercial reprocessing facility which is not licensed to receive spent fuel or otherwise operate, but has about 400 MT of unused storage capacity which could be expanded to about 2000 MT in the future.[12]

The general situation surrounding spent fuel storage is convoluted by several factors. First, new storage facilities could not be made ready in time to ameliorate storage capacity needs.[13] Use of transshipment as a method of aleviating capacity shortages has been set back by an October 31, 1980, ruling by the NRC Atomic Safety and Licensing Board stating that all reracking and neutron poisoning techniques must be used to expand at-reactor capacity before transshipment can be allowed.[14] In another case, San Diego Gas & Electric's San Onofre-1 power reactor, which is running out of at-reactor storage space will be forced to shut down in 1983 because of lack of space. The San Onofre-1 reactor's storage capacity is already insufficient for a full core discharge and has a contract with GE Morris to accept excess spent fuel for storage. However, the Illinois state legislature passed, over the governor's veto, a statute barring acceptance of spent fuel from states which will not reciprocate at similar facilities.[15]

A further complication which will be considered in a later section is that of state and local bans on spent fuel transport. The Department of Transportation proposed regulations for spent fuel transport which would preempt state and local bans in January 1980 and issued its final regulation on January 19, 1981.[16]

2. Safeguards. Spent fuel in storage is not attractive as a target of theft because of its lethal radioactivity and low concentration of plutonium. In addition, spent fuel is not in a form suitable for easily dispersing toxic radioactive materials. Contingency plans required for licensing[17] include NRC approved arrangement for support of local law enforcement personnel. Adequate response time is defined as the time necessary for intruders to gain access, remove fuel elements from storage, transfer them to a shielded container, and place them in a vehicle. A single fuel assembly weighs more than one-quarter of a metric ton and the process of disassembly is time consuming and difficult.[18] Analysis has shown that sabotage is similarly difficult and an unlikely threat to the public health and safety.[19]

Spent fuel in transport is more vulnerable to theft and sabotage because of its increased accessibility. NRC requires physical security for spent fuel shipments similar to that required for all special nuclear material shipments. In addition, concealing a contraband spent fuel storage cask from detection would be very difficult because of the size of the cask and radiation which is emitted. If a stolen shipping cask containing spent fuel were in a one-story storage building, it could be detected by airborne detectors. If it were shielded by placement in a multi-story building or underground garage, it could be detected by mobile surface searching equipment.[20]

3. IAEA Participation. The IAEA would be invited to include an AFR storage facility in its U.S. inspection program. If IAEA were to inspect such a facility, it could use previously developed techniques to verify the operator's claims.

B. Jurisdictions

1. Nuclear Regulatory Commission. In addition to its general authority to regulate source, by-product, and special nuclear materials,[21] the NRC will have licensing and regulatory jurisdiction over a national AFR. Under Section 202, subsection (3) and (4) of the Energy Reorganization Act, NRC has licensing and regulatory jurisdiction over:

> (3) Facilities used primarily for the receipt and storage of high-level radioactive wastes resulting from activities licensed under the [Atomic Energy] Act.
> (4) Retrievable Surface Storage Facilities and other facilities authorized for the express purpose of subsequent long-term storage of high-level radioactive waste generated by the Administration, which are not used for, or are part of, research and development activities.[22]

The NRC has taken the posture that this authority was prospective in intent and has not taken licensing or regulatory jurisdiction over high-level wastes at Savannah River or Hanford.[23] However, NRC has defined spent fuel as "high-level waste," making any AFR subject to the provisions of Section 202.[24] It is possible that an AFR which accompanies a storage site for defense wastes may escape NRC licensing authority because of the word "primarily" in Section 202 (3). If NRC declined to license the facility or DOE did not apply for license, it is probable that litigation would result. Upon receipt, DOE will take title to all spent fuel.[25]

NRC has published regulations for the licensing of AFR storage facilities. These regulations are covered in detail in Section II-D.

2. The Department of Energy. The Department of Energy Organization Act provides express statutory authority over spent fuel storage activities. The functions of DOE include:

> (a) the establishment of control over existing Government facilities for the treatment and storage of nuclear wastes, including all containers, casks, buildings, vehicles, equipment, and all other materials associated with such facilities;
> (b) the establishment of control over all existing nuclear waste in the possession or control of the Government and all commercial nuclear waste presently stored on other than the site of a licensed nuclear power electric generating facility, except that nothing in this paragraph shall alter or effect title to such waste;
> (c) the establishment of temporary and permanent facilities for storage, management, and ultimate disposal of nuclear wastes;
> (d) the establishment of facilities for the treatment of nuclear wastes;
> (e) the establishment of programs for the treatment, management, storage, and disposal of nuclear wastes;
> (f) the establishment of fees or user charges for nuclear waste treatment or storage facilities, including fees to be charged Government agencies; and
> (g) the promulgation of such rules and regulations to implement the authority described in this paragraph, except that nothing in this section shall be construed as granting to the Department regulatory functions presently within the Nuclear Regulatory Commission, or any additional functions than those already conferred by law.[26]

The Senate Report on the bill indicated an intent to provide "a comprehensive statement of responsibilities relating to nuclear waste management that the committee wants centralized and coordinated at a high level in the Department."[27]

3. Environmental Protection Agency (EPA). In 1976 EPA successfully defended its interpretation under the Atomic Energy Act that it has no authority to regulate discharges of source, by-product, and special nuclear material.[28] EPA does, however, assert its authority to regulate general levels of radioactive materials introduced into the environment by operations associated with the nuclear fuel cycle. NRC has acknowledged that the EPA regulations which establish such standards[29] are binding on the NRC licensing process.[30]

The Clean Air Act Amendments of 1977[31] grant EPA some authority over emissions of radioactive pollutants including source, by-product, and special nuclear material which indicates congressional intent to involve EPA in an AFR licensing proceeding.[32]

Other areas of EPA guidance deal with radionuclides in drinking water[33] and exposure to transuranic elements in the environment.[34]

4. The Department of Transportation (DOT). Various statutes have shaped the historical development of DOT jurisdiction over transportation of spent fuel. In 1907 the Transportation of Explosives and Dangerous Articles Act[35] was enacted, giving regulatory authority over dangerous materials, to the Interstate Commerce Commission (ICC).[36] The Federal Motor Carrier Safety Regulations[37] comprise the bulk of transport operation safety regulations for motor carriers, including those carrying hazardous materials. The Dangerous Cargo Act[38] authorized the U.S. Coast Guard to exercise jurisdiction over carriers of hazardous materials by water.

In 1976, DOT was created as a cabinet level department. The new department received the authority formerly held by ICC and the U.S. Coast Guard.[39]

In an effort to consolidate and strengthen regulatory authority over transportation of hazardous materials, the Hazardous Materials Transportation Act (HMTA) was enacted as Title I of the Transportation Safety Act of 1974. The Act gives the Secretary of DOT authority to promulgate and enforce regulations for "safe transportation in commerce" of "hazardous materials" and specifically suggests radioactive materials as typically hazardous cargo.[40]

Under the recently concluded Memorandum of Understanding between DOT and NRC,[41] DOT exercises primary responsibility to develop regulations for the safe shipment of radioactive materials. Common and contract carriers, freight forwarders, and warehousemen subject to DOT regulations are generally exempt from NRC's regulations when transportating nuclear materials, except when strategic quantities of plutonium or uranium are involved.[42] As such, NRC retains some jurisdiction over spent fuel shipments (which contain strategic quantities), requiring a safeguards plan for all spent fuel in transit.[43]

The DOT has published the final regulations on transportation of nuclear materials including spent fuel. These regulations are reviewed in Section II-D.

5. The State/Federal Interface. The right of states to regulate aspects of the nuclear energy fuel cycle is a controversial issue which is not yet resolved, and which will probably be settled by congress in legislation, not by the executive or judicial branches. Most commentators agree that in a strictly legal sense the federal government can preempt state regulatory activity over virtually any aspect of nuclear energy production.[44] Moreover, it is also generally agreed that states have de facto authority to veto any projects on activities considered by them to be undesirable.[45] This anomaly has occupied a prominent position in AFR storage facility discussions.

At this time thirty states have enacted legislation which would subject a substantial portion of AFR storage facility activities to state authority, either through approval or regulation.[46] It can be assumed that since most of these statutes require approval of site selection by the state legislature, conflict will occur if a state vetoes, under state law, a site selected under federal law.

If a state chose to directly contradict a federal decision on AFR storage facility siting, then the dispute would go to the courts. The history of such litigation strongly supports the contention that the state law would be preempted.

The federal government's authority to regulate the use and disposition of nuclear materials is based on the U.S. Constitution's grant of federal authority over common defense and security, interstate commerce, and promotion of the general welfare.[47] In what is generally considered the seminal case on federal authority over nuclear regulation, the eighth circuit Court of Appeals stated of the Atomic Energy Act that:

> There can be no doubt but that Congress was acting within its constitutionally delegated authority in establishing a system of regulation over the entire spectrum of atomic energy, including the imposition of federal controls over health and safety standards.[48]

Federal preemptory power is based mainly on the supremacy clause of the U.S. Constitution which states that:

> This Constitution and the Laws of the United States which shall be made in Pursuance thereof; and all Treaties made, or which shall be made, under the Authority of the United States shall be the supreme Law of the Land; and the Judges in every State shall be bound thereby, anything in the Constitution or Laws of any State to the contrary notwithstanding.[49]

Of course, states are traditionally charged with broad areas of health and safety regulation, but only where Congress has not indicated an intent to comprehensively occupy the field of regulation in question. The Congress expressed such in the Department of Energy Organization Act which gave

DOE prime responsibility for nuclear waste management.[50] What has been most problematic is that DOE's record of performance has been poor,[51] prompting the landslide of state legislation.

Another seeming contradiction is the amendment in 1959 of the Atomic Energy Act granting states the opportunity to regulate certain aspects of nuclear energy production.[52] This amendment created the concept of Agreement States to which certain regulatory authority is transferred, but the federal government still maintained cognizance over management and disposal of all nuclear wastes. If state and federal regulations conflict, then "a holding of federal exclusion of state law is inescapable and requires no inquiry into congressional design."[53]

For example, "the scheme of federal regulation may be so pervasive as to make reasonable the inference that Congress left no room for the states to supplement it,"[54] or if "the state policy produces a result inconsistent with the objectives of the federal statute,"[55] or "stands as an obstacle to the accomplishment and execution of the full purposes and objectives of Congress,"[56] then the state law and regulation is preempted by federal law. For where the federal government has, pursuant to its constitutional authority, enacted a system of regulation "states cannot, inconsistently with the purposes of Congress, conflict or interfere with, curtail, or complement the federal law, or enforce law, or enforce additional or auxiliary regulations."[57]

More recently the U.S. District Court for Southern California held that the Atomic Energy Act preempted a California law which set conditions on the future licensing of nuclear power plants in that state.[58] The Court observed that:

> Congress' policy to encourage the development and utilization of nuclear energy would decidedly be frustrated if all fifty states had statutes similar to California Public Resources Code section 25524.2 [the disputed state law]. Although the Atomic Energy Act certainly leaves room for the states to regulate on the subject of nuclear energy within the confines of section 2021 (k) and 2021 (b) [Agreement States sections]the power to regulate is not necessarily the power to prohibit. There seems little point in enacting an Atomic Energy Act and establishing a federal agency to promulgate extensive and pervasive regulations on the subject of construction and operation of nuclear reactors and the disposal of nuclear waste if it is within the prerogative of the states to outlaw the use of atomic energy within their borders.[59]

The Court also relied on a letter sent from the Chairman of the Congressional Joint Committee on Atomic Energy to the General Manager of the (then) Atomic Energy Commission which, concerning Agreement State authority, stated that:

> We did not intend to leave any room for the exercise of concurrent jurisdiction by the States to control radiation from those materials. Our sole purpose was to leave room for the courts to determine the applicability of particular State laws and regulations dealing with matters on the fringe of the preempted area in the light of all the provisions and purposes of the Atomic Energy Act, rather than in the light of a single sentence.[60]

It seems clear that, in a legal sense, Congress could impose its will to site an AFR storage facility within any state's borders. The obvious need to allow the states some say in a site's selection has been reflected in recent attempts at legislation on waste management. For instance, a version of a House bill in the last Congress on waste repository siting allowed a state or an Indian tribe to veto a siting decision, but the veto would have to be upheld by one house of Congress. The effect of a state's claim to authority is reflected in the rejection of an amendment making the state veto subject to approval of both the House and Senate, instead, allowing the one-house approval to stand in the bill. At the time of this writing no legislation has actually been enacted concerning state veto rights.[61]

C. Costs, Pricing, and Liability

Subsequent to the governmental decisions to defer reprocessing, DOE announced a spent fuel policy which would enable utilities to deliver spent fuel to a federally owned and operated AFR storage facility in lieu of reprocessing.[62] A fee is to be collected by the government which will pay for the service. The exact nature and magnitude of this charge is, as yet, unresolved. The format contemplated by DOE allows for storage and disposal costs to be figured into the fee. The total cost of such a program includes:

- Capital Investment in the Facility
- Operation and Maintenance
- Decommissioning
- Post Operation Surveillance
- Research and Development
- Overhead
- Carrying Charges

DOE will be legally required to levy a charge to recover the costs of the program under the Independent Offices Appropriations Act which provides that:

> "It is the sense of the Congress that any work, service, publication, report, document, benefit, privilege, authority, use, franchise, license, permit, certification, registration, or similar thing of value or utility performed, furnished, provided, granted, prepared, or issued by any Federal agency...to or for any person...shall be self sustaining to the full extent possible, and the head of each Federal agency is authorized by regulation...to prescribe therefore such fee, charge, or price, if any, as he shall determine...to be fair and equitable taking into consideration direct and indirect cost to the Government, value to the recipient, public policy or interest served, and other pertinent facts...."[63]

This section has been interpreted to mean that benefits over and above those to the general public should be charged for.[64] It may be difficult to distinguish between the benefits to the public and those to the utilities storing spent fuel.

It is very likely that the federal government will take title to all spent fuel deposited in an AFR storage facility whether it is private (e.g., a licensed corporation) or public (e.g., DOE owned and operated). In that case, liability for damages to persons and property arising out of the handling, transportation, storage, and disposal of such fuel will lie with the government or its contractors. A charge for spent fuel storage would include insurance premiums paid by contractors plus a factor designed to compensate the government for sums it might be required to pay as an indemnitor pursuant to the Price Anderson Act or as a self-insurer.[65]

The costs entailed in constructing an AFR storage facility have been estimated by several studies. Figure 1 shows these estimates. Operating and maintenance costs have also been estimated to vary between $4 and 8 million per year.[66]

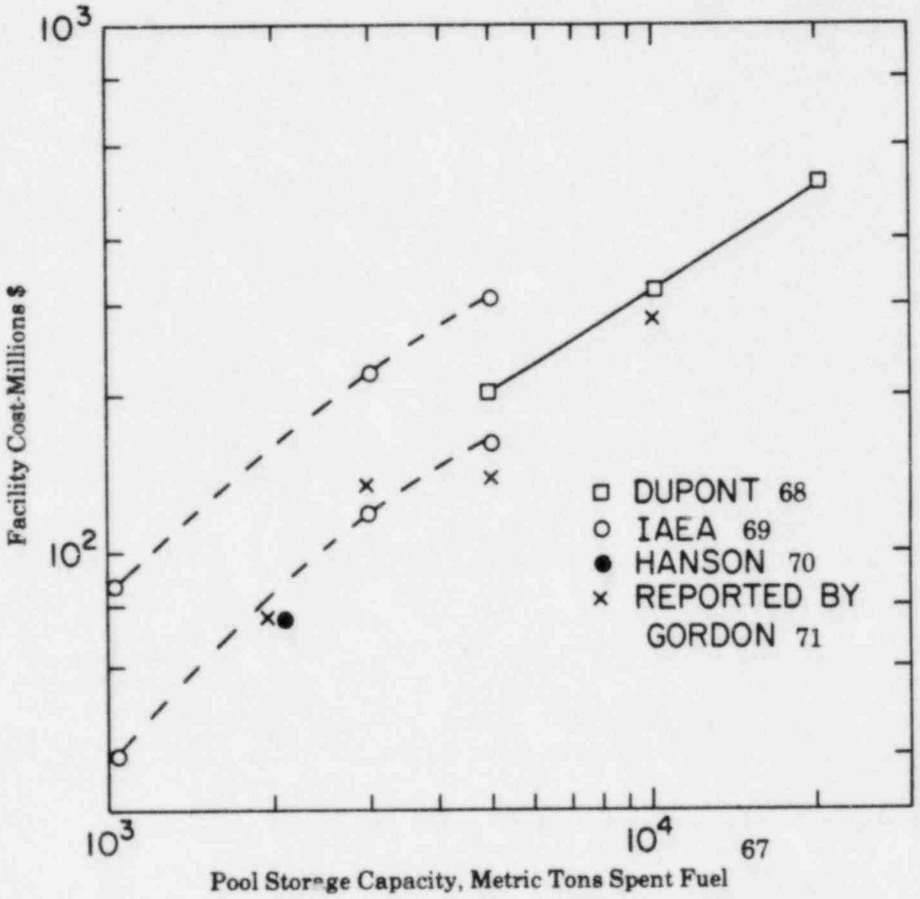


Figure 1

The Congressional Budget Office has estimated total costs and calculated a one-time unit charge on the basis of acquiring two private spent fuel storage facilities with capacities of 750 and 1,750 MT and a construction of a third with a capacity of 5,000 MT. Assuming the 750-MT facility is available in 1983 and the 1,750-MT facility in 1984, those acquisition costs total approximately $230 million. The new facility completed by 1988 is estimated to average $20 million annually in capital costs and operating costs, beginning in 1983, are estimated at an additional $20 million per year. The unit charge is estimated to be $306,000 per MT of stored spent fuel.[72]

D. Existing Licensing Regulations

1. Nuclear Regulatory Commission. NRC has published the final version of its regulations concerning the licensing of an independent spent fuel storage installation (ISFSI).[73] In these regulations, provisions are made for application,[74] issuance and conditions of license,[75] records and reports,[76] siting criteria,[77] design criteria,[78] quality assurance,[79] physical protection,[80] and training and qualification of personnel.[81] These regulations took effect November 28, 1980.[82]

The general provisions of licensing procedures for an ISFSI include the provision that fuel must be aged for at least one year before it can be transferred from the reactor site.[83] The new regulations apply to both wet and dry storage of spent fuel.[84] An ISFSI is defined as independent if it is sited in isolation from other nuclear-related activities or, if co-located, an ISFSI may be provided with services from an existing facility and still be considered "independent." The use of services from an existing facility (i.e., electricity, makeup water, waste treatment, etc.) is allowable provided the commission finds reasonable assurance that the construction and operation of the ISFSI will provide adequate protection to the health and safety of the public from the standpoint of both facilities involved.

Any physical connection between facilities must be evaluated. Any penetration of the reactor storage pool walls will be considered a conclusive showing that the ISFSI is not "independent" and hence is not within the scope of Part 72 and should be covered by licensing action under Part 50.[85]

The General Provisions also allow the Commission to waive some licensing requirements if the waiver is in accordance with safety considerations[86] and specifically denies the right of licensing to Agreement States.[87]

Regulations for filing a license application specify that an applicant can incorporate any information filed for a previous license by reference into an ISFSI application.[88] As a result, licensed sites may be more desirable from an administrative standpoint. The applicant is also required to demonstrate financial qualifications to cover estimated construction costs, estimated operating costs, and estimated shutdown and decommissioning costs.[89]

An applicant is required to file a Safety Analysis Report (SAR) describing how the facility will be operated. The SAR must include a safety assessment, description of design and operating characteristics, various characteristics of design bases, adequacy of structures, planned managerial and administrative controls, technical qualifications, control equipment, dose rates for postulated accidents, quality assurance techniques, physical security plans, preoperational testing techniques, and a decommissioning plan.[90]

Licenses are issued for a fixed period of time not to exceed twenty years. If renewal applications are received two years prior to expiration, the current license stays valid until the conclusion of Commission consideration of its renewal application.[91] This will negate the possibility of closing a facility because of administrative or judicial delay.

Surveillance measures are a condition of the license once granted. The licensee must inspect spent fuel, maintain inspection, test, and calibration activities to ensure the integrity of support systems, confirm that all operations occur within functional limits, and meet all requirements for safe storage. An annual report is required specifying the type and quantity of all radioactive effluents.[92] During the licensing proceeding, a public hearing will be held upon request.[93] NRC is also authorized to take possession of all spent fuel if national security or health and safety are threatened[94] as well as to mandate backfitting if desirable.[95]

The SAR is to be updated every six months before operation and annually after initial receipt of spent fuel.[96] Inventory records must be kept showing location and disposition of all spent fuel with a complete inventory every twelve months.[97] Transfers of spent fuel are filed on the standard NRC 741 reports.[98] Inspectors are to be given free access to inventory records and provided with office space and facilities sufficient for one full-time inspector, transient inspectors, and a part-time secretary.[99]

Site selection procedures are to include "consideration of the characteristics of the population, including its distribution, and of the regional environs, including its historical and esthetic values."[100] Natural events such as earthquakes and floods, as well as man-made events such as accident and sabotage, are to be factored into site selection.[101]

For any potential site, an "impact" region must be identified. Those impacts considered include effects on the population and environment, effects on future development, and areas potentially affected by an accident.[102] Seismic and geologic factors are to be taken into account. The regulations divide the U.S. at the east of the Rocky Mountain front (104° West Longitude) so that all sites to the east, except in areas of known seismic activity, can be easily licensed while those to the west must satisfy the criteria in 10 CFR 100, Appendix A. Criteria for seismic evaluation are also given.[103]

Four site-related zones are to be included in site evaluation and operation. The "site" is where the facility is located. A "controlled area" must be defined and can be the same as the site, but actually denotes the area under the direct control of the licensee and is to be bounded by a physical barrier. An "emergency planning zone" must be established to include all areas for which protective measures should be taken during an emergency. A "region" is to be established to encompass all areas which may be affected by an accident or contingency.[104]

General design criteria are mandated in the regulations including quality standards, protection from natural threats and fires, testing and maintenance, confinement barriers and systems, instrumentation and control, and effluent standards.[105] Plans for decommissioning must also accompany a license application.[106]

Physical security plans must be developed, including contingency plans, training programs, tests, inspections, and other means to demonstrate compliance. All changes in physical security plans must be reported to NRC.[107]

The immediate effectiveness rule does not apply to an ISFSI.[108] Agreement States are not given authority to license an ISFSI.[109]

It is noteworthy that the licensing process for an ISFSI is a one-step procedure, not the traditional construction permit and operating license stages usual to reactor licensing. The ALARA concept has been adopted as well.

2. Department of Transportation (DOT). On January 19, 1981, DOT published its final regulations on the transportation of radioactive materials which take effect February 1, 1982.[110] The prior lack of federal regulation of such activities gave rise to states and localities enacting laws governing safety and safeguards requirements for transport of radioactive materials. For example, New York City's ban on radioactive shipments forced Brookhaven National Laboratory on Long Island, N.Y., to use ferries instead of land routes for shipment of spent fuel from its research reactors. After an extensive rulemaking proceeding, including several hearings and public inquiries, the final regulations taking into account local, state, and federal interests were issued.

The new regulations contain several new provisions in response to state and local interests. The state governments are authorized to designate routes based on substantive consultation with affected local jurisdictions. These routes, called "state-designated routes," become part of DOT's "preferred routes" which are any state-designated routes plus any interstate highway for which an alternative highway has not been designated.[111]

New regulations for "large quantities" of radioactive materials, which include spent fuel shipments, require that shipping papers classify these shipments such that they are subject to routing controls including distinct placarding[112] and physical security equivalent to that now required by NRC.[113] New regulations require filing of route plans within 90 days after the shipment occurs, although prenotification is not required.

DOT also allows transport of radioactive materials through tunnels in spite of any local or state ban or such shipments.[114] Route planning requires that carriers choose routes that minimize radiological risks to the public. A preferred route must be used unless emergency conditions dictate that another route is safer; rest, fuel or repairs are necessary; or if it is necessary to pick up, deliver, or transfer radioactive materials off preferred routes.[115] Carriers have the responsibility for compliance with these regulations.[116] A driver training program, to be implemented by the carrier, is also required.[117]

Departments of Defense and Energy are exempted from the physical security requirements of the new regulations when the materials are defense related and shipped by personnel specifically designated by or under the authority of those agencies to preserve national security.[118] This exemption does not apply to transport of radioactive materials used by DOE in research and development activities.[119]

States cannot make transport between two points impossible. Interstate highways are to be used in all cases (because of lower accident rates) except where an alternative route is designated as safer and localities have been consulted.[120] State law enforcement authorities (e.g., state police) are granted power to enforce DOT regulations within state jurisdictions.[121]

For a complete account of DOT policy related to radioactive transport routing, see DOT's discussion accompanying the final rule in the Federal Register.[122]

E. Pending Legislation

Insight into the legislative arrangements for spent fuel storage can be gained by examining the statute passed by the Senate on July 30, 1980 pertaining to policy on waste management. The statute, named "The Nuclear Waste Policy Act,"[123] establishes a program for federal storage of spent fuel from civilian energy reactors as well as setting forth a federal policy for the disposal of wastes. The House has failed to act on the bill so that it will probably be reintroduced in the next legislative session. Since Senate passage was by an overwhelming majority (88-7), it can be assumed that most features of this legislation will be retained in the next session for consideration in the Senate. The House versions of nuclear waste legislation deal with permanent disposal rather than interim storage. It must be recognized that the following discussion concerns legislation not yet enacted as law and is meant only to provide a background for further discussion.

Title III of the bill, "Interim Storage of Spent Fuel From Civilian Nuclear Powerplants," consists of eight sections which will be considered separately.

Section 301 provides for maximizing at-reactor storage capacities and calls for the establishment of a "federally owned and operated system for interim storage of spent fuel at one or more away-from-reactor facilities."

Section 302 stipulates that the following factors be considered in expanding at-reactor storage facilities:

- protection of public health and safety
- economic considerations
- continued operations of the reactor
- sensibilities of local populations
- all applicable law

Section 303 stipulates that DOE may enter into contracts with reactor operators which provide that the federal government will:

- take title to spent fuel
- transport spent fuel to and store it in federally owned and operated AFR storage facilities
- dispose of associated wastes

It also restricts such contracts to reactors in the U.S.

Section 304 outlines the conditions of contracts for storage of spent fuel. It calls for a one-time unit charge adequate to cover transportation costs, construction operation, maintenance, and decommissioning of the facility, and a surcharge for long-term disposal of wastes. It also stipulates that the utility which used the fuel will retain the nontransferable right to the remaining value of fissile material until reprocessing occurs and compensation less recovery costs is paid to the utility. It goes on to provide that DOE will take title to the spent fuel at the reactor at the time it is transported and that the contracts will become effective at the time an AFR storage facility is available.

Section 305 mandates that DOE will provide notice in the Federal Register no later than 1[illegible] days after enactment of the legislation containing information on terms and conditions of the contracts. The one-time unit charge is to be effective for the period of one year.

Section 306 concerns acquisition of at least one AFR storage facility which must be capable of accommodating all contracts entered into and subject to NRC licensing. This section goes on to require utilization of private carriers to transport spent fuel to the AFR storage facility whenever possible.

Section 307 mandates that DOE will take possession of spent fuel within 30 days of notification that it is available.

Section 308 provides funding for an AFR storage facility and its operation.

Title V of the bill, "Financial Arrangements," establishes a separate treasury account ceiling of $300 million for AFR storage and waste disposal. The amount spent is to be repaid with interest once the program is in effect.

III. AFR STORAGE FACILITY UNDER INTERNATIONAL AUSPICES

Under the Nuclear Non-proliferation Act (NNPA)[124], the President is directed to pursue establishment of repositories for the storage of spent nuclear reactor fuel under effective international auspices and inspection.[125] The Act goes on to suggest that financial compensation for the energy content of spent fuel placed in such a facility should be offered by the U.S. if deemed necessary or desirable.[126]

The terms "international auspices and inspection" are vague. There is virtually no legislative history associated with their usage in NNPA although it appeared in various versions of the bill while under legislative consideration.[127] International inspection is generally taken to mean IAEA safeguards, but international auspices is a vague concept at best.[128]

The very nature of NNPA's mandate indicates that a domestically sited international AFR storage facility would be subject to international, not domestic, authority. Accordingly, it can be assumed that the form of the institution would not be that of a commercial organization which must be formed on the basis of national laws, but rather as an international organization based in international law.

A. Functions of an International AFR Storage Facility

An international AFR storage facility would be a solution to competing influences. The first objective of such an institution would be to accept spent fuel from nations which have a shortage of storage capacity and, therefore, seek retransfer as a solution to spent fuel congestion. The competing objective is one of continuous fuel assurance which arises because only 2 to 3% of the potential energy in nuclear fuel is used before it must be removed from the reactor. Reprocessing and recycling spent fuel is a way of significantly improving the efficiency of fuel utilization, thereby increasing a nation's assurance of a domestic fuel supply. However, reprocessing and recycling is, in itself, expensive and, at current nuclear fuel prices, is not economically attractive to nations with moderate nuclear energy programs. Economies of scale dictate that a large throughput facility, serving around 50 reactors, may be the most economically efficient reprocessing and recycling facility.[129]

Currently, both France and the United Kingdom offer reprocessing services on a commercial basis. Each has several contracts with other nations to reprocess spent fuel. Neither has large-scale plants in service at the present time, but France expects to complete its La Hague facility during the 1980's and the U.K. intends to complete planned Windscale facilities in a similar time frame.[130] Many transfers of spent fuel have been made to these countries in the last several years from Japan, Sweden, Switzerland, and Spain. The U.S. has a right of prior approval over retransfers of spent fuel under agreements between the U.S. and those nations retransferring and has granted that approval in all cases either on the basis of contracts in existence before passage of the Nuclear Non-Proliferation Act (NNPA) or because of a lack of indigineous storage capacity. The U.S. still maintains the right of prior approval over the retransfer of separated plutonium, uranium, and fission products back to nations procuring commercial reprocessing services.[131]

The NNPA authorizes the President to:

> seek to negotiate as soon as practicable with nations possessing nuclear fuel production facilities or source material, and such other nations and groups of nations, such as the IAEA, as may be deemed appropriate, with a view toward the timely establishment of binding international undertakings providing for—
>
> (*) devising, consistent with the policy goals set forth in section 403 of this Act, feasible and environmentally sound approaches for the siting, development, and management under effective international auspices and inspection of facilities for the provision of nuclear fuel services, including the storage of special nuclear material;
>
> (*) the establishment of repositories for the storage of spent nuclear reactor fuel under effective international auspices and inspection;
>
> (*) the establishment of arrangements under which nations placing spent fuel in such repositories would receive appropriate compensation for the energy content of such spent fuel if recovery of such energy content is deemed necessary or desirable.[132]

The purpose of providing for storage of spent fuel is to eliminate the need to reprocess spent fuel because of a lack of storage capacity. In addition, if a nation is guaranteed a supply of nuclear fuel equivalent to the value of its recycled spent fuel then reprocessing becomes less desirable. Two parts of this plan present difficulties. They are the concept of "international auspices" and calculating "appropriate compensation for the energy content of...spent fuel."

1. International Auspices. As discussed above, the term international auspices is a vague one, but can be taken to mean international, rather than national, control of the functions of the AFR storage facility. Presumably this will serve to insulate the international facility from the political influences of the host nation—in this case the U.S.

A high level of sovereign immunity afforded an international AFR storage facility as an international organization would ameliorate most objections to U.S. influence over the facility. Participation in ownership and decision making by participants is vital to the political acceptability of any such scheme.[133]

An institutional arrangement which will be acceptable to foreign participants should include two principal features: (1) separation of ownership and control which is necessary if governments, at the political level, are to be kept out of day-to-day management to a reasonable extent; and (2) a pool of capital subject to the control of the enterprise. If any one nation could withhold its capital or operating contribution, it would probably result in undue influence on the facility's operation.[134]

The essential risk that participating nations face is the seizure of their spent fuel by the U.S while it is in storage. A properly drawn charter for such an international organization could make such a seizure both a violation of international law (treaty abrogation) and grounds for demanding return of the spent fuel. In essence, the U.S. may be forced to acquiesce to participating nations on the return of spent fuel if requested. It is possible, however, that the U.S. could maintain its prior approval rights over retransfer of the spent fuel once back in the participant's domain.

As opposed to more complicated endeavors such as international reprocessing or enrichment, an international AFR storage facility would have few critical operational decisions beyond the disposition of spent fuel in storage. If the establishing charter specifies the manner of and method for storage with well defined criteria for release of stored spent fuel, there are few operational decisions which could adversely affect the interests of the participants.

2. Appropriate Compensation for Energy Content. The idea of providing compensation for the energy content of spent fuel is aimed at eliminating the impetus for foreign nations to reprocess their own spent fuel for recycling. By providing economic compensation through payments or credits toward new fuel, the impetus for indigenous reprocessing is presumably reduced. There are two difficulties with this concept as framed in NNPA. First the phrase "if recovery of such energy content is deemed necessary or desirable," and, second, establishing the value of the "energy content" in spent fuel.

The NNPA is viewed by nations engaged in nuclear activities as a U.S. law designed to inhibit the growth of reprocessing and other advanced fuel cycle technologies because of their potential for nuclear weapons proliferation. Many nations also view NNPA as an intrusion on their sovereignty to decide how to supply energy to their industry and residents. It is doubtful that many nations would agree to leave the decision as to the necessity or desirability of reprocessing to another nation because the attractiveness of fuel cycle alternatives will vary from one nation to another. Participation in an international AFR storage facility would be made more attractive by U.S. acquiescence over the question of desirability or necessity. Specifically, the charter establishing the organization could make that choice available to participants with little likelihood of *increasing* proliferation risks if the alternative is commercial or indigenous reprocessing. If a participant finds such compensation desirable or necessary then the U.S., pursuant to NNPA, could supply low enriched fuel of the same energy value as the reprocessed spent fuel in storage. It should be noted that those nations likely to request appropriate compensation are those who expect to forego fast plutonium breeders since they would receive nuclear fuel of value only in an LWR fuel cycle. Presumably, those nations which may pursue fast breeders would want to reprocess to recover plutonium. This regime would be particularly useful to the U.S. if commercial breeder reactors were pursued. Appropriate compensation could also include financial credits, fossil fuels, or alternative energy technologies.

However, establishing an appropriate value for spent fuel energy content may be very difficult. In the simple sense, the net value of energy content in spent fuel is equal to the gross value of uranium and plutonium in the spent fuel minus the cost of extracting this material and converting it to new reactor fuel. Put a different way, the net value of spent fuel energy content equals the cost of an equivalent value of uranium LWR fuel minus the excess costs of reprocessing and fuel fabrication plus the savings in yellow cake and enrichment services.[135]

In negotiations regarding the valuation of spent fuel, opinions may vary widely regarding the fuel cycle parameters which would dictate "appropriate compensation." Different fuel cycle plans affect the price of nuclear fuel significantly. For instance, if a nation forsees large-scale breeder development, then the "energy content" of plutonium may be far greater than if breeders are not planned. In addition, there may be disagreement concerning the costs of storing, safeguarding, transporting, reprocessing, and fabricating spent fuel as well as the price of yellow cake and enrichment services. There may be disagreement about the strategy of lease, bailment, exchange, or buyback and about the value of uranium in spent fuel and accounting methods reflecting those differing values. Analyses have indicated that the value of spent fuel is highly sensitive to uncertainty in a number of relevant factors. It may be very difficult to reach early agreement on "appropriate compensation" and it is important, therefore, that negotiations aimed at establishing an international AFR storage facility pursuant to NNPA be conducted on the basis of a realistic appraisal of these difficulties.[136]

B. Sovereign Immunity

The purpose of international arrangements involving the nuclear energy fuel cycle is to place the security of supply to a nation's fuel cycle outside the influence of foreign national politics. In the case of an international AFR storage facility, participating nations will want to maintain some degree of direct control over spent fuel stored at the facility. If the facility is located in the U.S., then some guarantee of access and control by foreign nations must be maintained. The concepts of international and domestic law guaranteeing that type of access are those of sovereign immunity which free international organizations and agents of foreign governments from the jurisdiction of national laws.

The doctrine of sovereign immunity is essentially a judicial concept. Traditionally, the courts of one country refuse to accept jurisdiction over another government's sovereign, and the U.S. courts have followed this custom. The rationale for the doctrine of sovereign immunity combines the notions of quid pro quo, a carryover of the divine right of kings, and a sense that larger political issues are at stake, including matters affecting each country's foreign relations in general.[137] Sovereign immunity is limited, however, to cases of the official actions of the organization and its agents.

The problem of delineating proper limits to immunity for an international organization and its agents while still maintaining adequate protection of foreign interests in stored spent fuel may be difficult. If the international AFR storage facility is considered an international organization (as declared by executive order), then the International Organizations Immunities Act[138] (IOIA) will determine the limits of immunity. The Foreign Sovereign Immunities Act, cited by some as the ruling legislation, was enacted primarily as a result of foreign governments functioning in the U.S. primarily in a commercial manner. Examples are India's commercial, but government-owned and operated, banks, Brazil's nationally-owned steamship company, Mexico's government-operated petroleum industry, and Italy's nationally-owned and operated airline.[139] The Diplomatic Relations Act[140] is aimed solely at defining the duties and liabilities of agents of foreign nations. Nations have been defined as bodies politic or societies of men occupying a definite territory, politically organized under one government, and engaging in foreign relations.[141] In contrast, international organizations are created by international agreement with memberships consisting primarily of nations.[142] More important, nations possess the totality of international rights and duties recognized by international law; the rights and duties of international organizations, however, depend upon each organization's purposes and functions as specified in its charter and related documents.[143]

Courts have interpreted IOIA as codifying, not creating, the U.S. obligation to provide organizations designated under IOIA with immunities consistent with the organization's charter.[144] Most international organizations provide for immunity from legal processes and it is from the charter, accepted by the host nation, that real authority for sovereign immunity can be found.[145] Therefore, the charter establishing the international organization with cognizance over an international AFR storage facility will contain specifics concerning its sovereign immunity.

An individual nation's grant of sovereign immunity while conducting foreign relations is based on comity and sovereign equality, while an international organization bases its grant on the need to discharge its responsibilities. There are three general arguments put forth in the literature favoring nearly absolute immunity from the national legal process for international organizations.

- International organizations are democratically constituted international bodies in which all member nations and their interests are represented and, therefore, should be protected from interference by any single nation.

- An international organization's assets come from common national resources so no single country should recognize a financial advantage by levying a charge on them.
- International organizations should receive, at a minimum, the immunities afforded between nations.[146]

The type of immunity which applies to international organizations, including the proposed international AFR storage facility, follows the concept of functional immunity.[147] Inherent in this concept is the tenet that international organizations may define and interpret the scope of their privileges and immunities without outside interference.[148] Two good examples of functional immunity for international organizations operating in the U.S. are found in the United Nations (UN) Charter and the Organization of American States (OAS) Charter.[149] Article 105(3) of the UN charter assumes "such priveleges and immunities as are necessary for the fulfillment of its purposes" and goes on to empower the UN General Assembly to establish specific privileges and immunities. The UN General Assembly adopted the 1946 Convention on Privileges and Immunities of the United Nations[150] which specifies that "the United Nations, its property and assets, wherever located and by whomever held, shall enjoy immunity from every form of legal process except insofar as in any case it has expressly waived its immunity."

Article 139 of the OAS charter[151] and the Agreement on the Privileges and Immunities of the Organization of American States[152] contain language nearly identical to that in the UN Charter and Convention.

The fact that an international AFR storage facility will provide a commercial service (storage of excess spent reactor fuel) may indicate that immunity should be somewhat more limited than for those organizations which are more purely political. The concept of functional immunity is conditional to the immunity of an international organization in that its agents must accept primary responsibility for the legal effects of their acts if not performed as an agent for the international organization.[153] To ensure that immunity is not abused, most international organizations have established procedures for impartial adjudication on questions of fault and methods of remedy to aggrieved parties.[154] In addition, the President retains the right to revoke IOIA coverage of any organization he feels has abused its immunities.[155] In light of this, the charter establishing the international AFR storage facility could include a commitment to return all spent fuel to all nations if such immunities are revoked and participating nations agree to receive it.

The Foreign Sovereign Immunities Act,[156] which is aimed primarily at foreign commercial enterprise within the U.S., makes the assets of a foreign nation held by an international organization immune from "any action brought in the courts of the United States or of the States." This means that seizure of assets pursuant to a suit brought against a foreign government's commercial activity in the U.S. cannot extend to those assets kept under the charter of an international organization. In other words, spent fuel deposited in an international AFR storage facility will be automatically immune from any legal action brought against any participating nation.[157]

Litigation which has arisen from claims against international organizations indicates that a high level of immunity can be anticipated for an international AFR storage facility.[158]

C. Characteristics of International Organizations

The literature describing potential international arrangements in the field of nuclear energy commerce has suggested various questions regarding the structure and legal status of international organizations.[159] It is worthwhile to examine the history of international cooperation through institutional arrangements.

Most literature concerning establishment of international cooperative arrangements having to do with the nuclear fuel cycle indicates a paucity of such arrangements. However, there are hundreds of examples of international cooperation, many of which have been very successful, in fields related to such an endeavor. This section will detail various options which have evolved from this development.

1. Classifications

a. Public Versus Private International Organizations. For an international organization to be public, and therefore eligible for privileges and immunities under the International Organization Immunities Act,[160] it must fulfill three requirements: (1) it must be established by international agreement, (2) it must have organs, and (3) it must be established under international law.[161]

The funding arrangements must take the form of an agreement between nations. The usual form of such agreements is a multilateral treaty. Some international organizations, have been founded simply on the decision of representatives of nations assembled in conference, but this method is not widely recognized or used.[162] Another purpose of the international agreement is to establish the separate and discrete legal personality of the new organization. Its legal personality may be completely independent or part of another organization (e.g., the UN family of international organizations.) Lastly, the agreement contains mutual commitments by participating nations requiring a certain amount of cooperation within, and with, the organization. The network of commitments in an agreement are comprehensive in that a nation cannot withdraw from certain obligations only. All participants must accept the disadvantages as well as the advantages of membership.

An international organization can function only if it has organs formed by delegates of two or more nations and is not dependent on any one nation.[163] The General Agreement on Tariffs and Trade (GATT) was originally an agreement between nations without organs and was, therefore, denied status, as an international organization.[164] Gradually, decision-making organs were formed, starting with a Council of Representatives, and subsequently status as an international organization was granted.

A last condition that international organizations are established under international, not national, law is generally satisfied by the existence of an international agreement. Unless the agreement specifically subjects the organization to national law, it is considered subject to international law.[165]

Private international organizations are always subject to the national law of the nation of establishment. If such an arrangement were used to establish an international spent fuel storage organization, it would not be eligible for status as an international organization.

b. Universal Versus Regional Organizations. Universality connotes an organization operating on a global scale and open to all nations wishing to participate.[166] Regionalism may take the form of organization along geographic, economic, cultural, or political lines, among others.

A universal character is desirable if a global solution to spent fuel congestion in all nations is a goal. Participation on a wide level would minimize the opportunity for non-members to band together to thwart the purpose of the organization. Universality, however, makes it difficult to set strict conditions for membership.[167]

Regional organizations, on the other hand, are shaped by various influences. Usually the reasons for regional cooperation are the threat of outside influence and a desire to combine common interests. These generally take the form of nations with comparable political systems and compatible cultural and economic backgrounds. The homogeneity of participants in regional organizations will play a role in determining how much power nations will transfer to a regional organization.[168]

Some constitutions do not contain provisions for withdrawal,[184] while others have found it necessary for reasons of political acceptability.[185] In practice, nations have withdrawn regardless of constitutional provisions so that, as in the case of the World Health Organization, procedures have been implemented for designating status after withdrawal as "inactive," levying a small assessment on the inactive nation, thus allowing for revocation of a withdrawal.[186] The Vienna Convention on Treaties permits unilateral withdrawal from any international organization in the case of a fundamental change in circumstances.[187] In order to complement this provision, some organizations provide legal remedies when organs do not perform as originally intended, thereby partially mitigating such fundamental changes.[188]

The U.S. has exercised the right of withdrawal in the case of the International Labour Organization (ILO). In 1970 a Soviet national was nominated, without U.S. consultation, to the position of Assistant Director General. Because this act was considered a direct affront to the U.S., Congress eliminated funding for the ILO in its FY 1971 appropriations. In 1975 the

Palestinian Liberation Organization was granted observer status to the ILO and at the same time a pro-Israel, U.S. sponsored resolution was defeated. Again Congress withheld funrding for 1975 and 1976 - a total of $22.3 million - and the U.S. began to seriously consider withdrawal.[189]

Later in 1975, the U.S. gave the ILO formal notice that it would withdraw after the mandatory two-year waiting period. The U.S. indicated that it would use the two years for initiatives that would ameliorate the conditions which made continued U.S. participation impossible. Specifically, the U.S. objected to communist participation since the separation of the communist delegations did not distinguish between the government and labor. In 1977 the U.S. terminated membership in the ILO because of a lack of progress towards its goals.[190]

Members can be expelled or suspended in certain circumstances. While suspension connotes a temporary situation, in practice, there is little difference between expulsion and suspension.[191] Expulsion as a sanction is rarely used because, by-and-large, it serves only to lessen the influence of the organization over a troublesome nation. The presence of that nation during debates concerning relevant affairs is considered essential to the purpose of most international organizations.[192] Expulsion has been considered, on the other hand, as a means to remove a member which has taken obstructionist positions or no longer qualifies under the organization's constitution.[193] In most regional organizations, a common political attitude forms the core of activities. If a member changes its political system, expulsion may outweigh the detrimental effect of the smaller forum.[194]

Many constitutions of international organizations contain provisions for expulsion.[195] Decisions are generally based on the same voting procedure as for any important plenary decision. Some constitutions provide that cooperation is a necessary characteristic of its members and expulsion can be justified on the basis of noncooperation.[196]

b. Associate and Partial Members. Associate membership is possible in some organizations. Such membership is, in large part, a historical legacy from the days when nonautonomous territories had the right to participate without a vote.[197] As the number of non-autonomous territories decreased, the use of associate membership has declined. Members of some organizations serve only on certain organs and are, therefore, considered partial members sharing only certain duties and obligations.[198] At times, nonmember states, public and private international organizations, and individuals are asked to participate in debates. They are normally referred to as consultants in that capacity.[199]

3. General Structure and Rules of Operation. All international organizations have a principal organ in which all members are represented. The number of parties in each nation's delegation is usually not regulated and is proportional to the importance of the organization's activities.

Members cannot carry out the business and administration of an international organization. Effective functioning depends on the formation of organs in which members can meet and make decisions. A completely separate operational organ may be desirable in some cases. In a spent fuel storage facility most decisions would be inconsequential from a policy standpoint. Decisions which are completely managerial in nature are usually left to a technical organ in which a diversity of viewpoints is not considered essential. For spent fuel storage these decisions may include fuel deposition, accounting methods, physical security, personnel clearances, and criticality concerns. Important decisions should be based on a concensus by members in larger, more broad-based discussion and, therefore, a larger organ. Historically, small, nonplenary or "technical" organs are composed of members with the greatest expertise and most at stake.[200] Organs are usually led by a director or director-general.

a. Secretariat. The proper functioning of an international organization requires some organ for accomplishing administrative tasks. The name "secretariat" originated in the negotiations of the League of Nations and was chosen as an accurate designation of the administrative and secondary nature of its functions. Some secretariats do not head any particular organ and instead oversee a broad level of activity.[201] The power and authority of secretariats vary from organization to organization.

The secretariat normally decides all administrative matters, including those of policy concerning administration (i.e., travel, living expenses, suppling or withholding of administrative services). It generally prepares the budget, proposes new programs, and oversees disbursement of funds. The secretariat can normally serve as a conduit for information, as record keeper, as coordinator, as the representative in legal proceedings, as a depository of treaties, and it can exercise the right of initiative, act as mediator, and is at times charged with executive functions in specialized organs.[202]

The secretariat is normally an influential position in technical organizations by nature of its expert knowledge. This could well be a desirable characteristic in an organization for spent fuel management. The secretariat can delegate very technical matters to an outside consultant which may also be desirable in managing spent fuel.

The "seat" of the organization is generally held to be where the secretariat resides. It is not necessary that the secretariat be located at the central location of activity unless direct supervision is necessary. There are many considerations in establishing the location of an organization's seat such as the consent of a host nation, demographics, regional politics, communications, language, and sufficient physical plant. Some international organizations have decentralized secretariats to handle some matters in a regional and somewhat autonomous manner.[203]

International organizations are served by a body of international civil servants. As a rule, international civil servants are appointed by the secretariat of the organization while the secretary-general, assistant secretaries-general, and directors-general are elected by the major plenary organ,[204] the board,[205] or both.[206] International civil servants for a secretariat need not always be picked on the basis of geography, but this is mandated in some constitutions.[207] Such strict allocation of positions in the secretariat can be counterproductive because the most capable personnel may not be selected, there is reduced power because of continued recruitment outside the secretariat, and nations are usually consulted before selections are made official in any event.[208] Recruitment of nonmember nationals is very rare. Equitable geographic distribution is probably appropriate for professional and senior posts, but lower grade employees are usually recruited locally for economic reasons.

The conditions of employment for international civil servants has been harmonized across the lines of various international organizations. Grades, remuneration, permanent or temporary status, and internships have become standardized to prevent gross discrepancies and interorganizational competition for the best employees.[209]

b. Major Plenary Organ. The major plenary organ consists of all members of the organization. This is sometimes called the general assembly, congress, parliamentary organ, and so on. It is the body which exercises control over the executive, budget, advisory functions, and all major decisions of policy nature. Voting is sometimes weighted by requiring a certain majority, unanimity, or varying the number of votes per member. As stated previously, regional organizations often require unanimous votes on matters of importance while others require some fraction, usually two-thirds or three-quarters. In some organizations votes are weighted according to financial contributions. In order to ameliorate discrimination by one or two nations, many weighted voting systems also allocate "basic" votes to nations without great financial or technical influence.[210]

c. The Major Plenary Board. For the most part, international organizations do not make decisions in general assembly. Instead, a board is convened which has the major elements of the organization represented and is usually responsible only to the major plenary organ. Its composition usually reflects the major policy considerations and constellation of national concerns.

As an example, the Board of Governors of the International Atomic Energy Agency (IAEA) consists of thirty-four members, of whom about half are designated by the outgoing board and the remainder are elected by the General Conference (major plenary organ). The provisions for selecting the members designated by the Board are very complex. The statute divides the world into eight regions. The five most advanced nuclear nations are designated to head their regions, and the most advanced nations in the remaining regions are appointed. The two major producers of source material are also appointed. One nation is included on the board to provide technical assistance. The members elected by the General Conference are selected according to geographical equity, and it is mandated that Latin America and the region of Africa and the Middle East must be represented on the board by at least four members each.[211] Voting on the board is by majority except on matters of finance and budget, amendments to the statute, and appointment of the director-general when a two thirds majority is required. In the IAEA, the Board of Governors, in fact, exercises most of the Agency's authority. In practice, the General Conference serves mainly as a forum for member nations to voice their opinions on matters before the board.[212]

The board of an international AFR storage facility could be constituted during negotiations to reflect the concerns of members by manipulating the powers of the board, its composition, and its voting requirements.

d. Judicial Organs.

(1) Functions. Control over the functions of an international organization can be guaranteed only by a judicial organ which interprets the requirements of its constitution. This is especially true when there is any significant element of supranationality in the organization's character. Many nations may be less reluctant to transfer some sovereign power to an international organization if a guarantee is given that the constitutional restrictions on that power would not be violated.[213]

The voting procedure used in the decision-making process will influence the need for judicial organs. When a unanimous vote is required for major actions, clearly no court need be involved. If majority and/or weighted voting were used, the possibility of disagreement is far greater.

Judicial review is available, in most international organizations, to settle disputes between a staff member and the organization which employs him. Such review is not generally available in-house, but rather, since most international organizations have similar staff/organization relationships, through the judicial organ of another organization.[214]

Many times when an international organization is established, its legal rules must be applied within the legal orders of member nations. Usually such rules are laid down in conventions and require separate ratification by the members. These rules achieve the purpose of obtaining uniform legal provisions necessary for pursuing the aims of the organization.[215] The decisions of judicial organizations are only as binding as the constitution allows and, in a practical sense, to the extent that a member accepts them.

Disputes on the functioning of the organization and disputes on matters not directly related to the function of the organization are the two types of suits that may arise between members of an international organization. Neither of these generally surface in litigation since the general plenary body can decide the former and any case of the latter type is brought, generally, to the International Court of Justice or submitted to international arbitration.[216]

Disputes arising over a matter of national law (i.e., purchase of goods and services under host nation law) are rarely settled in an international court. Most of the contracts used for such purposes contain a waiver of immunity concerning the purchase. Where no waiver is included, a contractual obligation to accept arbitration is usually included, eliminating the need for a special judicial organ.[217]

(2) Composition. As a rule, judicial organs operate with an odd number of less than eight. They are usually larger than national courts to reflect the diversity of national law systems affected by its decisions. In some cases an equitable geographic distribution of justices is required. In others a national from each side of the dispute is required to be on the bench.[218]

Arrangements for appointing justices attempt to maximize the independence of the appointees. As a rule, the major plenary organ approves the appointment before it is effective. In some organizations, lots are drawn from national nominations to further the independence of the court as finally constituted.[219] Independence has been sought in many ways, for instance, long term appointments, minimizing individual state influence in elections, and keeping secret the personal opinions of each justice.[220]

Some organizations have adopted the use of advocates general,[221] who present publicly, with impartiality and independence, reasoned conclusions on matters before the court. The use of advocates-general is not widespread, however.

(3) Examples.

(a) International Court of Justice. The International Court of Justice (ICJ) was originally an organ of the League of Nations and was adopted as a principal organ of the UN in 1945.[222] The ICJ functions mainly as a court for settlement of disputes between nations. Members and nonmembers of the UN may be parties to the ICJ,[223] but a nation cannot always be summoned before the ICJ unless that nation accepts the means of settlement or has recognized ICJ jurisdiction.[224]

Virtually all UN organizations may ask the ICJ for advisory opinions, but such opinions have no binding force and are not available to members or individuals.[225] Some organizations hold advisory opinions to be binding.[226]

(b) The Court of Justice of the European Communities. The Court of Justice is the most supranational international court. It can decide cases between members,[227] decide the legality of Community Acts,[228] and functions as an administrative tribunal for the staff of the Communities.[229] It rules in arbitration proceedings brought under contracts containing no waiver clause.[230] On appeal it may hear disputes concerning licenses granted by Euratom.[231]

The Court of Justice can rule on the compatibility of bilateral agreements, both within and without the European Communities, with the constitution of the Communities.[232] The Court of Justice can also rule on the compliance of a member with rules and regulations promulgated by the Community.[233]

4. Representative Structure of International Organizations.

a. International Telecommunication Union (ITU)[234] ITU was established over a long period of time to coordinate matters attendant upon telecommunications. Its functions include allocation and registry of radiofrequency assignments, efforts to reduce interference, minimizing communications costs, promoting communications in less developed nations, promoting safety, undertaking relevant studies, and making regulations and resolutions for the benefit of all members.

As a result of its various interests, ITU has a very complex institutional structure. The supreme organ of the organization is the plenipotentiary conference consisting of delegations from all members and associate members. It meets about every five years to determine the general policies of the ITU, elect the secretary-general and the deputy, and select member nations to serve as the administrative council.

The administrative council consists of twenty-nine members meeting annually or at the request of its members. It oversees the administrative functions of the ITU and can act on behalf of the plenipotentiary conference.

Administrative conferences are held on both global and regional bases to periodically revise completely or partially the Telegraph Regulations, Telephone Regulations, Radio Regulations, and Additional Radio Regulations. Voting privileges in the administrative conferences are limited to full-member states although attendance tends to be much broader.

Two international consultative committees, considered the permanent nonplenary working organs of the ITU, are the International Radio Consultative Committee and the International Telegraph and Telephone Consultative Committee. These committees meet often to study technical and operational questions and issue recommendations. Participation is wide scale because of the nonpolicy, and rather technical, nature of their tasks, but their recommendations can only be adopted by the plenary organs (i.e., plenipotentiary conference or administrative council.)

The secretariat of the ITU is comprised of four parts. The general Secretariat and the International Frequency Registration Board are both large and descrete elements of the secretariat. Both of the international consultative committees are also considered part of the secretariat.

The ITU is a "convention," rather than "charter" organization. A convention organization differs from a constitutional organization in that the latter is based on a constitution containing fairly elaborate and stringent procedures for amendment. Convention organizations can revise the entire agreement by, in the case of the ITU, a simple majority vote of the plenipoteniary conference.

ITU's budgetary arrangements are similarly flexible. Budgets are voted annually by the administrative conference, but the plenipotentiary conference sets a ceiling to apply for the period between meetings. There are fourteen classes of financial contribution, members are free to choose their own commitment, and there are no penalties for failure to pay annual contributions.

ITU has very limited power, but its purpose is universally accepted as vital even by nonmembers. It is dominated by the major communications powers, including major private firms, but serves as a valuable forum for discussing issues on which nations feel compelled to cooperate.

b. International Labour Organization (ILO)[235]. The ILO was first established after World War I to protect western Europe from the revolutionary situation emerging in the east. The early history of the organization was marked by lack of governmental interest and was, in fact, dominated by nongovernmental entities. Even today the ILO has a uniquely nongovernmental orientation as is reflected in their representation scheme in the International Labour Conference, the major plenary organ. Each country sends a delegation of three individuals, one from the government, one representing organized workers and one representing employers. The work of the conference is organized by groups, in which delegates representing government, employees, and workers meet separately to consider their points of view on issues in the committees or plenary sessions of the conference.

The Governing Body is the main executive organ of the ILO. It is tripartite in representational composition along the same lines as the conference. Of the twenty-four government seats in the Body, ten are automatically allocated to be "states of chief industrial importance." These ten states are determined by a committee of statistical experts. The rest of the seats are elected by the government delegates without participation of the ten already sitting while employer and worker groups elect their own delegates for all twenty four seats available to them. The Governing Body decides the composition of other major committees and conferences usually following the same tripartite principle of representation.

It was the breakdown of the tripartite scheme of representation which, in part, led to U.S. withdrawal in 1977.

c. United Nations Educational, Scientific, and Cultural Organization (UNESCO)[236]. UNESCO was established in 1946 to "foster and promote all aspects of education, science, and culture, in the widest sense of these words." The major plenary organ of UNESCO is the General Conference which is comprised of delegates from all member nations. The General Conference is authorized to determine the policies and main lines of the organization's work and make decisions on programs suggested by the executive board. The Conference can summon government representatives for international conferences on education, the sciences and humanities, and the dissemination of knowledge. It also has the capability to bring together nongovernment organizations for the same purpose.

The executive board is composed of over thirty representatives elected for staggered four-year terms from among the General Conference delegates. The president of the General Conference sits in an advisory capacity on the executive board. The board's duties include preparation of the General Conference agenda and examination of the director-general's proposed program and estimated budget. The organization's constitution mandates the board to "be responsible for the execution of the programme adopted by the Conference by taking all necessary measures to ensure the effective and rational execution of the program by the Director-General."

The major plenary organ is the board of governors in which each nation has one governor. Each has equal voting power based on a system of quotas. This arrangement has given the U.S. a controlling vote and, on important matters, a veto. Most important decisions are left to the board. Any revision of voting quotas must be approved by a four-fifths majority of the total voting power. Any change in the constitution has to be approved by a three-fifths margin of members having four-fifths of the vote.

The executive board consists of appointed directors and elected directors. The appointed members are nominated by and act in behalf of the five members with the largest quotas. The elected directors are nominated by and act for groups of member countries casting votes that cannot be split and must be cast as a unit. Voting is also weighted, but the practice of consensus has become predominant so that votes are not generally taken.

5. Reservations, Arbitration, and Sanctions. Any international organization which can function in such a way as to alter the balance of interests between nations will often experience objections to actions taken. When a nation wishes to join an international organization, it may object to certain provisions of its constitution by declaring a reservation when accepting membership. The acceptability and authority of reservations can vary extensively. When disputes do arise, it may be necessary to conduct arbitration proceedings to clarify legal questions and decide on affected interests. International arbitration has occurred frequently, and procedural and substantive issues have developed. Ultimately, when an organization has power it must be able to levy sanctions when violations occur and it is decided that the offending nation should be penalized for its actions.

a. Reservations.

> A reservation is defined as "a unilateral statement, however phrased or named, made by a State [nation], when signing, ratifying, accepting, approving, or acceding to a treaty, whereby it purports to exclude or to modify the legal effect of certain provisions of the treaty in their application to that State."[239]

The nature of the reservation is that it is a declaration, made unilaterally, outside the treaty, not within it. However, a statement which is explanatory or merely a declaration of intent is not a reservation unless it denotes a variation in the legal effect of the treaty vis-a-vis the reserving nation. Since consent is the basis of treaty power, the underlying validity of a reservation lies in the consent of other member nations. Consent to a reservation can be given by member nations either tacitly, impliedly, or expressly, either at the time of formulation of the reservation or in advance when the reservation is formulated in accordance with a specific reservations clause in the organization's constitution. When one nation accepts the reservation of another, a reciprocal agreement exists between the reserving and the accepting nations. This does not, however, alter the relationship of an accepting nation with other nonaccepting nations, and the result can be circumstances dictating a multiplicity of levels of participation.[240]

Reservations can be classified as either reciprocal or normative depending on their impact. A reciprocal reservation is appropriate in most circumstances since it affects only the nations involved and not third party nations. Normative provisions, conversely, operate for the reserving nation in relation to all party nations and not one, per se.[241]

Given the crucial role that reservations play in the formation and interpretation of international law, the General Assembly of the UN, at its sixth session, made the following recommendations:

> That organs of the United Nations, specialized agencies and States should, in the course of preparing multilateral conventions, consider the insertion therein of provisions relating to the admissibility or non-admissibility of reservations and to the effect to be attributed to them;....[242]

The options available during formulation of a treaty in terms of reservations are:

- the prohibition of all reservations
- specific enumeration of permissible reservations
- prohibitions of some reservations
- noninclusion of a reservation clause[243]

b. Arbitration. Arbitration has been extensively used in the area of multinational corporate disagreements. It generally takes place pursuant to a clause in a contract which specifies the type and form of arbitration to be used if disputes arise. International organizations can waive sovereign immunity when contracting for goods or services, or the contract may include such an arbitration clause.[244]

Arbitration auspices or fora are usually divided into two classes; those arising from a specification in the agreement or contract to use one of the specialized arbitration institutions and those where ad hoc fora are used.[245]

There are many rules and fora available for international arbitration and specification of an arbitration procedure during negotiation of a treaty may reduce the reluctance of nations to join a supranational organization having some degree of supranational authority such as contemplated in some forms of an AFR spent fuel storage regime. Arbitration rules may be adopted and applicable on a global basis,[246] a multilateral basis,[247] established under national law,[248] or according to rules established by various trade associations and exchanges.[249]

Any combination of rules and fora may be used. An agreement can provide, for instance, arbitration by the International Chamber of Commerce (ICC) under the rules of UNCITRAL[250] rather than ICC rules.[251] If no institutional forum or set of rules is adopted in the international agreement, than ad hoc arbitration is generally used. When ad hoc arbitration is specified, procedures for constituting the arbitration board and governing rules must be includend in the agreement.[252]

c. Sanctions. Sanctions constitute the systematic reactions to a detected violation of a defined obligation of a nation. Such sanctions can be "individual" or "collective" depending on whether nations act indivdidually or in concert with other nations. Sanctions can also be "informal" or "formal" depending on whether the sanctions take the form of actions allowed under international law without special justification or are illegal except if properly a response to an international violation. Any sanction can take on some combination of these two sets of modifiers. The most effective type of sanction is the formal, collective sanction.[253]

The ultimate purpose of a sanction is to prevent undesirable behavior or make such behavior less likely. Ane type of sanction can make an undesirable action impossible (e.g., a cutoff of supplies necessary to the offending nation's undesirable activity.) Another type of sanction is the imposition of unpleasant circumstances upon the offending nation, but this tactic will be successful only if the offending nation does not consider the actions vital to its well-being and it perceives rationally that the offensive action is no longer worth the consequences. A sanction need not be directly "linked" to the activity in question.[254] For instance, a nonweapons state which makes overt progress towards fabrication of a nuclear explosive device may already have access to the necessary equipment and materials, but it may be possible to put utterly ruinous pressure on the offending nation's economy.[255]

For sanctions to be effective, five conditions are necessary. First, the application of the sanctions must be certain, not subject to subsequent consideration. Second, the sanction must be clear and a graduated response still possible. Third, the sanctions must be legal under international law as a reaction to an illegal act so that all nations are free to uphold sanctions as they are imposed. Fourth, sanctions must be appropriate to the offense which usually dictates that linkage to other issues is inappropriate. Lastly, the fewer beligerent states that are involved, generally, the more effective the sanction.[256]

In general, sanctions should be linked to a specific undertaking or agreement by the offending nation and should be applied only to an activity clearly illegal in that the offending nation has agreed in some fashion not to pursue tthe offensive activity. The burdens of applying sanctions should also be shared or borne by those nations most able to bear the costs. This is particularly true where the offending nation can threaten, economically or militarily, any allies involved in the sanction activity. Sanctions can be supply oriented (a cutoff of resources), political (withdrawal of diplomatic relations), economic (cutoff of aid on assistance), or military (use of force).[257]

D. Potential Institutional Alternatives for International Auspices

In this section the characteristics described in Section C are discussed as they might apply to an international spent fuel storage regime. The objective of this discussion is not to arrive at the "optimal" multinational arrangement, since that depends on interests and goals which have not yet been made clear. In addition, it may be expected that the post-INFCE period will produce more coherent international policies concerning the back end of the fuel cycle. That view is strengthened by the recent policy changes of Australia and Canada on prior approval for reprocessing.[258]

1. Classifications.

a. Public or Private International Organizations. It seems evident that member nations would have more confidence in a public than in a private international organization since assets held in a private international organization can be subject to attachment and seizure by a private lawsuit in national courts. The concept of sovereign immunity is important to all member nations and the limits of such immunity will be dictated by the charter establishing the organization. The tradeoff of protecting the health and safety of the host nation against the desired immunity from the host nation's legal proceedings must be established during negotiation. The host nation will desire substantial control over safety and safeguards operations, but the level of direct control may be limited by the authority of member nations to exercise control over spent fuel movements or transfers. It may be reasonable to include contingency plans for the protection of the host nation's public in the event of a real threat. During the charter negotiations, credible generic threats could be enumerated along with appropriate responses by the host nation. Because of the limited threat presented by a spent fuel storage facility, contingencies requiring host nation corrective action will probably be limited and relatively easy to plan for.

b. Universal or Regional Organizations. The scope of an international organization's operations are difficult to predict because the general goal of a spent fuel storage regime is still unclear. Universality is a character which must be accompanied by a commitment on the part of the organization to achieve a global solution to a common problem. The attitudes of various nations toward spent fuel disposition vary widely, and an agreement on global goals is unlikely. On the other hand, if non-proliferation is the goal of such an institutional arrangement, universality may be desirable since all nations are able to participate. Since nations do not have consistent spent fuel disposition goals, as is the case with radio communication and world health, a more regional arrangement may be preferable.

A regional organization is what NNPA contemplates since the proposed International Nuclear Fuel Authority is meant to be open only to those nations adhering to U.S. non-proliferation goals. If non-proliferation is the goal common to all members, it is clear that nations not adhering to the Treaty on the Non-Proliferation of Nuclear Weapons, for example, would not qualify for membership. If qualification for membership is significantly restricted by national defense or energy policies, then the organization is regional rather than universal.

c. Supranational or Intergovernmental. If the international spent fuel storage facility is solely a depository for excess spent fuel with members able to withdraw their spent fuel at any time (given sufficient operational notice) then it will have little supranational authority. On the other hand, if the organization has release conditions for spent fuel or other types of power to thwart member nation's intentions, then it is supranational to some degree. The degree of supranationality is directly related to the purpose of the organization.

If the international organization is a regional organization with purposes which aggregate various national interests, it is more likely to be supranational. A typical goal for such an organization may be that spent fuel is to be released only for a nation's energy program needs. The establishing charter of the organization may include a set of release criteria which link members energy needs with acceptable releases such that a nation desiring to reprocess spent fuel in spite of sufficient reserves of low enriched uranium may be denied permission. It is important to bear in mind that release criteria may be discriminatory (i.e., different release criteria for nuclear weapons states) or may be equally applicable to all member nations. A large degree of supranational authority can only come from a group of nations in a highly cooperative endeavor with a great commonality of goals.

d. General or Functional. An international organization for spent fuel storage may be very limited in function or could have expansive goals including the creation of an international forum for matching and complementing member nation's nuclear energy objectives. As the goals of the organization become more comprehensive, the organization becomes more general. It may be appropriate to establish the organization as very functional in order to minimize initial differences, but allow for evolution of the organization to become more general as member nation's energy policies become more coherent. The future needs of advanced breeder nations will complement the waste disposal problems of those nations intending to use only light water or natural uranium reactors. An international organization for spent fuel management may be a good forum for negotiating the specifics of an international nuclear fuel cycle in which breeder nations purchase spent fuel in exchange for new reactor fuel for nonbreeder members. An important consideration in such a scheme is the immunity an international organization would enjoy from national politics which private international organizations (i.e., a multinational corporation) would not receive. An international organization offers a far more stable form of international cooperation than private enterprise. If stability in long-term energy cooperation is desired, then a functional organization with the potential for more general forms of cooperation would be a reasonable goal.

2. Participants. If the international organization involved in operating an AFR spent fuel storage facility is universalist and functional, then participation would be open to any nation and the organization would avoid politically sensitive issues. It is doubtful that any international organization could be completely universal and functional since energy issues in general are regionally biased and politically charged. The complexity of the organization and the types of memberships available will be strongly tied to the goal of the organization. Adherence to non-proliferation norms, in itself, contributes greatly to the political nature of the organization since a status quo among weapons and nonweapons nations is sought.

If the organization is regional, it will be much less difficult to dictate conditions for membership and the character of participation rights. Conditions for new membership can also be enumerated in a regional organization more easily. The right of withdrawal may be discussed during negotiation of the charter. While it is not possible to prohibit withdrawal, it can be made difficult for member nations by requiring a period of notice and continued participation during that period. Sanctions may also be included in the charter for members not upholding their commitments to the organization.

3. Structure. Much of the literature on international organizations functioning in the nuclear energy sphere indicates that two-tiered management may be desirable, especially if some insulation between the operational tier and political tier is deemed necessary. The secretariat is the most logical entity to control the operation of a spent fuel storage facility. The availability of international civil servants and the highly technical nature of spent fuel management suggest that the secretariat could manage organs specifically designated for technical tasks. Organs could be created for management of spent fuel in storage, for directing transportation of spent fuel, for interaction with the IAEA, and for developing new techniques of spent fuel transport and storage.

The next structural arrangement may be a board of delegates specifically instructed to oversee and advise the secretariat. The board may be enpowered to make policy decisions as in the case of the IAEA or given very limited powers as in the ITU. The structure of decision making power on the board will be dictated by the goals of the organization and the relative importance of the various participants. The major plenary organ could consist of delegates of all members with power to decide various larger issues such as budget, assessments, membership, and so on.

4. Judicial Functions. If the charter of the organization contains rules and sanctions, it will be necessary to have some forum for appeal of decisions by the board or major plenary organ in order to assure, to some degree, that rules and sanctions are applied on a nondiscriminatory basis. It would be reasonable to assign jurisdiction to the ICJ or a similar forum. The acceptance of the charter by a member nation can constitute acceptance of a judicial forum and, therefore, its jurisdiction.

REFERENCES

1. "Spent Fuel Storage Fact Book," DOE/NE-0005 (UC-85), April 1980, pp. 5-9.
2. "Federal Facilities for Storing Spent Fuel — Are They Needed," GAO-EMD-79-82, NTIS No. PB-297 071, June 1979, p. 1.
3. Note 1, supra, pp. 15-21.
4. J. M. Viebrock, "Alternatives fror Water Basin Spent Fuel Storage," Report NAC-C-7915, Nuclear Assurance Corp., October 1979.
5. Note 1, supra, p. 22.
6. "Spent Fuel Storage Requirements — The Need for Away-From-Reactor Storage," DOE Report cited in "Federal Facilities," Note 2, supra.
7. Note 2, supra, p. 9.
8. Note 6, supra.
9. See also, "Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Reactor Fuel," NUREG-0404, March 1978, Vol. 1, p. ES-3.
10. "Final Environmental Impact Statement: U.S. Spent Fuel Policy," Vol. 2, U.S. DOE, DOE/EIS-0015, May 1980, p. II-20.
11. Id; Anderson and Meyer, "Dry Storage of Spent Nuclear Fuel," NUREG/CR-1223, April 1980.
12. Note 10, supra, p. II-19.
13. Ann MacLachlan, "AFR Storage Outlook Dimming," *Energy Daily*, August 22, 1980, pp. 2-3.
14. "Duke Power Appeals Spent Fuel Transport Rule," *Energy Daily*, Nov. 12, 1978, pp. 1-2.
15. *Nucleonics Week*, Dec. 11, 1980, p. 12.
16. See Notes 110 - 112, infra, and associated text.
17. See note 107, infra, and associated text.
18. Note 10, supra, Vol. 1, pp. 4.112-13.
19. E.E. Voiland, et al, "Sabotage Analysis for Fuel Storage at Morris, General Electric Company," NEDM-20682, 1974, p. 7.
20. Note 10, supra, Vol. I, pp. 4.113-14.
21. Atomic Energy Act of 1954 as amended, Sections 5, 6, and 7, 42 USC 2071-2078, 2091-2099 and 2111-2111 (1976).
22. Energy Reorganization Act of 1974, Section 202 (3), (4), 42 USC 5842 (1979).
23. NRDC (Request Concerning ERDA High Level Wastes Storage Facilities), CLI 77-9, 5 NRC 550 (1977), Affd. *NRDC v. Administrator, ERDA*, 451 F. Supp. 1245 (D.C.Cir. 1978).
24. Proposed General Statement of Policy, "Licensing Procedures for Geologic Repositories for High Level Radioactive Wastes," 43 Fed. Reg. 53869, Nov. 17, 1978; see also Howard K. Shapar, "Licensing and Regulation of Nuclear Waste," Atomic Industrial Forum Meeting, Las Vegas, Nevada, January 16, 1979, p. 6.
25. 10 CFR 50, Appendix F, 2 (1980).
26. Department of Energy Reorganization Act of 1977, Section 203 (a)(8), 42 USC 7133 (a)(8), (A)-(G).

27. S. Rep. No. 95-164, 95th Congress, 1st Session 23 (1977) reprinted in 1977, U.S. Code Cong. & Ad. News, p.877.
28. *Train v. Colorado Public Interest Research Group, Inc.*, 426 US 1 (1976).
29. 40 CFR 190.10 (1979).
30. "Workshop Materials for State Review of USNRC Site Suitability Criteria for High-Level Radioactive Waste Repositories," NUREG-0326, 1977, pp. 13-15.
31. 42 USCA 7401-7642.
32. 42 USCA 7422.7
33. "Safe Drinking Water - Primary Standards on Radionuclides," 41 Fed. Reg. 28403, July 9, 1976.
34. "Federal Guidance for Persons Exposed to Transuranium Elements in the Environment" 42 Fed. Reg. 60956, Nov. 30, 1977.
35. Transportation of Explosives and Dangerous Articles Act of 1907, 18 USC 831-836 (1976).
36. 18 USC 834(a) (1976).
37. 49 CFR 390-397 (1979).
38. 46 USC 170 (1976 & Supp. II 1978).
39. 49 USC 1655(b)(1),(e)(4) (1976).
40. 49 USC 1803-1804 (1976).
41. 44 Fed. Reg. 38960, July 2, 1979.
42. 44 Fed Reg. 26850, May 8, 1979.
43. 44 Fed. Reg. 34466, June 15, 1979; 45 Fed. Reg. 37399, June 3, 1980.
44. See L.M. Trosten and R. Ancarrow, "Federal-State-Local Relationships in Transporting Radioactive Materials: Rules of the Nuclear Road," Kentucky Law Journal, Vol. 68, 1979-80, p.251; J.F. Sieberling, "Radioactive Waste Disposal: The Emerging Issue of States' Rights," Akron Law Review, Vol. 13, Fall 1979, p.261; M.L. Daugherty, "Disposal of High Level Nuclear Waste: An Abdication of Responsibility?", Univ. of Illinois Law Forum, Vol. 1979, 1979, p.915; R.L. Handler, "California's Nuclear Power Siting Legislation: A Preemption Analysis," Southern California Law Review, Vol. 52, May 1979, p.1189; C.B. Wiggins, "Federalism Balancing and the Burger Court: California's Nuclear Law as a Preemption Case Study," U.C. Davis Law Review, Vol. 13, Winter 1979-80, p.1; E. Jaksetic, "Legal Aspects of Radioactive High-Level Waste Management," Environmental Law, Vol. 9, 1979, p.347; Patricia Lucas, "Nuclear Waste Management: A Challenge to Federalism," Ecology Law Quarterly, Vol. 7, 1979, p.917; F.A. Morris and M.A. Condon, "Federal Preemptione of State and Local Nuclear Transportation Regulation," B-HARC-311-043, October 26, 1979.
45. See testimony of John M. Deutch and Morris Udall in "Oversight Hearing Before the Subcommittee on Energy and the Environment of the Committee of Interior and Insular Affairs on the House on Nuclear Waste Management" 96th Cong., 1st Session 1979, p. 11.

46. Virginia, SB-298; New York, A-10604-A, A-319713, A-7363; South Carolina, HB-3350; Arizona, SB-1283; Kansas, SB-532, S-170; Maryland, S-536; Kentucky, H-98; Mississippi, S-2063; Vermont, S-2063; Alabama, H-176; Arkan-

sas; Colorado, S-335; Connecticut, H-5097; Maine, H-799; New Hampshire, H-91; New Jersey, H-1288; New Mexico, H-106, H-360, H-500, H-527; North Carolina, H-886, H-1139; North Dakota, S-468, H-822; Alaska, S-45; Delaware, HR-124; Louisiana, S-38, H-14; Michigan, S-144, S-153, S-688, S-689, S-690; California, A-1593; Hawaii, H-199; Minnesota, H-1215; Montana, H-254; Nevada, S-38; Oregon, S-272; Texas, H-1560.

47. 42 USC 2012 (1976).
48. *Northern States Power Company v. Minnesota*, 447 F.2d. 1143, 1147 (8th Cir. 1971).
49. U.S. Constitution, Art. VI, Clause 2.
50. Department of Energy Organization Act of 1977, 42 USC 7133.
51. U.S. Government Accounting Office, Report to the Senate Committee on Environment and Public Works, "Nuclear Energy's Dilemma: Disposing of Hazardous Radioactive Waste Safely," 1977; U.S. Department of Energy, "Report to the President by the Interagency Review Group on Nuclear Waste Management," 1979, pp. 45-46; John F. Seiberling, "Radioactive Waste Disposal: The Emerging Issue of States' Rights," Akron Law Review, Vol. 13, Fall 1979, pp. 263-66.
52. 42 USC 2021 (b), (k).
53. *Florida Lime Avocado Growers v. Paul*, 373 U.S. 132, 142-143 (1963).
54. *Rice v. Sante Fe Elevator Corp.*, 331 U.S. 218, 230 (1947).
55. Id.
56. *Hines v. Davidowitz*, 312 U.S. 52, 67 (1941).
57. Id.
58. *Pacific Legal Foundation v. California Energy Commission*, Civil No. 78 711-E (S.D. Cal. 1979).
59. Id.
60. Quoted in Id.
61. *The Energy Daily*, December 5, 1980, p. 4; *Nuclear Fuel*, December 8, 1980, p. 12; H.R. 8378 (1980).
62. "DOE Announces New Spent Nuclear Fuel Policy - Press Release" U.S. D.O.E., October 18, 1977.
63. Independent Offices Appropriations Act of 1952, 31 USC 483a.
64. "Final Environmental Impact Statement: U.S. Spent Fuel Policy" DOE/EIS-0015, May 1980, Vol. 4, p. II-2.
65. Id. p. II-3.
66. See Notes 69-71, infra.
67. Note 3, supra, p. II-16.
68. DPST-ISFS-78-1, Savannah River Laboratory (1978).
69. "Regional Nuclear Fuel Cycle Centers," International Atomic Energy Agency, ISBN-92-0-159277-9 (1977).
70. A.S. Hanson, "A Utility Perspective on the Cost and Scheduling of Spent Fuel Storage Facilities," presented at ANS Conference, April 5, 1978.
71. E. Gordon, "Comments on Spent Fuel Storage, Costs, Prices, Schedules, and Pool Capacities" presented at ANS Conference, April 5, 1978.
72. Senate Report No. 96-548, Jan. 3, 1980, pp. 24-25.
73. 45 Fed. Reg. 74693-74712, Nov. 12, 1980.
74. 10 CFR 72.11-.21 (1980).

75. Id. 72.31-.42.
76. Id. 72.50-.57.
77. Id. 72.61-.70.
78. Id. 72.71-.76.
79. Id. 72.80.
80. Id. 72.81-.84.
81. Id. 72.91-.93.
82. 45 Fed. Reg. 74693, Nov. 12, 1980.
83. 10 CFR 72.2(a).
84. Id. 72.2(c).
85. 45 Fed. Reg. 74698, Nov. 12, 1980; also 10 CFR 72.3(m) (1980).
86. 10 CFR 72.7 (1980).
87. Id. 72.8 (1980).
88. Id. 72.12 (1980).
89. Id. 72.14 (1980).
90. Id. 72.15 (1980).
91. Id. 72.32 (1980).
92. Id. 72.33(c)(3),(d)(3) (1980).
93. Id. 72.34 (1980).
94. Id. 72.41 (1980).
95. Id. 72.42 (1980).
96. Id. 72.50 (1980).
97. Id. 72.51, 72.53 (1980).
98. Id. 72.54 (1980).
99. Id. 72.56(a),(c)(2) (1980).
100. Id. 72.61(e), (1980).
101. Id. 72.62, 72.63 (1980).
102. Id. 72.64 (1980).
103. Id. 72.66 (1980).
104. Id. K72.68, 72.69 (1980).
105. Id. K72.71-72.75 (1980).
106. Id. 72.75 (1980).
107. Id. 72.81-72.84 (1980).
108. Id. 2.764 (1980).
109. Id. 150.15 (1980).
110. 46 Fed Reg. 5298, January 19, 1981.
111. 49 CFR 171.8.
112. 49 CFR 172.507, 172.527.
113. 49 CFR 173.22(b),(c).
114. 49 CFR 177.810.
115. 49 CFR 177.825(a),(b).
116. 49 CFR 177.825(c).
117. 49 CFR 177.825(d).
118. 49 CFR 177.825(e).
119. Id.
120. 49 CFR 177, Appendix A.
121. 46 Fed. Reg. 5313, January 19, 1981.
122. Id. pp. 5298-5318.

123. S.2189, 96th Cong. 2d Sess.
124. Nuclear Non-Proliferation Act of 1978, 22 USC 3201 (1978).
125. Id. Sec. 104(a)(4), 22 USC 3223(a)(4).
126. Id. Sec. 104(a)(5), 22 USC 3223(a)(5).
127. The terms were used in the Administration, Bingham, and Percy versions (123 Cong. Rec. S6788, 123 Cong. Rec. H1714, and 123 Cong. Rec. S3381 respectively) as well as versions introduced in the 94th Congress (Hearings on S.1439 and S.3370 and H.R. 15273, JCAE, 94th Cong. 2nd Sess. 1976).
128. Harry R. Marshall, Jr., "Section 104 of the Nuclear Non-proliferations Act of 1978 - Establishment of International Nuclear Supply Assurances," New York University Journal of International Law and Politics, 1979, pp. 427-28.
129. INFCE, "Reprocessing, Plutonium Handling, Recycle: Report of Working Group 4," INFCE/PC/2/4, pp. 7-11.
130. "Nuclear Proliferation Handbook," Comm. on Gov't Affairs, U.S. Senate, Sept. 1980, pp.208-9.
131. Nuclear Non Proliferation Act of 1978, 22 USC 2121 (1978).
132. Id., 3223.
133. Smith and Chayes, "Institutional Arrangements for a Multinational Reprocessing Plant," in *International Arrangements for Nuclear Fuel Reprocessing* (Ballinger, Cambridge, 1977) p. 146.
134. Id. p. 150.
135. Solomon and Triplett, "A Procedure for Nuclear Reactor Spent Fuel Valuation" RAND/P-6240, November 1978, pp. 11-13.
136. Id. pp. 33-34.
137. Allan Roth, "The Foreign Sovereign Immunities Act of 1976," The Corporation Law Review, Vol. 2, No. 4, Fall 1979, p. 335.
138. International Organizations Immunities Act of 1945, 22 USC 288a-288f (1976).
139. Note 137, supra, p. 334.
140. Diplomatic Relations Act of 1978, 22 USC 254a-254e; 28 USC 1251, 1351, 1364 (1978).
141. Restatement (Second) of Foreign Relations Law of the United States.
142. Id. p.5.
143. Note, "Sovereign Immunity and International Organizations: *Broadbent v. OAS*," The Journal of International Law and Economics, Vol. 13, No. 3, pp. 679-680.
144. *U.S. v. Melekh*, 190 F. Supp. 67, 84 (S.D.N.Y. 1960).
145. Note 143, supra, p. 681.
146. C. Jenks, *International Immunities* (1961) p. 17.
147. This is distinct from absolute or restrictive immunity; See John N. O'Brien, "Institutional Problems Associated with a Domestically Sited Multinational Fuel Cycle Facility," NUREG/CR-1028, December 7, 1979. Reprinted in edited form in the previous section, esp. IV. A.1.
148. D. Botwett, *The Law of International Institutions*, 308 (3rd Ed. 1975).
149. Note 143, supra, pp. 686-87.
150. U.N.T.S. 15, February 13, 1946.
151. 119 U.N.T.S. 3, April 30, 1948, Additional Protocol 721 U.N.T.S. 264, February 27, 1967.

152. Pan-Am T.S. No. 22, I(3) Ann. OAS 271 (1949).
153. Note 143, supra, p. 689.
154. For example, see Article 12(a) of the OAS Convention, Note 20, supra.
155. 22 USC 288a (1976).
156. Foreign Sovereign Immunities Act of 1976, 28 USC 1611(a) (1976).
157. H.R. Rep. No. 94-1487, 94th Cong., 2nd Sess; U.S. Code Cong. & Ad. News 6604, 6614 (1976).
158. *Curran v. City of New York,* 77 N.Y.S. 2d. 206 (1947); *Herbert Harvey, Inc. v. NLRB,* 424 F. 2d. 770 (D.C. Cir. 1969); *Edison Sault Electric Co. v. United States,* 552 F. 2d. 326 (Ct. Cl. 1977); *Weidner v. INTELSAT,* 392 A. 2d 508 (1978).
159. "International Fuel Service Centers," Burns and Rod, DOE Contract No. EN-77-C-01-5066, August 1978; "Regional Nuclear Fuel Cycle Centers," IAEA, STI/PUB/445, 1977; W.R. Harris, "Nuclear Responsibility and Nuclear Trade: International Rules and Institutions to Manage Nuclear Fuel Cycles," RAND-P-5792, 1977; "Alternative Institutional Arrangements for Developing and Commercializing Breeder Reactor Technology" RAND-PB-263479, 1976; M.B. .Kratzer and E.F. Wonder, "Institutional Arrangements for the Reduction of Proliferation Risks," IEAL, 1979; H. Mendershausen, "International Cooperation in Nuclear Fuel Services: European and American Approaches," RAND P-6308, December 1978
160. See Notes 138-144, supra, and associated text.
161. H.G. Schermers, *International Institutional Law,* (A.W. Sijthoff, Leiden, 1972) p. 6.
162. The official UN approach dictates that an international agreement is required, ECOSOC Resolutions 288B(x) and 1296 (XLIV) on Non-Governmental Organizations.
163. F. Syersted, "Objective International Personality of Intergovernmental Organizations," Nor disk Tidsskrift for International Ret (1964), Vol. 34, p. 47.
164. K.W. Dam, "The GATT as an International Organization," Journal of World Trade Law (1969), Vol. 3, pp. 374-389.
165. Note 161, supra, p. 11.
166. This was the concept used by the International Law Commission of the UN in the "Draft Articles on Representatives of States to International Organizations," General Assembly Official Records, 23 Suppl. No. 9 (A/7209/Rev. 1), p.4.
167. M.S. McDougal and R.M. Goodman, "Chinese Participation in the United Nations: The Legal Imperatives of a Negotiated Solution," American Journal of International Law, 1966, Vol. 60, pp. 682-683.
168. Note 161, supra, p. 18.
169. Id. pp. 19-24.
170. UPU Resolution C4, United Nations Juridicial Yearbook 1969, p. 119-20.
171. Note 161, supra, p. 25.
172. UN Charter, Art. 3,4; Council of Europe, Art. 4, Organization of American States, Art. 4; Organization of African Unity, Art. 4.
173. F. Seyersted, "International Personality of Inter-governmental Organizations," Indian Journal of International Law, 1964, Vol. 4, pp. 15-16.

174. For example, The Food and Agriculture Organization of the UN, Art. 2; International Momentary Fund, Art. 2; International Bank for Reconstruction and Development, Art. 2; International Atomic Energy Agency, Art. 4.
175. Note 161, supra, p. 33.
176. This is the case in both the UN and the European Communities.
177. International Monetary Fund, Art. 2, sec. 2; GATT, Art. 33; European Economic Community, Art. 237; European Free Trade Ass'n, Art. 41.
178. World Health Organization, Art. 6; Organization for African Unity, Art. 28.
179. Note 161, supra, p. 39.
180. European Economic Community, Art. 237; Euratom, Art. 205, North Atlantic Treaty Organization, Art. 10.
181. Art. 56.
182. International Atomic Energy Agency, Art. 18D (5 years); Food and Agriculture Organization of the UN, Art. 19 (4 years); International Civil Aviation Administration, Art. 95 (3 years); Intergovernmental Maritime Consultive Organization, Art. 59 (1 year); North Atlantic Treaty Organization, Art. 13 (20 years).
183. Central Office for International Railway Transport, Art. 2, para 2: 242 UNTS 325; International Organization of Legal Metrology, Art. 29.
184. UN, World Health Organization, European Communities.
185. See, L.M. Goodrich and E. Hambro, *The Charter of the United Nations*, (2d. ed., London, 1949) p. 143.
186. Official Records, WHO, No. 71, p. 19.
187. Vienna Convention on the Law of Treaties, Art. 62.
188. See, for example, Court of Justice of the European Communities, 13 NW 1964, in L.J. Brinkhorst and H.G. Schermers, *Judicial Remedies in the European Communities* (1969), p. 12-13.
189. C.C. Joyner, "The United States' Withdrawal from the ILO: International Politics in the Labor Arena," International Lawyer, Vol. 12, Fall 1978, p. 726.
190. Id. pp. 731-34.
191. Note 161, supra, p. 54-55.
192. Id.
193. C.W. Jenks, "Expulsion from the League of Nations," British Yearbook of International Law, 1935, Vol. 16, p. 156; League of Nations Covenant, Art. 16, para 4.
194. Note 161, supra, p. 56.
195. UN; International Monetary Fund, Art. 15, Sec. 2; International Bank for Reconstruction and Development, Art. 6, Sec. 2.
196. For example, Organization for European Economic Cooperation.
197. World Health Organization, Art. 8; Food and Agriculture Organization, Art. 2, para 3-5.
198. Note 161, supra, pp. 70-72.
199. Id. pp. 72-81.
200. C.S. Manno, "Problems and Trends in the Composition of Non-plenary UN Organs," International Organization, 1965, Vol. 19, pp. 37-55.
201. For example, UN; International Labor Office.
202. Note 161, supra, pp. 182-92.

203. The World Health Organization, The UN, and the International Labour Organization all have regional offices in the Secretariats.
204. For example, the Food and Agriculture Organization, Art. 7; World Meteorological Organization, Art 21.
205. For example, The International Labour Organization, Art. 8, International Monetary Fund, Art. 12, Sec. 4.
206. For example, the UN, Art. 97; UNESCO, Art. 6; International Atomic Energy Agency, Art. 7
207. UN, Art. 101; Food and Agriculture Organization, Art 8, para. 3; World Health Organization, Art. 35; Organization of American States, Art. 126.
208. See Jackson Report, UN document DP/5, Vol. II, pp. 345-50.
209. See UN document A/5599, p. 13.
210. For example, the International Monetary Fund.
211. L. Scheinman, "IAEA: Atomic Condominium?," in *The Anatomy of Influence*, (ed. Cox and Jacobson, Yale, 1974) pp. 217-218.
212. Id.
213. Note 161, supra, pp. 241-44.
214. Id.
215. Id.
216. Id.
217. D.W. Bowett, "The Law of International Institutions" (2d. ed., London, 1970), p. 305.
218. For example, International Court of Justice and the European Court of Human Rights.
219. For example, the Western European Union
220. Note 161, supra, p. 263.
221. European Economic Community, Ant. 166; European Coal and Steel Community, Art. 32; Euratom, Art. 138.
222. UN Charter, Art. 7.
223. Id., Art. 93.
224. International Court of Justice, Art. 36.
225. See K.J. Keith, *The Extent of the Advisory Jurisdiction of the International Court of Justice* (Sijthoff, Leiden, 1971).
226. Administrative Tribunal of the International Labour Organization, Art. 13 (2).
227. European Economic Community, Art. 170; European Coal and Steel Community, Art. 80; Euratom, Art. 142.
228. European Economic Community, Arts. 173, 175, 184; European Coal and Steel Community, Arts. 33, 35, 36; Euratom, Arts. 146, 148, 156.
229. European Economic Communities, Art. 179.
230. Id. Art. 183; Euratom, Art. 155
231. Euratom, Art. 18.
232. For example, Euratom, Art. 103.
233. European Economic Communities, Art. 172.
234. Section adapted from H.K. Jacobson, "ITU: A Potpourri of Bureaucrats and Industrialists," in *Anatomy*, Note 211, supra, pp. 59-101.
235. Section adapted from R.W. Cox, "ILO: Limited Monarchy," in *Anatomy*, Note 211, supra, pp. 102-138.

236. Section adapted from J.P. Sewell, "UNESCO: Pluralism Rampant," in *Anatomy*, Note 211, supra, pp. 139-174.
237. Section adapted from H.K. Jacobson, WHO: Medicine, Regionalism, and Managed Politics," in *Anatomy*, Note 211, supra, pp. 175-215.
238. Section adapted from S. Strange, "IMF: Monetary Managers," in *Anatomy*, Note 211, supra, pp. 263-297.
239. Vienna Convention on the Law of Treaties, Art. 2(d), May 23, 1969, UN Doc. A/Conf. 39/27 (1969).
240. Linda L. Hazou, "Determining the Extent of Admissibility of Reservations: Some Considerations with Regard to the Third United Nations Conference on the Law of the Sea," Denver Journal of International Law and Policy, Vol. 9, Winter 1980, pp 69-70.
241. Mandelson, "The Constitutions of International Organizations," British Yearbook of International Law, 1973, pp. 145-46.
242. G.A. Res. 598, 6 U.N. GAOR, Supp. (No. 20) (Jan. 12, 1952).
243. Note 240, supra, p. 72.
244. S.V. Goekjian, "The Conduct of International Arbitration," Lawyer of the Americas, Vol. II, Summer/Fall 1979, p. 410.
245. Id.
246. For instance, the rules of arbitration recently enacted by the United Nations Commission on International Trade Law called the UNCITRAL Rules.
247. Arbitration rules have been adopted by Economic Commission of Europe, Economic Commission for Asia and the Far East, and the Council for Mutual Economic Assistance.
248. For example, the Arbitration Act of the United Kingdom, and the United States Arbitration Act, 8 USC 1-14 (1970).
249. For example, the Coffee Exchange.
250. See Note 246, supra.
251. Note 244, supra, pp. 411-413.
252. Id. p.414.
253. P.C. Szasz, "Sanctions and International Nuclear Controls," Connecticut Law Review, Vol. II, Spring 1979, pp. 546-47.
254. Id., pp. 548-49.
255. International Security Assistance Act of 1977, Sec. 12, 22 USC 2429 (Supp. I 1977).
256. Note 253, supra, pp. 551-54.
257. Id. pp. 569-80.
258. "A Draft Agreement Between Euratom and Australia," *Nucleonics Week*, Feb. 5, 1981, pp. 6-7.

Institutional Problems Associated With A Domestically Sited Multinational Enrichment Facility

John N. O'Brien
June 1981

TABLE OF CONTENTS

		Page
I.	Introduction	73
II.	Safeguards	73
III.	The Structure of the International Organization	75

ABSTRACT

This report examines the factors which are of importance in considering a multinational arrangement for supplying low enriched uranium fuel to members. It does not reiterate points made in the previous report, but rather builds upon the information developed there.

The problem of denying access to sensitive technology while allowing international safeguards inspectors sufficient access to verify operator safeguards is addressed. The potential arrangements for an international organization including structure, access, conditions, prior approval rights, sovereign immunity, and participation are discussed in the context of an enrichment facility.

I. INTRODUCTION

The institutional aspects associated with a domestically sited multinational enrichment facility are, for the most part, similar to those described in the previous two chapters on a multinational fuel cycle facility modeled after INFA and an AFR spent fuel storage facility. It is assumed here that a public international organization would be the institutional form of a multinational enrichment arrangement and that all rights and obligations of the organization itself and its various members would be analogous to those previously described for international organizations. The major difference would most likely be the structure of safeguards.

II. INTERNATIONAL SAFEGUARDS

International safeguards, including material accounting and control may be conducted by the organization itself, by the host nation, by the IAEA, or by any combination of these entities. Generally, the operator conducts material accountancy which is verified by the IAEA through its inspections. The particular types of non-proliferation threats vary depending on whether the enrichment facility can or does produce highly enriched uranium (HEU). The particular type of enrichment technology employed directly affects the general safeguards risks involved as well, although physical security is not a direct concern in international safeguards.

If a facility is capable of producing only low enriched uranium (LEU), then a subnational adversary cannot remove material capable of producing an explosion. LEU which is usually only 3-4% U^{235} must be enriched to at least 20% (at which point it becomes HEU) in order to be used in a nuclear explosive device. While it is substantially easier to enrich LEU to HEU then to enrich natural uranium (0.7% U^{235}) to HEU, enrichment of any kind is still generally considered beyond the capability of subnational adversaries. The major safeguards concern at an enrichment facility capable of producing only LEU is that the operator may misuse the facility or may divert either natural uranium or LEU to a separate enrichment facility capable of HEU production or to a clandestine plutonium production reactor. As a result, international safeguards at a facility which produces only LEU are mainly concerned with material accountability. Therefore, international safeguards would probably be less intrusive than for those described for an AFR spent fuel storage facility (which contains unprocessed plutonium) discussed in the previous report.

Some enrichment technologies for producing LEU can be used to produce HEU more easily than others. If a facility can be used to make HEU, but its declared use is solely to produce LEU fuels, then the simple presence of HEU is an indication of wrongdoing. As a result, international safeguards at such a facility would include examination of the process, as well as material control and accounting.

Three general aspects of an IAEA safeguards system designed to verify that an enrichment facility operator is not participating in efforts to secure weapons useable material can be defined. First, international safeguards must verify the operators accountancy for all declared nuclear material. Second, they must ensure that no nuclear materials are introduced and withdrawn, without record. Third, and most importantly, they must verify that the enrichment facility is not used to produce uranium of higher than declared enrichment.

A significant problem exists in the independent verification of the three aspects noted above. Much of the technology used for enriching uranium is sensitive both from the standpoint of the proprietary interests of the nations which developed the technology for profit and in light of the proliferation potential created by many nations learning about and potentially implementing enrichment techniques. Thus, most nations wish to minimize access by international inspectors.

The level of inspector access needed to verify the three aspects listed above varies according to the type of enrichment technology used. The process most used in currently operating enrichment plants is the "gaseous diffusion" type. Gaseous diffusion involves the use of pressurized uranium hexafluoride (UF_6) gas pumped through multiple barriers which allow lighter molecules (containing U^{235}) to move through more quickly than the heavier molecules (containing U^{238}) so that, after a series of such barriers, the U^{235} content of the gas increases. Since each barrier increases U^{235} content very slightly, a series, or "cascade," of barriers must be used to reach the desired enrichment. A typical gaseous diffusion enrichment facility must use about 1400 stages, each consisting of several barriers to produce LEU. In order to produce weapons-grade HEU (90% U^{235}), a larger number of stages are required. Thus, a gaseous diffusion plant designed for the production of LEU could only be used to create weapons-grade material through modification and non-standard operation or through repeated recycling of product to feed. Such an endeavor would take months to produce a significant quantity of weapons-grade material, so it would be extremely time consuming even if technically feasible.[2] As a result, international inspector access can be relatively limited if gaseous diffusion is the enrichment technology employed.

The enrichment technology being employed in most enrichment facilities being built or planned rely on the "gas ultracentrifuge" technology. By rotating a UF_6 mixture of molecules in a cylinder at high speed, the heavier ones (containing U^{238}) are pushed to the outside and enriched UF_6 (containing more U^{235}) can be extracted mechanically from the inside.

Each centrifuge contains very little UF_6 but the enrichment obtained per centrifuge is much higher than for a gaseous diffusion stage. As a result, centrifuge cascades are run in parallel since only about 12 centrifuges are necessary in a single cascade to produce LEU. However, the small throughput per centrifuge dictates that hundreds of thousands of individual centrifuges may be necessary to produce as much LEU as a typical gaseous diffusion plant with 1400 stages.[3]

In contrast to gaseous diffusion, the rearrangement of centrifuge cascades to produce weapons grade material is relatively simple. If 12 centrifuges are necessary to produce LEU, about 35 arranged into a single cascade could produce weapons-grade material. In addition, such a process could be completed in a matter of days.[4]

Access to a centrifuge enrichment plant and visual examination of centrifuge machines, especially in a disassembled condition may reveal sensitive technology. Therefore, nations deploying centrifuge technology may designate certain areas of centrifuge plants or special material balance areas to which international inspectors would be denied access, as provided in Section 46(b)(iv) of INFCIRC/153. Section 80 of INFCIRC/153 specifies the maximum routine inspection efforts for various types of facilities based on the types and quantities of nuclear material while they contain or process. A larger enrichment facility would qualify for continuous inspection while a pilot plant would not.

These provisions in INFCIRC 153 allow an operator to legally restrict the intrusiveness and frequency of inspections. In a centrifuge facility these limitations can seriously affect the quality of safeguards since rearrangement of cascades to produce weapons-grade materials is relatively simple. The trade-off between access and international safeguards effectiveness at enrichment facilities is presently being discussed by a group of negotiators from the nations now possessing enrichment facilities. This group, called the "Hexapartite Safeguards Project" is meeting as of this writing and is expected to make a recommendation concerning the level of inspector access by November of 1982. The product of this project can be expected to influence the level of access granted not only to IAEA inspectors in a multinational enrichment facility, but also the level of access granted to participating nations not privy to "commercially sensitive" information.

III. STRUCTURE OF THE INTERNATIONAL ORGANIZATION

Properly insulating foreign assets held in multinational enrichment facility from attachment in a domestic law suit requires that the institutional arrangement be one of an international organization. However, the particular type of organizational structure that is used will be dictated, in large part, by the proprietary and non-proliferation concerns of the nation supplying the technology — in this case the U.S.

In order to restrict "commercially sensitive" information on enrichment, the U.S. may require that only U.S. nationals be granted access to certain areas. The restricted areas will most likely be those inside a centrifuge cascade or gaseous diffusion process area and archives containing sensitive information.

The nature of the restricted information can be characterized by distinguishing between three types of enrichment plant components according to their sensitivity. These are freely available components which can be used without modification, those which are available and can be modified for use, and those components designed specifically for the purpose of enrichment. No denial of access is necessary for the first type of component and information about components in the second category before modification can be freely disseminated. Restricted information is that information necessary to modify the second type of available components to make them useful for enrichment and all information regarding the third type.[5]

Eurodif, which is an international joint stock company under French law, (not a public international organization)[6] has an institutional arrangement for restricting sensitive information. Each nation uses its own technology in its domestic facility and shareholders are entitled to their appropriate share of enriched uranium product. The agreements in relation to Eurodif include clauses to ensure the control of the use of enrichment technology.[7] For instance, the Tricastin enrichment plant in France utilizes French technology which is restricted to French nationals.

Urenco, actually consisting of two companies, Centel which manufactures centrifuge components and Urenco which enriches uranium, is owned equally by three nations. The United Kingdom, West Germany, and the Netherlands all had essentially equal enrichment technologies when the agreement was concluded so that all three do share enrichment technology information. Transfer of sensitive information must be unanimously agreed upon according to a provision in Urenco's charter (Treaty of Almelo).[8] Such matters are taken up by a Joint Committee while nonpolitical matters are decided by the Urenco Board which has all three nations represented, but is constituted as a UK-based corporation.[9]

A multinational enrichment endeavor based in the U.S. would likely fall between these examples since it would be an international organization similar to URENCO, but have information controls much like Eurodif. As a result, it is likely that the operational organ of the facility (possibly the Secretariat) would be staffed by U.S. citizens while non-sensitive operations and political decision-making may be done by a board in which all participating nations are represented. As in Eurodif, all participants would be entitled to a share of enriched uranium, possibly proportional to their investment.

Such an arrangement has the potential for being very universalist in that many nations could participate without gaining access to sensitive information. Membership could still be restricted by certain conditions such as NPT adherence and absence of indigenous, domestically operated enrichment capability.

The issue of whether U.S. prior approval rights would be applied to the enrichment uranium product will be a subject of negotiations. Potential member nations will surely press for this and some general level of U.S. acquiescence over sovereign control of enriched uranium may be asked. If the U.S. can gain a desirable position on the governing board of the organization, for instance a veto power over potentially critical decisions, acquiescence on prior approval rights may be beneficial in terms of non-proliferation interests.

The level of sovereign immunity a multinational enrichment facility would enjoy is not clear. Due to the problem of foreign access to sensitive enrichment technology, the U.S. may require that only U.S. nationals be allowed access to certain areas. U.S. nationals in a domestically sited international organization would not be immune to legal proceedings brought against them in a U.S. court. Federal legislation does preclude attachment of the international organization's assets. However, a great deal of pressure could be brought to bear on a Secretariat staff which might be forced to choose between obeying the directive of the international organization or complying with U.S. law. This dual jeopardy problem can be addressed during charter negotiations.

It would be appropriate to consider negotiating toward a very functional type of international organization which would have very well defined goals. Under this type of arrangement, political considerations could be put off until the nature of international trade in nuclear fuels becomes more coherent. In the meantime, nations which are considering indigenous enrichment or reprocessing facilties may delay such plans and join an internationally owned enrichment facility as an alternative. Making arrangements for withdrawal in the charter would render the concept more politically acceptable and further non-proliferation goals by, at least, delaying the spread of enrichment technology. This would be consonant with the directives of NNPA.

REFERENCES

1. "Enrichment Availability," International Nuclear Fuel Cycle Evaluation, Report of Working Group 2, INFCE/PC/2/2, Feb. 1980, p. 129.
2. "Safeguarding Uranium Enrichment Facilities," IAEA-AG-110, September, 1979, pp. 3-4.
3. Id p. 6.
4. *Id* p. 7.
5. Note 2, supra, p. 142.
6. "Regional Nuclear Fuel Centres," IAEA, STI/PUB/445, 1977, Vol. II, p. 68.

7. Note 2, supra.
8. Id., p. 143.
9. Note 6, supra, pp. 68-69.

Impacts Of Alternative Nuclear Fuel Cycles On The U.S./IAEA Safeguards Agreement

John N. O'Brien

NUREG-CR 1049

April 1980

TABLE OF CONTENTS

		Page
I.	Introduction	81
II.	Background	81
III.	The Choice of Alternative Fuel Cycles	93
IV.	Generic Safeguards Variations, and their Relation to U.S./IAEA Safeguards	100
V.	Analysis of Individual Fuel Cycles	104
VI.	Conclusions and Summary of Results	107
Appendix A:	NASAP Reactor/Fuel Cycle Systems for NRC Review	109

ABSTRACT

This report examines the U.S./International Atomic Energy Agency (IAEA) bilateral agreement to determine whether U.S. adoption of alternative nuclear fuel cycle arrangement would affect U.S./IAEA relations. The general form of IAEA safeguards is analyzed for various reactors and fuel cycle facilities. Safeguards options, including spiking, coprocessing, use of thorium fuel cycles, denaturing, use of heavy water, and storage of spent fuel and waste, are then compared to IAEA safeguards to reveal inconsistencies or discrepancies. An analysis of specifically proposed fuel cycle arrangements follows.

I. INTRODUCTION

A. Purpose of the Report

This report is one of a series examining problems related to the use of alternative nuclear fuel cycles in the U.S. The purpose of this report is to analyze those problems associated with implementation of the U.S./IAEA Safeguards Agreement as it may apply to the use of alternative fuel cycles. At this time extensive negotiations are going on regarding implementation of the Agreement and the direction and agenda for completing its implementation. This report will detail the potential problems that may arise from a decision to alter the existing fuel cycle for reasons of proliferation resistance. The primary concern of this report is to identify problems which could impede implementation of the Subsidiary Arrangement and negotiation of Facility Attachments between the U.S. and the International Atomic Energy Agency (IAEA).

B. Scope of Inquiry

It must be recognized that the development and character of U.S./IAEA safeguards are as yet incomplete, which makes detailed commentary difficult. This report is also limited to examination of the impacts on the safeguards agreements, not technical safeguards measures, which are addressed in another report in this series.*

II. BACKGROUND

A. The Nature of U.S./IAEA Safeguards in the U.S.[1]

An important factor in the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) is that none of the weapons states (the U.S., USSR, UK, France, and China) is obliged to accept IAEA safeguards. To encourage wider adherence to the NPT, the U.S. volunteered to place all its nuclear activities under IAEA safeguards excluding only those with direct national security significance. In order to implement this voluntary offer ("The President's Offer"), an agreement for the Application of Safeguards[2] has been negotiated by the U.S. and IAEA, which defines in general terms the purpose of IAEA safeguards in the U.S., the responsibilities of the U.S. and the IAEA, and the structure of the safeguards to be applied. In overall form, the Agreement follows INFCIRC/153,[3] the IAEA model for safeguards agreements under NPT, but it differs in detail to take account of the fact that the U.S. is a nuclear weapons state. Upon Senate approval of the agreement negotiated between the U.S. and the IAEA, nuclear facilities throughout the United States will begin to implement International Atomic Energy Agency safeguards under the terms of that agreement.

---

*See Weinstock and Keisch, "Technical Safeguards Issues for Alternative Fuel Cycles," BNL-NUREG-25557 (1979) reprinted in edited form in Chapter Five.

The next legal instruments required for implementation of IAEA safeguards in the U.S. are the Subsidiary Arrangements and Transitional Subsidiary Arrangements,[4] which are formally part of the Agreement, but which are separate documents to be negotiated after the content of the Agreement has been made final. Where the Agreement defines the structure of safeguards in a general way, the Subsidiary Arrangements define the details of the application of safeguards on a countrywide basis for the technologies being used. The U.S./IAEA Safeguards Agreement specifies that not all facilities in the U.S. will necessarily be subject to full IAEA safeguards; most facilities will not be inspected by the IAEA, but will have to fulfill IAEA requirements pertaining to records, reports, and accountability. Under the terms of the U.S./IAEA Agreement, the IAEA will choose from a list of eligible non-national-security-related facilities those to which it will apply full or partial safeguards. Thus there are two sets of Subsidiary Arrangements for the U.S.: the Subsidiary Arrangements, which define full safeguards including IAEA inspection; and the Transitional Subsidiary Arrangements, which define safeguards for those facilities which will not be inspected initially. The IAEA is given broad discretion to change the list of facilities to which inspection will be applied or which will be required to report.

In order to implement the provisions of the Subsidiary Arrangements and Transitional Subsidiary Arrangements, some changes were necessary in U.S. safeguards regulations. The new regulations which incorporate these changes are proposed 10 CFR 75 and conforming amendments to 10 CFR 40, 50, 70, 150, and 170;[5] revised instructions for completion of Reporting Forms 741 and 742 by NRC licensees; and revisions in the DOE Orders (especially those parts dealing with Forms 741 and 742). It is important to note that these changed U.S. regulations, although they are domestic law rather than international agreements, nonetheless must conform with the internationally agreed upon (and therefore difficult to change) U.S./IAEA Safeguards Agreement. Thus, while it may appear that U.S. domestic regulations could be modified fairly easily to take into account possible problems associated with alternative fuel cycles, in some cases the U.S. regulations are constrained by the Agreement, so that any such changes would require formal IAEA approval.

Taken together, the U.S./IAEA Agreement, the Subsidiary Arrangements and Transitional Subsidiary Arrangements, and the new U.S. regulations define on a U.S.-wide basis the general structure and content of the implementation of IAEA safeguards in the U.S. Two other documents remain which define the specific information required for implementation. The first is the Design Information Questionnaire (DIQ) which is to be prepared by the facility and submitted via the U.S. government to the IAEA. Basically, DIQs are detailed descriptions of specific facilities and their nuclear materials measurement and accounting systems and procedures (including typical values of, and calculation procedures for, measurement uncertainties).

The purpose of the DIQ is to provide the IAEA with sufficient information about a specific facility to allow the IAEA to formulate the facility-specific details of the safeguards to be applied. These details are contained in the last of the set of documents which define IAEA safeguards, the Facility Attachment. Facility Attachments are part of Subsidiary Arrangements, and as with the Subsidiary Arrangements, there are two types of Facility Attachments: regular Facility Attachments, for those few facilities which will be subject to full IAEA safeguards including inspection; and Transitional Facility Attachments, for the majority of facilities, which will comply with IAEA records and reporting requirements but are exempt from inspection.

Facility Attachments and Transitional Facility Attachments, since they are formally part of the U.S./IAEA Agreement, are negotiated documents which must be agreed to by the U.S. Government and the IAEA. Spokesmen for the NRC have said that it is the NRC's intention to consult with licensed facilities and allow them to review Facility Attachments for their facilities prior to final approval.[6] This is quite important, because the topics covered in the Facility Attachment (e.g., material balance areas and key measurement points structure, definition of typical batches, and if appropriate, containment and surveillance measures, and inspection effort) are facility specific and can profoundly affect the impact of safeguards on the operation of the facility.

Taken together, then, the U.S./IAEA Agreement, Subsidiary Arrangements, domestic regulations, and Facility Attachments form the legal basis which defines the specific structure and content of IAEA safeguards in the U.S. for those facilities under U.S./IAEA safeguards.

All safeguards reports are to be submitted by the facility on U.S. forms to the Nuclear Materials Management and Safeguards System (NMMSS), located in Oak Ridge, Tennessee. The NMMSS will then process the reported data, and use them as required for domestic safeguards purposes. The data will then be reformatted and converted to the reports specified in Code 10 of the Subsidiary and Transitional Subsidiary Arrangements, and transmitted to the IAEA in Vienna.

A very important consideration is that the Subsidiary Arrangements can not be broadened to include a new technology or fuel cycle unless all measurements and accounting procedures have been formalized. For most of these fuel cycles there are unknowns in the material control and accounting procedures. The major purpose of this report is to identify those unknowns.

REFERENCES

1. For a complete description of the structure of U.S./IAEA safeguards arrangements see A.M. Bieber and S.C. Suda, "An Introduction to the Structure of Safeguards Under the U.S./IAEA Agreement," Journal of the Institute for Nuclear Materials Management, Spring 1979, p. 63; A.M. Bieber, "DIQs: An Introduction to IAEA Facility Information Requirements," Journal of the Institute for Nuclear Materials Management, Fall 1978, p. 59. This section has been extracted primarily from these sources.
2. "Agreement with the International Atomic Energy Agency for the Application of Safeguards in the United States of America, with Protocol," transmitted by President Carter to the U.S. Senate, February 9, 1978.
3. "The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," International Atomic Energy Agency, INFCIRC/153 (corrected), Vienna, June 1972.
4. "Subsidiary Arrangements and Transitional Subsidiary Arrangements to the Agreement between the Government of the United States of America and the International Atomic Energy Agency for the Application of Safeguards in the United States of America," drafts initialed by representatives of the U.S. and the IAEA, June 1, 1978.
5. "Proposed 10 CFR Part 75 and Conforming Amendments to 10 CFR Parts 40, 50, 70, 150 and 170," Federal Register, Vol. 44, No. 138, July 17, 1979.
6. Note 1, supra.

B. The Application of IAEA Safeguards

1. General Approach. The development of IAEA safeguards has reached different stages for various facilities and processes, in part because the Agency's* experience in safeguarding fuel cycles is greater for some types than for others. For example, the Agency has had broad experience in safeguarding light water reactors and very little in safeguarding fast breeder reactors. Further, safeguards for conversion plants and fuel fabrication facilities have been developed for some time while safeguards for reprocessing and enrichment facilities are in the early stages of development. Where experience falls short, the Agency has prepared broad outlines of the approaches to be followed which will be reviewed here.[1] It is also important to recognize that Agency safeguards are continually evolving as new and better methods for safeguarding facilities are developed.

> The major objective of IAEA safeguards is the "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."

Both "timely detection" and "significant quantities" have been defined and quantified. Significant quantities have been expressed in terms of "threshold amounts" which are the quantities necessary for fabrication of a

---

*The term "Agency" refers expressly to the IAEA; the terms are used interchangeably.

nuclear explosive device. These are not yet established requirements, but are tentative goals upon which safeguards are designed. Table 1 lists these values. Timely detection is expressed as "detection time" which has been defined as the minimum time required to convert specific forms of nuclear material to the form necessary for fabrication of a nuclear explosive device. These times are given in Table 2 and are considered guidelines since some flexibility is allowed. The a priori goal for the probability of detection has

Table 1

Threshold Amounts and Quantities of Safeguards Significance[2]

A. Threshold Amounts

Material	Threshold Amount (TA)	TA Applies To:
Pu ($Pu^{239} > 95\%$)	8 kg	Total Element
U^{233}	8 kg	Total Isotope
U ($U^{235} > 95\%$)	25 kg	U^{235}

B. Quantities of Safeguards Significance

Material		Quantity of Safeguards Significance (SQ)	SQ Applies To:
"Direct-Use" Material	Pu	8 kg	Total Element
	U^{233}	8 kg	Total Isotope
	U ($U^{235} > 20\%$)	25 kg	U^{235}
	Plus rules for mixtures where appropriate		
"Indirect-Use" Material	U ($U^{235} < 20\%$)*	75 kg	U^{235}
	Th	20 t	Total Element
	Plus rules for mixtures where appropriate		

*Including natural and depleted uranium.

been set as a policy matter by the Agency at 90% or higher.

The main thrust of IAEA safeguards is to validate the records of a facility by inspection and measurements. These measurements include monitoring the flows of nuclear material, periodic closing of material balance and physical inventory, and performance of chemical analysis and nondestructive assay (NDA) on samples taken by inspectors. In essence, the Agency's safeguards independently verify the state's (op[illegible]'s) information.

In addition to the material control and accounting (MCA) techniques described above, the Agency performs certain surveillance and containment measures. It is important to note that containment and surveillance are not primary methods for guarding against diversion, but rather serve to complement MCA techniques.

For MCA, Material Balance Areas (MBAs) are designated. An MBA is an area where all material entering and leaving is measurable and physical inventories can be performed. These are generally defined in the Facility Attachments. Key Measurement Points (KMPs) are located at flow and inventory points where material can be measured. On the basis of inventory measures and material flows at KMPs, the Agency keeps a parallel set of accounts and compares them to the state's and operator's accounts for accuracy. The Agency's parallel set of accounts is based upon periodic verification measures on random samples. The Agency takes far fewer measurements than the plant operator.

Containment measures take advantage of existing structural arrangements such as containers, pipes, tanks, and so on, to insure against the undetected movement of materials. In addition, containment measures rely heavily on IAEA seals and locks. Surveillance is the observation, either human or instrumental, of material and equipment movements within the facility.

2. Reactors. Reactor material inventories are verified by material measurements from the fuel fabrication facility and calculations of burnup and plutonium production in the reactor core.

A reactor is generally considered one MBA with three inventory KMPs at the fresh fuel storage area, the core itself, and the spent fuel storage area.

a. Light-Water Reactors (LWRs). If the fuel for the reactor is low-enriched uranium (LEU), then greater safeguards attention is paid to the spent fuel which contains plutonium than to inventories at either of the other two KMPs. The detection target for LWRs is the diversion of one or more spent-fuel assemblies within two or three months and one or more fresh fuel assemblies within one year.

In terms of accounting, the Agency accounts for the number of fuel assemblies present to verify material inventories. Containment and surveillance measures are used at the spent fuel area. The specific measures used at LWRs include (1) an audit and verification of accounting records, (2) examination of operating records, (3) verification of fresh fuel prior to core reload, (4) core verification, (5) item control and identification on the spent fuel in storage, (6) calculation of burnup and plutonium production, and (7) item counts in inventory Key Measurement Points.

b. Heavy-Water Reactors (HWRs). HWRs require the use of on-line refueling techniques. Refueling is automatic and spent fuel is discharged at

Table 2

Estimated Material Conversion Times[3]

Classification	Beginning Material Form	End Process Form	Estimated Conversion Time
1	Pu, HEU[a], or U^{233} metal.	Finished plutonium or uranium metal components	order of days (7-10)
2	PuO_2, $Pu(NO_3)_4$ or other pure compounds. HEU or U^{233} oxide or other pure compounds. MOX or other non-irradiated pure mixtures of Pu or U (($U^{233}+U^{235}$) >20%). Pu, HEU and/or U^{233} in scrap or other miscellaneous impure compounds.	"	order of weeks[b] (1-3)
3	Pu, HEU or U^{233} in irradiated fuels (> 10^5Ci/kg HEU or U^{233} or Pu).	"	order of months (1-3)
4	U containing <20% U^{235} and U^{233}; thorium.	"	order of one year

---

[a] Uranium enriched to 20% or more in the isotope U^{235}.

[b] While no single factor is completely responsible for the indicated range of 1-3 weeks for conversion of these plutonium and uranium compounds, the pure compounds will tend to be at the lower end of the range and the mixtures and scrap at the higher end.

the rate of 7 to 10 fuel bundles a day which are then stored in baskets in the spent fuel pond. This system does not easily lend itself to fuel element counting because the baskets are often stacked in three-dimensional arrays. Automatic fuel bundle counters have been developed, but have not yet been adopted by the Agency.[4] Since reprocessing or spent fuel processing schedules may vary, irradiated fuel may be shipped offsite regularly or, instead, retained in storage for long periods of time.

Because most HWRs use either natural uranium or slightly enriched uranium (SEU = 1 to 2% U^{235}), the discharged fuel contains more fissile plutonium than that from an LWR and is, therefore, more significant from a safeguards standpoint. The inspector usually counts the number of fuel bundles in the inventory and, at times, may make qualitative measurements of nuclear material. Some HWRs use LEU or highly-enriched uranium (HEU) "booster rods" which help maintain criticality during plant power changes. These rods do not carry the same classification as fuel and must be handled and verified separately. In addition to these difficulties, HWRs use an extremely large number of fuel bundles compared to LWRs and the core is inaccessible for core verification.

Specific safeguards measures for HWRs include (1) audit and verification of accounting records, (2) determination of fuel charge and discharge rates, (3) calculation of plutonium discharged, (4) containment and surveillance activities, (5) examination of operating records, and, in some cases, (6) verification of heavy water inventory. Because of the low strategic value of fresh fuel, the inventory in the fresh-fuel storage area is verified annually. The inaccessibility of the core dictates that containment and surveillance measures must be substituted for actual core verification. Lastly, because spent fuel is generally in the form of tens of thousands of fuel bundles, its physical inventory is extremely difficult. As a result, heavy reliance is placed on optical surveillance to assure that no unreported spent fuel inventory changes occur.

c. Fast Breeder Facilities. The Agency has had experience only with the Liquid Metal Fast Breeder Reactor (LMFBR) cycle. The major difference between fast breeder (FBR) cycles and LWR cycles is that the material used in the FBR is generally in a form directly convertible to weapons material throughout most of the cycle. The seed blankets used in LMFBRs contain plutonium even better suited to conversion to explosives use than the spent fuel. In addition, LMFBRs generally have many times the fuel inventory of LWRs.

Fuel assemblies are kept in a sodium or inert gas environment and are loaded remotely so that no optical core verification is possible. New sonic imaging techniques are currently being developed for this purpose. Because of this feature, verification of spent-fuel stores is also extremely difficult.

The detection target for the LMFBR fuel cycle is one significant quantity being diverted slowly and continuously over a one-year period and one significant quantity diverted abruptly in one to three weeks.

Specific safeguards measures for LMFBRs include (1) KMPs at strategic points within the facility or reactor, (2) verification of physical inventories twice a year employing item counting and NDA, (3) verification of new fuel through the use of NDA and seals, (4) thorough checks of all seals and surveillance devices consistent with the detection time and whenever containment integrity becomes questionable, (5) inspector presence during core reload and sealing of the core, (6) constant automated surveillance of the core in operation and the spent fuel area, (7) audit and verification of accounting records, and (8) calculation of burnup and plutonium production.

3. Bulk Handling Facilities. INFCIRC/153, paragraph 6(c), requires that the Agency should concentrate its "...verification procedures on those stages in the nuclear fuel cycle involving the production, processing, use, or storage of nuclear material from which nuclear weapons or other nuclear explosive devices could readily be made." At least two physical inventories per year are expected at bulk handling facilities, four when weapons usable material is involved.

a. Conversion and Fuel Fabrication Facilities. In facilities where both conversion and fuel fabrication occur, it is normal IAEA practice to make the conversion area and the fabrication area two separate MBAs. The feed storage area is usually considered a separate MBA where the shipper/receiver data are verified; the product storage area is also considered a separate MBA. In the U.S., however, the national safeguards system is sufficiently developed that the entire facility may be considered an MBA.

KMPs are established for the measurement of all feed material received, fuel elements and assemblies prior to shipment, and waste discards. KMPs are also established between all MBAs. When possible, discrete item counts are used and the integrity of the discrete items is assured by sampling and testing, then sealing with tamper-indicating seals.

The detection target is one significant quantity per year. When the facility handles plutonium, HEU, or U^{233}, an additional target of detecting the sudden diversion of a significant quantity of material in one to three weeks is specified.

Containment and surveillance measures are of limited value at some bulk handling facilities; thus heavy reliance is placed on MCA techniques, and the operators' claims regarding material received, shipped, stored, or lost are carefully verified.

At facilities handling either depleted, natural, or low enriched uranium, the basic approach to IAEA safeguards is MBA verification, with particular reliance on random sampling. Specific safeguards measures include (1) visual inspection by inspectors of the operator's physical inventory, (2) audit and verification of operator accounting, (3) determination of material flows, and (4) determination of inventories.

b. Enrichment Facilities. The Agency has had no experience safeguarding enrichment facilities. It is probable that the first facilities to be safeguarded will be centrifuge facilities. However, the first gaseous diffusion plant which may be safeguarded is now under construction and the Agency may also be requested, eventually, to safeguard nozzle facilities. DOE is now conducting research with the IAEA on safeguards for enrichment facilities.

Enrichment facilities are important from a safeguards standpoint because, in certain configurations of certain processes, they can produce weapons-usable material. Some reactors will require HEU (e.g., HTGR) so that the enrichment plant — where HEU is separated prior to fuel fabrication — is very sensitive. In fact, MCA techniques capable of detecting a diversion of one significant quantity have not been developed for enrichment plants producing HEU in large quantities. At an enrichment facility which produces LEU, the simple existence of HEU indicates a violation. No such signal exists for a facility designed to produce HEU. At facilities producing only LEU, the most important consideration is whether the plant can be adapted or operated to produce HEU. The Agency also verifies that no material has been diverted.

For LEU facilities, different processes offer different options for producing HEU. Because of the large number of machines used, a centrifuge facility may be rearranged by placing many stages or cascades in series instead of in parallel. Centrifuge facilities represent a serious problem because it is possible to use an insignificant fraction of the cascades to produce HEU while the rest of the facility operates normally producing LEU. The connections between the cascades do not even have to be rearranged since feed and product are easily transported in small cylinders.

Adaptation of a LEU production process to produce HEU is more difficult at a gaseous diffusion facility. All stages in the process are in series necessitating an alteration of the entire output of the facility, and the operator is faced with the choice of low enrichment and high production or high enrichment and low production.

Because of the proprietary nature of enrichment techniques, the Agency may treat the entire process area as a "black box." This area will be identified as a "special material balance area" (SMBA). The exact nature of the safeguards being employed are embodied in the Subsidiary Arrangements.

Material accounting is the primary safeguards measure at an enrichment facility. All material entering and leaving the facility is measured and a material balance is periodically calculated. In addition, containment and surveillance serve to complement data verification and to detect any undeclared feed or product at the facility.

INFCIRC/153, Section 80, permits continuous inspection at facilities with throughputs greater than 500 kg. As a result, large facilities qualify for continuous inspection while pilot facilities do not. However, most nations have agreed to subject even small enrichment facilities to safeguards. INFCIRC/66/Rev. 2 does not provide for inspection of enrichment facilities.

Safeguards techniques capable of detecting a diversion of one significant quantity at enrichment plants providing HEU are not yet developed and thus the IAEA cannot effectively safeguard such a facility. When access to a LEU facility is allowed, specific safeguards measures include (1) identification and verification of design to confirm the absence of secondary feed and take-off lines, (2) routine inspection of MBAs, (3) verification of products and tails data by in-process sampling, and (4) careful attention to wastes. When access is not allowed, IAEA safeguards can only be used at the borders of the SMBA. As noted above, this is a serious problem at centrifuge facilities where HEU could be produced at a large facility without changing the tails and product significantly, and could thereby go undetected.

c. Facilities Processing Plutonium, HEU, or U^{233}. Because of the sensitive nature of the material processed, additional safeguards measures are required for these facilities. The Agency, therefore, relies on continuous or frequent inspections and measures which show that the operator maintains adequate flow controls in order to extend the validity of MBA. In addition, inspectors need unrestricted access to all material to meet the short detection time necessitated by the sensitive nature of the material.

Specific safeguards measures include (1) complete semiannual physical inventory, (2) complete verification of all receipts, stores, and shipment within short detection time parameters, (3) extensive use of seals, (4) separate Agency records, (5) verification of in-process inventory, (6) visual observation of all containers in the process area, and (7) in-process sampling to verify detection procedures (chemical analysis of samples is used to update calibration of NDA equipment).

The Agency has not yet developed a safeguards scheme for a commercial-sized reprocessing plant and is limited to safeguards exercises at small facilities in the U.S., Belgium, Japan, and Italy. Only the Purex process has been safeguarded, therefore, little can be said about other processes.

Reprocessing facilities are very important from a safeguards standpoint because of the production of purified plutonium. The problem is exacerbated in that the composition of irradiated fuel rods is calculated from their initial composition (known from the fabrication stage) and information about burnup. This leads to relatively large uncertainties in plutonium input. Most of the plant is inaccessible and, therefore, unviewable during operation because of the high radioactivity of the spent fuel. Measurement vessels are similarly hidden from view. These considerations, coupled with the fact that reprocessing plants run continuously for long periods of time, have led the Agency to conclude that continuous inspection is required.

Reprocessing facilities are generally divided into three MBAs. The first is the feed storage area where the content of unreprocessed spent fuel is calculated and recorded. The second is the process area where the spent fuel is dissolved and products are separated. Measurements taken at the flow KMP between the first and second MBA are used to corroborate the shippers' data. The third MBA is the product output and storage area where product composition is calculated and compared to measurements at the flow KMP between the first and second MBA and those data collected in the process area.

The detection target is one significant quantity diverted slowly over one year or an abrupt diversion over one to three weeks.

Specific safeguards measures include (1) independent log books kept by the Agency, (2) strict electronic surveillance of the spent fuel receiving area, (3) verification of data in the first MBA (receiving area) by determination of the volume and concentration of plutonium at the flow KMP between the first and second MBA, (4) measurement vessel calibration, (5) comparison of process area inventory with calculations from the reactor operator, (6) calculation and measurement of plutonium and uranium content of the acid recycled for dissolving spent fuel, (7) careful measurement of plutonium output from the process area, (8) measurement of the uranium/plutonium ratio and comparison with reactor operator's calculations, and (9) intermediate inventory of the product storage area every two to three weeks.

At a commercial-sized facility (e.g., 1500 MT throughput), the uncertainty level associated with traditional accounting techniques might result in large amounts of material unaccounted for (MUF). Continuous verification of the integrity of surveillance and containment techniques guards against diversion. To this end, the design of any large reprocessing facility should incorporate strong containment and surveillance features worked out in advance with the Agency.

In the processing areas three complementary systems are being considered by the IAEA: (1) improved measurement systems for flow KMPs, (2) application of containment and surveillance at the perimeter of processing cells or equipment, and (3) application of real-time accounting and control techniques. Many of the technologies needed to implement these measures already exist and the means to improve them are understood; however, more information is needed to evaluate their effectiveness.

REFERENCES

1. For an excellent discussion of this entire topic, see Hans Gruemm, "The Present Status of IAEA Safeguards on Nuclear Fuel Cycle Facilities," American Law Institute - American Bar Association, *Nuclear Export Control*, 1979, p. 267.
2. Id. p. 273, originally developed in "Standing Advisory Group on Safeguards Implementation (SAGSI)," AG-43/10, December 1977.
3. Id. p. 275.
4. M. Homani, "A Safeguards Approach for a CANDU-600 Reactor," D. Tolchenkov, D. Jung, STR-72, IAEA, August 1978; V.H. Allen and A.J. Stirling, "Performance of a Prototype Spent Fuel Bundle Counter for 600-MW CANDU Reactors," paper presented at 20th Annual Meeting of the Institute for Nuclear Materials Management, Albuquerque, New Mexico, July 16-18, 1979.

III. THE CHOICE OF ALTERNATIVE FUEL CYCLES

In April 1977, President Carter announced a new national policy regarding nuclear proliferation, which brought into question some of the basic planning assumptions about the future of nuclear power. In response to the President's direction that the United States investigate alternatives to the breeder reactor and reprocessing that would reduce the risk of proliferation, the Energy Research and Development Administration established a Non-Proliferation Alternative Systems Assessment Program (NASAP). This program, now under the direction of the Department of Energy (DOE), represents one of the technical inputs to the International Nuclear Fuel Cycle Evaluation (INFCE) being conducted by the major suppliers and consumers of nuclear energy.

The goal of NASAP is to recommend development of nuclear systems which have the potential for reducing the risk of diversion of nuclear materials to make explosives. DOE planners have established three distinct objectives to meet this goal.

- Delineation, characterization, and evaluation of alternatives in sufficient detail to permit a sound choice by decision makers.
- Establishment of recommended R&D priorities and identification of R&D needs for nuclear system alternatives with high resistance to proliferation.
- Development of a program for implementing preferred nuclear system alternatives.[1]

A new fuel cycle would most likely not begin operation for at least 10 to 15 years, and more than one cycle would operate simultaneously during the changeover. Many of the proposed fuel cycles would operate in symbiosis with others to supply the necessary feed materials before reaching equilibrium. To facilitate examination of the problems that may arise from U.S./IAEA safeguards agreements and the use of alternative fuel cycles, generic safeguards variations will be reviewed.

The candidate NASAP fuel cycles and safeguards variations are described in detail in a separate report in this series. However, a brief description of the major safeguards features of those fuel cycles and their possible safeguards implications is given here as background to discussing the U.S./IAEA Safeguards Agreement.*

A. Radiation Barriers (Spiking)

Spiking may be defined as the introduction of radioactivity into nuclear fuel materials for safeguards purposes. The radioactivity may be introduced by the addition of a radioactive agent, by retaining some of the fission products during the reprocessing of spent fuels, or by irradiating the fuel before its use in the reactor for which it is intended. According to the information supplied NRC by DOE, NASAP is considering a combination of the first two: that is, partial retention of certain fission products (Zr, Nb, and Ru) plus the addition of a radionuclide (Co^{60}) during reprocessing (i.e., before conversion of the product to an oxide).

The degree of concentration of radioactivity in the spiked materials depends on the purpose of spiking. So-called deterrent spiking, which is spiking at lethal or near-lethal levels, requires high concentrations, whereas detection spiking, designed to make the nuclear material easier to detect, requires very low and relatively innocuous levels. The type of spiking under consideration by NASAP, deterrent or lethal spiking, would require a sufficient concentration of radioactivity in the nuclear fuel to produce a gamma dose which is lethal at close range.

The two most promising fission-product chains for selective retention with the plutonium are the mass 95 and the mass 106 chains, of which the first members with reasonably long-half lives are Zr^{95} (half-life 64 days) and Ru^{106} (half-life 368 days). The most promising radioactive additive is Co^{60} (half-life 5.27 years). Although a few other potential candidates have been identified, most alternatives have been ruled out on the grounds of half-life, availability, or chemical or physical properties.

The chief advantages of spiking are its deterrent effect on potential diverters because of the considerable resources required to remove the spiked material from its authorized location and to convert it to weapons-

---

*This section is repeated in O'Brien, "Export Licensing Problems Associated with Alternative Nuclear Fuel Cycles," NUREG/CR-1050, pp. 29-38 reprinted in edited form in Chapter Two.

usable material, and the ease of detection of its removal by portal radiation monitors.

B. Coprocessing

Coprocessing means the processing of mixtures of uranium and plutonium or their compounds in such a way that the plutonium is always diluted by uranium. Most often the term is used for a possible mode of operation of spent fuel reprocessing plants in which the product consists of a mixture of uranium and plutonium oxides, coprecipitated from a mixture of nitrates in solution.

Thermal recycle fuels typically consist of mixed uranium and plutonium oxides with a plutonium concentration of 2 to 5%. Feed to a mixed-oxide fabrication plant would have to have somewhat higher plutonium content to allow for blending; a mixture with 10% plutonium oxide has been suggested. Fast-breeder reactors (FBR) require still higher plutonium concentrations; mixed-oxide feed to an FBR fuel fabrication plant would probably have a plutonium oxide concentration of about 25%.

The major safeguards advantages of coprocessing are the increased quantity of material that a diverter would have to take for the same amount of plutonium and the increase in the time and resources required to convert the mixed oxide to a form suitable for use in an explosive weapon. The concentration of plutonium in mixed oxides for thermal recycle fuels would probably be too low for direct use in an explosive. This may not be true for FBR mixed oxide feed, with its much higher concentration of plutonium. In both cases, the maximum allowable percentage of plutonium would have to be set by NRC regulation, and the values selected would have to be based on a consideration of both the practical needs of the fabrication plants and the explosive utility of mixed oxides as a function of plutonium concentration.

The needs of the fabrication plants for large batches (master blends) of mixed oxides with specific plutonium concentrations and fissile composition would probably require prior blending at the reprocessing plant, either in the liquid nitrate or in the converted powder stage. If the former, then large nitrate storage and mixing tanks with associated pumps and piping would have to be provided and safeguarded, possibly as a separate material balance area. Identification of the accountability problems in this area would require detailed analysis.

Apart from the problem just mentioned, coprocessing would be expected to have a minimum effect on material accountability. Because an additional measurement is required for the feed to a fabrication plant (the Pu/U ratio), the uncertainty in the Pu content of the feed will be slightly greater than for pure plutonium oxide, although this is probably not significant. There may be some minor problems of inhomogeneity, but these could be solved by blending and improved sampling. The same remarks apply to the product of the conversion plant. Fabrication plants using mixed oxide feed are essentially identical to those using mechanical blending of uranium and plutonium oxides after the blending stage so, from this point on, the accountability should be unaffected by the nature of the feed.

Scrap recovery facilities processing dirty mixed oxide scrap will have to be operated in a coprocessing mode also. Accountability should be essentially the same as for facilities producing separated oxides.

C. The Use of U^{233}/Th Fuels

A number of the fuel cycles proposed by NASAP use of U^{233}/Th fuels. U^{233} has the advantage over plutonium that it can be denatured (i.e., rendered unsuitable for direct use in an explosive) with U^{238}; this advantage is shared by U^{235}, of course. The use of denatured fuels is discussed in Section III.D., below, where a general description is given of safeguards problems associated with the use of U^{233}/Th fuels.

Current NRC regulations treat U^{233} as similar to plutonium rather than to U^{235}. Thus, U^{233} occurring in any enrichment is regarded as strategic special nuclear material (SSNM), whereas uranium must be enriched to 20% or more in U^{235} to be so treated.

There has been little experience with the commercial reprocessing of highly irradiated thorium fuels. Some fabrication has been performed for the light water breeder reactor program. It is, therefore, difficult to say at this stage whether existing NRC material accountability regulations can be met in commercial-size reprocessing and fabrication plants for U^{233}/Th fuels. Most likely it will be necessary to operate pilot plants owned by or under contract to the federal government for a period of time in order to gain experience with these materials.

The unique characteristic of U^{233} fuels is the high radiation levels associated with the presence of even trace quantities of U^{232} and its daughters. The high levels necessitate remote fabrication, which has the advantage of limiting physical access to the material. However, it also greatly complicates the assay of U^{233} by nondestructive techniques, because of the high gamma activity from U^{232} and its daughters. The magnitude of this gamma background depends strongly on the age and processing histories of both the U^{233} and the thorium in the fuel mixture. For a given amount of U^{232} the older the U^{233} (i.e., the longer the elapsed time since its last purification) the higher is the radiation. For some U^{232} concentrations and ages likely to be encountered in any U^{233} recycle program, this radiation will completely swamp the gamma rays from U^{233}. High backgrounds will be produced in any gamma sensitive detector, whether or not it is used for gamma detection (e.g., organic scintillators used for neutron detection). Nondestructive assay techniques will, therefore, have to be developed for any fuel cycle using U^{233}. Some effort along these lines has already been made in the HTGR recycle program, primarily of an exploratory nature. The feasibility of performing near real-time accountability in U^{233} fabrication plants will depend on the successful outcome of such efforts.

Accountability in reprocessing plants for U^{233}/Th fuels would be less affected by the radiation from the U^{232} decay chain because most assays in plants of this type are by standard chemical analysis, and radiation levels in much of the process, due to fission-product activity, are already very high.

The more difficult chemistry of thorium may cause problems for accountability because of its tendency to polymerize in solutions.

Verification will be hampered by the high radiation levels in U^{233} fuels. As with spiked fuels (but to a lesser degree), sample taking will be laborious and time consuming, and the samples will have to be sent offsite for analysis, with an attendant loss of timeliness.

The physical security of U^{233} fuels will be superior to that for plutonium fuels because of the remote nature of the fabrication process and because of the abundant and penetrating gamma rays from the U^{232} daughters (principally, those from Tl^{208}), which should result in a greatly increased sensitivity of detection by portal radiation monitors.

D. Denaturing

Denaturing may be defined as the addition of a nonfissile isotope to a fissile isotope of an element in such proportions as to make the fast critical mass of the mixture impractically large for a nuclear explosive weapon.

Since all plutonium isotopes have appreciable fast-fission cross sections, plutonium cannot be denatured. The fast-fission cross section of U^{238} is small enough, however, to allow the fissile isotopes U^{233} and U^{235} to be denatured by its addition.

The choice of a threshold enrichment for denaturing is important. It will be noted that the above definition does not imply a sharp enrichment cut off. Such a cutoff could be defined as the enrichment at which the fast critical mass becomes infinite, but this choice would limit the use of U^{233} to enrichments in the neighborhood of 3% and U^{235} to those in the neighborhood of 5%. NRC regulations define a threshold enrichment of 20% for U^{235}-bearing materials to be considered strategic special nuclear material, subject to the full requirements for physical security. This corresponds to a bare spherical critical mass of ~ 850 kg of U. The enrichment in U^{233} at the same critical mass is about 12%, which is usually assumed to be the threshold enrichment for denaturing of U^{233} fuels in NASAP studies. The use of appropriate reflectors may substantially reduce the total mass of a nuclear explosive, however, so that review of the data for U^{233} may be desirable before selecting an enrichment limit for uranium containing this isotope. Enrichment limits for uranium containing both U^{233} and U^{235} may also have to be set. Another consideration that may enter into setting threshold enrichments for uranium containing U^{233} is that this isotope is easier to separate from U^{238} than is U^{235}.

The effect of the decay of U^{232} and its daughters on the nondestrucive assay of U^{233} fuels was noted in the previous section. This effect will occur in denatured U^{233} fuels as well, of course, and will subject material accountability for these fuels to all the disadvantages already noted. However, since by definition denatured fuels are not useful for nuclear explosives, the consequences of the somewhat lower accuracy of material balance and the impairment of the prospects for real-time accountability are not as serious.

In some of the fuel cycles involving denatured U^{233} fuels, such as the LWR, substantial quantities of plutonium appear in the spent fuel. The fuel will therefore have to be reprocessed by a combination of the Purex and Thorex processes. There has been very little, if any, experience with reprocessing such fuels and, therefore, it is very difficult to say how well NRC's accountability requirements can be met in such a reprocessing plant, at least without detailed study. Certainly the chemical analysis of such mixtures will be more difficult than that of ordinary spent LWR fuels.

The disposition of the plutonium separated from spent denatured fuels of this type is also important. It may be either stored, for eventual use in the fast-breeder reactor cycle, or recycled in "secure" energy centers. Neither the form of nor the responsibility for spent fuel storage has been worked out, and if the federal government accepts responsibility for storage, NRC may not have a domestic safeguards role. If storage is in licensed facilities, the safeguards problems will be essentially the same as those already considered in the GESMO proceeding. Accountability for plutonium in storage is particularly simple if it is stored in discrete containers, each containing a few kilograms of Pu. Surveillance devices could be incorporated to give an instantaneous alarm in case of tampering.

If the plutonium recovered from spent denatured fuel is recycled in energy centers, the safeguards technical problems are essentially the same as for the U-Pu cycle, with the modifications associated with the physical and administrative nature of energy centers. The safeguards regulatory issues involved in the operation of a multinational center are discussed in a separate report.* An additional complication would arise from the occurrence of non denatured U^{233} in the blanket of a Pu-U/U^{233}/Th breeder, but the U^{233} could be denatured during the recovery process or shortly thereafter.

To summarize, the major safeguards technical problems associated with denatured U^{233} fuels are those common to any fuel using U^{233}, discussed in a previous section, and the lack of experience with the reprocessing of mixed U Pu/U^{233} fuels and the refabrication of the denatured fuel. An important regulatory issue is the threshold enrichment at which U^{233} is considered to be denatured.

---

*See O'Brien, "Institutional Problems Associated with Domestically Sited Multinational Fuel Cycle Facility" NUREG/CR-1028 reprinted in edited form in this Chapter.

E. The Use of Heavy Water as a Moderator

One of the alternative fuel cycles under consideration in the NASAP program is based upon the use of heavy-water reactors (HWRs). There are two important safeguards problems associated with this type of reactor: the availability of heavy water in large quantities, and on-line refueling. The issue of on-line refueling is specifically considered earlier in this report.

The significance of heavy water for safeguards is that it can be used to moderate reactors fueled with natural uranium, and these can be used to produce plutonium. A substantial commitment to the heavy-water reactor fuel cycle in the U.S. would probably require, therefore, the imposition of safeguards on heavy water, not now required by NRC regulations. Safeguards consisting mainly of material accounting and surveillance and containment would be required on the heavy water in reactors, in the concentrators for contaminated (i.e., light water diluted) heavy water, in production facilities, and in storage. Since heavy water cannot be used directly in an explosive and is not highly toxic, physical protection would probably not be required. However, the tritium content of irradiated heavy water presents a radiological safety hazard.

Safeguards on heavy water are not required under the NPT-INFCIRC/153 system of the IAEA, but may be under bilateral or trilateral agreements or voluntary submissions. Consequently, the IAEA has not defined quantities of heavy water of safeguards significance. The trigger list of the London Suppliers Group requires the imposition of safeguards when a country imports 200 kg of deuterium or more in any compound in which the ratio of deuterium to hydrogen exceeds 1:5000 (0.02 mole %), in one year. To set this number in perspective, a heavy-water moderated reactor with a plutonium production capacity of 8 kg/yr would require an initial inventory of 10 to 20 tonnes of heavy water with a deuterium oxide concentration of ~ 99.7% (concentration in normal water is 0.014 mole %). The contained deuterium would amount to 2000 to 4000 kg.

It should be noted that safeguards, including accountability, are required by the Department of Energy for heavy water under its control.[2]

F. Storage of Spent Fuel and Waste

A once-through fuel cycle implies the indefinite, perhaps permanent, storage of spent reactor fuel in repositories. Under present IAEA regulations, there would appear to be no grounds for terminating safeguards, unless spent fuel were classified as residues. NRC would, therefore, have to ensure that safeguards on such repositories were carried out in a manner consistent with IAEA requirements.

Safeguards for indefinitely stored, retrievable spent fuel would consist primarily of periodic assurance of the presence and integrity of all fuel elements. This would be accomplished by a combination of sealing and surveillance operations. The large number of such elements at a central repository would put a premium on the ability to seal off groups of elements or whole sections of the repository. If a seal were broken (as could happen accidentally), it would be necessary to conduct another inventory of the affected area. This would imply a capability for close inspection, either visually or instrumentally (e.g., by radiation signatures). The ability to do this would depend on how the elements were stored (whether in air, on the surface, or underground, etc.). Possible problems can be identified only for specific storage schemes.

Irretrievable (presumably underground) storage does not appear to pose any serious domestic safeguards problems. It is barely conceivable that a non-governmental adversary could gain access to fuel stored in this manner, and periodic inspection should detect any serious attempt. What the requirements of the IAEA would be for the safeguarding of irretrievably stored fuel is under development at this stage, so an assessment of the problems of the NRC in assuring compliance is premature.

REFERENCES

1. Booz, Allen, and Hamilton, "Viewpoints on Key Issues and Evaluation of Criteria for Assessing the Potential of Alternative Nuclear Energy Systems for Improving Proliferation Resistance," prepared for the Department of Energy (1977).
2. DOE Internal Management Directive 6104-A, p. 8.

IV. GENERIC SAFEGUARDS VARIATIONS AND THEIR RELATION TO U.S./IAEA SAFEGUARDS

Generic safeguards variations will be reviewed for problems they entail. Specific fuel cycles will be considered in the next section.

A. The Use of Strategic Special Nuclear Material (SSNM)*

A number of the candidate fuel cycles require SSNM at the fuel fabrication stage and, therefore, demand stricter safeguards at the front end of the fuel cycle. The definition of SSNM for NASAP is different from the IAEA material classification currently used in that U^{233} is classified as "direct-use material" (IAEA's equivalent to SSNM) regardless of its enrichment level (see Table I). As a result, the only front end fuels considered less significant than others are those containing $<20\%$ U^{235} and/or thorium fuels. All others are considered more sensitive from a safeguards standpoint.

For those fuel cycles which incorporate SSNM or direct-use material in fresh-fuel, the fresh fuel storage area and fuel conversion and fabrication facilities must be subject to stricter safeguards than those employed for LEU facilities.

B. Radiation Barriers

The presence of high levels of radioactivity has been recognized by NRC as a theft deterrent. The threshold level chosen by NRC for a physical security exemption [illegible] fixed-site facilities is 100 rem/hr at a distance of 3 ft from any accessible surface.[2] Physical security is required for the same material in transit. IAEA currently sets a similar threshold at 100 rad/hr at 1 m. While the NRC standard exempts material (spent fuel) from the physical security requirements of part 73, the IAEA standard lowers the significance category of the material.[3] Table III shows these values.

The four methods proposed for producing radiation barriers differ in impact on IAEA safeguards. These methods are (1) spiking which is the addition of a radioactive spikant during the conversion and fabrication stage, (2) partial reprocessing which involves retention of some of the fission products in the fuel, (3) preirradiation in which the fresh fuel is irradiated before shipment to the reactor or in bulk form before fabrication, and (4) mechanically attached radioactive sources.

Both partial reprocessing and spiking would adversely affect material accountability. At bulk handling facilities where SSNM is handled, IAEA depends strongly on verification of in-process inventory by chemical analysis of samples and NDA techniques. Both of these MCA measures would be adversely affected by the high radioactivity of the fission products or spikant present.

The major effect is not expected to be serious at reprocessing facilities which routinely handle very radioactive spent fuel. However, conversion and fabrication facilities will face a new problem. These facilities would have to be operated remotely, calling for new or modified MCA techniques. It may be borne in mind that while partial reprocessing and spiking do interfere significantly with MCA techniques, the level of physical protection suggested for these materials by IAEA is significantly lower.[4] However, IAEA strongly depends on NDA methods at flow KMPs to track materials flows, and this difficulty will be hard to overcome.

---

*SSNM is defined here as Pu, $> 12\%$ U^{233}, or $> 20\%$ U^{235}.

Table III.

Categorization of Nuclear Material[e]

Material	Form	Category I	 II	 III
1. Pu[a,f]	Unirradiated[b]	2 kg or more	Less than 2 kg but more than 500 g	500 g or less[c]
2. U^{235}[d]	Unirradiated[b]			
	- U enriched to 20% U^{235} or more	5 kg or more	Less than 5 kg but more than 1 kg	1 kg or less[c]
	- U enriched to 10% U^{235} but less than 20%	-	10 kg or more	Less than 1 kg[c]
	- U enriched above natural, but less than 10% U^{235}	-	-	10 kg or more
3. U^{233}	Unirradiated[b]	2 kg or more	Less than 2 kg but more than 500 g	500 g or less[c]

[a] All plutonium except that with isotopic concentration exceeding 80% in Pu^{238}.

[b] Material not irradiated in a reactor or material irradiated in a reactor but with a radiation level equal to or less than 100 rads/hour at one meter unshielded.

[c] Less than a radiologically significant quantity should be exempted.

[d] Natural uranium, depleted uranium and thorium and quantities of uranium enriched to less than 10% not falling in Category III should be protected in accordance with prudent management practice.

[e] Irradiated fuel should be protected as Category I, II or III nuclear material depending on the category of the fresh fuel. However, fuel which by virtue of its original fissile material content is included as Category I or II before irradiation should only be reduced one Category level, while the radiation level from the fuel exceeds 100 rads/hr at one meter unshielded.

[f] The State's competent authority should determine if there is a credible threat to disperse plutonium malevolently. The State should then apply physical protection requirements for category I, II or III of nuclear material, as it deems appropriate and without regard to the plutonium quantity specified under each category herein, to the plutonium isotopes in those quantities and forms determined by the State to fall within the scope of credible dispersal threat.

Partial reprocessing would involve inventory verification at the product stage of the reprocessing stream prior to conversion. MCA techniques for this stage of a fuel cycle using partial reprocessing are not yet developed and IAEA has had no experience in safeguarding this type of fuel cycle.

Preirradiation and mechanically attached sources present fewer problems because high radioactivity occurs only at the input stage at the reactor. The lessened need for physical security must also be balanced against the extra time needed to verify inventories and flows. This may make the detection targets difficult to attain.

C. Coprocessing

The actual mode of coprocessing to be used is still not resolved. As stated earlier, the only reprocessing scheme for which IAEA now has safeguards experience is the Purex process. This process does not require the separation of plutonium and uranium and, therefore, may be used in a coprocessing scheme. The co-conversion process is not as well known because the developed methods of conversion of uranium and plutonium are not useful for mixtures of these elements.

In any event, Weinstock and Keisch have concluded that MCA problems can be overcome for coprocessing within the time frame necessary for commercialization.[5]

D. The Use of U^{233}/The Fuels

A majority of the fuel cycles proposed by NASAP involve the use of $^{U\text{-}233}$/Th fuels. These fuels are currently classified as "direct-use material" regardless of the concentration of U^{233}. In addition, the high radioactivity associated with U^{233}/Th fuels causes the same type of accountability problems associated with radiation barriers. While the radioactivity level provides the advantage of limiting physical access to the material, it also complicates MCA techniques used for verification of U^{233} content.

It must be noted that the IAEA Safeguards Technical Manual (IAEA 174) states that:

> Based upon the above considerations the quantities of nuclear material required for the manufacture of a single nuclear explosive device, for material types not requiring enrichment or irradiation, are taken by the IAEA to be 8 kg of plutonium for all types of plutonium for which the isotopic concentration of Pu^{238} does not exceed 80 percent; and for uranium in which the combined weights of the U^{233} and U^{235} isotopes equal or exceed 20 percent of the total uranium weight, 8 kg of contained U^{233} and U^{235} when the U^{233} isotopic concentration is the larger of the two and 25 kg of contained U^{235} and U^{233} when the U^{235} isotopic concentration is the larger.[6]

This section of the manual is a discussion of the weapons significance of certain nuclear materials and does not directly address the question of isotopic concentrations of safeguards significance. The contradiction of INFCIRC/ 225/Rev. 1 and the Technical Manual on the significance of isotopic concentration of U^{233} deserves attention.

Since IAEA treats U^{233} fuels the same way as Pu fuels, a high degree of material accountability is required. Methods for assuring this accountability do not yet exist and development in this area has not proceeded very far.[7] Before IAEA could safeguard U^{233}/Th fuels, a system must be developed.

E. Denaturing

Since only uranium fuels can be denatured, these methods do not apply to plutonium fuels. However, at this point there is no threshold enrichment level stipulated for U^{233} fuels so that their classification of denatured U^{233} fuels will not change under the present scheme. Experience is lacking in reprocessing of mixed U-Pu/U^{233} fuels and fabrication of denatured U^{233} fuels.

F. The Use of Heavy Water

Safeguards are not required under the NPT-INFCIRC 153 system of IAEA safeguards although they may be required under bilateral or trilateral agreements or voluntary submissions. NRC does not now require safeguards on heavy water. If the U.S. adopted a heavy water reactor cycle it is probable that both NRC and IAEA would have to arrive at material accountability methods, a de minimis quantity of safeguards significance, and a threshold concentration of significance. In addition, it is expected that containment and surveillance methods would be of great significance in an IAEA safeguards scheme for safeguarding heavy water.

REFERENCES

1. INFCIRC 225/Rev. 1, p. 6.
2. 10 CFR 73.6(b) (1978).
3. See Table III, Note e.
4. Id.
5. See Chapter Five, p. 404.
6. "IAEA Technical Safeguards Manual," IAEA 174, p. 33.
7. See Chapter Five, p. 407.

V. ANALYSIS OF INDIVIDUAL FUEL CYCLES

It should be noted that although the fuel cycles reviewed here are treated as isolated and discrete entities, in actual practice they would operate simultaneously and, possibly, in symbiosis with each other. The first cycle (Standard PWR-Once Through) is what the U.S. is now operating and, except for permanent waste disposal, it is fully developed. Any other fuel cycles would evolve out of this or operate at the same time. In addition, some of the fuel cycles would require operations other than those directly associated with them since feed materials are required (e.g., prebreeders to provide feed for breeders). For detailed analyses of safeguards problems associated with individual fuel cycles, see Weinstock and Keisch, Chapter Five.

A. Light-Water Reactors

4.1.1[*] "Standard" Once-Through PWR Using LEU (U^{235}) Fuel. This is the fuel cycle with which the Agency has the most safeguards experience and it is the cycle now used in the U.S. The present negotiations for Facility Attachments will provide the basis for the U.S./IAEA Safeguards Agreement and, as such, no impacts are expected.

4.1.2 Once-Through PWR Using LEU (U^{235}) Fuel with Extended Burnup. This fuel cycle is the same as the previous cycle except for the slightly higher enrichment level for fresh fuel and a lower discharge rate for spent fuel.

4.1.3 PWR Using LEU (U^{235}) Fuel and Spiked, Self-Generated U-Pu Recycle Fuel. Although spiked fuel presents problems for accurate fresh-fuel inventory verification, required because of the use of plutonium, these problems can be overcome. More significant problems will arise at the reprocessing stage, depending on the type of radiation barrier selected.

4.1.4 PWR Using Denatured U^{233}/Th Fuel, with Recycle of U^{233}. The fresh fuel for this cycle has the same problems as the previous cycle, but they can most likely be resolved. The problems of MCA techniques not developed for U^{233} fuels must be resolved for the entire fuel cycle, however. The source of U^{233} for initial fresh-fuel feed and makeup must also be considered since this material must originate from some other fuel cycle or dedicated facility.

B. Light-Water Breeder Reactors

4.2.1 Prebreeder and Breeder Reactors on Shippingport LWBR Type I Modules. In this fuel cycle U^{233}/Th fuels are used which would give rise to the MCA problems associated with high radioactivity. In addition, HEU would be involved in the conversion and fabrication processes, further exacerbating safeguards concerns. The radioactivity level of the fresh fuel is 23 r/hr at 1 m and, therefore, does not drop a category for physical security purposes in spite of the radioactivity present.

4.2.2 Light-Water Back-fit Prebreeder Supplying Advanced Breeder. This fuel cycle involves the use of plutonium and U^{233}. In the reprocessing conversion and fabrication stages, MCA techniques must be developed for U^{233}. MCA techniques for plutonium are, at present, adequate. The radiation from the U^{232} content of the fuel is not enough to constitute a "radiation barrier" so that the material remains sensitive direct-use material in terms of physical security.

---

[*] The numbers designating each fuel cycle are those used in Chapter Five.

4.2.3 Light Water Backfit Prebreeder and Seed-Blanket Breeder System. This reactor is fueled with HEU (93% U^{235}) and, therefore, requires the highest level of physical security throughout the fuel cycle. The reactor produces U^{233} which is recovered, along with unburned U^{235}, by the Thorex process. The Agency has had no experience safeguarding the Thorex process. In addition, the enrichment facility used to produce HEU could not be subject to safeguards with currently used techniques.

C. Heavy-Water Reactors

4.3.1 CANDU Type Using Slightly Enriched Uranium (~ 1.2% U^{235}), Once-Through. The use of SEU presents no new problems. The safeguards issues associated with the use of on-line refueling have been considered in Section II-B. The issues attendant upon the use of heavy water are discussed in Section III-E.

D. High-Temperature Gas Cooled Reactors (HTGR)

4.4.1 Once-Through Medium Enriched HTGR. Because this NASAP fuel cycle uses medium-enriched fuel (20% U^{235}), strict physical security must accompany the fuel throughout the cycle. In addition, the fuel elements lose their identity if processed for storage.[1] There are no other novel problems for this cycle.

4.4.2 Recycle Medium-Enriched HTGR. This fuel cycle involves the production and use of U^{233} fuel with its associated problems. In addition, plutonium is produced. The detection target of the IAEA for fresh fuel may be less difficult to meet for this reactor cycle than for others because the threshold quantity of SNM for weapons purposes would be on the order of seven fuel elements assuming 100% recovery of U^{233}. There has been no experience in reprocessing HTGR fuels, and high errors in accountability for fresh fuel manufacture have been encountered in the past indicating a need for development of material accounting techniques.

E. Gas-Cooled Fast Reactors (GCFR)

4.5.1 GCFR U-Pu/U-Spiked Recycle with Th Blankets. This reactor cycle is designed to produce U^{233} for other reactors in a denatured form. Pu is recovered in reprocessing and preirradiated as fresh fuel assemblies. Since U^{233} is not recycled to this reactor, an outside Pu source is needed.

At the reprocessing stage, the U^{233} recovery, conversion, and fabrication cannot be subject to developed material accounting techniques. Preirradiation of fresh-fuel assemblies negates conversion and fabrication material accounting problems for plutonium since high radioactivity is not present until the post-fabrication stage.

F. Liquid-Metal Fast Breeder Reactors (LMFBR)

4.6.1 "Standard" LMFBR with Homogeneous U-Pu Core and U Blanket. This cycle has been heavily studied and material accounting techniques are well developed. Ordinary techniques cannot be used for spent fuel inspection, however, ultrasonic viewing techniques are under development and should be available for IAEA use.

The plutonium produced is in weapons-grade form and, as such, will require strict physical security.

4.6.2 LMFBR with Heterogeneous U-Pu Core and U Blanket, Pu-Spiked Fuel. The same problems exist here as in the previous cycle; in addition there are also the problems which spiking imputes to the cycle. Since preirradiation is unlikely,[2] this cycle will probably involve addition of Co^{60} which will affect MCA techniques.

4.6.3 "Standard" LMFBR with Homogeneous Core and Spiking. This cycle involves the same problems noted for the previous cycle.

4.6.4 LMFBR with Spiked U-Pu Core, U Axial Blanket, and Th Internal and Radial Blanket. This reactor cycle involves the generation of U^{233} for use in other reactors and, as such, gives rise to accountability problems for conversion and fabrication of fuel produced. This reactor is not self-sustaining and, therefore, requires another unspecified source of plutonium. All other problems associated with this cycle are noted for the previous LMFBR cycles.

4.6.5 LMFBR with Spiked Homogeneous U-Pu Core and Th Blankets. This cycle presents, essentially, the same problems as the previous cycle.

4.6.6 LMFBR with Homogeneous Spiked Pu-Th Core and Th Blanket. This cycle presents, essentially, the same problems as the previous cycle.

4.6.7 LMFBR with Denatured U^{233} Core and Th Blanket. This cycle presents, essentially, the same problems as the previous cycle.

REFERENCES

1. Chapter Five, p. 423.
2. Chapter Five, p. 389.

VI. CONCLUSIONS AND SUMMARY OF RESULTS

In an examination of how the use of alternative nuclear fuel cycles will affect the U.S./IAEA Safeguards Agreement, it is important to recognize that the Subsequent Arrangements as well as Facility Attachments are parts of the Safeguards Agreement. Any factors preventing conclusion of a Subsequent Arrangement or Facility Attachment would affect the Agreement, and it is these factors associated with alternative fuel cycles which this report sets out to identify.

Some fuel cycles do present problems, mainly because, at this point in their development, safeguards measures have not evolved to the degree necessary to conclude a Subsequent Arrangement. Although it is expected that the long lead times associated with implementation of alternative fuel cycles will allow sufficient time for adequate safeguards development, it is useful to know in advance the nature and types of problems which will have to be resolved.

There are four ways of using radiation barriers (commonly called "spiking"), and their impacts are different. Use of partial retention of fission products or addition of a spikant gives rise to Material Control and Accounting (MCA) problems due to loss of nondestructive assay techniques and unavoidable multiplication of uncertainties in chemical analysis. If fuel assemblies are preirradiated, or if mechanically attached sources are used, the MCA problems are mitigated.

The use of U^{233}/Th fuels carries the same problem as radiation barriers because of the high radioactivity of the daughters of U^{232} which are present in the material. An MCA system for U^{233}/Th materials has not been developed and must be before the U.S./IAEA Safeguards Agreement could be applied to facilities processing the fuel. In addition, there is presently no threshold enrichment for U^{233} fuels and one would have to be arrived at by both NRC and IAEA for coordinated safeguarding of these fuels.

Reprocessing of any fuel on a commercial level (i.e., 1500 MT throughput) will create difficulties in meeting the detection targets set by IAEA because of the necessarily high uncertainties propagated over a large throughput of material. This is especially true when plutonium or highly enriched uranium is present, since the detection targets are quite strict.

Enrichment facilities pose novel problems for implementation of IAEA safeguards. An operating gaseous diffusion plant presents the fewest problems since the process can be changed to produce highly enriched uranium (HEU) only if the entire process is changed. In gas centrifuge facilities, a small part of the process can be used to produce HEU while the rest of the facility produces low-enriched uranium (LEU) normally. If the "black-box" approach is taken and perimeter safeguards are adopted, it may be impossible to assure that HEU is not being produced inside the process areas at a gas centrifuge enrichment facility. There are no established safeguards at an enrichment facility producing HEU for legitimate purposes which can detect the diversion of one significant quantity. HEU enrichment facilities present another problem. The normal signal of wrongdoing at an enrichment facility producing LEU is the simple presence of HEU. If the facility is designed to produce HEU, no such signal exists.

For heavy-water-moderated fuel cycles, two problems may cause difficulties in arriving at Subsidiary Arrangements and Facility Attachments. Accounting techniques for heavy water must be developed and a better system for verifying spent fuel stores is desirable. However, since heavy-water facilities have been safeguarded by IAEA pursuant to existing Agreements, it is clear these obstacles are not overwhelming.

LMFBR cores and fuel stores will be difficult to safeguard since the fuel assemblies are kept under sodium or in an inert atmosphere making them inaccessible. Automated control techniques are currently under development and will most likely be available when LMFBRs are actually constructed.

The essential problem for many fuel cycles is the weak state of MCA techniques. If this is the case for the chosen fuel cycle heavy reliance will have to be placed on containment and surveillance (C/S) measures. The basic problem with a drift toward greater reliance on C/S techniques is that diversion verification (IAEA's basic obligation) becomes far more difficult. Even if C/S measures show that some material has been or may have been moved, tampered with, substituted, or otherwise diverted or stolen, the only real way to verify that material is missing is through an inventory of the material. When this is very difficult or impossible because of inadequate MCA techniques, verification that a diversion or theft actually occurred may not be possible. These arguments seem to dictate that a principal consideration in choosing a fuel cycle is that it be responsive to MCA techniques so that diversion can be verified in a timely fashion.

APPENDIX A

List and Description of Fuel Cycles

NASAP Reactor/Fuel Cycle Systems For NRC Review

1.0 Light Water Reactors[1]

1.1 PWR-OT: standard PWR using 3% low-enriched uranium oxide fuel achieving 30 MWD/kg burnup; once-through fuel cycle with spent fuel sent to long-term storage.[2]

1.2 PWR Mod-OT: PWR using 3% low-enriched uranium oxide fuel modified to achieve 50,000 MWD/MT average burnup, and other means to decrease uranium requirements; spent fuel is sent to long-term storage.

1.3 PWR-U/Pu spiked recycle: PWR using 3% low-enriched uranium oxide fuel and self-generated recycle fuel of co-processed uranium and plutonium oxide; the recycle fuel is spiked or pre-irradiated.[3]

1.4 LWR-DU(3)/Th: PWR using 12% U^{233}/thorium oxide fuel; the spent fuel is reprocessed to recover the U^{233}/U^{238} mixture which is recycled after blending with additional U^{233} to 12%; Pu is sold for spiked recycle.

2.0 Light Water Breeder Reactors[1]

2.1 Prebreeder, Shippingport Type I:. PWR using 20% enriched UO_2-ZrO_2 CaO/ThO_2 fuel; the spent fuel is reprocessed to recover U^{233} which is stored for use in LWBR; Pu is stored.

2.2 Breeder, Shippingport Type I: same as 2.1 except it uses U^{233}/thorium oxide fuel which is reprocessed to recover U^{233} for re[illegible] as spiked fuel.[3]

2.3 Backfit Prebreeder: standard PWR using 15% enriched uranium oxide/thorium oxide fuel; the spent fuel is reprocessed to recover U^{233} which is stored for use in LWBR; Pu is stored.

2.4 Advanced Breeder: standard PWR except modified for tight lattice, hexagonal fuel bundle and thoria control rods; using U^{233}/thorium oxide fuel which is reprocessed to recover U^{233} for recycle as spiked fuel.[3]

2.5 HEU Backfit Prebreeder: standard PWR using 93% enriched uranium oxide/thorium-oxide fuel; PWR-type fuel bundles with poison control rods; non-fissioned U^{235} and bred U^{233} recovered and accumulated for startup of LWBR.

2.6 Breeder, seed-blanket type: seed consists of UO_2-ThO_2 pellets, blanket of ThO_2 pellets; initially fueled with HEU (mixture of non-fissioned U^{235} and bred U^{233}) recovered from HEU Backfit Breeder, eventually self-sustained by bred U^{233}; ThO_2 and poison control rods.

3.0 Heavy Water Reactors[1]

3.1 HWR DU(5)-OT: CANDU-type HWR using 1.2% slightly enriched uranium oxide fuel; plant designed for 1300 MWe, 2200 psi reactor coolant pressure; spent fuel is sent to long-term storage.

4.0 High Temperature Gas-Cooled Reactors[1]

4.1 HTGR DU(5)-OT: 20% enriched uranium-thorium oxycarbide particle fuel; the spent fuel is sent to long-term storage.

4.2 HTGR DU(3)/Th: 12% enriched U^{233}/thorium oxycarbide particle makeup fuel; spent fuel is reprocessed to recover the U^{233} and recycle it after denaturing to 12%; Pu is stored.

5.0 Gas-Cooled Fast Breeder Reactors[1]

5.1 GCFR U-Pu/Th spiked recycle: uranium-plutonium oxide homogeneous core and thorium oxide blanket; core and blanket reprocessed; core is co-processed U and Pu subsequently pre-irradiated;[3] the U^{233} is recovered and sold as denatured fuel.

6.0 Liquid Metal Fast Breeder Reactors[1]

6.1 LMFBR U-Pu/U recycle: standard U-Pu oxide homogeneous core, uranium oxide blanket; core and blanket reprocessed separately; core is co-processed U and Pu; blanket is co-processed U and Pu with excess Pu used for LWRs and LMFBRs.

6.2 LMFBR U-Pu/U, spiked recycle: same as 6.1 except co-processed U/Pu is pre-irradiated.[3]

6.2.1 Heterogeneous core design

6.2.2 Homogeneous core design

6.3 LMFBR U-Pu/Th spiked recycle: uranium-plutonium oxide core and thorium oxide blanket; same as 6.2 except U^{233} is recovered from blanket fuel and sold as denatured fuel; Pu makeup from LWRs.

6.3.1 Heterogeneous core design

6.3.2 Homogeneous core design

6.4 LMFBR Th-Pu/Th, spiked recycle: thorium-plutonium oxide homogeneous core and thorium oxide blanket; core and blanket reprocessed separately; recovered Pu is recycled to LMFBR core; Pu is co-processed with thorium and pre-irradiated;[3] the U^{233} is recovered and sold as denatured fuel.

6.5 LMFBR DU^{s}-Th/Th: denatured U^{233} mixed with thorium oxide fuel in homogeneous core and thorium oxide in blanket; core and blanket reprocessed separately; recovered U^{233} is denatured and sold; recovered plutonium is mixed with uranium and pre-irradiated and sold.

Footnotes for Table 1.-1.

(1) Enrichment, reprocessing, Pu conversion, Pu fabrication, Pu storage and U^{233} fabrication in secure locations.

(2) For reference only.

(3) To a radiation level of 1000 rad/hr at 1 meter from a fuel bundle when loaded into the reactor 6 months after fuel fabrication.

Survey Of Recent Reports And Trends

John N. O'Brien
November 1981

TABLE OF CONTENTS

		Page
I.	Introduction	115
II.	International Plutonium Storage	115
III.	The Second NPT Review Conference	118
IV.	GAO Reports and Recommendations	118
V.	The Convention on the Physical Protection of Nuclear Materials	127

ABSTRACT

This report examines several major events of importance to near and middle-term regulatory planning in NRC. Major changes in administrative policy are discussed along with examinations of recent advances in International Plutonium Storage, the second NPT Review Conference, two recently released Government Accounting Office reports on non-proliferation, and the newly ratified Convention on the Physical Protection of Nuclear Materials. Those events are analyzed to identify areas where they may affect exercise of NRC authority.

I. INTRODUCTION

During the preparation of this anthology several significant changes occurred - most notably in the Administration of the U.S. Government. With this, many U.S. policies, which first took shape in 1975-76 under President Ford, have been called into question, although major changes in U.S. policy have not actually taken place.

President Reagan has called for more predictability of U.S. nuclear exports which is in consonance with the Ford and Carter non-proliferation policies. Reagan also asked for completion of the Clinch River Breeder Reactor (CRBR) and ended the U.S. ban on domestic, commercial reprocessing of spent nuclear fuel; both actions are direct reversals of prior U.S. policy. The current Administration has also sought to change U.S. policy on the exercise of prior approval rights to relax foreign animosity over unilateral U.S. case-by-case approvals.

Several other events have occurred which have bearing on NRC's exercise of licensing and regulatory authority. The IAEA has conducted very serious talks on the concept of International Plutonium Storage (IPS) to which the U.S. may soon become party. The IPS talks are covered in the second part of this section with the intent of describing those aspects which may have some effect on NRC jurisdiction.

The third part of this section briefly reviews the 1980 NPT review conference. The fourth part summarizes, in a comprehensive manner, two recent GAO reports which have direct bearing on NRC jurisdiction. While the conclusions of these reports have been contested by various segments of the U.S. nuclear industry and government agencies, their influence on the legislative and regulatory decision makers may be significant. Lastly, the newly ratified international Convention on the Physical Protection of Nuclear Materials is examined to assess its potential impact on NRC authority.

This survey of recent reports and trends is not comprehensive, but represents the more significant changes in the arena of U.S. non-proliferation policy which may affect the exercise of authority within NRC's jurisdiction.

II. INTERNATIONAL PLUTONIUM STORAGE

The International Atomic Energy Agency (IAEA) has sponsored an Expert Group on International Plutonium Storage (IPS) which has met frequently during the last three years.[1] Many studies have been completed during this non-binding negotiation and substantial progress has been reported.[2] In addition, Urenco is requiring that Brazil must use some form of IPS arrangement in order to qualify for continued fuel shipments if they pursue reprocessing.

A. Legal Authority

Section XII A.5 of the statute of the IAEA[3] can be read to provide the IAEA with authority to store and monitor "excess plutonium stocks." The relevant section of the statute allows the IAEA:

> to require that special fissionable materials recovered or produced by a by-product be used for peaceful purposes under continuing Agency [IAEA] safeguards for research or in reactors, existing or under construction, specified by the member or members concerned; and to require the deposit with the Agency of any excess of any special fissionable materials recovered or produced as a by-product over what is needed for the above stated uses in order to prevent stock-piling of these materials, provided that thereafter at the request of the member or members concerned special fissionable materials so deposited with the Agency shall be returned promptly to the member or members concerned for use under the same provisions as stated above.

This provision is not self-executing and, therefore, requires governmental actions to bring it into force.

The Nuclear Non-Proliferation Act of 1978[4] (NNPA) proves a legal basis for IPS in Section 104 which is reviewed in the first section of this Chapter.[5] of this Chapter.[5]

B. NRC Jurisdictional Concerns

The purpose of IPS is to (1) avoid national stockpiling of separated plutonium, (2) enhance international controls over the use of separated plutonium, (3) bring about the potential reduction of proliferation risks associated with nations of particular concern and, (4) help insure the durability of safeguards coverage.[6]

An IPS facility has been designed and institutional arrangements discussed by the IAEA Expert Group. Some of these arrangements are of direct concern to NRC jurisdiction. These are:

1. Designation of IPS Facilities. The Expert Group reached the general consensus that, while the IAEA should not be in the business of owning and operating IPS facilities, it should have the power to designate what sites are appropriate.[7] Under present proposals, the Board of Governors of the IAEA would decide the number, size and design of IPS sites, the locations appropriate to IPS goals, the safeguards and physical protection to be employed at IPS sites, and would approve of host nation arrangements including liability for accidents, privileges and immunities, health and safety requirements and so on.[8]

Because of the present U.S. government intentions to allow domestic reprocessing and the application of IAEA safeguards to U.S. facilities, the U.S. may very well end up with a domestically-sited IPS. Since NRC has licensing jurisdiction over such a facility (used for energy purposes), an awareness of IPS progress will allow NRC to bring up issues pertinent to its jurisdiction as negotiations move toward completion.

2. Control of Stored Plutonium. IPS negotiations have lead to tentative acceptance of a "two-key" system of plutonium inventory control.

The host nation or operator will control one key while the IAEA controls the other.[9] This approach is meant to allow the heart of the IPS system to be "international custody," thereby making unauthorized removal of plutonium by a host nation a clear violation of international law.

Plutonium which is stored will be released according to some set of criteria which have yet to take substantive form. The Draft Guidelines for IPS provide that stored plutonium will be released only for (1) a specific use, (2) exclusively peaceful purposes, and (3) only if IAEA safeguards are continuously applied.[10]

3. U.S. Right of Prior Approvals. The U.S. has bilateral consent rights over the transfer and disposition of nuclear materials derived from U.S. exports. IPS will have some effect on those rights although the scope of effect is not clear currently.

The idea has been advanced that storage at an IPS site could be regarded as necessary for approval of transfer or reprocessing of spent fuel to recover plutonium by U.S. trading partners. This, however, does not imply that IPS would be sufficient, by itself, to result in U.S. approvals. Further, under current U.S. law, transfer to a specific site may not be approved even if it has been designated an IPS by IAEA.[11]

The pressure during negotiation to substitute IPS for bilateral consent rights may be very great. Several foreign participants in the Expert Group on IPS have stated directly that such a substitution is their sole interest in such an institution. While it is doubtful that supplier nations would give up or significantly dilute consent rights, it is possible that IPS could be used to enforce compliance, since IPS would be in a superior position to withhold release of plutonium if consent were not granted.[12]

4. The Nature of Participation. The Expert Group on IPS presented three approaches to establishing participation. These are (1) a single multilateral treaty to which any state could adhere by depositing an instrument of acceptance, (2) separate agreements between the IAEA and each participant, and (3) supplements to existing IAEA safeguards agreements.

The single multinational treaty arrangement has received a great deal of attention, but the universalist nature of such an arrangement may be disadvantageous since purely political motivation may compel the actions of nations who join without depositing any plutonium. A two-tiered membership has been proposed to alleviate this problem by allowing no legal voice in IPS affairs unless a member has a material interest (i.e., deposited plutonium) in IPS. However, this option is made less likely because of the discriminatory aspects of weapon-states versus non-weapons-states and the institutional problem associated with the distinct nature of the European Communities nuclear energy arrangements.

Separate IPS agreements make it easier to deal with the differences in members; the problem of overly universal membership still would exist, however. As an alternative aimed at making IPS a more regional international organization, it has been proposed that IPS be incorporated into existing IAEA safeguards agreements. In addition, all new IAEA bilateral safeguard agreements could contain an IPS clause. As a result, supplements to existing IAEA safeguards agreements would incorporate disparities, such as weapons status, into the IPS concept without exacerbating the claims of discrimination that a new set of agreements would undoubtably bring to bear.[13]

A last option which has received surprisingly little attention in negotiations on IPS is the establishment of an IPS organization comprised of only industrialized, interested parties. Such an organization would have well over ninety-percent of all separated plutonium in IPS, but problem nations would not be included, possibly making IPS applicable to only those nations which are not considered proliferation prone.

All of these options point to changes in the exercise of NRC jurisdiction. As IPS negotiations proceed, NRC should closely monitor developments relevant to its jurisdiction in order to avoid problematical results from a State Department dominated negotiation which, otherwise, may not take NRC concerns fully into account. This will be especially true during the 1982-84 period during which many authorities see strong movement toward the IPS concept.[14]

III. THE SECOND NPT REVIEW CONFERENCE

The Second Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons convened in August 1980. It was attended by seventy-five nations party to the treaty, one signatory (Egypt, which has since become a party), eleven non-signatory nations, and two regional organizations.[15]

While the conference was characterized by a generally derisive posture between supplier and consumer nations, several important points of consensus occurred. There was a great deal of support for a "well designed" IPS scheme and for the Convention on the Physical Protection of Nuclear Materials.

In addition, there was strong general support for the committee on Supply Assurance and efforts toward institutional arrangements such as regional fuel cycle centers, emergency back-up supply systems, international stockpiles, and an international nuclear fuel bank.[16]

IV. GAO REPORTS AND RECOMMENDATIONS

A. Evaluation of Selected Features of U.S. Nuclear Non-Proliferation Law and Policy (EMD-81-9, November 1980)

This GAO report analyzes the impact of several recent non-proliferation policies on the actual spread of sensitive technologies and materials. The report details U.S. non-proliferation policy and draws out several issues of importance in future policy making. Its major inquiries and conclusions are covered in the following sections.

1. Are uranium supplies adequate to defer developing reprocessing technologies and breeder reactors? GAO surveyed major projections of uranium supply and expected demand. It found that demand projections have been routinely high and presented factors which could further reduce demand. Simultaneously, according to GAO, projections of available uranium ore deposits continue to grow for a number of reasons. However, the most important facet of supply and demand figures are their uncertainty. GAO's estimate is that available reserves will be adequate for, at least, the rest of this century and probably into the next.

2. Can the United States use its enrichment capability to promote non-proliferation? The U.S. relied for some time on a monopoly in commercial enrichment technology to guarantee adherence to U.S. non-proliferation policies. GAO maintains that that reliance is no longer sound because of unattractive contract conditions and entry of several other suppliers into the market. By the mid-1980's, foreign enrichment suppliers alone could supply the entire foreign demand for enrichment services.

GAO points out that the emergence of new suppliers is probably a positive gain in terms of non-proliferation because of the increased diversity of suppliers and the consequent lessening of potential fuel embargos. The strength of the old U.S. position on fuel supplies was based upon the potential embargo of U.S. fuel so that the erosion of that leverage can be viewed positively.

3. Is more U.S. enrichment capacity needed to meet foreign demand? After examining the current U.S. enrichment capacity available and the probable level of foreign demand, it was found that construction of additional enrichment capacity is not "justified at this time." However, the issue of replacing existing, energy inefficient gaseous diffusion plants was left open. Advanced isotope separation was discussed in terms of being "available in the 1990's" and GAO pointed out that waiting for those technologies may make more sense than pursuing centrifuge technology as in the Portsmouth complex.

4. How well are U.S. controls over exports of nuclear materials and equipment working to remove doubts about U.S. reliability? GAO's comments on U.S. controls is especially significant for NRC because of the Commission's central role in conducting export licensing proceedings. Particular issues raised are: the length of export licensing processing time, the existence of U.S. controls over foreign reprocessing and plutonium use, controls over exports of highly enriched uranium, and controls on retransfer of previously exported nuclear material and equipment.

The length of time consumed in export licensing proceedings was analyzed and it was found that during the first year of NNPA-required licensing proceedings (March 1978-79), many licenses were held up unreasonably. However, during the second year, the situation improved substantially, although not to levels expected to be acceptable to foreign interests. For example, in March 1980, thirty-two percent of all export licenses had been under review for a full year or more.

GAO found that the statutory time limits in NNPA, which were included to pressure the relevant agencies to expedite the export licensing process, were routinely passed. However, as in the case of export licensing generally, adherence to statutory time limits improved during the second year of operation under NNPA. A complication in these data is the executive branch policy of allowing export license applications to "sit" until approval can be made or the application withdrawn rather than having it formally denied.

Many of the reasons for time slippage in the export licensing process are not attributable to NRC. Typical problems are the lack of appropriate nuclear cooperation agreements, lack of recipient government assurances, difficulty in implementing administration policy on highly enriched uranium, the need for additional information to be supplied to NRC by foreign governments and U.S. agencies, and various unique situations such as EURATOM negotiations.

GAO also comments that NRC has worked to improve the export licensing process by adopting "streamlined review and approval procedures." These include staff authority to independently approve certain exports, more use of precedents, expanding general license authority, and licensing of multiple fuel load licenses for nations with good non-proliferation credentials.

The effect of prior approval rights over reprocessing and plutonium use were examined by GAO. Besides the generally derisive view many U.S. trading partners have of U.S. prior approval rights, several questions were raised about future use of these rights. First, to what extent will the government claim approval rights when a U.S. export is co-mingled with the export of another nation? Second, what happens when more than one nation claims approval rights on the same commodity. Third, what conditions will be required to obtain U.S. approval for retransfer of reactor component exports? These issues have not been clarified and are of concern to NRC.

The U.S. has been supplying highly enriched uranium to foreign nations to use in their research reactors. GAO comments that, in spite of U.S. efforts to convert research reactors to use lower enrichment levels, the vacillation of U.S. policy in this area has contributed to perceptions that the U.S. is not a reliable supplier. GAO recommends that the U.S. decide what foreign research reactors merit continued U.S. supply, the quantities needed to meet legitimate reactor needs and fuel fabrication schedules, and the level of enrichment to be supplied.

B. The Nuclear Non-Proliferation Act of 1978 Should Be Selectively Modified (OCG-81-2, May 1981)

Section 602(e) of NNPA directs GAO to complete a study, and report to Congress three years after enactment, on the implementation and impact of the Act on nuclear non-proliferation policies, purposes, and objectives. GAO was also directed to provide recommendations to correct problems associated with the Act's implementation.

GAO's evaluation centers on U.S. efforts to be a reliable supplier, uranium supply and demand, U.S. efforts to expand NPT adherence, U.S. efforts to strengthen international safeguards, reprocessing of spent fuel, export licensing procedures, renegotiation of Agreements for Cooperation, non-nuclear energy assistance, foreign acceptance of U.S. non-proliferation policy, and on the impact of NNPA on the competitiveness of U.S. export in the world market.

GAO used many sources of information including relevant federal agencies, national laboratories, U.S. enrichment and reprocessing facilities, private U.S. industry, international meetings, international organizations, foreign nations, private consultants, and various literature sources.

GAO's analysis is divided according to each title of NNPA. A summary of GAO's findings is presented here title by title as in the report.

1. Title I - United States Initiatives to Provide Adequate Nuclear Fuel Supply. GAO found that the incentives proposed in NNPA to enhance the reputation of the U.S. as a reliable fuel supplier have not been successful. For instance, the need for additional U.S. enrichment services to provide adequate supplies to foreign customers has not been shown to be necessary. In addition, endeavors, such as INFA, have not materialized and, therefore, offer no impetus toward accepting U.S. assurances of fuel supply.

GAO recommends that a small international fuel bank be established if the efforts of the IAEA Committee on Assurance of Supply (which is scheduled to finish its work in mid-1983) does not meet with success. GAO also recommends that the U.S. put its full weight behind the IPS negotiations discussed earlier in this report. In addition, serious consideration of accepting foreign spent fuel for storage as required by Title I is recommended.

The basic thrust of GAO's analysis of progress under Title I of NNPA is that the Government's lack of commitment to the international undertakings described in NNPA has seriously affected foreign perceptions of U.S. sincerity as a reliable supplier. GAO also raises significant questions about the wisdom of completing additional centrifuge enrichment capacity until DOE "fully and objectively" considers the option of postponing current centrifuge construction and the feasibility of introducing more efficient and cost-effective advanced enrichment technologies.

2 . Title II - United States Initiatives to Strengthen the International System. Title II calls for U.S. support to strengthen IAEA safeguards. Specifically, it calls for the U.S. to contribute financial, technical, informational, and other resources to assist IAEA in effectively implementing safeguards. Title II also calls for U.S. cooperation in establishing international arrangements for recovery of diverted nuclear material and sanctions for violators.

GAO found that the financial resources provided by the U.S. Government (almost $19 million through the Program of Technical Assistance to Safeguards - POTAS) have substantially improved IAEA Safeguards, particularly in the area of inspector training. Equipment technology and development has also benefited from the POTAS program. However, GAO points out that most equipment-related progress has yet to surface in the field. This is due to the fact that such progress has not provided timely or practical solutions to correct problems, the emphasis of these studies has been too broad in scope, and national rather than international safeguards have generally received the most attention. GAO was generally critical of the management of POTAS projects in spite of some improvements in international safeguards. In addition, GAO cites certain POTAS equipment development as too expensive for IAEA to afford its use.

GAO cites several reasons for a general failure of research to improve IAEA safeguards. These are (1) a limited number of inspectors, (2) lack of suitable techniques and equipment, (3) inadequate accounting procedures used by some nations, and (4) political constraints. Generally speaking, GAO concludes, the magnitude of IAEA safeguards responsibilities has outpaced efforts aimed at improvement and, thus, continues to encounter the same basic problems.

U.S. negotiators have found it impossible to reach an international consensus on sanctions against nations that violate international safeguards. Other nations have asserted that inflexible and specific sanctions may not be sufficiently threatening to make a nation forego diversion.

Title II also directs the U.S. to negotiate a convention on physical protection of nuclear materials. These negotiations were successful and the convention was opened to signature in March 1980. This is cited by GAO as an achievement in accord with the mandates of NNPA; however, it will probably take 2 or 3 years for enough nations to ratify it and bring it into force.

GAO recommends that the U.S. reconsider the scope and direction of POTAS projects in light of the original intent of the program, the provisions of NNPA, the increasing dependence of the IAEA on this U.S. program, and the need to retain the international character of the IAEA safeguards system.

3. Title III - Export Organization and Criteria. GAO reiterates several assertions concerning the export licensing process made in the previous GAO report "Evaluation of Selected Features of U.S. Nuclear Non-Proliferation Law and Policy." First, they state that the time frame involved in export licensing proceedings is steadily becoming shorter. Specific GAO recommendations for improvement in the export licensing process follow. These recommendations may directly affect NRC jurisdiction.

GAO raises the point that every export proceeding requires an "assurance letter" from the recipient nation which states that the export will be subject to the conditions of the Agreement for Cooperation between it and the U.S. Many times, this single action, because of its case-by-case nature, holds up export licenses. GAO suggests use of a generic assurances where foreign nations are willing to provide them. This could be done by revising executive branch regulatory procedures to allow such generic assurances.

It is also pointed out by GAO that applicants often do not know the status of their export license application. The reason for this is that NNPA requires notice of delay only from NRC and most delays, by far, occur in the executive branch review process which occurs before NRC even receives the application. While an application is being held by the five executive branch agencies, no notice of delay is required except to Congress. This, coupled with the fact that it is difficult, if not impossible, for applicants to track down their license application before it reaches NRC, means that shipping schedules and contractual obligations are difficult to meet. Under present practice, the executive branch must report delays over sixty days only to Congress, not to the applicant. GAO suggests that executive branch and NRC notification requirements be reversed. Since only one in ten licensing delays occur at NRC, this would allow applicants to follow their applications through the processes most likely to delay processing and for NRC to report to Congress when it cannot expeditiously process a complete application forwarded from the executive branch. This, it is thought, would improve accountability in the licensing process and allow the applicant more confidence in the process.

GAO also contends that there is no "streamlining" process available for applicants operating under a new or renegotiated Agreement for Cooperation. Such expedited procedures could provide long-term licensing for exports of low-enriched uranium fuel and reactor replacement parts under new or renegotiated Agreements for Cooperation. This would, presumably, further the U.S. commitment to be a reliable supplier while also providing an impetus for some nations to conclude renegotiations of their Agreements.

Another facet of export licensing which clouds the perception of the U.S. as a reliable supplier is the provision in NNPA that the President can exempt any Agreement for Cooperation from an agreement requirement if its inclusion would be prejudicial to U.S. interests. However, NRC is bound by export licensing criteria which may conflict with the exemption. This means that NRC may not be able to issue an export license even though the President and Congress have agreed to an exemption. GAO suggests amending Section 401 of NNPA to correct this anomoly.

GAO commented on the fragmented responsibility for Government distributions of nuclear materials and related materials such as heavy water and reactor grade graphite. GAO suggests that all exports be handled by NRC because these types of exports are rarely held up by NRC and this would remove a source of confusion for foreign governments in procuring these materials from the U.S.

An important matter in the export licensing process is the extent to which the effectiveness of IAEA safeguards must be considered. The executive branch has indicated that the existence of an agreement between IAEA and a recipient nation is sufficient to satisfy NNPA requirements that all exports be subject to IAEA safeguards. Congress, however, specifically left this issue open to NRC scrutiny. Both NRC and the executive branch have sought clarification on this from Congress, but an indication of congressional intent has not been forthcoming. As a result, NRC and the executive branch have continued to disagree on the extent to which NRC must independently evaluate IAEA safeguards on a case by-case basis. This issue should receive congressional attention and clarification.

GAO makes a strong case for adopting some general policy regarding U.S. consideration of foreign requests for reprocessing and plutonium use when U.S. origin fuel is involved. If such a policy were adopted, U.S. trading partners could request approvals before they enter into fuel supply contracts and enhance the predictability of their nuclear power programs.

In order to improve the control of U.S. firms and individuals operating within foreign commercial spheres, GAO recommends several actions. First, the distinction between communist and "free-world" nations is not sufficient since it allows trade with non-nuclear weapons states not adhering to full-scope safeguards. NNPA should be amended, according to GAO, to restrict commerce in reactor technology and assistance to only those nations which adhere to the full-scope safeguard requirement. Second, DOE is required to terminate nuclear material and equipment exports when a nation conducts certain prohibited activities such as detonating a nuclear explosive device. In such circumstances, however, there is no requirement for withdrawal of DOE's "general authorization." DOE should be required to withdraw the general authorization as well. Third, the Secretary of Energy should be allowed to delegate specific authorizations for trade to DOE staff. Of the 20 to 25 specific authorization requests processed yearly by the Secretary, very few are of a nature requiring the attention of the Secretary. It has been shown that these requests are typically held up unreasonably and have resulted in a loss of business to several U.S. firms. Lastly, GAO recommends that the process by which the executive branch considers requests for approval of U.S. activities in foreign nations should be as open as NRC's approval process.

GAO addressed the issue of whether NRC should retain its export licensing functions in light of licensing delays which have, allegedly, caused a loss of business for U.S. firms. GAO found that the arguments in favor of removing export licensing from NRC jurisdiction were not compelling. The first of these arguments is that NRC has too much power in export licensing proceedings. In fact, NRC cannot deny an export license, it can only trigger executive and Congressional involvement. Since Congress has traditionally exercised control over nuclear exports, NRC, a congressional commission, is viewed as a reasonable form of independent review over Executive Branch decision-making. In addition, once an export reaches its destination, NRC's authority ends and DOE picks up regulatory controls. Although DOE is required to "consult" with NRC on subsequent arrangements, it is not required to concur. As a result, NRC is not able to exercise an inordinate level of influence.

GAO also found that the objection to NRC operating in a sphere directly related to foreign policy (i.e., whether to export nuclear materials and facilities) is not compelling because NNPA allows the President to override or supersede NRC export licensing deliberations. GAO recommends, however, that NRC adopt a policy of referring license applications to the President if delayed by 120 days or more.

As to objections that NRC dilutes its attention from safety matters to address export license applications, GAO found that the vast majority of export licenses never reach the Commission, but rather are issued by NRC's Office of the Assistant Director for Export/Import and International Safeguards. This office employed fifteen of over three thousand NRC personnel in Fiscal Year 1981, which could not be construed as diluting NRC's safety objectives.

4. Title IV - Negotiations of Further Export Controls. Title IV requires the negotiation of existing Agreements for Cooperation to comply with NNPA export criteria. This effort has not been successful and may, in fact, be counterproductive according to GAO. However, no change in this title was recommended since trading acquiescense over NNPA criteria for more harmonious relations may actually signify another vacillation in U.S. export policy. GAO does recommend that Euratom negotiations be discontinued since Euratom may never accept U.S. overtures to this end.

GAO analyzes and details the state of negotiations with all U.S. nuclear trading partners. While renegotiation of existing agreements has not progressed well, at least twelve unrevised agreements are presently in compliance with the requirements of Title IV. In addition, all new agreements have provisions required by NNPA and those nations with expiring agreements have indicated a willingness to accept new provisions. GAO points out that a generic policy on U.S. prior approval rights would enhance the ability of negotiators to pursue new agreements.

Lastly, GAO recommends eliminating the yearly Presidential review of export licensing criteria to determine whether additional criteria are necessary. This is viewed as contributing to doubts about the consistency of U.S. export policy while doing little to enhance non-proliferation.

5. Title V - United States Assistance to Developing Countries.

While the U.S. has provided support and funding for non-nuclear alternatives to energy production, as Title V requires, none of that funding was appropriated under NNPA. It comes instead under other foreign assistance legislation. GAO recommends deleting Title V because it has not been implemented and would serve no real purpose if put into effect.

6. General Conclusions. GAO suggested that a large variety of factors influence foreign perceptions of the U.S. as a nuclear energy trading partner. These factors include infringement on sovereign rights, slowing regional development, stifling energy independence, big brotherism, imposition of unilateral conditions, discrediting NPT, and placing undesirable controls on reprocessing and enrichment. In almost each nation, a different set of factors dominates their view of the U.S. as a reliable supplier. GAO then summarized the views of twelve nations — Argentina, Australia, Brazil, Canada, West Germany, France, India, Japan, Pakistan, South Korea, Spain, and the United Kingdom. These summaries point out how diverse foreign views actually are, concerning U.S. non-proliferation policy.

GAO pointed out that it is difficult to determine the extent to which the business of U.S. nuclear energy vendors has been affected directly by NNPA. A number of other considerations arise which include foreign criticism aimed at executive policy, as well as at NNPA, the general decline in the world market for reactors, absence of domestic reactor orders (which are not affected by NNPA), the emergence of foreign competition, and U.S. policies on human rights, political trade restrictions, environmental impacts, and the Foreign Corrupt Practices Act. It is pointed out, however, that a loss of U.S. export diminishes the U.S. influence derived from those exports.

In view of short-term progress toward the general goal of retarding proliferation, the results have been mixed. On the positive side, no additional nations have acknowledged exploding a nuclear device, twelve additional nations have joined NPT, Spain has moved toward full-scope safeguards, and the foreign drive to acquire enrichment and reprocessing capability has abated. On the other hand, some nations (notably Pakistan) have moved toward nuclear weapons capability, several nations considered proliferation-prone have not joined NPT despite the existence of a U.S. bilateral Agreement for Cooperation (e.g. India and South Africa), and other supplier nations have exported sensitive nuclear technology in spite of U.S objections.

In the long-term, NNPA is a sound statute, according to GAO, and should not be subject to major amendments. In order to accomplish the basic objectives of NNPA, to be a reliable supplier to nations who use nuclear materials for purely peaceful purposes, more than three years is necessary. Since cooperation is the only way to foster non-proliferation, the many international initiatives sought in NNPA may take several years to materialize and, therefore, can only be assessed in the long term.

V. THE CONVENTION ON THE PHYSICAL PROTECTION OF NUCLEAR MATERIALS

On July 30, 1981, the U.S. Senate unanimously agreed to ratification of the Convention on the Physical Protection of Nuclear Materials which will create a framework for preventing the diversion of sensitive nuclear materials while in transit and storage. Although the NNPA was not enacted when negotiations were opened in 1977, both Section 203 and Section 403 of NNPA contain language covering the Convention.

Article 1 of the Convention defines terms to be used. Article 2, 3, 4 and part of Article 5 pertain directly to international transport of nuclear materials. Article 2 states that the Convention only covers peaceful uses and does not impose burdens on domestic rights if not specifically addressed. Article 3 requires that national laws be enacted to comply with the Convention for all materials in transport within or in transit over a nation. The Convention specifies safeguards which are very close to those already required by NRC and only minor regulatory adjustment should be necessary.

Article 4 requires each nation to "receive assurances" that exported nuclear material will be protected in compliance with the Convention prior to shipment. If the U.S. is an importer and the exporting nation is not party to the treaty, this obligation falls on the U.S. If two foreign nations, not party to the Convention, wish to transport nuclear materials by land, sea, or airspace within U.S. jurisdiction, the U.S. must gain the same assurances from both parties. The nation on whom the obligation falls is to identify and inform, in advance, any nations such transport is expected to transit. Regulatory adjustments can be expected to be requested to implement this Article.

In Article 5, all parties agree to specify the central authority and point of contact for physical protection responsibility within their national jurisdiction. This Article also requires all parties to cooperate in notification of a theft event and exchange information relevant to recovery of the contraband material. In addition, parties are required to cooperate in research and development aimed at improving physical protection during transport. No provision of this article should require regulatory or legislative adjustments in NRC's jurisdiction.

Article 6 requires the application of information controls to any confidential information transferred in compliance with this Convention. Articles 7-14 define offenses which party nations agree to make punishable. Article 9 defines theft or robbery of nuclear material by all means including embezzlement, fraud, blackmail, force or other means of intimidation. Article 8 commits parties to establish national laws defining these actions as offenses. Article 9 provides for extradition of offenders. Article 10 requires that, if offenders are not extradited, the arresting nation will expeditiously pursue prosecution in its national courts. Article 11 regulates extradition procedures. Article 12 guarantees fair treatment under the law for offenders. Article 13 requires all parties to cooperate in prosecution proceedings and Article 14 provides for exchange of information during prosecution.

The Convention will not take force until twenty-one nations deposit instruments of acceptance. This process is expected to take several years during which time NRC will make required regulatory adjustments. Any party may withdraw after 180 days notice. A five year review conference is required and disputes are directed to the International Court of Justice or arbitration if both parties agree to such jurisdiction.

REFERENCES

1. See generally, C.N. Van Doren, "Toward an Effective International Plutonium Storage System," prepared for The Congressional Research Service under contract CRS 81-34, 1981.
2. F.F. McGoldrick, "International Plutonium Storage," presented to American Nuclear Society, September 1980, also reprinted in id.
3. 8 UST 1093, as amended by 14 UST 135 and 24 UST 1637.
4. Pub. L. No. 95-242.
5. See pp. 7,8, supra.
6. Note 1, supra, p. 9.
7. See Draft Guidelines, IAEA/IPS/EG/81, p. 11.
8. Note 1, supra, pp. 25-31.
9. IAEA/IPA/EG/63 (Rev. 1).
10. Note 7, supra.
11. Note 1, supra, pp. 96-101.
12. Id.
13. Id. pp. 90-91.
14. "Strong Headway Seen for Plutonium Storage Accord," *Nucleonics Week*, Vol. 22, No. 45, Nov. 12, 1981, p. 1.
15. "Second Look at Non-proliferation Discovers Divergent Views," IAEA Bulletin, Vol. 23, No. 1, March 1981, pp. 28-32.
16. Id.

International Nuclear Power Program Development

Kun Mo Chung
February 1980

TABLE OF CONTENTS

		Page
I.	Introduction	131
II.	Capacity	132
III.	Reactor Type	134
IV.	Major Features of Nuclear Power Programs	135

ABSTRACT

This report details the development of nuclear energy around the world. Its purpose is to demonstrate which global region may present the greatest potential for international or multinational cooperation. Tables, detailing factors of importance, are presented and it is concluded that Asia and Oceania constitute the best areas for regional development of international nuclear fuel cycle services.

I. INTRODUCTION

The feasibility of any international institutions for nuclear fuel services is dependent on future projections of nuclear power development in potential participating nations. Although the most reliable data on these projections will be available at the conclusion of INFCE during 1980. An examination of the general trends and rough estimates of the global nuclear power program as of Fall, 1979 are presented here.

Any nation choosing to be involved in nuclear energy generation must make a set of key policy decisions:

- How much nuclear power generating capacity should be planned?
- What type(s) of reactor system should be selected?
- Which vendors should be selected to furnish key plant components?
- What fuel cycle services should be purchased and from whom?
- How should the import substitution plan be structured and what is the market viability of the domestic capital equipment industry?
- How should spent fuel and waste management be handled?
- What should the extent of domestic research and development efforts be?

These decisions are not irreversible and may evolve as techno-economic situations change. For example, France originally developed and constructed gas cooled reactors, but now concentrates on the light water reactor (LWR) technology. Also, projections of nuclear power reactors have a wide margin of flexibility. They depend on the projection of the peak power load demand which is, in turn, a sensitive function of overall economic indicators. If the long-term economic growth rate is increased by a few percent, the electricity demand escalates and, because conventional fuels may be more expensive, nuclear power demand might increase substantially. The demand for domestic fuel cycle facilities is also linked to the availability of foreign nuclear facilities and materials for export.

II. CAPACITY

More than sixty-five nations will have either operating nuclear power programs or planned facilities within the next twenty years. Regional nuclear energy programs are summarized in Table I. In Table I, nations are grouped according to geopolitical proximity: North America, Latin America, Asia & Oceania, middle East and North Africa, Western Europe and Eastern Europe. South Africa and Israel are grouped with Western Europe and Pakistan is grouped with middle Eastern and North African nations.

Table I.

Regional Nuclear Energy Projections (GW)

	1977	1985	1995
North America	53	150	250
Latin America	0.4	6	5
Asia & Oceania	8	40	125
Middle East & North Africa	0.1	9	47
Western Europe	27	118	283
Eastern Europe	8	40	124

Major nuclear nations, which include USA, USSR, France, W. Germany, U.K., Canada and Japan account for more than 87% of all installed nuclear generating capacity. Although their relative share is expected to decline in the coming years, these major nuclear energy nations will lead the world-wide development of nuclear power programs. Also, the relative share of nuclear weapons states in the world-wide power reactor trade will probably steadily decrease from 70% at present to about 50% in 1995. The impact of the nuclear power programs in non weapons states and other newcomer nations can be expected to increase with time.

From the view of international nuclear policy, the most interesting regions are the Latin American region and the Asia and Oceania region. Besides them, countries with heavy water reactors (Argentina, India, Pakistan, and Rumania in the future) constitute an interesting group. Eastern European countries with the exception of Yugoslavia and Rumania are under the close control of the Soviet Union. All the nations in the Eastern Europe region have the Nuclear Non-Proliferation Treaty (NPT) in force and nuclear fuel cycle needs are satisfied by USSR. In the forseeable future, the Soviet Union will maintain close control over Eastern European nations.

North African and Middle Eastern nations have small nuclear programs and their energy situation cannot easily justify the need for nuclear power. Pakistan is grouped in this region and has emerged as a country with proliferation potential. The unstable political situation and competition with India may easily push the Pakistani government to produce a nuclear explosive. Besides Pakistan, Iran had a major nuclear program. Iran's nuclear program is uncertain as the Iranian government is experiencing substantial confusion.

Western Europe's dependency on nuclear energy may be beyond the point of no-return. In some Western European countries, the commitment to the breeder reactor is already a reality. The heavy commitment in nuclear energy in this region requires a stable long-term nuclear policy and already the Western European governments are working together. Although initially gas-cooled reactor technology was adopted widely, long-term plan, show a heavy reliance on the LWR technology. It should be noted that the Western European LWR technology is mainly transferred from the U.S. Since many of the countries in the Western European region have stable governments and the present geopolitical setup does not provide incentives for nuclear weapons, the nuclear policy in this region is relatively free from non-proliferation considerations. This is the only region where multinational cooperation does exist and is expected to grow. However, Western European nations strive for regional self-sufficiency and the U.S.-based multinational nuclear fuel facility may not have direct implications for these countries.

The Asian countries which have significant nuclear programs (e.g., Japan, Korea and Taiwan) have strong ties with the U.S. They adopted the U.S. LWR technology purchased from U.S. vendors. Through turnkey projects, joint venture and licensing agreements, U.S. nuclear industry holds a strong relationship with these countries. These nations are dependent on the U.S. for nuclear fuel services and will continue to be unless the Western Europe interests can make an advance. Geopolitical reasons, however, will make it difficult for western European nations to compete against the U.S. Even the People's Republic of China is showing some preference toward U.S. technology. Most of the nations in this region signed the NPT and have it in force. The near-term projection of 40GW capacity by 1985 justifies the need of fuel processing facilities for this region. This region is probably most ideal for a U.S.-initiated multinational fuel facility. Australia as a uranium supplier would make an effective participant in such an endeavor.

The Latin American region has considerably smaller nuclear programs than the Asia and Oceania region. Furthermore, major countries in this region (e.g, Argentina, Brazil and Chile) have not joined NPT. The international technology linkages are also heterogeneous: Argentina with Canada and West Germany, Brazil with West Germany and the U.S., and Mexico with the U.S. The nuclear power programs are much more politicized and decision-makers in this region often link the domestic development of nuclear technology to general technological self reliance. They have demonstrated a built-in resistance to the U.S. initiatives in technological projects. Since the magnitude of nuclear programs in this region can justify regional nuclear fuel facilities only for a long-term basis, any effort to set up an international fuel cycle center involving Latin American countries may be premature at the present time.

The region by region examination of the nuclear capacity planning reveals that multinational nuclear fuel facilities may be needed in the Western Europe region and the Asia and Oceania region. Since Western European countries are already cooperating closely and have formed some multinational nuclear facilities, the primary target area for such an endeavor should be the region of Asia and Oceania. This observation coincides with the current marketing effort of the U.S. nuclear industry.

III. REACTOR TYPE

The power reactors currently in use can be grouped into four types: Light Water Reactors (PWR or BWR), Heavy Water Reactors (CANDU or PHWR), Gas Cooled Reactors (Magnox, AGR or HTGR), and Breeder Reactors (LMFBR, LWBR). The U.S. Light Water Reactor technology is by far the most advanced and popular. Gas Cooled Reactors are not available in the market and Breeder Reactors are still in an experimental stage. France, which switched from Gas Cooled reactor technology to pressurized Light Water reactor technology of the U.S., is now spearheading the commercial application of a pool-type LMFBR. Light water technologies of France, Germany and Japan are all developed through licensing and joint venture arrangements with the U.S. vendors. The recent trend toward favoring Pressurized Water Reactors (PWR) over Boiling Water Reactors strengthens the PWR technology as the leading reactor technology of the world. Exotic variations of the currently available reactor systems are remote possibilities for commercial applications in the near future. CANDU, however, is a unique alternative to PWR and nations having CANDU programs are expected to grow. In many ways, CANDU offers different technological choices from PWR; CANDUs use natural uranium, heavy water and pressure tubes. Except for heavy water, the CANDU technology is considered less demanding and import substitution is easier. CANDU users are not dependent on foreign suppliers of nuclear fuel enrichment services. Self reliance is more readily achievable for the CANDU. This is why it is more than a coincidence that leading semi-industrialized nations and non-NPT states have opted for CANDU. It should be noted that few nations have both CANDU and PWR reactors. Only one nation, Korea, is constructing commercial reactors of both types.

Although CANDU is technologically far different from PWR, it was developed by Canada with strong inputs from the U.S. nuclear industry. The U.S. and Canada share a similar philosophy in connection with export of nuclear reactors and are strongly committed to nuclear non-proliferation. Therefore, it is quite feasible to have Canadian participation in a multinational arrangement. Canada, as a major supplier of uranium, is an important supplier nation whose nuclear policies would have impacts on nations without CANDU. In a similar context, Australia is an important uranium supplier nation and would be another logical choice for a membership in a multinational fuel cycle arrangement.

IV. MAJOR FEATURES OF NUCLEAR POWER PROGRAMS.

This section presents a compliation in the form of tables of the state of global nuclear energy development.

Major Featurés of Nuclear Power Programs

Nation	NPT Status	Bilateral Agreement with U.S.	Reactor Type	1985 Capacity (GW)	1995 Capacity (GW)	Uranium Mining & Milling (t/y)	Enrichment	Reprocessing	Domestic Capital Equipment Industry	Overall Nuclear Capability	Remarks
(N.America):											
Canada	In Force	Research & Power	CANDU	11	42.5	Yes	—	—	Fully Capable	Fully Capable	Major export nation of uranium and CANDU.
(L.America):											
Argentina	—	Research & Power	PHWR	1.5	7	120	—	Lab Scale	Partially Capable	Self-sufficiency by 1985	One of the most active LDC nuclear programs. KWU, AECL provides technology.
Brazil	—	Research & Power	PWR	3	15.5	3	Nozzle	Pilot Planned	Partially Capable	Self-sufficiency in 1990	Has a most comprehensive bilateral agreement with KWU
Chile	—	—	—	—	1.7	—	—	—	—	Early stage	
Cuba	—	—	—	—	2.1	—	—	—	—	Early stage	
Columbia	Signed	Research	—	—	4.4	—	—	—	—	Early stage	
Jamaica	In Force	—	—	—	1.8	—	—	—	—	Early stage	
Mexico	In Force	Research & Power	LWR	1.3	13.3	210	—	—	Partially Capable	Rapidly Developing	US provides technology
Peru	In Force	—	?	—	1.3	—	—	—	—	Early stage	

Major Features of Nuclear Power Programs (Cont'd)

Nation	NPT Status	Bilateral Agreement with U.S.	Reactor Type	1985 Capacity (GW)	1995 Capacity (GW)	Uranium Mining & Milling (t/y)	Enrichment	Reprocessing	Domestic Capital Equipment Industry	Overall Nuclear Capability	Remarks
(L.America:) (Cont'd)											
Uruguay	In Force	—	?	—	1.1	—	—	—	—	Early stage	
Venezuela	In Force	Research & Power	?	—	1.7	—	—	—	—	Early stage	
(Asia & Oceania):											
Australia	In Force	Research & Power	?	—	3	760	Planned	—	Partially Capable	Early stage	Major uranium supplier
New Zealand	In Force	—	?	—	1.2	—	—	—	—	Early stage	
Japan	Ratified	Research & Power	Mainly LWR	30.6	74	30	Centrifuge	Demo Scale	Fully Capable	Fully Capable	Emerging as a major vendor, close tie with US industry.
S. Korea	In Force	Research & Power	Mainly PWR	3.7	25	—	—	—	Partially Capable	Rapidly Developing	US provides technology. One CANDU reactor.
Philippines	In Force	Research & Power	PWR	0.6	3	—	—	—	—	Early stage	US technology.
Taiwan	Ratified	Research & Power	LWR	6.0	11.6	—	—	—	Partially Capable	Rapidly Developing	US provides technology.

Major Features of Nuclear Power Programs (Cont'd)

Nation	NPT Status	Bilateral Agreement with U.S.	Reactor Type	1985 Capacity (GW)	1995 Capacity (GW)	Uranium Mining & Milling (t/y)	Enrichment	Reprocessing	Domestic Capital Equipment Industry	Overall Nuclear Capability	Remarks
(Asia & Oceania): (Cont'd)											
Hong Kong	—	—	?	—	3.2	—	—	—	—	**Early stage**	
Thailand	In Force	Research & Power	PWR(?)	—	3.7	—	—	—	—	**Early stage**	
Malaysia	In Force	—	?	—	1.3	—	—	—	—	**Early stage**	
Singapore	In Force	—	?	—	4.3	—	—	—	—	**Early stage**	
Indonesia	Signed	Research	?	—	6.2	—	—	—	—	**Early stage**	
Bangladesh	—	—	?	—	4.0	—	—	—	—	**Early stage**	
India	—	Power	CANDU & BWR	5.1	5.5	Yes	No	Yes	Fully Capable	Fully Capable in CANDU	
(Middle East & N.Africa):											
Algeria	—	—	?	—	0.5	—	—	—	—	**Early stage**	
Egypt	In Force	Power	PWR	0.6	4.6	—	—	—	—	**Early stage**	**Westinghouse technology**

Major Features of Nuclear Power Programs (Cont'd)

Nation	NPT Status	Bilateral Agreement with U.S.	Reactor Type	1985 Capacity (GW)	1995 Capacity (GW)	Uranium Mining & Milling (t/y)	Enrichment	Reprocessing	Domestic Capital Equipment Industry	Overall Nuclear Capability	Remarks
(Middle East & N.Africa): (Cont'd)											
Iran	In Force	Research	PWR	7.0(?)	30.3(?)	—	Participate in MNFS	—	—	Early stage	Future uncertain. Nuclear Programs.
Iraq	In Force	—	PWR	—	1.1	—	—	—	—	Early stage	French technology.
Kuwait	Signed	—	?	—	1.3	—	—	—	—	Early stage	
Libya	—	—	PWR	—	0.3	—	—	—	—	Early stage	Russian technology.
Morocco	In Force	—	?	—	0.4	—	—	—	—	Early stage	
Nigeria	In Force	—	?	—	0.5	—	—	—	—	Early stage	
Pakistan	—	—	CANDU PWR	1.3	6	Yes(?)	—	Lab Scale(?)	Partially Capable	Active development	
Saudi Arabia	—	—	?	—	0.2	—	—	—	—	Early stage	
Tunisia	In Force	—	?	—	0.2	—	—	—	—	Early stage	
Turkey	Signed	Research	PWR	0.6	2.2	—	—	—	—	Early stage	Russian technology.

Major Features of Nuclear Power Programs (Cont'd)

Nation	NPT Status	Bilateral Agreement with U.S.	Reactor Type	1985 Capacity (GW)	1995 Capacity (GW)	Uranium Mining & Milling (t/y)	Enrichment	Reprocessing	Domestic Capital Equipment Industry	Overall Nuclear Capability	Remarks
Western Europe											
Austria	In Force	Research & Power	BWR	0.7	2.0	—	—	—	Partially Capable	Partially Capable	KWU technology. Operation not approved.
Belgium	In Force	—	PWR	5.5	9.4	Yes	Yes	Pilot Scale	Capable	Capable	Ties with French program.
Denmark	In Force	—	LWR	1.8	8.2	Yes	—	—	Partially Capable	Partially Capable	
Finland	In Force	Research & Power	LWR	2.7	6.2	—	—	—	Partially Capable	—	Russian and Swedish technology.
France	N.A.	—	Mainly PWR & GCR, BR	39.5	81.6	Yes	Yes	Yes	Fully Capable	Fully Capable	Major supplier.
W. Germany	In Force	—	LWR	20.5	458	250	R&D	Pilot Scale	Fully Capable	Fully Capable	Major supplier.
Greece	In Force	Research	LWR	0.6	2.6	—	—	—	Some	—	US technology most likely.
Ireland	In Force	—	LWR	0.7	4.0	—		—	—	—	US technology most likely.
Italy	In Force	Research & Power	LWR	3.3	19.3	Yes	Yes	Pilot Scale	Fully Capable	Capable	Ties with US Archetect /Engineer.

Major Features of Nuclear Power Programs (Cont'd)

Nation	NPT Status	Bilateral Agreement with U.S.	Reactor Type	1985 Capacity (GW)	1995 Capacity (GW)	Uranium Mining & Milling (t/y)	Enrichment	Reprocessing	Domestic Capital Equipment Industry	Overall Nuclear Capability	Remarks
Western Europe: (Cont'd)											
Luxemburg	In Force	—	PWR	1.2	1.2	—	—	—	—	—	Indefinite postponement.
Netherlands	In Force	—	LWR	0.5	4.1	—	Yes	—	Capable	Capable	Ties with German technology
Norway	In Force	—	LWR	—	2.9	—	--	Lab Scale			
Portugal	—	Research & Power	LWR	1.4	5.5	130	—	—			
Spain	—	Research & Power	LWR	12.2	30	340	Yes	Pilot Scale	Capable	Partially Capable	Mostly US technology.
Sweden	In Force	Research & Power	BWR	9.5	10.5	Yes	—	Demo Scale	Fully Capable	Fully Capable	Own technology.
Switzerland	Signed	Research & Power	LWR	41	6.0	Yes	—	Capable	Fully Capable	Fully Capable	US & German technology.
UK	N.A.	Research & Power	Mainly GCR	11.5	28.1	—	—	—	Fully Capable	Fully Capable	Major vendor.
Yugoslavia	In Force	Power	LWR	0.6	6.4	Yes	—	Lab Scale	Partially Capable		US technology.

Major Features of Nuclear Power Programs (Cont'd)

Nation	NPT Status	Bilateral Agreement with U.S.	Reactor Type	1985 Capacity (GW)	1995 Capacity (GW)	Uranium Mining & Milling (t/y)	Enrichment	Reprocessing	Domestic Capital Equipment Industry	Overall Nuclear Capability	Remarks
Western Europe: (Cont'd)											
Israel	—	Research	LWR	—	2.7	Yes(?)	—	Yes(?)	Capable	Capable	
S. Africa	—	Research & Reactor	LWR	1.8	6.8	9200	Yes	?	Partially Capable	Partially Capable	French reactor technology.
(Eastern Europe):											
Bulgaria	In Force	—	PWR	3.5	?	—	—	—	—	—	Russian technology.
Czecho-lovakia	In Force	—	Mainly PWR	4.2	?	—	—	—	Capable	Partially Capable	Russian technology.
E. Germany	In Force	—	PWR	5.0	?	—	—	—	Capable	Partially Capable	Russian technology.
Hungary	In Force	—	PWR	2.2	?	—	—	—	Partially Capable		Russian technology.
Poland	In Force	—	PWR	0.4	?	—	—	—	Capable	Partially Capable	Russian technology.
Rumania	In Force	—	PWR PHWR	0.4	?	—	—	—	Partially Capable		Russian technology. CANDU introduced.
USSR	N.A.	—	Mixed	16.3	?	Yes	Yes	Yes	Fully Capable	Fully Capable	Major supplier

Chapter Two

NRC Licensing of Nuclear Technology

The NRC has regulatory jurisdiction over the commercial use of nuclear energy in the U.S. and over commercial exports of nuclear facilities and technology to foreign nations. The nature of NRC licensing actions is presented in this chapter.

The first report examines the "licensability" of several alternative nuclear fuel cycles contemplated for domestic use. The NRC licensing process is examined to determine if new fuel cycle arrangements or technologies would encounter licensing obstacles if an attempt was made to use them commercially.

The second report discusses licensing problems associated with the export of alternative fuel cycle technologies and facilities. The export licensing function of NRC is examined and candidate alternative fuel cycles are considered.

Lastly, an analysis of the "timely warning" requirement of NNPA is examined to determine the extent to which it may impede progress toward the use of alternative nuclear fuel cycles.

Safeguards Licensing Problems Which Could Restrain Implementation of NASAP Fuel Cycles

Jerry J. Cadwell
NUREG/CR-1051
February 1980

TABLE OF CONTENTS

		Page
I.	Introduction	147
II.	Description of the Nuclear Facility Licensing Process	148
III.	Administrative Licensing Procedures	151
IV.	Regulatory and Licensing Issues Involved in the Safeguarding of a Fuel Cycle	157
V.	Applications of the Analysis Technique to the Licensing Process for Each Major Safeguards Variation	162
References		168
Appendix A:	Glossary	173
Appendix B:	Summary of Safeguards Licensing Conditions	174
Appendix C:	Key Licensing Actions in Connection with North Anna Units Nos. 1 and 2 License Applications	178

ABSTRACT

This report reviews the licensing problems attributable to safeguards variations peculiar to the NASAP fuel cycles being considered by the U.S. Department of Energy.

The purpose of this report is to address the U.S. Nuclear Regulatory Commission's obligation to assure the U.S. Government Accounting Office that the NASAP fuel cycles now under consideration are licensable within current NRC authority. This report has the narrow scope of reviewing the

licensability problems attributable only to safeguards; licensability problems caused by environmental safety or concerns other than safeguards are not covered.

Safeguards licensability problems associated with spiking, coprocessing, use of uranium-233 and thorium, denaturing, heavy water, and storage of spent fuel are considered herein.

The techniques of investigation consisted of reviewing federal regulations and extracting from those regulations the safeguards requirements which must be met to obtain (1) a construction permit, (2) an operating license, and (3) a license for possession of special nuclear material (SNM). The main objective of this report is to illuminate those licensing problems which would impede the implementation of a fuel cycle. Implementation is defined as the final issuance of an operating license and a SNM possession permit. For each safeguards variation, the mandatory requirements for licensing are reviewed to determine if there were any conflicts or licensing impediments; licensing conditions are reviewed only briefly.

In general, except for the heavy water cycle, there seems to be no major safeguards impediment to obtaining a SNM possession license or an operating license for a facility. The major area of regulation is in the area of conditions of the license.

Some new regulations will be required if certain fuel cycles are implemented. The major safeguards concerns will be at the operational level and will be those of satisfying the conditions of license.

I. INTRODUCTION

A. Purpose

At the suggestion of the U.S. General Accounting Office, the U.S. Nuclear Regulatory Commission (NRC) was asked to evaluate the "licensability" of each fuel cycle under consideration by the U.S. Department of Energy (DOE). Through the Non-Proliferation Alternative System Assessment Program (NASAP), DOE is evaluating various fuel cycles in order to determine which fuel cycle may be the most feasible and attractive from the standpoint of non-proliferation.

The goal of non-proliferation requires that special nuclear material (SNM) be adequately safeguardable. Safeguarding requires that the SNM be monitored, measured, sampled, guarded, transported, licensed, and subjected to strict accounting techniques as set forth in the NRC regulations.

B. Scope

This report reviews each of the 21 fuel cycles, chosen by DOE as candidates worthy of further consideration, for licensing problems which might occur under the present regulatory system. These fuel cycles were chosen after considerable and extensive discussion and consideration of many fuel cycle schemes. The description of the fuel cycles and the safeguards problems of each cycle have been identified in a companion report by Weinstock and Keisch entitled "Technical Safeguards Issues for Alternative Fuel Cycles," BNL-NUREG-25557 contained in Chapter Five.

In this report, a fuel cycle is treated as an existing technology which must be licensed under the current regulatory scheme. The work scope for this task did not request, and no attempt is made to describe, any detailed changes to the fuel cycle to make it more licensable. Such changes would alter the nature and character of the fuel cycle which was originally chosen because of many extrinsic considerations relating to non-proliferation.

As previously indicated, the fuel cycle's licensability is only one of many parameters to be used by DOE in choosing candidate fuel cycles. Therefore, the scope of work, which mandated a display of "...those licensing problems which could restrain the implementation of commercial operation," is interpreted with heavy reliance on the term implementation. Accordingly, safeguards problems are dealt with only in terms which affect the issuance of a construction permit, an operating license and a license for possession of SNM.

A "licensing problem" is defined as a situation where the mandate of a federal licensing regulation cannot be met because of lack of technical knowledge or of a commercially viable technique. The fact that a regulatory requirement is viewed by the applicant merely as a nuisance, an inconvenience, or an expense would not, for the purposes of this report, be considered a safeguards "licensing problem."

In summary, the scope of this paper is limited to making a preliminary determination of the licensability problems of the 21 fuel cycles in order to help prevent DOE from selecting a fuel cycle which is not presently licensable.

C. The Problem

To obtain a license for a fuel cycle facility, the licensee must submit an application for each proposed facility. An application involves the preparation and review of a Preliminary Safety Analyses Report, an Environmental Impact Statement, and finally a Final Safety Analyses Report. During the license review period, considerable exchange occurs between the NRC staff and the license applicant. Historically, this interchange has been concerned principally with safety matters, with only a small part of the application examination process expended on safeguards.

This report is intended to provide a preliminary review and is meant to highlight those safeguards problems which are unlikely to be settled during the normal NRC license review process. Environmental problems, which were the subject of a multi-volume report entitled "Preliminary Safety and Environmental Information Document" (DOE/NE-0003) published by DOE in 1978 for NASAP, are not considered.

II. DESCRIPTION OF THE NUCLEAR FACILITY LICENSING PROCESS*

Of primary importance are the statutes (Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974) and regulations (Code of Federal Regulations (CFR), Title 10) administered by the Nuclear Regulatory Commission. These statutes and regulations provide the basis for the licensing and regulation of all major activities involving radioactive material, including the construction and operation of nuclear power plants, fuel fabrication and reprocessing facilities, and the transportation and storage of radioactive material and wastes.

A. Issuance of Construction Permit and Operating License

The Atomic Energy Act does not contain any explicit standards or criteria for the issuance of construction permits. Rather, it provides that when an application for a license to construct a facility is "otherwise acceptable to the Commission," the applicant will initially be granted a construction permit.[1] For all purposes, a construction permit is deemed to be a

---

*This section is an excerpt from the *Energy Law Guide*, Chapter 6, Vol. 1, p.17 et seq., edited by Harold P. Green, August 1978.

"license."[2] It is, therefore, necessary to ascertain the statutory standards and criteria for issuance of a construction permit, in order to understand the standards and criteria that are applicable in the issuance of facility licenses in general. It should be noted, however, that the Commission's rules set forth special standards and criteria for the issuance of a construction permit separately.[3]

The affirmative standards and criteria for issuance of a facility license are not of great significance. Licenses are issued on a nonexclusive basis to applicants whose proposed activities will serve a useful purpose proportionate to the quantities of special nuclear material or source material to be utilized;[4] who are equipped to observe and agree to observe NRC safety standards;[5] and who agree to make available to the NRC such technical information and data concerning the licensed activities as the NRC determines to be necessary to promote the common defense and security and to protect the health and safety of the public.[6] Section 182 of the Atomic Energy Act requires an applicant to provide such information as the Commission determines to be necessary to decide the applicant's technical and financial qualifications and to determine that the utilization or production of special nuclear material will provide adequate protection to the health and safety of the public.[7] These requirements are regarded as establishing statutory criteria, as reflected in an NRC rule establishing as criteria for the issuance of the license, that the application provides "reasonable assurance...that the health and safety of the public will not be endangered"[8] and that the applicant is "technically and financially qualified" to engage in the proposed activities in accordance with the NRC's regulations.[9]

The Atomic Energy Act is quite clear as to certain conditions that pre-clude the issuance of a facility license. No license may be issued if, in the opinion of the Commission, issuance would be inimical to the common defense and security or to the health and safety of the public.[10] In addition, no license will be issued to an alien[11] or for activities beyond the jurisdiction of the U.S. except for export.[12]

The NRC's rules with respect to the issuance of construction permits are based on the premise that an application for a construction permit will not contain all of the required technical information relating to the details of the proposed facility. This premise in turn reflects the reality of the situation. The Commission's rules provide that if all the required technical information is not contained in the application, a construction permit may nevertheless be issued if the NRC finds that the information provided has described the proposed design of the facility and identified the major features or components incorporated therein for the protection of the health and safety of the public; that the omitted technical information will be supplied in the final safety analysis report (i.e., at the operating license state); that safety features which may require research and development have been described; that the research and development program will be conducted; that there is reasonable assurance that outstanding safety questions will be resolved by the time construction is completed; and that there is reasonable assurance that the proposed facility can be constructed and operated at the proposed location without undue risk to the health and safety of the public.[13] The regulations take into account the possibility that an applicant for the construction permit may initially supply all of the required technical information, in which event "the findings required above will be appropriately modified to reflect that fact."[14]

A construction permit constitutes an authorization to proceed with construction, but does not constitute NRC approval of the safety of any particular feature unless such approval is specifically requested and is incorporated in the construction permit.[15] The construction permit may be, and generally is, amended from time to time to incorporate such approvals.[16]

It is unlawful for any person to commence construction of a production or utilization facility on the site on which the facility is to be operated until a construction permit has been issued.[17] "Construction" is deemed to include pouring the foundation for, or the installation of, any portion of the permanent facility on the site,[18] but not site exploration, excavation, or preparation for construction;[19] procurement or manufacture of components;[20] or construction of nonnuclear facilities such as turbogenerators and turbine buildings, and temporary buildings used for construction.[21] Where, however, an environmental impact statement is required for the issuance of a construction permit, "commencement of construction" is defined to include any clearing of land, excavation, or other substantial action that would adversely affect the environment of a site.[22]

B. Conversion of the Construction Permit to an Operating License

Upon completion of construction in accordance with the terms and condition of the construction permit, and subject to any necessary testing for health and safety purposes, the NRC will, in the absence of good cause shown to the contrary, issue an operating license for the facility.[23] The operating license will be issued for a period of 40 years or less[24] upon findings by the NRC that: construction has been substantially completed in accordance with the construction permit, the Atomic Energy Act, and the NRC's regulations; the facility will operate in conformity with the application, the Act, and the Commission's rules and regulations; there is reasonable assurance that the activities authorized by the license can be conducted without endangering the health and safety of the public, and that such activities will be conducted in compliance with the NRC's regulations; the applicant is technically and financially qualified to engage in the licensed activities; and the issuance of the license will not be inimical to the common defense and security or to the health and safety of the public.[25] Although there has been no case to date in which a construction permit has not been duly converted into an operating license, as a matter of law there is no assurance that an operating license will be issued upon completion of construction in accordance with the construction permit. The findings discussed above must be made in every operating license case, and they must be made independently of any findings that were made at the construction permit stage of the proceeding.

C. Regulation After Issuance of an Operating License

An operating licensee is subject to an array of continuing regulatory requirements. There is, to begin with, a requirement for amendments to the license for any change in technical specifications[26] or any changes in the facility that involve "an unreviewed safety question."[27] Records must be maintained of all changes made in the facility and operating procedures.[28] Licensed activities are subject to inspection[29] by representatives of the Nuclear Regulatory Commission and the operators are required to maintain various records and to make various reports to the NRC.[30]

The NRC may require the addition, elimination, or modification of structures, systems, or components of the facility after the construction permit has been issued where such action is required for the public health and safety or the common defense and security.[31]

III. ADMINISTRATIVE LICENSING PROCEDURES

A. Construction Permit Proceedings

There are detailed requirements for the contents of applications for a construction permit.[32] In general, such application cannot be docketed to initiate construction permit proceedings until a determination has been made that the application is complete and acceptable for docketing.[33] Applicants are, however, permitted to submit their application in three separate parts. These are: (1) the environmental report containing detailed information about the environmental impact of the proposed facility as required in Part 51 of the NRC's regulations; (2) details concerning the technical aspects of the facility and plans for controlling radioactive releases; and (3) information required for antitrust review of the facility.[34]

Any of these three parts will be docketed if it is complete, and additional parts will be subsequently docketed when they are determined to be complete.[35] Upon docketing and assignment of a docket number, copies of the application will be served upon the municipality or county in which the facility is to be located and to federal, state, and local officials who have an interest in, or responsibilities with respect to, the facility.[36]

B. Staff Review

Following docketing of the application for a permit to construct a nuclear power reactor, the application is reviewed in detail by the NRC's

Office of Nuclear Reactor Regulation. Staff members of that office meet personally with representatives of the applicant, visit the proposed site, and put numerous written questions to the applicant. As a result of this process, numerous changes are usually made in the technical details and design of the facility. It is at this stage of the licensing procedure that safeguards requirements are reviewed for their technical suitability.

C. ACRS Review

The Atomic Energy Act requires that the Advisory Committee on Reactor Safeguards[37] (ACRS) review every application for a construction permit for a nuclear power plant.[38] The ACRS is required to submit a report that is made part of the record of the license application and available to the public.[39] The Advisory Committee on Reactor Safeguards is a prestigious group of not more than 15 members appointed by the Commission for four-year terms. The Committee members are generally drawn from outside the Commission and serve on the ACRS on a part-time basis.

D. Mandatory Hearings

The Atomic Energy Act requires that a mandatory hearing be held on each application for a construction permit for a nuclear power plant[40] regard-less of whether there is opposition to the issuance of the construction permit. In the absence of opposition, the only parties in the hearing are normally the applicant and the NRC staff. In recent years, however, most construction permit proceedings have been attended by outside groups with interest in issuance of the construction permit.

E. Issues Considered

Regardless of whether a construction permit proceeding is contested or uncontested,[41] the issues to be determined are limited to those directly relevant to the findings that must be made under the Atomic Energy Act to support the issuance of a construction permit. These findings include whether the application has adequately identified the design and major features of the facility, subject to provision of further technical or design information which can reasonably be postponed for later consideration and which will be provided in the final safety analysis report (i.e., at the operating license stage), whether further research and development to resolve any remaining safety questions have been identified with reasonable assurance that outstanding safety questions will be satisfactorily resolved by the time the proposed facility is completed, whether the proposed facility can be constructed and operated at the proposed site without undue risk to the health and safety of the public, whether the applicant is technically and financially qualified to design and construct the proposed facility, whether the issuance of a construction permit will be inimical to the common defense and security or to the health and safety of the public, and whether the construction permit should be issued as proposed in light of environmental considerations under the National Environmental Policy Act of 1969.[42] If the proceeding is not contested (i.e., if there are no intervenors), these questions will be resolved without a de novo evaluation of the application on the basis of a decision as to whether the record contains sufficient information and the Commission's review has been adequate to support the requisite finding.[43] If, however, the proceeding is contested, there must be a de novo review with respect to all the above issues.

F. Operating Licenses

Upon completion of construction of the facility and amendment of the license application to bring it up to date, consideration will be given to issuance of a license to operate the facility. The Atomic Energy Act provides that an operating license will be issued upon a finding that the facility has been constructed and will operate in conformity with the amended application, the provisions of the Act, the Nuclear Regulatory Commission's Rules and Regulations, and in the absence of any good cause shown.[44] The specific findings required for the issuance of an operating license are esentially the same as for the issuance of a construction permit, except that the most important finding required with respect to health and safety considerations is "reasonable assurance that the activities authorized by the operating license can be conducted without endangering the health and safety of the public."[45] It should also be noted that the findings made in a construction permit proceeding are, as a practical matter, based on less than a complete application, while the findings made at the operating license stage are presumably based on a final and complete application.

G. Hearings

Unlike construction permit proceedings in which there is a mandatory hearing, there will be a hearing on an operating license application only if an intervenor wishes to contest issuance of the license. The issues in an operating license proceeding are limited to, and are generally the same as, those in a construction permit proceeding. Except in extraordinary circumstances, however, consideration will be given in the hearing only to those particular matters within the purview of issues that are "in controversy among the parties.[46] Such matters are placed in controversy by their inclusion among the contentions advanced in a petition for intervention and their acceptance by the hearing tribunal as valid contentions.

H. Atomic Safety and Licensing Boards

Construction permit and operating license proceedings are conducted before three-member Atomic Safety and Licensing Boards (ASLB), drawn in each case from the members of the Atomic Safety and Licensing Board Panel.[47] One member of each such board is required to be "qualified in the conduct of administrative proceedings," and the other two members are required to have "such technical or other qualifications as the Commission deems appropriate to the issues to be decided."[48] Following the completion of an evidentiary hearing and the submission of proposed findings of fact and conclusions of the law by the parties,[49] the Board renders an initial decision that will constitute the final action of the Commission after 45 days unless exceptions to the initial decision are taken by a party.[50] Exceptions to the initial decision are the vehicle for appealing the initial decision. [51,52] The initial decision by the Atomic Safety and Licensing Board directing the issuance of a construction permit or operating license is, however, usually immediately effective,[53] subject to review thereof and final decision by the Commission upon exceptions filed by a party.[54]

I. Atomic Safety and Licensing Appeal Boards

Most of the appellate functions of the Nuclear Regulatory Commission are performed by three-member Atomic Safety Licensing and Appeal Boards[55] drawn in each case from the Atomic Safety and Licensing Appeal Board Panel.[56] The Commission has delegated to the Appeal Boards most of its review functions.[57] Ordinarily, the Appeal Board will undertake its review function only upon exceptions taken by a party to a final decision by an ASLB. The Appeal Board does, however, have authority to review decisions by ASLB on its own motion.[58] Interlocutory appeals will be entertained only on a limited basis. The Appeal Board may, either in its discretion or on direction of the Commission, certify major or novel questions of policy, law, or procedure to the Commission itself.[59]

J. Other Administration Licensing Procedures

1. Review by the Commission. The Commission may review a decision or action of the Appeal Board on its own motion[60] or, in sharply limited circumstances, on a petition for review filed by a party.[61]

2. Intervention. The Commission is required in any licensing proceeding to grant a hearing "upon the request of any person whose interest may be affected by the proceeding."[62] Any such person is admitted as a party to the proceeding.[63] A petition for leave to intervene must be in writing, under oath or affirmation.[64] The Atomic Safety and Licensing Board will, after opportunity is provided for the other parties to file an answer to the petition, rule on the petition. The ASLB's finding is subject to appeal to the Appeal Board.[65] The ruling involves two distinct aspects. The first of these is whether the petitioner has shown that he has an interest in the proceeding. There are numerous decisions by ASLB, ASLAB, and the Commission discussing the question of whether particular petitioners have shown sufficient interest to have standing to intervene. The second question is whether the petitioner has stated any specific valid contentions[66] with supporting factual allegations.

The determination by the ASLB as to which contentions will be admitted is of considerable importance. In a construction permit proceeding, the contentions accepted by the ASLB frame the bounds within which an intervenor may engage in discovery[67] and of the evidence which he may introduce. In an operating license proceeding, the admitted contentions not only frame such boundaries but establish the particular issues on which the ASLB will hear evidence.[68]

3. Discovery. Parties in a licensing proceeding, including intervenors, have broad rights to engage in discovery[69] by way of interrogatories,[70] depositions,[71] and requests for admissions.[72] There are, however, special provisions and limitations on discovery against the Nuclear Regulatory Commission itself.[73]

4. Consideration of NRC Rules in Adjudicatory Proceedings. The Commission's rules[74] and decisions preclude any attack by way of discovery, proof, argument, or otherwise on the Commission's rules and regulations in any licensing proceeding. This means that the validity of a Commission rule may be challenged only in a rulemaking proceeding or in a judicial proceeding.[75]

5. Judicial Review. Any final order of the Nuclear Regulatory Commission is subject to judicial review upon an appeal taken to a United States Circuit Court of Appeals.[76]

6. National Environmental Policy Act (NEPA). All construction permit and operating license proceedings involving nuclear power plants,[77] and numerous other proceedings before the Nuclear Regulatory Commission, are regarded as major federal actions significantly affecting the quality of the human environment and therefore fully subject to the National Environmental Policy Act. The Nuclear Regulatory Commission's regulations contain quite detailed and sophisticated procedures relating to environmental considerations in licensing cases.[78] These procedures include requirements for submission of an environmental report by the license applicant,[79] preparation and circulation of a draft environmental impact statement[80] and a final environmental impact statement[81] by the NRC staff, and requirements as to specific NEPA findings that must be made by the ASLB in each proceeding.[82]

K. Environmental Reports

An applicant for a construction permit is required to submit with its application for a construction permit a separate environmental report.[83] The environmental report contains essentially the same kinds of information that must be included in the NRC's environmental impact statement.[84] At the operating license stage, the applicant is again required to submit an environmental report, but this report need contain only information differing from that discussed in the environmental report submitted at the construction permit stage.[85] The environmental reports are available for public inspection.

L. Environmental Impact Statements

As soon as practicable after the applicant's environmental report is filed, the NRC staff prepares a draft environmental impact statement as required by NEPA.[86] The draft environmental statement is distributed[87] and comments thereon are solicited.[88] After receipt of comments, the NRC staff prepares a final environmental impact statement.[89]

M. Adequacy of Environmental Impact Statements

One of the issues in a construction permit or operating license proceeding is whether the NRC's final environmental impact statement adequately satisfies the requirements of the National Environmental Policy Act.[90] Under the NRC's rules, if the Atomic Safety and Licensing Board reaches findings and conclusions different from those contained in the final environmental impact statement prepared by the staff, the environmental impact statement is deemed to be amended by the ASLB's findings and conclusions.[91] Similarly, if at the successive levels of review the Atomic Safety and Licensing Appeal Board or the Commission reaches conclusions differing from those of the ASLB, the findings and conclusions of the Appeal Board or the Commission, as the case may be, are deemed to modify the final environmental impact statement.[92] Where the final environmental impact statement is amended in such a manner, the decision constituting the amendment is required to be distributed in the same manner as the final environmental impact statement itself.[93]

N. Substantive Considerations

As noted above, the Atomic Safety and Licensing Board is required to make findings whether, in view of all environmental factors, the construction permit or operating license should be issued.[94] Thus, although the jurisdiction and authority of the Nuclear Regulatory Commission under the Atomic Energy Act are limited to matters of radiological health and safety and the common defense and security,[95] as a consequence of the National Environmental Policy Act and the Commission's rules for implementation of NEPA, consideration is given in nuclear power licensing cases to a number of other factors such as the need for power,[96] conservation efforts,[97] the environmental effects of transmission lines for the distribution of electricity produced in the nuclear power plant,[98] etc.

O. Antitrust Considerations

Section 105 of the Atomic Energy Act authorizes the NRC to suspend or revoke any license issued under the Atomic Energy Act in the event the licensee is found to have violated the antitrust laws in the conduct of the licensed activity by a court of competent jurisdiction.[99]

IV. REGULATORY AND LICENSING ISSUES INVOLVED IN THE SAFEGUARDING OF A FUEL CYCLE

A. Introduction

Most of the discussion in this report concerns licensing problems peculiar to generic safeguards measures which several of the proposed fuel cycles and nuclear facilities have in common.

As can be seen from the schematic of the licensing process shown in Figure 1,[100] the licensee prepares an application containing a plan which describes how he intends to comply with the safeguards regulatory requirements. This plan is then reviewed by the proper sections of NRC. This NRC review includes interaction with the licensee and, where necessary, revision of the application by the licensee. This method of review dictates that a valid "licensing problem" would be defined as a matter which could not be resolved at the staff review and, after consideration by the NRC Licensing Board, is appealed to the Atomic Safety and Licensing Appeal Board.

This definition of a "licensing problem" is chosen so that the potential for a true delay in the commercial licensing of a fuel cycle can be determined. If a matter arises during the staff review of the license application which cannot be resolved between the NRC staff and the licensee, the next step is to proceed to the Licensing Board, then to the Atomic Safety and Licensing Appeal Board, and ultimately to the federal courts. In this report a licensing problem is defined as a threshold safeguard problem which would likely cause an appeal to the Atomic Safety and Licensing Appeal Board and possible subsequent court action.

B. Safeguards Regulation by the Nuclear Regulatory Commission and Social Risks

The licensing of a fuel cycle includes the balancing of potential social benefits and risks. This administrative balancing process takes the form of considering the social, political, and institutional issues presented in the prepared Environmental Impact Statement.

The balancing of safeguards licensing requirements in terms of dollars and other civil, social, and political costs has traditionally been discussed and litigated as environmental issues. Since environmental issues were the subject of other referenced reports,[101] civil, social, or political costs of safeguards will not be discussed here.

C. Historical Analysis of What Constitutes a Safeguards Problem

1. Licensing Problems Recently Considered. A list of key licensing actions taken in connection with the licensing application for a reactor such as North Anna Units 1 and 2 shows 102 line items in the licensing

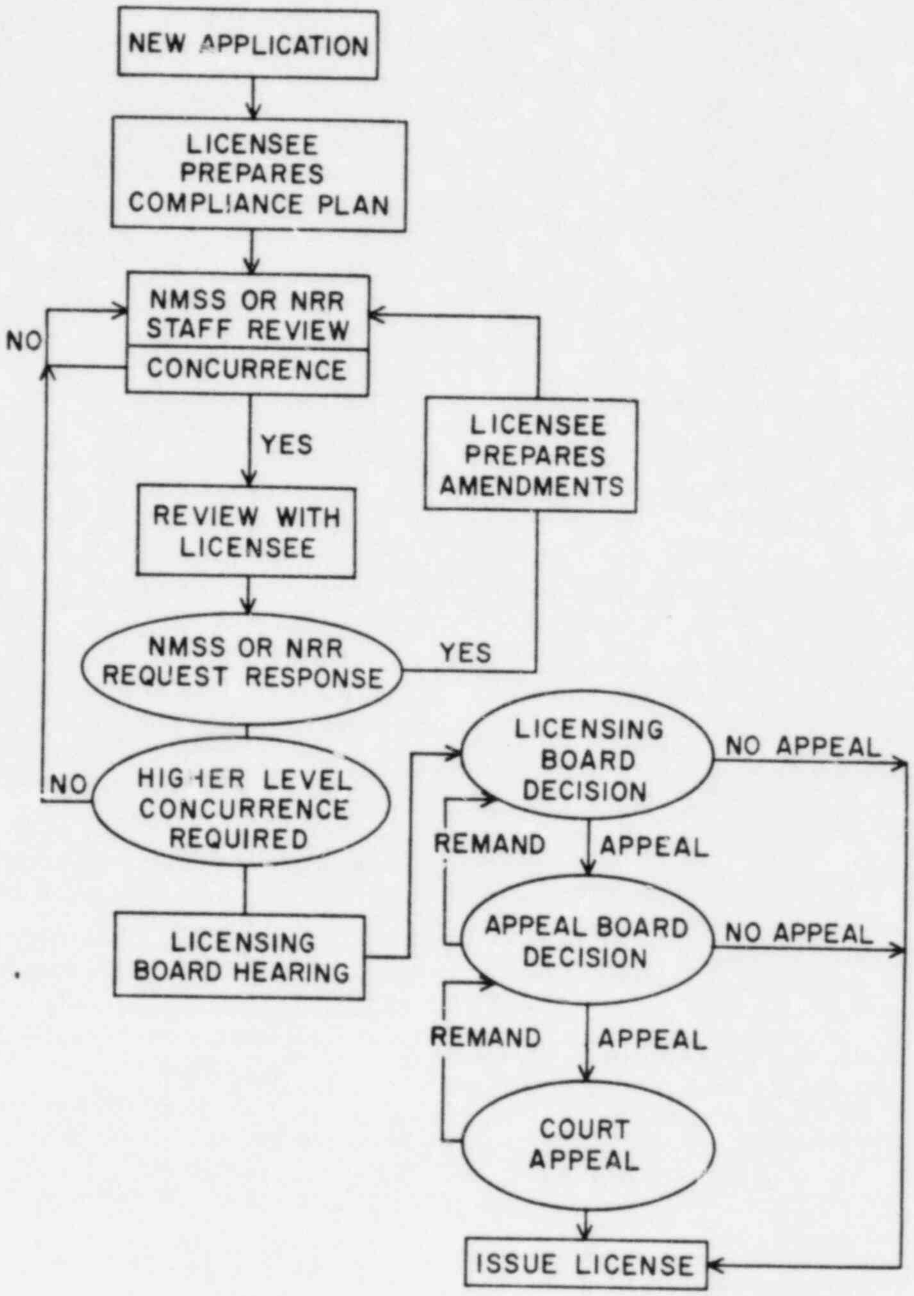


Figure 1 NRC Licensing Process

process considered important by the National Governors Conference Energy Program.[102] Similar lists are cited in the same referenced source for nine other nuclear power station licensing cases.

The list of important North Anna licensing items is cited and included in an Appendix C to illustrate that no safeguards licensing problems are mentioned. It would be instructive to examine licensing problems of recent applicants seeking to license fuel cycle facilities such as fuel fabrication and reprocessing, however, there are no recent applications to use as examples. Allied Chemical, the owner of The Barnwell Reprocessing facility is the most recent applicant, however, its construction permit was issued before many of the current safeguards requirements were in force and the operation license was never granted because the license proceedings were terminated by the Carter Administration.

2. A Review of Historical Safeguards Problems. A review of historical safeguards problems is helpful in predicting future safeguards problems. The review that follows indicates that safeguards have historically played a very small part in the total licensing process. In spite of the safeguards upgrade rules recently put in place, the safeguards review will still be, by comparison, only a small part of the total licensing process for any fuel cycle facility.

The Nuclear Regulation Reporter[103] (citator for NRC decisions on Title 10 Code of Federal Regulations) reviews only one instance where safeguards licensing matters reached the level of open controversy in the licensing pro-cess. The case was in the Diablo Canyon Nuclear Power Plant[104] proceeding where intervenors opposed (unsuccessfully) the granting of a license for possession of SNM under Part 70 under Title 10 of the Code of Federal Regulations (CFR) because, among other things, the plant security system plant was unavailable for inspection. The same contention was made by intervenors when Diablo Canyon applied for its operating license.[105] In this case the security plans were made available to qualified individuals in a closed proceeding in the Judge's chamber.

A review of the "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors"[106] (GESMO) indicates a number of safeguards concerns which are considered under the general heading of environmental problems. The licensing concerns of safeguards problems and costs reviewed in GESMO were considered in the environmental investigations and comparisons in the Environmental Impact Statement. The separate GESMO document entitled "Safeguarding a Domestic Mixed Oxide Industry Against a Hypothetical Subnational Threat"[107] states in the foreword to the executive summary that the safeguards document "...was originally intended to provide the basis for a supplement to the generic environmental impact statement (NUREG-002) on the use of recycle plutonium in mixed-oxide fuel for light water reactors (GESMO)."

In terms of safeguards, the existing record of proceedings indicates no predictable significant unresolved (or unresolvable) licensing problems.

3. Historical Evaluation of Licensing Procedures Involving Safeguards. The Draft Environmental Statement (DES) for the Clinch River Breeder Reactor Plant[108] (CRBR) stated that "Implementation of the physical protection requirements therein is evaluated in conjunction with the radiological safety review of the application." That is to be interpreted as meaning that physical protection safeguards were not reviewed alone and are important only as the safeguards affect radiological safety.

The CRBR DES described the three stages which the licensing procedure has historically followed:[109]

> **Current NRC Safeguards Program**
>
> NRC publishes specific safeguards requirements for materials and plant protection in 10 CFR Parts 70 and 73 and carries out the following activities to assure effective compliance with the requirements: (1) prelicensing evaluation of a license applicant's proposed nuclear activities, including safeguards procedures; (2) issuance of a license to authorize approved activities subject to specific safeguards requirements; and (3) inspection and enforcement to assure that applicable safeguards requirements are met by implementation of approved procedures.
>
> **Licensing Activities**
>
> The prelicensing review addresses information submitted by the applicant to the NRC for approval—including the applicant's technical qualifications; a description of the process, equipment, and facilities to be used; the material control and accounting program, including measurement performance capability; and a physical security plan.... The prelicensing review includes consideration of other regulatory aspects of the facility design and operation. Account is taken of the interrelated effects of safety requirements and of the inherent features of the facility that contribute to the protection afforded by the safeguards system. For example, the requirements that SNM be safely contained during normal operation, operational accidents, and natural phenomena, such as earthquakes and tornadoes, also provide significant physical protection....

Historically, inquiries about safeguards at the licensing stages (by opponents of the license) have centered on first the advisability of building the facility because of the envisioned risks caused by the facility, and second the adequacy of safeguards.[110]

The first question is outside the scope of this report. The second question was raised in the GESMO and CRBR proceedings. Many upgraded rules and safeguards improvements have been implemented by the NRC since the GESMO and CRBR proceedings, for example, 10 CFR 73.55; guard training as required in 10 CFR 73.55 Appendix B and the current Physical Protection Upgrade Rule 44 FR 68184.

Table I provides a paraphrased list of the safeguards licensing requirements which have been met by each facility of each fuel cycle and their

Table I

SUMMARY OF SAFEGUARDS LICENSING REQUIREMENTS

Regulatory Activity Paraphrased	Reference Section of Part 10 CFR
I. Type of License	
A. Material	
1. General	70.19 70.20
2. Specific	70.18
B. Commercial Facilities Class 103	50.22
II. Procedure and criteria for issuance of license to receive title to, own, acquire, deliver, receive, possess, or use SNM.	70.1 70.2
A. License shall be subject to and licensee shall observe all applicable rules, regulations, and orders of the Commission.	70.32(a)(8)
B. Description shall be provided of control and accounting procedures.	70.22(b)
C. Description of plan for physical protection of SNM in transit including training of guards, escorts, and special equipment designs.	70.22(g)
D. Description of physical security plans for fixed site possessing 5 kg or more equivalent SNM. Meet Part 73 requirements.	70.22(h) 50.34(c) 73.55
E. Emergency coping plans required for processing SNM, fuel fabrication, scrap recovery and conversion of uranium hexafluoride.	70.22i
F. Each application to possess or use 5 kg or more SNM must include safeguards contingency plan defined in 10CFR73 & 50.	70.22(j) 50.34(d)
G. Technical qualifications, training and experience of staff.	70.22(a)(6)
H. Standards for licenses and construction permits.	50.40
1. Commission considers if processes, use of facility, and proposals collectively provide reasonable assurance applicant will comply with regulations of this chapter, including Part 20, and health and safety of public will not be endangered.	50.40(a)
2. The issuance of a license to applicant will not in the opinion of the Commission be inimical to the common defense and security or to the health and safety of the public.	50.40(c)

safeguards variations before an operating or possession of SNM license was issued.

As pointed out in the CRBR Draft Environmental Statement previously quoted, the licensing process involved three distinct stages. The first stage was to obtain the administrative and engineering approval from the NRC staff of the proposed design submitted to be licensed. The evaluation of the proposed design as shown in Figure 1 has been based on the license requirement shown in Table I. In this prelicensing evaluation, a technical review was made by the NRC to confirm that the licensing conditions could in actual fact be met after the operating license was granted.

For the purposes of this report these licensing requirements, which have historically been met by past license applicants, are assumed to be the same requirements that new fuel cycle facilities will have to meet in future licensing proceedings. Conditions of a license which must be met by each future licensee are paraphrased in a list provided in Appendix B. The technical problems associated with the conditions of the license are raised in a companion report.[111]

D. Analysis Technique

The investigative procedure shown in Figure 2 leads to a determination of whether and to what extent safeguards requirements could delay or interrupt the licensing scheme. Licensing obstacles of three types are addressed:

(1) Existing or presently anticipated license requirements which might significantly delay implementation of a fuel cycle which incorporates a generic safeguards issue.

(2) Features of the licensing process which might cause significant delay in licensing a facility which presents new safeguards issues.

(3) Safeguards features of generic safeguards issues which are not presently covered by existing regulations and so would require new or modified licensing requirements.

This report concentrates on the first obstacle with some discussion of the others.

V. APPLICATIONS OF THE ANALYSIS TECHNIQUE TO THE LICENSING PROCESS FOR EACH MAJOR SAFEGUARDS VARIATION

To operate a nuclear facility a licensee must obtain a construction permit, an operating license, and a permit to possess SNM. To obtain these licenses and permits, descriptions must be provided of the proposed accounting and control procedures and of the proposed physical protection emergency and contingency plans. These license submissions will be reviewed to see if the proposed plans can meet the physical security requirements of CFR Part 73 and the SNM licensing requirements of CFR Part 70 and CFR Part 50.

The safeguards regulations as presently constituted have never been applied in-total to a complete set of fuel cycle facilities as new facilities. Because of the recent vintage of most of the safeguards regulations and the lack of license applications for fuel fabrication facilities and fuel reprocessing facilities, the only experience and history available of the imposition of the safeguards regulations are as license conditions. Even for newer facilities, most of the safeguards regulations were imposed after an operating license or SNM possession license was obtained.

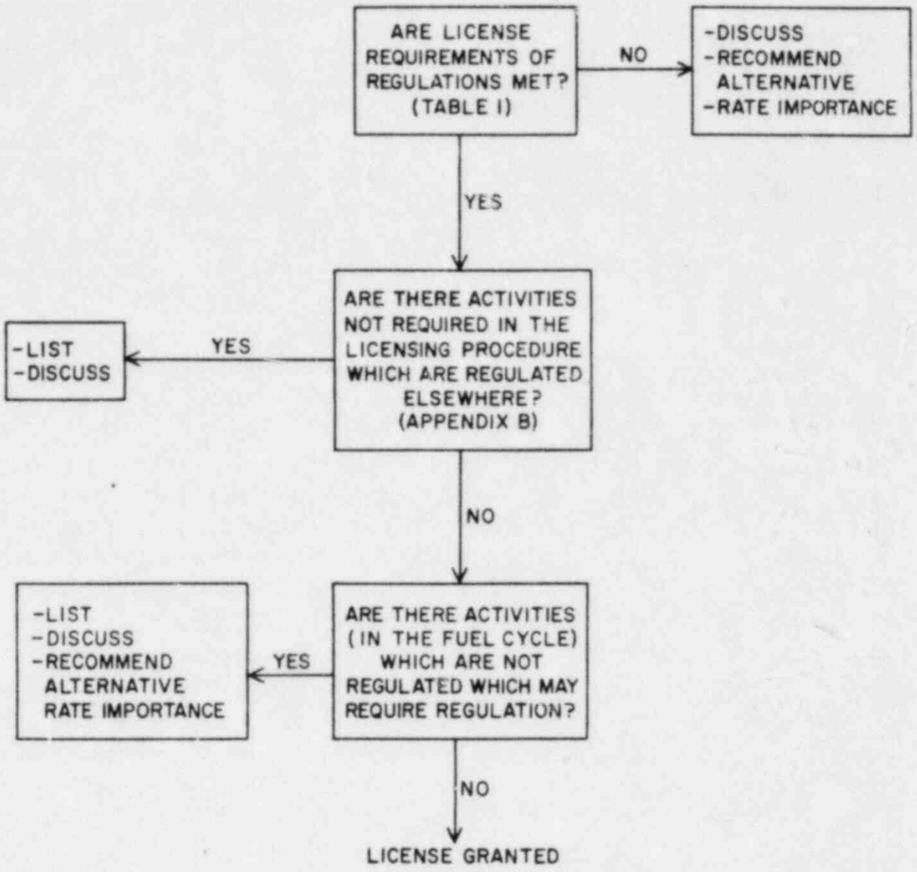
A. Radiation Barriers

Radiation barriers have been the subject of several technical reports authored principally by E.V. Weinstock.[112] These reports discuss the techniques of providing spiking or a radiation barrier and the technical and potential regulatory problems which radiation barriers would cause.

A separate report[113] discusses the possible civil liabilities that a fuel owner might encounter should radiation barriers be used. A licensing review of radiation barrier problems would occur when the Environmental Impact Statement is prepared after a construction permit application is made by a licensee for a nuclear facility. The facility most likely to have this licensing problem would be a fuel fabrication or fuel reprocessing plant. If the radiation barrier is imposed by irradiation after the fuel is fabricated, the facility used for irradiating the fuel would be the first to have a radiation barrier licensing problem.

1. Licensing a Spiked Fuel Cycle. A review of the licensing requirements in Table I and of the criteria developed in Figure 2 does not reveal any obvious safeguards licensing difficulty with spiking. For licensing purposes, spiked fuel would probably be treated as spent fuel and subjected to physical safeguard transportation requirements of 10CFR73.37 and 10CFR Part 73, Appendix D.

One of the difficulties of evaluating the licensability of a safeguard variation such as spiking is to distinguish between licensing requirements and licensing conditions. For example, a fuel cycle using spiking can receive its operationing license only after a proposed control and accounting procedure is approved (see 10CFR70.22(b) which requires that 10CFR70.58 requirements be met). The question of licensability then involves the judgment on how completely a problem such as a material control and accounting problem due to spiking must be solved before the issuance of an operation license (or SNM possession license) and how much of the problem can be solved at the operational level as a condition of license.



Will the Safeguard Activity Delay Licensing?

The licensing of the fuel cycle would be simplified if the radiation barrier were provided by mechanically attached sources.[114] The licensing problems of attached sources would then revolve around transportation and temporary storage issues

2. Conditions of License. Certain environmental problems may become apparent when an environmental impact statement is prepared. Environmental licensing problems were the subject of the Preliminary Safety and Environmental Information Document published by the U.S. Dept. of Energy, Washington, D.C., in January 1979, for the Non-Proliferation Alternative System Assessment Program and are not addressed here.

Some safeguards difficulties may arise after the issuance of an operating and possession of SNM license. These difficulties would be accounting and material control concerns caused by the radioactivity of the material.

These operational difficulties may constitute a barrier to an issuance of the operation or SNM license.

3. New Regulations Required. New regulations may have to be developed to adjust the MUF and LEMUF requirements such as required in 10CFR70.53(b), (1) and (2), as well as 10CFR70.51(e), (5) and (6). These new regulations may be required because the high radiation fields would inhibit sample taking, chemical analysis, nondestructive assay, and material balance verification. This impediment would be felt mostly at new fuel fabrication facilities since reprocessing facilities will routinely deal with highly radioactive samples.

It is difficult to provide an accurate estimate of the licensing impact of radiation barriers because the overall effect of high radioactivity on accountability has not been studied quantitatively.[115] However, slower and more of a finished fuel rod for chemical analysis) could be used to obtain an operating license.

There are questions about the extent of civil liability which the owner of spiked fuel might incur as the result of intentionally providing a radiation barrier to theft or diversion.[116] These questions might be resolved by appropriate rules which would view a radiation barrier as promoting the interests of national defense and security.

The various schemes for providing a radiation barrier prescribe different dose rates for effective deterrence. These dose rates range from 100 R/hr to 100,000 R/hr at 1 meter. New regulations are needed to specify an acceptable dose rate and possibly the means to achieve this dose. In addition, new regulations are needed to specify the type of physical protection required in fuel fabrication, fuel reprocessing (if any), and the transportation and storage of new fuel.

This licensing requirement, if imposed, would involve some subjective judgment about the dose rate required to provide an acceptable deterrence effect. An additional concern is that the spiking material itself might require safeguarding to prevent its theft and dispersal in populated areas. This would include transportation safeguards similar to those required in 10 CFR73.37.

Weinstock and Keisch[117] indicated that a serviceable preirradiation facility would require considerable design and experimental effort to develop. A facility that requires new design and experiments also suggests new licensing problems. However, similar experimental facilities have been licensed in the past.

B. Coprocessing

Coprocessing is the simultaneous processing of mixtures of uranium and plutonium or their compounds so that a diverter must take a larger quantity of material and separate it to obtain the same amount of SNM as in a contained mixture which is not coprocessed.

1. Licensing a Fuel Cycle Using Coprocessing. A review of the licensing requirements listed in Table I does not reveal any regulations which cannot be met by coprocessing. The safeguards licensing regulations which require accountability plans to be proposed and approved should be met by fuel cycles using coprocessing. The measurement problems associated with coprocessing are thought to be minor operational problems subject to research and development, and not an impediment to licensability.

This lack of measurement problems according to Weinstock who quotes Pietri et al.,[118] is due to wet sampling analysis techniques applied to coprocessing which are expected to return results equal in quality to those obtained on separately processed materials.

In addition, it also appears that the current NDA methods can be applied with no foreseeable difficulties.[119]

2. Conditions of License. Coprocessing involves procedures which are listed as conditions of the operating license and the construction permit. The principal safeguard concerns are minor accountability problems which are viewed as resolvable and not as a licensing impediment.

Before an operating license and probably before a construction permit are issued, the maximum allowable percentage of plutonium will have to be set by NRC regulation. The allowable percentage selected will be based on consideration of the practical needs of the fabrication plants, the explosive utility of mixed oxides as a function of plutonium concentration, and the attractiveness of the material to terrorists or other subnational groups.

C. The Use of U^{233} and Thorium

1. Licensing a Fuel Cycle Using U^{233} or Thorium. There is little experience with the commercial reprocessing of highly irradiated thorium fuels, and the little that exists was gained at Nuclear Fuel Services at West Valley, New York, and at Oak Ridge National Laboratory. It is, therefore, difficult to say at this stage whether present NRC material accountability regulations can be met in commercial reprocessing and fabrication plants for U^{233}-Th fuels.

U^{233} fuels provide high radiation levels associated with the presence of U^{232} and its daughters. Because of this high radiation, nondestructive assay techniques will have to be developed before definitive statements can be made about the licensability of the fuel cycle. Accountability in reprocessing plants would be less affected by the radiation from the U^{232} decay because most plants of this type are accustomed to dealing with high radiation. The ultimate accuracies of chemical analyses of these materials will be poorer than those of the more usual plutonium-uranium material.

It appears that, before the NRC regulatory requirements for material accountability can be met, a great deal of development and demonstration of accountability techniques will have to be done on U^{233}-Th fuels.[120]

2. Conditions of License. This safeguards variation presents operational uncertainties which may cause licensing problems. Briefly stated, these safeguards concerns are lack of commercial experience with these fuels, high radiation levels associated with U^{232}, nondestructive assay complications due to radioactivity, and unknown feasibility of performing real time accountability.

3. New Regulations. New regulations will have to be promulgated to establish the enrichment limits and classifications for uranium containing U^{233}.

D. Denaturing

1. Licensing A Fuel Cycle Using Denaturing. Denaturing consists of mixing U^{233} and U^{235} with U^{238}. Plutonium cannot be denatured. Since there has been very little experience in reprocessing denatured fuel, it is difficult to say how easily the NRC safeguards account ability requirements can be met in a reprocessing plant. The licensing of a fuel cycle using denatured U^{233} will be similar to that discussed previously under U^{233} and thorium fuels.

2. Conditions of License. Those items which may cause problems with licensing are the effect (previously discussed) of radioactive daughter products of U^{233} on nondestructive assay, difficult chemical analysis, and the disposition of the plutonium separated from the denatured fuel.

3. New Regulations. Regulations setting limits for uranium containing both U^{233} and U^{235} may have to be made before licensing proceedings can proceed. This may be a difficult determination considering that U^{233} can be more easily separated from U^{238} than U^{235}.

E. Heavy Water

1. Licensing a Fuel Cycle Containing Heavy Water. Several safeguards concerns associated with licensing heavy water production plants and reactors and which will need to be addressed in a safeguards plan (required by the licensing process) are at this time unresolved. These safeguards concerns involve the material accountability problems caused by on-line refueling at reactors, and the potential problems associated with heavy water accountability.

2. Conditions of License. Regulations, which are conditions of licenses, dealing with accountability of safeguarded material are presently not applicable to large amounts of heavy water.

3. New Regulations. New regulations will be required for the safeguarding and accountability of heavy water. Regulations defining the fuel-accounting requirements during on-line refueling will be required.

F. Storage of Spent Fuel

1. Licensing a Fuel Cycle Requiring Storage of Spent Fuel. The licensing of fuel storage at a reactor is covered by the licensing requirements of the reactor. Interim fuel storage away from reactor sites would utilize the physical protection regulations of fixed sites rather than those of reactors.

Spent fuel stored at a reprocessing plant would be subject to the safeguards regulations controlling the reprocessing plant, the only difference being that the material control and accounting would be by item counting and identification.

2. Conditions of License. No unique conditions of license problems are known at this time. The proposed new rule 44 Federal Register 61372 may cause some operational difficulties before the rule is completely implemented.

3. New Regulations. The principal new regulation would be the proposed 44 Federal Register 61372. Other regulations specifying physical protection similar to that now used in fuel processing facilities would have to be designed and implemented. However, no new or unique physical protection problem is anticipated. The accounting procedure at a storage facility will probably be a newly regulated system which utilizes existing safeguards technology.

G. Geological Spent-Fuel Repositories

1. Licensing of Fuel Cycles Requiring Spent-Fuel Repositories. The procedure for licensing high level wastes "...is likely to be quite similar to that which has been used for the licensing of nuclear power plants."[121] The safeguards aspects of high level waste disposals are not settled. However, it is likely that the current NRC regulations on physical protection, material control, and accounting would be appropriate (with minor changes) to safeguarding high level wastes.

Section 202 of the Energy Reorganization Act provide statutory authority for licensing DOE facilities designed for the long-term storage of high level radioactive waste generated by NRC licensed requirement.

2. Conditions of License. These are unknown at this time, but are very likely to be the current NRC safeguards now in force.

3. New Regulatory Requirements. There will very likely be minor changes to adapt the current safeguards schemes to spent-fuel repositories.

REFERENCES

1. 42 USC 2235.
2. Id.
3. See p. 151, infra.
4. 42 USC 2133(b)(1).
5. 42 USC 2133(b)(2).
6. 42 USC 2133(b)(3).
7. 42 USC 2232(a).
8. 10 CFR 50.40(a).
9. 10 CFR 50.40(b).
10. 42 USC 2133(d).

11. Id; The AEC interpreted this provision to refer to "relationships where the will of one party is subjugated to the will of another, and that the Congressional intent was to prohibit such relationships where an alien has the power to direct the actions of the licensee." In re General Elec. Co. and Southwest Atomic Energy Associates, 3 AEC 99, 101 (1966).
12. 42 USC 2133(d).
13. 10 CFR 50.35(a).
14. Id.
15. 10 CFR 50.35(b).
16. Id.
17. Commencement of construction prior to issuance of a construction permit is not explicitly prohibited by the Act, but is prohibited by 10 CFR 50.10(b).
18. Id.
19. 10 CFR 50.10(b)(1).
20. 10 CFR 50.10(b)(2).
21. 10 CFR 50.10(b)(3).
22. 10 CFR 50.10(c).
23. 42 USC 2235.
24. 42 USC 2133(c); The license may, however, be renewed.
25. 10 CFR 50.57.
26. See 42 USC 2232(a); 10 CFR 50.36.
27. 10 CFR 50.59(c).
28. 10 CFR 50.59(b).
29. 10 CFR 50.70.
30. 10 CFR 50.71.
31. 10 CFR 50.109.
32. 10 CFR 50.34.
33. 10 CFR 2.101(a)(2)-(3).
34. 10 CFR 2.101(a)(5).
35. Id.
36. 10 CFR 2.101(a)(3).
37. 42 USC 2039.
38. 42 USC 2232(b).
39. Id.
40. 42 USC 2239(a)
41. To date, there have been contested hearings only where outsiders have intervened in opposition to a license application.
42. 10 CFR 2.104(b).
43. 10 CFR 2.104(b)(2).
44. 42 USC 2235.
45. 10 CFR 50.57(a)(3)(i).
46. 10 CFR 2.104(c).
47. See generally 42 USC 2241; 10 CFR 2.721.
48. 42 USC 2241(a).
49. 10 CFR 2.754. Intervenors may submit proposed findings and conclusions with respect to any matter in issue. Northern States Power Co. (Prairie Island Units 1 and 2), 8 AEC 857, 863(1974). A party may be precluded from seeking review of an initial decision on issues with respect to which the party did not

file proposed findings and conclusions. Id., 864.

50. 10 CFR 2.760.
51. 10 CFR 2.762.
52. See p. 179, infra.
53. It is immediately effective unless the ASLB finds that a party has shown good cause why it should not be. 10 CFR 2.764(a).
54. Id.
55. 10 CFR 2.785.
56. 10 CFR 2.787.
57. 10 CFR 2.785(a), (b).
58. 10 CFR 2.786(a).
59. 10 CFR 2.785(d). The certification authority is excercised sparingly. Vermont Yankee Nuclear Power Corp., 6 NRC 25(1977).
60. 10 CFR 2.786(a).
61. 10 CFR 2.786(b).
62. 42 USC 2239(a).
63. Id.
64. 10 CFR 2.714(a).
65. 10 CFR 2.714(a).
66. The contentions requirement is not explicitly set forth in the NRC's rules but has been developed in Appeal Board and Commission decisions for the purpose of limiting the scope of interventions.
67. 10 CFR 2.740(b); Allied-General Nuclear Services, 5 NRC 489, 492(1977).
68. 10 CFR 2.104(c).
69. 10 CFR 2.740 et seq.
70. 10 CFR 2.740(b).
71. 10 CFR 2.740(a).
72. 10 CFR 2.742.
73. 2.520(h)(2)(ii), 2.744.
74. 10 CFR 2.758.
75. e.g., Vermont Yankee Nuclear Power Corporation, 6 AEC 520, 528(1973).
76. 42 USC 2239(b).
77. 10 CFR 51.5(a)(1), (2).
78. 10 CFR Part 51.
79. See p. 156, infra.
80. See p. 156, infra.
81. Id.
82. See p. 156, infra
83. 10 CFR 51.20(a).
84. Id.
85. 10 CFR 51.21.
86. 10 CFR 51.22.
87. 10 CFR 51.24.
88. 10 CFR 51.25.
89. 10 CFR 51.26.
90. 10 CFR 2.104(b)(3)(i).
91. 10 CFR 51.52(b)(3).
92. Id.

93. Id.; 10 CFR 51.26(c).
94. 10 CFR 2.104(b)(3)(ii); (c)(7); 51.52(c).
95. *New Hampshire v. AEC,* 308 F2d 648 (1962).
96. *Aeschliman v. NRC,* 547 F2d 622 (1976).
97. Id.
98. Tennessee Valley Authority (Hartsville Units 1 and 2), 4 NRC 353 (1976).
99. 42 USC 2135(a).
100. The Table was developed by R.J. Code et al., in NUREG-0377 Volume 2 Appendices; "Structure and Drafting of Safeguards Regulatory Documents," Page 78 et seq.
101. The licensing effect of environmental and safety concerns of NASAP fuel cycles are the subject of a seven volume study entitled "Preliminary Safety and Environmental Information Document," April 1979, DOE/NE-0003.
102. National Governors Conference, "Federal/State Regulatory Permitting Actions in Selected Nuclear Power Station Licensing Cases," PB-272-499, June 1977 at page A-54.
103. Nuclear Regulation Reporter - Commerce Clearing House, Inc., Chicago, Illinois. Citator for Laws and Regulations, p. 26,501.
104. ALAB-334, June 22, 1976, Diablo Canyon Nuclear Power Plant, Units Nos. 1 and 2.
105. See also Diablo ALAB-410, June 1, 1977.
106. NUREG-0002, Volume 1-5, U.S. Nuclear Regulatory Commission, August 1976.
107. NUREG-0414, U.S. Nuclear Regulatory Commission, May 1978.
108. NUREG-0024, "Draft Environmental Statement related to the Construction of the Clinch River Breeder Reactor Plant," February 1976, Docket No. 50-5037, p. 7-13.
109. Id.
110. See, for instance, Comment letter No. 25 from Natural Resources Defense Council, Inc. by J.G. Speth to U.S. AEC commenting on GESMO proceedings, located in NUREG-0002, Vol. 5, GESMO. See also "Safeguards Related Questions and Answers for the CRBR Hearings" by TSO, Brookhaven National Laboratory, December 29, 1976.
111. Weinstock, E.V. and Keisch, B., "Technical Safeguards Issues for Alternative Fuel Cycles," BNL-NUREG-25557, August 9, 1979; see Chapter Five.
112. See E.V. Weinstock, "The Spiking of Special Nuclear Material as a Safeguards Measure," Vol. 1, September 8, 1979; E.V. Weinstock, Study Coordinator of Vol. 2 written by T.B. Taylor and W.J. Reinhardt, "Modification of Strategic Special Nuclear Materials to Deter Their Theft or Unauthorized Use," IRT-378-R, November 6, 1975; Note 16, pp. 3-4 to 3-26.
113. Cadwell, J.J., "The Possible Legal Consequences of Protective Radioactive Spiking of Nuclear Fuel," BNL-NUREG, Nov. 30, 1979.
114. See Weinstock, Note 112, supra.
115. See Weinstock, Note 112, supra.
116. See Cadwell, Note 113, supra.
117. See Weinstock, Note 112, supra.
118. C.E. Pietri, J.S. Paller, C.D. Bingham, "The Chemical and Isotopic Analysis of Uranium, Plutonium, and Thorium in Nuclear Fuel Materials," in

Analytical Methods for Safeguards and Accountability Measurements of Spiked Nuclear Materials, H.T. Yolken and J.E. Bullard, Eds., National Bureau of Standards Spec. Pub. No. 528, November 1978, pp. 1-18.

119. J.P. Shipley, D.D. Cobb, R.J. Dietz, M.L. Evans, E.P. Schelonka, D.B. Smith, R.B. Walton, "Coordinated Safeguards for Material Management in a Mixed-Oxide Fuel Facility," LA-6536, Appendix C, Los Alamos Scientific Laboratory, Feb. 1977.
120. See Weinstock, Note 112, page 3-33 supra.
121. Howard K. Shapar, "Licensing and Regulation of Nuclear Waste," AIF Seminar on Legal and Legislative affairs, Las Vegas, Nevada, Jan. 16, 1979.

APPENDIX A

Glossary

1. Radiation Barriers

A radiation barrier may be introduced for safeguards purposes by mechanically attaching radioactive sources to fuel elements or by the introduction of radioactivity into nuclear fuel materials. The radioactivity may be introduced by the addition of a radioactive agent, by retaining some of the fission products during the reprocessing of spent fuels, or by irradiating the fuel before it is used. According to the information supplied NRC by DOE, NASAP is considering a combination of the first two: that is, partial retention of certain fission products (Zr, Nb, and Ru) plus the addition of a radionuclide (Co^{60}) during reprocessing (i.e., before conversion of the product to an oxide).

2. Coprocessing

Coprocessing means the processing of mixtures of uranium and plutonium or their compounds in such a way that the plutonium is always diluted by uranium. Most often the term is used for a possible mode of operation of spent-fuel reprocessing plants in which the product consists of a mixture of uranium and plutonium oxides, coprecipitated from a mixture of nitrates in solution.

3. The Use of U^{233}-Th Fuels

A number of the fuel cycles proposed by NASAP involve the use of U^{233}-Th fuels. Compared with plutonium, U^{233} has the advantage that it can be denatured (i.e., rendered unsuitable for direct use in an explosive) with U^{238}; this advantage is shared by U^{235}, of course.

4. Denaturing

Denaturing may be defined as the addition of a nonfissile isotope to a fissile isotope of an element in such proportions as to make the fast critical mass of the mixture impractically large for a nuclear explosive weapon.

Since all plutonium isotopes have appreciable fast-fission cross sections, plutonium cannot be denatured. The fast-fission cross section of U^{238} is low enough, however, to allow the fissile isotopes U^{233} and U^{235} to be denatured by its addition.

APPENDIX B

Summary of Safeguards Licensing Conditions:

Requirements to Maintain License After Its Issuance

REGULATORY ACTIVITY	REFERENCE CODE
I. Conditions of license	
A. General	
1. Maintain and follow programs for:	
a. Control and accounting and fundamental material control.	70.32(c) 70.58
b. Measurement control.	70.32(c) 70.57
2. No changes in material control and accounting procedures which reduce effectiveness without prior approval of the Commission	70.32(c)
3. No changes in physical protection of SNM in transit which reduce the effectiveness of the plan without approval of the Commission	70.32(d)
4. No changes which would decrease effectiveness of a security plan without prior approval of the Commission	70.32(e)
5. Transfer of SNM:	
a. Transfer limited to authorized persons.	70.42(a) 70.42(b)
b. Licensee must verify receiver is authorized to receive SNM.	70.42(c)
B. Material Control records, reports, and inspections (license conditions)	
1. Records:	
a. Records of inventory, disposal, acquisition, import, export, and transfer are required.	70.51(b)
b. Tamper-safe items: records of each such item and its identity, location, source, and disposition.	70.51(e) (1) (c)
c. Amounts added to or removed from process, amount in proceses; identity, location, and quantity of unique items and their source and identity.	70.51(e) (1) (ii) 70.51(e) (1) (iv)

d.	Material balance records.	70.51(e) (4) (iii) (iv) and (v)
e.	Measurement control records.	70.57(b) (2) and (12)
f.	Fundamental material control records review.	70.58(c) (2) and (g) (4) and (k)
2.	Material transfer reports:	
a.	Licensees who transfer or receive gram or more must file an NRC Form 741 with NRC and with the receiver or transferrer.	70.54
3.	Inspections of facilities and records	70.55(a) 70.55(b)
4.	Tests: licensees must perform or permit NRC to perform test of SNM	70.56
5.	Material status reports:	
a.	NRC-742 form to be filed twice each year to show SNM received, produced, possessed, transferred, consumed, disposed of, and lost.	70.53(a)
b.	MUF limits: if MUF>LEMUF and 200 g Pu, U^{233}, 300 g U^{235}>20% ENR U or 9000 g U^{235} in low ENR U state reasons and intended actions. And if LEMUF exceeds applicable limits, list probable reasons and planned actions.	70.53(b) (1) 70.53 (b) (2) also 70.51(e) (5) and 70.51(e) (6)
6.	Written material control and accounting procedures must be maintained and followed:	70.51(c)
a.	Tamper-safe vaults.	70.51(e) (1) (i)
b.	Unique identification of items and containers.	70.51(e) (1) (i)
c.	Documentation of transfer between MBAs and use of authorized signatures for control of transfer documents.	70.51(e) (1) (v) 70.51(e) (1) (vi) 70.51(e) (1) (vii)
7.	Physical Inventory:	
a.	Every 12 months over 350 grams U^{235}, U^{233}, or Pu except as required in (e).	70.51(d)
b.	Every 2 months for Pu enriched over 20%.	70.51(e) (3) (i)
c.	Every 6 months less than 20% U^{235}, Pu or U^{233}.	70.51(e) (3) (ii)
d.	Calculate MUF and LEMUF.	70.51(e) (4) (i)
e.	Reconçile and adjust book record.	70.519e) (4) (ii)
f.	Complete and maintain records as in B.1.a, b, c, and d.	70.51(e) (4) (iii) (iv) and (v)
8.	Limits on LEMUF:	
a.	200 g Pu, 300 g high ENR U or U^{235} in	70.51(e) (5)

	high ENR U or 9000 g U^{235} in low ENR U, or	
b.	1% of total in-process material balance for Pu or U^{233} in reprocessing plants, or	70.51(e) (5) (iii)
c.	0.7% of total in-process material balance for U element and fissile isotope, or	70.51(e) (5) (ii)
d.	0.5% of total in-process material balance for Pu, U^{235}, or high-enriched U element and fissile isotope.	70.51(e) (5) (ii)
e.	0.5% of total in-process material balance of low enriched U element and fissile isotope, or	70.51(e) (5) (ii)
f.	other limits as approved by NRC.	70.51(e) (6)
9.	Measurement control program - requires system to monitor and control errors of measurements used for SNM control and accounting.	70.57
10.	Fundamental material controls - requires written approved procedures for SNM control and accounting through use of designated MBAs and ICAs, material custodians, measured inventories, and system of records, internal controls, and accounting procedures.	70.58
C.	Physical protection of SNM (license condition)	
1.	Protection of SNM in transit:	
a.	General and miscellaneous requirements include protection of cargo by carriers, planned routing, sealed containers, use of guards, responsibility for security, protection of exports and imports, and notification and reports of shipments.	73.30 73.36 73.72
b.	Specific requirements for shipment by road, rail, air, and sea; includes planned routing, restrictions on transfers enroute, use of escorts and guards, radiotelephone communications, special designs of containers, and vehicles.	73.31 73.32 73.33 73.34
c.	Transfer of SNM - requires continuous monitoring by guard.	73.35
2.	Exemption for Spent Fuel 1 R at 3 feet.	73.6
3.	Physical protection of SNM at fixed sites:	
a.	Approved plan for protection against industrial sabotage and for protection of SNM.	73.40

b.	Specific physical protection requirements including access controls, search of packages and personnel, detection aids, intrusion alarms, and tests.	73.60
c.	Description of plan for physical protection of SNM.	73.30 73.70(g) 50.31(d) 73.1(b)

APPENDIX C

Key Licensing Actions in Connection With North Anna Units Nos.1 and 2 License Application

Date	Event
August 28, 1967	Letter of intent to purchase NSSS for Unit Nos. 1 and 2 (Westinghouse).
August 6, 1968	Date North Anna Unit Nos. 1 and 2 first announced: letter to H.L. Price from Stanley Ragone.
1968	Virginia Department of Highways issued seismic survey permit.
June 19, 1968	Virginia State Water Control Board issued certificate to discharge treated industrial waste waters.
1969	Virginia Department of Highways issued soil and core sample permit.
March 21, 1969	Application for construction permit filed with, then, the Atomic Energy Commission (AEC).
April 4, 1969	Date that application was docketed by the AEC.
July 20, 1969	Start of site clearance and grading.
November 17, 1969	Virginia Department of Highways and Louisa County Board of Supervisors issued permit to construct railroad grade crossings over public highways.
December 7, 1969	Commencement of Unit No. 1 containment excavation.
January 5, 1970	State Corporation Commission issuance of certificate of convenience and necessity for transmission line, construction of the North Anna Power Station and construction of the North Anna Dam.
February 23, 1970	Unit No. 1 excavation completed.
March 1, 1970	Dam construction started.
April 6, 1970	Containment excavation for Unit No. 2 commenced.
June 15, 1970	Applicant request to AEC for exemption to proceed with certain construction work at the North Anna Power Station.
June 25, 1970	Completion of Unit No. 2 containment excavation.
June 30, 1970	Site visit by Advisory Committee for Reactor Safeguards (ACRS).
August 13-15, 1970	ACRS meeting to review construction permit (CP) application.
August 20, 1970	ACRS letter issued for North Anna Unit Nos. and 2.
September 4, 1970	AEC issuance of exemption (Section 50.10(b)) for pouring of containment foundations, emplacement of rebar and construction of circulating water intake.

Date	Event
October 7, 1970	Virginia Department of Health issued permit to construct and operate two water supply systems.
October 14, 1970	AEC staff issues Safety Evaluation Report (SER) for North Anna Units Nos. 1 and 2.
November 23-25, 1970	Atomic Safety and Licensing Board (ASLB) hearing for construction permit application.
February 19, 1971	ASLB decision on construction permit application; AEC issuance of construction permit.
April 15, 1971	Louisa County Health Department issued sewage treatment system permit.
January 10, 1972	Completion of construction of North Anna dam.
January 14, 1972	Virginia Department of Highways issued special moving permit.
February 11, 1972	Virginia State Water Control Board issued certificate of assurance that applicable water standards will not be violated under Section 21B.
March 15, 1972	Applicant filed Environmental Report (ER) for North Anna Units Nos. 1 through 4.
November 28, 1972	Date of completion of flooding of North Anna reservoir to operational level.
March 16, 1973	Applicant filed Final Safety Analysis Report (FSAR) for mini-review by AEC staff.
March 30, 1973	VEPCO application to the State Water Control Board for a 401 permit.
April 1, 1973	AEC staff issues Final Environmental Statement (FES) for North Anna Units Nos. 1 through 4.
April 6, 1973	Final Environmental Analysis (FES) original.
April 30, 1973	Applicant formally filed FSAR for North Anna Unit Nos. 1 and 2.
May 2, 1973	Operating license application docketed by AEC.
May 17, 1973	AEC advised of existence of geological fault at North Anna Power Station.
June 21, 1973	Petition of intervention filed by Mrs. Geraldine Arnold, Trevillians, Virginia 23170, in operating license stage public hearing for North Anna Units Nos. 1 and 2.
July 25, 1973	ASLB decision in denial of Arnold petition for intervention.
August 29, 1973	State Water Control Board issuance of a 401 permit.
September 14, 1973	Atomic Safety and Licensing Appeal Board (ASLAB) reversal of the ASLB decision to deny the Arnold petition for intervention.
October 17, 1973	Issuance of show cause order by Director of Licensing, AEC, regarding continuance of construction of North Anna Units Nos. 1 and 2.
October 30, 1973	VEPCO application submitted for discharge under the provisions of Section 402, Federal Water Pollution Act.
October 22, 1973 to	Excavation of trenches for evaluation of extent and nature of geological fault.

Date	Event
November 13, 1973	AEC site visit to inspect trenches at North Anna - geological fault.
December 5, 1973	ACRS site visit.
December 27, 1973	Federal Register notice of ASLB hearing on show cause order.
February 18, 1974	AEC (technical staff) site visit in connection with geological fault.
February 26, 1974	AEC (technical staff) site visit in connection with geological fault.
March 7, 1974	ACRS meeting on North Anna Power Station geological fault.
March 20, 1974 to April 4, 1974	ASLB evidentiary hearing on show cause order.
March 25, 1975	Report by Region II Directorate of Operations on the results of the investigation and enforcement investigation to determine whether the geological fault at North Anna was known by VEPCO before it was reported to the AEC and if any information was willfully withheld. The results of this investigation indicated that the AEC was informed by VEPCO when the existence of the fault was verified. No violations of Federal regulation were identified during the investigation
June 27, 1974	ASLB decision on show cause order - an order of authorization to permit continuance of construction activities at North Anna Power Station.
August 1, 1974	Major portion of construction activity ceases at the North Anna Power Station.
October 13-15, 1974	ASLB Section B hearing (excluding transmission lines).
October 25, 1974	Federal Register notice of North Anna Environmental Coalition filing an appeal of the show cause initial decision by the ASLB.
October 30, 1974	ASLB issuance of partial initial decision (Appendix D, Section B).
November 8, 1974	Atomic Safety and Licensing Appeal Board hearing of oral arguments - North Anna Environmental Coalition appeal of show cause initial decision.
January 2, 1975	Construction activity at the North Anna Power Station resumes.
January 27, 1975	ASLB decision on North Anna Environmental Coalition (NAEC) appeal of ASLB show cause decision denial.
January 29-30, 1975	ASLB hearing on matters of disclosure in connection with geological fault - North Anna Power Station.
February 13, 1975	ASLB hearing on matters of disclosure in connection with geological fault - North Anna Power Station.
February 13, 1975	Continuance of ASLB disclosure hearing -Terrell testimony.
March 27, 1975	NAEC files appeal of the Atomic Safety and Licensing Appeal Panel decision, in USDC Circuit Court of Appeals.

Date	Event
May 28-29, 1975	ASLB hearing on matters of disclosure in connection with geological fault - North Anna Power Station.
September 10, 1975	ASLB initial decision on matters of disclosure in connection with geological fault -North Anna Power Station; penalty set at $60,000 in consideration of 12 statements assessed as false.
September 18, 1975	VEPCO filed with the ASLAB an exception to the ASLB initial decision of September 10, 1975.
September 19-30, 1975	ASLB hearing on Section B (transmission lines).
November 20, 1975	USDC Circuit Court of Appeals hearing on NAEC appeal.
December 16, 1975	Facquier League for Environmental Protection filed exceptions to ASLB initial decision. Culpepper League for Environmental Protection filed exceptions to the ASLB initial decision.
January 29, 1976	ASLAB hearing on VEPCO exceptions to ASLB initial decision of September 10, 1975.
March 3, 1976	DC Circuit Court of Appeals denies NAEC appeal of Atomic Safety and Licensing Appeal Panel decision.
March 26, 1976	Petition intervention in operating license proceeding by Sun Ship and Dry Dock Corporation.
April 15, 1976	ASLAB decision on Morrisville transmission line.
April 26, 1976	Atomic Safety and Licensing Appeals Board decision and statements on disclosure matters assessed as false in connection with North Anna geological faults. Penalty reduced to $17,500 and assessed false statements reduced to four (4).
May 28, 1976	Culpepper League for Environmental Protection filed petition in U.S. Court of Appeals in District Circuit for a review of the ASLAB.
June 2, 1976	NRC in order for filing briefs and oral arguments in connection with the Commission's review of the ASLB initial decision of September 10, 1975 and the ASLAB decision of April 15, 1976.
June 7, 1976	NRC staff issued Safety Evaluation Report (SER) (NUREG-0053) related to the operation of North Anna Power Station Unit Nos. 1 and 2.
June 8, 1976	Facquier League for Environmental Protection filed petition in U.S. Court of Appeals, District Circuit for the review of the ASLAB decision.
June 30, 1976	NRC staff issues Safety Evaluation Report Supplement No. 1 related to the operation of North Anna Power Unit Nos. 1 and 2.
July 7, 1976	Advisory Committee for Reactor Safeguards for North Anna Power Station subcommittee meeting, Washington, D.C.
August 2, 1976	NRC staff issues SER supplement No. 2 related to the operation of North Anna Power Station.

Date	Event
August 11, 1976	ACRS for North Anna subcommittee meeting, Washington, D.C.
August 12, 1976	Full ACRS committee meeting on North Anna Unit Nos. 1 and 2 license application; Washington, D.C. The NRC staff suggested committee issue an interim letter on the application but the ACRS deferred pending further review.
September 15, 1976	NRC staff issues SER - supplement No. 3.
October 5, 1976	Commission hearing on oral arguments by NRC and VEPCO in connection with Commission review of ASLB initial decision of September 10, 1975 and ASLAB decision of April 15, 1976.
October 13, 1976	North Anna subcommittee meeting (Okrent Subcommittee) on outstanding items outlined in Section 22 in Supplement No. 3 of the SER. North Anna subcommittee meeting (H. Etherington) on North Anna Unit No. 1 steam generator supports.
October 13, 1976 to November 15, 1976	Investigation initiated by NRC review of inspection and enforcement. October 13 investigation allegations made by three (3) construction workers concerning discrepancies in the quality control program by piping installation work at the North Anna Nuclear Power Plant.
October 14, 1976	ACRS full committee meeting on North Anna Unit Nos. 1 and 2 license application. The NRC staff again recommended an interim letter but the ACRS deferred and stated that it will continue the technical review of the North Anna Unit Nos. 1 and 2 license application in view of the still outstanding technical issues. References: Section 22 SER Supplement No. 3 - 11 technical issues.
October 26, 1976	ACRS issues reports on partial review of the North Anna Power Station Unit Nos. 1 and 2 license application.
November 1976	NRC staff issuance of an addendum to the Final Environmental Statement for the operation of North Anna Units Nos. 1 and 2.
November 12, 1976	Issuance of USNRC opinion affirming in part the ASLAB decision of April 15, 1976 and reinstating fines for three (3) additional statements assessed as false. Penalty set now at $32,500 in connection with seven (7) statements assessed as false.
November 12, 1976	VEPCO filed an appeal to the USNRC opinion of November 12, 1976 in the U.S. Court of Appeals - 4th Circuit.
November 26, 1976	Issuance by the NRC of the results of alleged discrepancies in the construction and quality control program at the North Anna Power Station.

Date	Event
December 6, 1976	NRC notification of certain items of noncompliance and nonconformance in connection with certain construction activities at the North Anna Power Station and the proposal for civil penalties in the amount of $31,900.
December 8, 1976	NRC staff issues SER Supplement No. 4.
December 29, 1976	NRC staff issues SER Supplement No. 5.
January 5, 1977	ACRS subcommittee meeting, Washington, D.C. on North Anna Unit Nos. 1 and 2 licence application for review, inter alia, of the status of the following five technical issues: design of groundwater control for service water reservoir; effects of loss of coolant accident (LOCA) on fuel assembly elements; seismic and environmental qualification of Category I instrumentation; overpressurization of the reactor coolant system; and reanalysis of the stress distribution in the spent fuel pool.
January 6-8, 1977	ACRS completes review of operating license application.
January 17, 1977	ACRS reports favorably to NRC on VEPCO operating license application.

Export Licensing Problems Associated With Alternative Nuclear Fuel Cycles

John N. O'Brien

NUREG/CR-1050

January 1980

TABLE OF CONTENTS

Page

I. Introduction 187
- A. Purpose of the Report 187
- B. Statement of the Problem 187

II. The U.S. Export Licensing Process 190
- A. Overview 190
- B. Executive Branch Concurrence Process 192
- C. NRC Review Process for Export License Applications 194
- D. Subsequent Arrangements 200

III. Export Problems Associated with Alternative Fuel Cycles 202
- A. The Use of Strategic Special Nuclear Material (SSNM) 202
- B. Radiation Barriers 202
- C. Co-Processing and Denaturing 203
- D. The Use of U^{233}-Th Fuels 203
- E. The Use of Heavy Water 204
- F. Storage of Spent Fuel and Waste 204

IV. Analysis of Export Licensing Problems Associated with Individual Fuel Cycles 205
- A. Light-Water Reactors 205
- B. Light-Water Breeder Reactors 205
- C. Heavy-Water Reactors (HWRs) 206
- D. High-Temperature Gas-Cooled Reactors 206
- E. Gas-Cooled Reactors 206
- F. Liquid Metal Fast Breeder Reactors 207

V. Conclusions 208
  A. Radiation Barriers 208
  B. Coprocessing 208
  C. U^{233}-Th Fuels 208
  D. Denaturing 208
  E. Heavy Water 209

ABSTRACT

This report details the export licensing process required by the Nuclear Non-Proliferation Act of 1978 and how various alternative nuclear fuel cycles may be affected under the Act. The licensing process is examined through the roles of the various agencies required to participate and the stage of the appraisal process. The safeguards measures being considered are then reviewed.

An analysis of each type of fuel cycle is then presented with conclusions as to their affect on the export licensing process.

I. INTRODUCTION

A. Purpose of the Report

The Nuclear Regulatory Commission (NRC) is responsible for weighing and deciding issues surrounding the export of nuclear energy-related materials and equipment. Export licensing has become very complicated because of conditions imposed on NRC by the Nuclear Non-Proliferation Act of 1978 (NNPA) and because of increased concern over global proliferation of nuclear weapons. The purpose of this report is to examine the problems that may arise from the application of the export licensing requirements of NNPA to the export of materials and equipment associated with alternative fuel cycles. The Act sets out a particular framework and several criteria to guide NRC in deciding on such exports.

B. Statement of the Problem

The Nuclear Non-Proliferation Act of 1978 outlines specific criteria and procedures for granting licenses and subsequent arrangements for nuclear exports. The provisions of the Act are specifically aimed at the present light-water-reactor cycle with an eye toward eventual reprocessing of spent fuel and use of liquid metal fast breeder reactors. The broad range of fuel cycles being considered in NASAP dictates that an examination of how NNPA may influence the decision to implement an alternative fuel cycle is desirable.

The NNPA is the most comprehensive public law dealing with nuclear exports legislated since the passage of the Atomic Energy Act of 1954. It establishes the conditions and criteria which govern U.S. cooperation with other nations in the peaceful use of nuclear energy, and seeks to balance concern over the dangers of nuclear proliferation with the legitimate use of peaceful nuclear power to meet energy demands. The central objectives of the Act are to encourage universal ratification of the Non-Proliferation Treaty; to develop a comprehensive set of controls, procedures, and incentives designed to provide a framework for predictable international nuclear cooperation and commerce; to improve the reliability of the United States as a nuclear supplier; and to limit the further diffusion of nuclear explosive capabilities.[1]

While seeking tighter controls over international nuclear commerce, the language and history of the Non-Proliferation Act indicate that its drafters recognized the international implications of nuclear proliferation and that United States non-proliferation policy must reflect the realities of the current international situation. Consequently, the Act reaffirms traditional United States support for the IAEA.[2] It also implicitly notes that the decision by many nations not to build nuclear explosives is political rather than a response to technical obstacles, and that a continued commitment not to develop sensitive nuclear technologies can best be maintained if nations not possessing them are assured that the United States is a reliable supplier of fuel.[3] The Act attempts to promote this perception by clarifying previously uncertain and informal licensing procedures and criteria,[4] authorizing the NRC to expedite license approval[5] seeking more comprehensive international safeguards,[6] and instituting a program for nuclear fuel assurances.[7] It further attempts to reflect worldwide realities by giving the executive branch substantial flexibility in implementing its provisions and by stating explicitly that nothing in the Act strictly prohibits the reprocessing of United States-supplied fuel[8] or prejudices United States review of the results of the International Nuclear Fuel Cycle Evaluation.[9]

The provisions of the Non-Proliferation Act are emblematic of the diverse themes underlying it. The Act requires the amendment of all existing bilateral agreements within two years, subject to Presidential extensions with Congressional review,[10] for the inclusion of more stringent safeguards rights than have previously been required in most existing agreements. The most controversial provisions mandate that Agreements for Cooperation with U.S. trading partners require that: (1) nonnuclear-weapons states agree to full-scope IAEA safeguards;[11] (2) retransfers of material of U.S. origin not occur without United States consent; (3) material originating in the United States or irradiated in United States-supplied facilities not be reprocessed, enriched, or otherwise altered in form or content without prior approval of the United States; (4) the United States approve the storage facilities used for plutonium, U^{233}, or highly enriched uranium that is of United States origin or derivation; and (5) derived material[12] be subject to all of the above conditions.[13]

The Act also greatly complicates the U.S. nuclear export decision making process. Before the enactment of the Nuclear Non-Proliferation Act , NRC needed only to "consult" the executive branch and was guided by the broad common defense and security authority granted in the Act.[14] NNPA significantly changed this administrative process. Under NNPA, NRC plays the focal role in the decision-making process, but cannot approve an export license without executive branch concurrence.[15] The new framework formed in NNPA establishes time tables and statutory requirements for interagency participation. When NRC denies a license or becomes deadlocked over a license application, the application is automatically referred to the President who may order issuance of the license. The President's action can subsequently be disapproved by Congress in concurrent resolution before a 60-day waiting period has elapsed.[16]

During the initial implementation of this export process, the International Nuclear Fuel Cycle Evaluation (INFCE) considered various technical measures which might be employed to contain global proliferation of nuclear explosives. These include consideration of several fuel cycles, reactor types, and safeguards variations. On a national level, the U.S. conducted the Non-Proliferation Alternative Systems Assessment Program (NASAP) in which twenty-one specific fuel cycles were considered. These fuel cycles involve the use of several technical and institutional variations including radiation barriers (spiking), coprocessing, use of U^{233}-Th fuels, denaturing, use of heavy water, storage of spent fuel and waste, and international fuel service centers.[17]

Up to now, application of the NNPA to exports has been somewhat ambiguous. This is due to the vague and unique nature of the delegation of authority NNPA makes to NRC in deciding to grant or defer an export license and the fact that the NRC, like other agencies, must develop procedures in what can be called a "shakedown period." The process itself will be more closely examined in part II; suffice it to say here that the current lack of clarity in the process makes the overall analysis in this report more difficult. However, the relation that alternative fuel cycles have to the export licensing process is important because of the wide range of commercial activity relating to nuclear energy which may take place in the future.

REFERENCES

1. Leonard Weiss, "The Nuclear Non-Proliferation Act of 1978 - The Congressional Interest," *American Law Institute-American Bar Association Nuclear Export Control*, 1978, p. 125.
2. 22 USCA 3241 (West Supp. I 1978).
3. Id 3221.
4. 42 USCA 2155-2157 (West. Supp. I 1978) (adding new 126-128 to the Atomic Energy Act).
5. Id. 2155(a)(2). This can be done in one of several ways: the Commission may make a single finding for more than one application to the same nation, or it may approve licenses merely by finding that there are no materially changed circumstances associated with the application from those existing at the time of the last export to the same recipient. The Commission also has authority under 161 of the Atomic Energy Act to issue general licenses for such activities. 42 USC 2201(h)(1976).
6. 22 USCA 3241 (West Supp. I 1978).
7. Id. 3223.
8. 42 USCA 2160(d) (West Supp. I 1978).
9. William O. Doub and Lawrence A. Weiss, "International Development in the Age of Interdependence," 32 Vanderbilt Law Review 843, May 1979, p. 860.
10. 42 USCA 2153. See also Id. 2155(a)(2), 2159 (adding a new 180 to the Atomic Energy Act). The Act requires submissions to Congress in accordance with the procedures of 2159 in four important instances: if the President decides to override the NRC on issuance of an export license, 2155(b) (2); if the President decides to exempt the nation from the additional full-scope safeguard criterion, 2157 (b); if the President decides to waive a requirement for the termination of exports, 2158; and if any new or amended agreements for cooperation are proposed, 2153.

11. With full-scope IAEA safeguards, agency safeguards are required for all nuclear activities within the jurisdiction of the recipient state. Id. 2153(a) (2).
12. Derived material consists of material which does not originate in the United States, but which is irradiated in a United States-supplied reactor. Id. 2153(a) Other requirements of this section include provisions that the recipient agrees to maintain IAEA safeguards in perpetuity on the materials over which it has control, not to use such material or equipment for explosive devices, and to permit the United States to request the return of such materials and equipment if the cooperating party abrogates IAEA safeguards or detonates a nuclear explosive. Section 2153 also requires the recipient to maintain adequate physical security, to request United States consent before retransfering restricted data, and impose similar conditions upon the product of any facility built with the use of United States supplied sensitive nuclear technology. Id. 2153.
13. Doub and Weiss, supra Note 9, at 861.
14. Exec. Order No. 11902, 3 C.F.R. 88(1976).
15. 42 USCA 2155(a)(1), (b)(2).
16. 42 USCA 2155(b)(2); see also Exec. Order No. 12,058, 43 Fed. Reg. 20, 947 (May 11, 1978).
17. For a complete discussion of these measures, see E.V. Weinstock and B. Keisch, "Technical Safeguards Issues for Alternative Fuel Cycles," BNL NUREG-25557, Report, 8/9/79 contained in Chapter Five.

II. THE U.S. EXPORT LICENSING PROCESS

A. Overview

When the Atomic Energy Commission was dissolved by the Energy Reorganization Act[1] in favor of separate regulatory and development agencies, the NRC was chosen as the proper focal point of export licensing.[2] This was due to a Congressional decision that all exports be subject to an independent review rather than left entirely to the discretion of the Executive Branch. Congress, however, narrowed the discretion of NRC in export licensing determinations with passage of the NNPA by requiring Executive Branch concurrence with NRC's decision and giving final authority to deny a license to the President.

The Department of State has been given the lead role in determining whether the export may be inimical to the common defense and security. NRC's final determination on the license application may not precede the judgment of the Secretary of State who, in concurrence with the Secretaries of Energy, Defense, and Commerce, and the Arms Control and Disarmament Agency, makes a determination of whether the export is inimical to U.S. common defense and security.[3]

The President has three options to override an NRC determination, further limiting NRC's authority in export licensing.[4] First, the President can override NRC denial of an export license which received a positive recommendation by the Executive Branch all subject to Congressional review.[5] Second, if the NRC cannot make the findings required by NNPA, the Commission is required to refer the application to the President.[6] Third, if the deadlines set in NNPA for NRC decision making are not met, the President may withdraw the pending application from the Commission on grounds of excessive delay.

It was recognized that NRC would need substantial information concerning the foreign nations receiving the export. NNPA requires that "The Secretary of State shall provide appropriate data and recommendations, subject to requests for additional data and recommendations, as required by the Commission..."[7] In addition, deadlines set by NNPA are made flexible in cases where the Commission "has identified and transmitted to the Executive Branch a set of additional concerns or requests for additional information."[8]

Before NNPA's enactment, the Department of Commerce had authority to approve exports of component parts of production or utilization facilities. NNPA transferred this authority to NRC for components on the Nuclear Suppliers' Group and IAEA Zangger Committee trigger lists, as well as for heavy water and nuclear-grade graphite — all considered significant from a proliferation standpoint.[9] NNPA also extends NRC licensing authority over distribution of U^{233} and U^{235} in any quantity, or of Pu in quantities greater than 500 grams per recipient per year. Distributions of source material are similarly limited to less than three metric tons per year per recipient without an NRC license.

NNPA also set up consultive arrangements which must be followed in the areas of technology transfer,[10] Subsequent Arrangements,[11] Agreements for Cooperation, and personnel training programs for safeguards and physical security. In all these areas NRC must be consulted before an Executive Branch determination can be formulated.

The U.S. is party to numerous Agreements for Cooperation with foreign nations. These Agreements broadly outline U.S. commitments and foreign responsibilities in the development of nuclear energy. Export licenses are granted pursuant to the Agreement for Cooperation the U.S. has with other nations. Subsequent Arrangements are, in a sense, amendments to the Agreement for Cooperation to allow activities barred or not addressed under the original Agreement. It is important to note that, while a wide range of concurrence is required in the Executive Branch for scrutiny of an export license, a Subsequent Arrangement must receive only the concurrence of DOE and the Department of State. In other words, the decision to allow retransfer for reprocessing or transfer of sensitive technology is arrived at in absence of NRC, ACDA, or Department of Commerce concurrence although these agencies are "consulted."

REFERENCES

1. Pub. L. No. 93-438, 88 Stat. 1233 (1974).
2. Id. 201(p).
3. NNPA 304(a); Atomic Energy Act Sec. 126a(1).
4. AEA 126b(2).
5. AEA 130.
6. In April 1978, NRC was deadlocked over the export license for India's Tarapur Power Reactor fuel reload. The President withdrew the application and determined that denial of the license would be "seriously prejudicial to the achievement of U.S. non-proliferation objectives" and authorized the export (E.O. 12055). The House and Senate held hearings as required by NNPA in May and June. In July the House voted to uphold the Presidential decision and the fuel was shipped in July.
7. AEA 126a(1).
8. AEA 126b(2).
9. AEA 109.
10. AEA 57b.
11. AEA 131; These include contracts for furnishing nuclear materials and equipment, approvals for transfer of materials, equipment and technology, government-to-government distribution of commodities, physical security and spent-fuel arrangements, safeguards application arrangements, and any other arrangements which the President deems important to non-proliferation objectives.

B. Executive Branch Concurrence Process

There are six Executive Branch agencies directly involved in the export licensing process. Although NRC has a central role in decision making, it can grant an export license only with the concurrence of the other five agencies, which comes in the form of an "Executive Branch judgment" transmitted through the Department of State to NRC.

The Executive Branch judgment is based on a coordinated examination of specific issues involving the export license. The Departments of Energy, Defense, Commerce, and the Arms Control and Disarmament Agency (ACDA) are all consulted by the Department of State with coordination provided by the National Security Council (NSC) ad hoc Group on Non-Proliferation. If there is an interagency disagreement, it is resolved in a stepwise fashion first by NSC procedures and then ultimately by the President.[1]

When an application is filed at NRC, it is immediately transmitted to all of the agencies noted above. Within 15 days of receipt, those agencies are to inform the Department of State (specifically, the Office of Export and Import Control) of their position on the following: First, whether there is any information needed that has not been provided, in which case the license application goes back to NRC and the process recommences. Second, whether the license application appears to raise issues requiring more extensive consideration than is normally afforded to an export licensing determination. If so, NSC initiates appropriate steps including those necessary to obtain policy decisions and initiate diplomatic consultations. Third, if requested by the Department of State to do so, these agencies are to provide their views on the license.[2]

Within five days of receipt of the application, the Department of Energy (DOE) is required to request written confirmation that the nations party to the Agreement for Cooperation (which the proposed export is pursuant to) will subject the export to all conditions of the agreement, have authorized a consignee to receive the export, and will maintain adequate physical security (as defined in INFCIRC 225/Rev. 1). If those written replies are not received within 55 days, the license application is returned to NRC and the process recommences.[3]

DOE is also required to determine whether the proposed export includes material for which the US has agreed to consult with or obtain approval of any other nation or group of nations prior to export. If consultation or approval is necessary, DOE must promptly inform the Department of State so those actions can proceed.

When the license application involves transfer of strategic quantities of special nuclear material, DOE must prepare, within 30 days of receipt, a technical and economic justification which is transmitted to the Department of State. The justification is then provided to all other participating agencies for their consideration.[4]

Within 30 days of receipt, the Department of State must prepare and submit a proposed Executive Branch judgment. Requests from NRC for additional information are noted in the proposed judgment. Within 10 days after receipt of the proposed judgment, the Departments of Energy, Defense, and Commerce, and ACDA are to respond with their views on the proposed judgment. At this point, DOE will transmit any confirmations it has obtained from the receiving nation.[5]

The Executive Branch judgment is to address the matters required by section 126(a)l of the Atomic Energy Act. In addition to addressing the six major criteria set forth in the NNPA (to be discussed in the next section), the Executive Branch judgment may also consider whether granting the license will materially advance the non-proliferation policy of the U.S. and whether its denial will seriously prejudice U.S. non-proliferation objectives.[6]

When the application is substantively identical to one already considered and granted, the Executive Branch judgment may express the view that there is "no materially changed circumstance."

The Executive Branch judgment must be transmitted to NRC no more than 60 days from the time of submission of the license application. If this deadline is not met, the Secretary of State must notify the Senate Committee on Foreign Relations and the House Committee on International Relations as well as all participating agencies.[7]

REFERENCES

1. "Procedures Established Pursuant to the Nuclear Non-Proliferation Act of 1978," 43 Fed. Reg. 25326 (June 9, 1978, Part VII).
2. Id. p. 25327.
3. Id.
4. Id.
5. Id.
6. Id. p. 25328.
7. Id.

C. NRC Review Process for Export License Applications

NRC consideration of an export license runs concurrently with the Executive Branch review in order to expedite the overall procedure. The exports to be specifically considered are those for production and utilization facilities, more than one effective kilogram (kg) of SNM (except when needed for routine fuel reload), 10,000 kg of source material, 1,000 kg of nuclear-grade graphite or heavy water, or any other export determined by the staff or any one Commissioner to warrant review. If the Commission does not issue or deny a license within 60 days of receiving the Executive Branch judgment, or when the judgment is not required, it must inform the applicant of the reasons for delay.[1]

For nuclear-grade graphite and heavy water, export licensing criteria are 1) submission to IAEA safeguards, 2) assurance that they will not be used for nuclear explosives or research for such, and 3) assurance that no retransfer will occur without U.S. approval.[2]

For all other nuclear exports, six criteria discussed below set standards for approval or denial. The Commission has several options for action. If a favorable Executive Branch judgment is received, a license may be issued upon a finding that 1) the six criteria are met, 2) the export is not inimical to the common defense and security, and 3) the material or facilities to be exported would be under the terms of an Agreement for Cooperation.[3]

If there is no material change in circumstances associated with the export license application from those of a previously issued license to the same country, NRC may approve the license.

If NRC cannot come to a timely decision because it is unable to make the necessary statutory determinations, the license is referred to the President. If the Executive Branch judgment does not recommend approval, NRC must either deny the application or return it without action. The applicant must be informed of the reasons for the action.[4]

1. The Criteria for NRC Export Licensing Determinations. In Section 126a(2) of the Atomic Energy Act (AEA), Congress set forth the method by which NRC is to make licensing determinations. Three important points are raised:

> [Commission determinations are to be] based on a *reasonable judgment of assurances provided and other information available to the Federal Government* including the Commission, that the criteria in. . . this act, *or their equivalent*... are met (emphasis added).

The "reasonable judgment" standard is meant to give a degree of discretion to the Commission it would otherwise not have. Congress realized that the Commission may not have available all information which may bear on a particular licensing determination so it was required to base its reasonable judgment on "the assurances obtained (from other nations) and other information available to the Federal Government including the Commission." Congress made decision-making even less rigid with the allowance that the criteria "or their equivalent" may be met.[5]

There are six immediately applicable criteria all of which must be appropriately met for any export license.

> (1) *IAEA Safeguards.* Criterion 1 provides that: IAEA safeguards as required by Article III(2) of the (Non-Proliferation) Treaty will be applied with respect to any such material or facilities proposed to be exported, to any such material or facilities previously exported and subject to the applicable agreement for cooperation, and to any special nuclear material used in or produced through the use thereof.

This criterion is generally satisfied by the historical U.S. commitment to IAEA safeguards. Most of the existing agreements for cooperation which the U.S. is party to already include, in a trilateral fashion, the IAEA. Adherence to safeguards administered according to INFCIRC 66/Rev. 2 (prior to NPT) or INFCRIC 153 will satisfy this criterion.

Two questions exist in regard to this criterion. First, it is left unclear whether the adequacy of IAEA safeguards can be called into question. This issue was exacerbated by a report entitled "Safeguards Implementation Report" issued to the Board of Governors of the IAEA in 1978 indicating inadequate implementation of IAEA safeguards in some countries.

Second, it is unclear whether "continued" safeguards are required. This was called into question specifically in the case of refueling India's TARAPUR reactor because a question of a breach of the agreement for cooperation led to the reasonable expectation that India may drop IAEA safeguards in the near future.

> (2) *No nuclear explosive devices.* Criterion 2 provides that: No such material, facilities, or sensitive nuclear technology proposed to be exported or previously exported and subject to the applicable agreement for cooperation, and no special nuclear material produced through the use of such materials, facilities, or sensitive nuclear technology, will be used for any nuclear explosive device or for research on or development of any nuclear explosive device.

The concept of "equivalency" becomes important here. The older agreements for cooperation do not incorporate the term "nuclear explosive device" and instead deny the use of nuclear material for military use. The

U.S. has maintained that this precludes the use of any nuclear explosive in that peaceful nuclear explosive devices are indistinguishable from a military device.[6] NNPA requires renegotiation of agreements for cooperation to make this more clear. While these international instruments are still in force, the "no military use" concept is considered equivalent. The Commission may also consider other forms of collateral understandings and assurances.[7]

> (3) *Physical security.* Criterion 3 provides: Adequate physical security measures will be maintained with respect to such material or facilities proposed to be exported and to any special nuclear material used in or produced through the use thereof. Following the effective date of any requirement promulgated by the Commission pursuant to Section 304(d) of the Nuclear Non-Proliferation Act of 1978, physical security measures shall be deemed adequate if such measures provide a level of protection equivalent to that required by the applicable regulations.

The issue of adequacy is clearly raised in this criterion. NRC promulgated a process by which this criterion can be evaluated.[8] For exports of strategic significance,[9] site inspections and information exchanges are required to assure that physical security is at least equivalent to that set forth in INFCIRC 225/Rev. 1. Written assurances must also be obtained from the recipient country (or group of countries) that the required level of security will be maintained. The judgment of adequacy is not to be made on a case-by case basis but rather countrywide with reassessment whenever circumstances are changed.

> (4) *Retransfers.* Criterion 4 provides: No such materials, facilities, or sensitive nuclear technology proposed to be exported, and no special nuclear material produced through the use of such material, will be retransferred to the jurisdiction of any other nation or group of nations unless the prior approval of the United States is obtained for such retransfer. In addition to other requirements of law, the United States may approve such retransfer only if the nation or group of nations designated to receive such retransfer agrees that it shall be subject to the conditions required by this Section.
>
> (5) *Reprocessing.* Criterion 5 provides: No such material proposed to be exported and no special nuclear material produced through the use of such material will be reprocessed, and no irradiated fuel elements containing such material removed from a reactor shall be altered in form or content, unless the prior approval of the United States is obtained for such reprocessing or alteration.

These last two criteria both require the "prior approval of the United States" and by withholding permission the U.S. can preclude any retransfer or recycle of fuel if of U.S. origin. The U.S. has not given reprocessing or retransfer permission broadly. The President can waive these criteria if failure to continue cooperation "would be seriously prejudicial to the achievement of U.S. non-proliferation objectives or otherwise jeopardize the common defense and security..."[10]

> (6) *Sensitive technology.* Criterion 6 provides: No such sensitive nuclear technology shall be exported unless the foregoing conditions shall be applied to any nuclear material or equipment which is produced or

> constructed under the jurisdiction of the recipient nation or group of nations by or through the use of any such exported sensitive nuclear technology.

This criterion is important in the event that the U.S. begins to participate in a global or regional nuclear fuel cycle and that reprocessing, enrichment, or heavy water production facilities are exported. The current U.S. policy not to export sensitive technologies makes this criterion moot until such time as that policy changes.

The NNPA defines sensitive technology as:

> any information (including information incorporated in production or utilization facility or important component part thereof) which is not available to the public and which is important to the design, construction, fabrication, operation or maintenance of a uranium enrichment or nuclear fuel reprocessing facility or a facility for the production of heavy water.[11]

Another section of NNPA states that:

> no major critical components of any uranium enrichment, nuclear fuel reprocessing, or heavy water production facility may be exported under a civil agreement for cooperation unless the agreement specifically designates such components as items to be exported. The term "major critical component" means any component part or group of component parts which the President determines to be essential to the operation of complete uranium enrichment, nuclear fuel reprocessing or heavy water production facility.

United States policy to date has prohibited the export of sensitive nuclear facilities. It is expected that this policy will continue, and that any exceptions will only be in extraordinary circumstances, such as the establishment of an international fuel center. Any future civil agreements which provide for such exports are to include conditions specifically designed to ensure that such exports are not used for nuclear explosive purposes.[12]

No current agreement for cooperation contains any provision for exporting major critical components.

The NNPA also requires that "full-scope" or "comprehensive" safeguards be in place by March 10, 1980 (24 months after enactment of NNPA), for all U.S. nuclear trading partners that are nonnuclear weapons states. Full-scope safeguards require all peaceful nuclear activity within a country to be subject to IAEA safeguards.

As a condition of continued United States export of source material, special nuclear material, production or utilization facilities, and any sensitive nuclear technology to nonnuclear-weapon states, no such export shall be made unless IAEA safeguards are maintained with respect to all peaceful nuclear activities in, under the jurisdiction of, or carried out under the control of such state at the time of the export.[13]

Any country adhering to the Nuclear Non-Proliferation Treaty (NPT) already satisfies this export licensing requirement. Problems arise, however, with nations that do not adhere to the NPT. IAEA safeguards could be implemented while a nation stays outside the NPT safeguards regime, but the practical effect is to provide an inducement for the receiving nations to join in the NPT.

2. Health and Safety. Public health and safety is set out by the AEA as a consideration in export licensing cases; NRC has interpreted this as referring to the U.S. public, not the foreign public.[14] Both AEC and NRC have always acknowledged this distinction in Federal Register notices of export license applications.[15]

NRC has, however, attempted to improve health and safety programs and standards in recipient countries through both bilateral and multilateral cooperative assistance programs. In 1977 the Commission requested its staff to study methods to improve approaches to health and safety. They reported[16] a broad range of actions, from augmenting current international agreements to conducting health and safety reviews in the export licensing process itself.

Congress has been asked to provide additional funding for further development of these programs. This aspect of export licensing is still unclear, as is demonstrated by the protracted state of an application for a reactor export to the Philippines. Allegations of seismic problems at the selected site, along with intervention by Philippine environmental groups, have led to a general reconsideration of the health and safety reviews of all nuclear exports.

3. Environmental Considerations The provisions of the National Environmental Policy Act (NEPA) have been extended to a broad range of federal activities since its enactment. In 1973, AEC was sued by intervenors to consider a NEPA review of nuclear exports. In 1976 DOE issued a "Final Environmental Impact Statement on U.S. Nuclear Power Export Activities."[17] In May 1976 and again in 1977, NRC reiterated that a NEPA review of exports was beyond its export licensing jurisdiction.[18] The Commission did, however, recognize section 102(2)(f) of NEPA which requires federal agencies to recognize the worldwide and long-range character of environmental problems and, where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment. The Commission has implemented this provision through a variety of programs, for example, by entering into formal "agreements" or "arrangements" with government agencies in 17 nations providing for exchange of regulatory, safety, and environmental information and for cooperation on specific safety research projects. Several more such agreements are currently being negotiated.[19]

On January 4, 1979, the President issued an executive order in an attempt to define NEPA's application abroad.[20] Nuclear exports are singled out,[21] but several issues are still not resolved at the time of this writing. First, as an independent regulatory agency, NRC may not be bound by the order. However, since the Department of State and the CEQ are singled out as the lead agencies in the order, it is not NRC which will decide on the order's authority. In that light, NRC could accept the Executive Branch Environmental Review as discharging its obligation or opt for a full NEPA review as in its domestic licensing activities. Indications now are that NRC will not conduct its own review.[22]

Another unresolved issue is the purpose of an Environmental Review. It could be used by NRC to decide whether to grant or deny an application. On the other hand, the Environmental Review could be transmitted to the recipient nation solely for use in its own domestic review.

The process for implementation of the order is nearing completion at the time of this writing; it is not possible, therefore, to comment on it in any detail.

REFERENCES

1. 10 CFR 110.40 (1978).
2. 10 CFR 110.42(b) (1978).
3. 10 CFR 110.44(a)(1) (1978).
4. 10 CFR 110.44(b)(c) (1978).
5. Carlton R. Stoiber, "Nuclear Export Licensing Procedures and Criteria," *American Bar Institute-American Bar Association Nuclear Export Control,* 1979.
6. Statement of Dwight Porter, 44th Meeting of the IAEA Board of Governors, GOV/OR-446 (6/20/72), p.2.
7. Stoiber, Note 5, supra, p.26.
8. 10 CFR 110.43 (1978).
9. 10 CFR 110 App. C (1978).
10. AEA 126a(2).
11. NNPA, 4(a)(6).
12. NNPA, 402(b).
13. AEA, 128(a)(1).
14. Edlow International Co., CLI-76-6, NRCI 76/5, 563, 582-3 (May 7, 1976); Westinghouse Electric Corporation, CLI-76-9, 739, 754 (June 21, 1976); Babcock and Wilcox, CLI-77-18, 5 NRC 1332, 1346-8 (June 27, 1977).
15. Stoiber, Note 5, supra, p.37.
16. "Health and Safety Considerations in NRC Reactor Export Licensing and Nuclear Assistance Programs," SECY-78-365 (July 3, 1978).
17. ERDA-1542 (April 1976).
18. See Note 14, supra.
19. Stoiber, Note 5, supra, p.41.
20. E.O. No. 12114, "Environmental Effects Abroad of Major Federal Actions," 44 Fed. Reg. 1957 (Jan. 9, 1979).
21. Id. sec. 2-3 (c)(2).
22. I.B. Rothchild, OGC, NRC, 9/26/79, private communication.

D. Subsequent Arrangements

NNPA provides that any arrangement entered into with a foreign government by any agency or department of the U.S. Government which involves the following actions be subject to a detailed concurrence, consultation, and review process.[1] These arrangements include:

- contracts for furnishing nuclear materials and/or equipment
- approvals for retransfer, reprocessing, or transfer for which prior approval is required
- arrangements for physical security
- arrangements for storage or disposition of irradiated fuel elements
- arrangements for application of safeguards
- any arrangement which the President finds to be important from the standpoint of preventing proliferation.

In entering into a subsequent arrangement, NNPA dictates certain conditions which must be met, specifically conditions for reprocessing, retransfer of plutonium, and storage of foreign spent fuel.

1. General Conditions. The Secretary of Energy pursuant to administration approval plays the lead role in entering into any subsequent arrangement. The Secretary of Energy must obtain concurrence from the Secretary of State and consult with ACDA, NRC, and the Secretary of Defense. The Secretary of State plays the lead role in any policy negotiation. Notice of the proposed subsequent arrangement along with a written determination by the Secretary of Energy that the arrangement will not be inimical to the common defense and security must be published in the Federal Register. In addition, ACDA may prepare a Nuclear Proliferation Assessment Statement at its own discretion. Congressional review follows this process.

2. Special Nuclear Material and Reprocessing. NNPA requires that the Secretary of Energy may not enter into an arrangement for reprocessing and/or retransfer of more than 500 g of plutonium resulting from reprocessing until the Committee on International Relations of the House and the Committee on Foreign Relations of the Senate have been informed of the reasons for entering into the arrangement. These committees are then given 15 days of continuous session to respond negatively. The President can shorten this period to 15 calendar days in an emergency situation.

The Secretaries of Energy and State must determine that the reprocessing and/or retransfer of plutonium will not significantly increase the risk of proliferation. The foremost consideration must be whether the U.S. will have timely warning of a diversion in a non-weapons state. This determination is a judgment which is discussed in detail in Appendix C.

For reprocessing facilities which are subject to arrangements concluded prior to enactment of NNPA, the Secretary of Energy is required to "attempt" to insure that the above standards are met for retransfer of plutonium to nonweapons states.

3. Storage of Foreign Spent Fuel. The Secretary of Energy may not enter into subsequent arrangements for storage or disposition of foreign spent fuel until the proposed arrangement has been submitted to Congress for 60 days of continuous session and the committees cited above have been informed. Congress can pass a concurrent resolution which would negate the arrangement during that 60-day period. In addition, the President must submit a detailed generic plan for the storage or disposition in question.

The President can waive the conditions above if he determines that 1) there is an emergency condition, 2) it is in the national interest to take immediate action, and 3) he notifies the House Committees on International Relations and Science and Technology and Senate Committees on Foreign Relations and Energy and Natural Resources with a detailed explanation and justification.

4. Current Practices and Policies. Subsequent arrangements which have been entered into up to this point have included several considerations. First, the "non-proliferation credentials" of the recipient countries are important.[2] In addition, all subsequent arrangements are handled on a case-by-case basis. A demonstrated physical need to retransfer spent fuel is generally considered important although this has been waived as a criterion at times.[3] The most important consideration, although hard to characterize, seems to be the advancement of U.S. non-proliferation objectives. The U.S. also regards subsequent retransfer of plutonium after initial retransfer and reprocessing as constituting another discrete subsequent arrangement and, therefore, requiring independent consideration.

The analysis by the Secretary of Energy generally includes consideration of the six immediately applicable export licensing criteria,[4] the likelihood that full-scope safeguards will be applied by the deadline stipulated for exports,[5] the implementation of safeguards, the general non-proliferation aspects of the proposed subsequent arrangement, and the physical need in terms of spent-fuel storage.[6]

REFERENCES

1. NNPA, Sec. 303, AEA Sec. 131.
2. Letter Douglas Bennet, Department of State to John Glenn, Senate Committee on Governmental Affairs, Oct. 2, 1978.
3. See "Analysis of Request Number RTD/EU(JA)-20 for Retransfer for Reprocessing," 9/22/78.
4. See pp. 195-197, supra.
5. See pp. 196,197, supra.
6. Note 2, supra.

III. EXPORT PROBLEMS ASSOCIATED WITH ALTERNATIVE FUEL CYCLES

Problems may arise for NRC in deciding licensing cases which involve the use of an alternative fuel cycle. To examine this problem each safeguards variation described previously (i.e., radiation barriers, coprocessing, etc.) will be examined separately for impacts, then the candidate fuel cycles will be evaluated generally. For a detailed description of safeguards variations see Weinstock and Keisch.[1]

A. The Use of Strategic Special Nuclear Material (SSNM)*

Several of the NASAP fuel cycles use SSNM. The export licensing process for those fuels and utilization facilities does not present an administrative problem significantly different from those now existing, because the Commission reviews even exports of low-enriched uranium (LEU) fuel as if it were SSNM. It is likely that the biggest concern facing NRC would be the adequacy of IAEA safeguards, although as discussed before, NRC may decide not to examine the adequacy of those safeguards as a matter of discretion. In addition, the need for intensified physical security at the front end of the reactor cycle may bring the adequacy of physical security under closer scrutiny.

If the fuel cycle involves the transfer of plutonium, the Subsequent Arrangement will require a higher degree of congressional intervention than transfers not containing plutonium. A determination will have to be made concerning the risk of proliferation associated with the export and the application of the timely warning criterion.

B. Radiation Barriers

For a number of the NASAP fuel cycles, radiation barriers are proposed. If deterrent spiking is considered (as opposed to detection or location spiking), the high levels of radioactivity may require consideration of the following issues: 1) the effect on IAEA accountability techniques, 2) the effect on adequacy of physical security, 3) some consideration of health and safety effects, and 4) the environmental impact of the increased radiation.

1. Effect on IAEA Material Accountancy and Verification. The principal effects of radiation barriers in material accountancy are in sample taking, chemical analysis, nondestructive assay (NDA), and material balance verification.

The procedure for taking samples for chemical assay would become both more time consuming and more laborious. The effect would be to minimize the number of samples taken (contrary to the need for more

---

*SSNM is Pu, > 12% U^{233}, or > 20% U^{235}, as defined in NASAP.

samples), since passive NDA techniques are unusable. IAEA is particularly dependent on NDA techniques and, as such, it could be reasonable to call the adequacy of IAEA safeguards into question.

2. Other Export Licensing Considerations. Radiation barriers would also enhance physical security, if such barriers are present at significant stages of the process in the production facility. This might weigh into the consideration of adequacy of physical security.

It is probable that radiation barriers would have environmental effects, which would be assessed by the Executive Branch in its Environmental Review (ER). It is not yet clear how NRC will use the ER in licensing proceedings as it considers the adverse environmental effects due to the use of radiation barriers. Environmental impacts may be substantial in which case the trade-off between improved physical security and adverse environmental effects will have to be resolved by NRC.

C. Coprocessing and Denaturing

The major issue in the use of coprocessing and denaturing is the consideration of reprocessing and retransfer. Other concerns are effects on material accounting for IAEA safeguards and increased need for physical security associated with some fuels.

1. Reprocessing and Retransfer. The NNPA requires that prior approval by the US be obtained before reprocessing or retransfers can occur. This is detailed in Chapter Two, Section D of this report. It is entirely likely that the timely warning criterion will be enhanced since, in both coprocessing and denaturing, it may take longer to convert material to a form usable in weapons. Denaturing, however, does not apply to plutonium-bearing fuels since plutonium cannot be denatured.

2. Material Control and Accounting. Since IAEA safeguards are required and the issue of their adequacy has not been resolved, it is important to note that NDA techniques and sampling are not significantly affected by either coprocessing or denaturing.

3. Increased Need for Physical Security. Since coprocessed fuel contains plutonium, it is assumed that physical security should be more stringent than the security currently provided for thermal reactor fuel. This is consistent with the application of standards contained in IAEA document INFCIRC 225/Rev. 1.

D. The Use of U^{233}-Th Fuels

Any fuel containing U^{233} is considered "direct-use" material by the IAEA[2] and, therefore, greater physical security is needed regardless of the enrichment with respect to U^{238} according to INFCIRC 225/Rev. 1. The IAEA has mentioned enrichment levels for U^{233} in its Safeguards Technical Manual (IAEA/174)[3] but the 20% level suggested is for weapons significance, not safeguards significance. The contradiction between INFCIRC/225/Rev.1 and IAEA/174 deserves attention. Unirradiated thorium fuels, by themselves, are not considered direct-use material and, therefore, do not require increased security. There is little experience with reprocessing highly irradiated thorium fuels so that it is difficult to say whether material accounting techniques would be seriously affected. If so, the adequacy of IAEA safeguards may be called into question.

An additional problem is that U^{233} fuels are highly radioactive which, in essence, amounts to a radiation barrier. The problems attendant upon this are discussed in Section B.

E. The Use of Heavy Water

The export of heavy water will no doubt require the negotiation of a Subsequent Arrangement; however, it must meet only general requirements.

At present IAEA has not arrived at parameters for accountability. Since IAEA safeguards are required by NNPA for export of heavy water, the adequacy of IAEA safeguards may be called into question. This is of particular significance since NRC, at present, does not require safeguards for heavy water.

The on-line refueling aspect of heavy-water reactors will be discussed in part IV.

F. Storage of Spent Fuel and Waste

Receipt and storage of foreign spent fuel or wastes require a Subsequent Arrangement which entails a large degree of congressional and executive involvement. The Secretary of Energy must first submit the proposed arrangement to Congress for 60 days in which time Congress, through concurrent resolution, can rescind the arrangement. The President, presumably through the Executive Branch, must also supply to Congress a detailed generic plan for the storage in question.

Probably most important in the current situation is the requirement of "physical need" to transfer spent fuel. While a foreign facility has or can construct adequate spent fuel storage, it is current U.S. policy to deny the transfer of spent fuel.

There is no current requirement for IAEA safeguards on spent fuel once it reaches the U.S. The probable requirement of IAEA safeguards on spent-fuel storage because the U.S. has offered all nonnational security-related nuclear facilities for international safeguards, indicates that NRC must establish safeguards requirements for such a facility. Since receipt of foreign spent fuel would not substantially increase safeguards efforts as compared with storage of only domestically generated spent fuel, the U.S. may establish U.S./IAEA safeguards concurrently.

REFERENCES

1. Weinstock and Keisch, "Technical Safeguards Issues for Alternative Fuel Cycles," NUREG/CR-1048, BNL-NUREG-25557, August 1979 in Chapter Five.
2. INFCIRC 225/Rev. 1, Table 1, p. 6.
3. "IAEA Technical Safeguards Manual," IAEA/174, p. 33.

IV. ANALYSIS OF EXPORT LICENSING PROBLEMS ASSOCIATED WITH INDIVIDUAL FUEL CYCLES

For a detailed discussion of generic problems, the reader is referred to Chapter Four. The numbers of the fuel cycles refer to those designated in the report by Weinstock and Keisch.[1]

A. Light-Water Reactors

4.1.1. Standard Once-Through PWR using LEU (U^{235}) Fuel. The export process associated with this cycle is the best that has been developed and there appear to be no unique export problems.

4.1.2. Once-Through PWR using LEU (U^{235}) Fuel with Extended Burnup. This fuel cycle appears to present no more problems than that above since the only real differences are that the fuel is slightly more enriched and the annual spent-fuel discharge is reduced.

4.1.3. PWR using LEU (U^{235}) Fuel and Spiked, Self-Generated U-Pu Recycle Fuel. The transfer of plutonium would require special congressional and executive participation. In addition, NRC must deal with environmental, health and safety, and IAEA accountability[2] problems associated with spiked fuels. Reprocessing is also assumed here with its attendant problems.

4.1.4. PWR using Denatured U^{233}-Th Fuel with Recycle of U^{233}. The questions concerning the IAEA accountability techniques and the problems attendant on spiked fuels are present in this fuel cycle. Reprocessing is assumed here which calls for subsequent arrangements granting the prior approval of the U.S.

B. Light-Water Breeder Reactors

4.2.1. Pre-Breeder and Breeder Reactors Based on Shippingport LWBR Type I Modules. This cycle involves the use of undenatured U^{233}-Th fuels. Thorium is contained in a seed blanket. This cycle necessarily involves reprocessing with its attendant problems. IAEA accountability techniques are called into question here. Plutonium must be separated and stored invoking those problems associated with plutonium transfer.

4.2.2. Light-Water Backfit Pre-Breeder Supplying Advanced Breeder. This cycle involves U^{233}-Th fuels and, in addition, requires re-enrichment for makeup of recycled fuel. If this cycle were exported, reprocessing and higher enrichment technologies would be required, making this cycle more sensitive than the others in terms of proliferation risk. In addition, this cycle involves a significant amount of plutonium production and storage.

4.2.3. Light-Water Backfit Pre-Breeder and Seed Blanket Breeder System. Highly-enriched uranium (93%) is used at the front end of this cycle which involves consideration of the adequacy of physical security. U^{233}-Th fuel problems are also present. Reprocessing is assumed with its attendant problems.

C. Heavy-Water Reactors (HWRs)

4.3.1. CANDU-Type Reactor. The use of heavy water has been discussed in part III. Since this is a once-through cycle, reprocessing presents no problems. The slightly enriched fuel considered here is not significantly different from that used in present-day LWRs.

The major problem associated with HWRs is the on-line refueling necessitated by the marginal reactivity of the core. IAEA openly acknowledges that it has no way of accounting for spent fuel comparable to the accounting accuracy in the LWR cycle.[3] A HWR discharges 7 to 10 fuel bundles per day into a spent-fuel pool which is not completely visible to inspectors. The bundles may be placed in sealed containers, but verification of those containers is very difficult. Special fuel bundle monitors are under development and in limited experimental use. It is clear that the adequacy of IAEA safeguards can be called into question in the export licensing of HWRs.

D. High-Temperature Gas-Cooled Reactors

4.4.1. Once-Through Medium-Enriched HTGR. Since this cycle is once-through, the reprocessing issue does not apply. This cycle does not use highly enriched uranium nor plutonium fuels so that physical security is of less significance. Even the spent fuel is low in SSNM content when compared to other fuel cycles.

4.4.2. Recycle Medium-Enriched HTGR. This fuel cycle uses U^{233}-Th fuel which is denatured; it also produces both plutonium, which is stored, and highly enriched U^{233}, which is denatured. Because some unspecified source of U^{233} is required, plutonium and HEU must be present somewhere else in the fuel cycle.

The problems associated with U^{233}-Th fuels are present in this fuel cycle. It is the reprocessing that is of prime importance; because there has been no commercial experience in reprocessing HTGR fuel, this calls into question material accountability and, therefore, the adequacy of IAEA safeguards.

E. Gas-Cooled Reactors

4.4.5. Gas-Cooled Fast Breeder Reactor. This cycle is designed to operate with other cycles because it requires an external source of plutonium. It produces U^{233} for use in other reactors in a denatured form. The issues raised by this cycle are the use of SSNM, reprocessing (coprocessing), and radiation barriers (U^{233}-Th).

F. Liquid Metal Fast Breeder Reactors

4.6.1. Standard LMFBR with Homogeneous U-Pu Core and U Blanket. This cycle involves the use of SSNM fuels and reprocessing. The recovered plutonium is directly usable as weapons material which may call into question the adequacy of physical security and the timely warning standard. Material accountability appears to present no major problems so that the adequacy of IAEA safeguards should not be at issue. An export of these components or materials will be subject to a new Subsequent Arrangement calling for a high degree of congressional and executive involvement.

4.6.2. LMFBR with Heterogeneous U-Pu Core and U Blanket, Pu Spiked Fuel. This cycle involves the problems cited above for 4.6.1. In addition, the issue of radiation barriers arises.

4.6.3. Standard LMFBR with Homogeneous Core and Spiking. This cycle raises the problems mentioned above in 4.6.1. and 4.6.2.

4.6.4. LMFBR with Spiked U-Pu Core, U Axial Blanket, and Th Internal and Radial Blanket. The cycle raises no additional issues to those covered above in 4.6.1. and 4.6.2.

4.6.5. LMFBR with Spiked Homogeneous U-Pu Core and Thorium Blankets. The cycle raises no additional issues to those covered above in 4.6.1. and 4.6.2.

4.6.6. LMFBR with Homogeneous Spiked Pu-Th Core and Th Blanket. The cycle raises no additional issues to those covered above in 4.6.1. and 4.6.2.

4.6.7. LMFBR with Denatured U^{233} Core and Th Blanket. The cycle raises no additional issues to those covered above in 4.6.1. and 4.6.2.

4.6.8. LMFBR Symbiotic Systems. The basic issues encountered for all LMFBR systems are present here.

REFERENCES

1. E.V. Weinstock and B. Keisch, "Technical Safeguards Issues for Alternative Fuel Cycles," BNL-NUREG-25557, Draft Report, August 9, 1979 in Chapter Five.
2. Id., p.3-18.
3. Hans Gruemm, "The Present Status of IAEA Safeguards on Nuclear Fuel Cycle Facilities," *American Law Institute-American Bar Association Nuclear Export Control* (1978), p. 267.

V. CONCLUSIONS

The fuel cycles have been covered both generically and individually. The following conclusions are presented.

A. Radiation Barriers

One effect of radiation barriers is to diminish the accuracy of IAEA safeguards and therefore call their adequacy into question. In addition, the health and safety aspects of excessive radiation would mandate that NRC should assist recipient countries in developing health and safety programs. The environmental effects of radiation barriers will be examined in the Environment Review called for in Executive Order No. 12114. It is not yet clear what type of consideration the ER will receive in the NRC export licensing proceeding. The trade-off between environmental effects and the diminished need for physical security will most likely be addressed. It is also probable that the timely warning criterion may be furthered because of the increased difficulty of processing fuel into weapons material. The value of radiation barriers in diminishing the need for physical security and increasing the difficulty of processing the material into weapons-usable material must be assessed.

B. Coprocessing

Reprocessing is implicit in the concept of coprocessing, and special procedures are required in the issuance of the subsidiary arrangements required for such processes. Coprocessing also eases the timely warning requirement for exports. Coprocessing would have minor effects on material accountability and should, therefore, not call into question the adequacy of IAEA safeguards.

C. U^{233}-Th Fuels

The high level of radiation associated with U^{233}-Th fuels would have serious diminishing effects on material accountability and, therefore, would raise questions about the adequacy of IAEA safeguards. This same high level of radiation would, however, enhance the physical security of the fuel.

D. Denaturing

The major effect of denaturing is to render the fuel, if U^{233} or U^{235}, useless as weapons material without enrichment capability. This has the effect of making the timely warning criterion more acceptable. Most discussion of denaturing is associated with a U^{233}-Th fuel cycle so that use of this technical safeguards measure will involve all those problems associated with U^{233}-Th fuel cycles.

E. Heavy Water

IAEA safeguards for heavy water are not well developed for production facilities and, as such, may cause the adequacy of IAEA safeguards at these facilities to come into question. Safeguarding heavy water at reactors is presently done and reasonably reliable. In addition, heavy water reactors require on-line refueling for which no method of fuel accountability comparable to that for LWRs has been developed, again causing IAEA safeguards to come into question.

An Analysis of The "Timely Warning" Requirement of NNPA

John N. O'Brien
May 1981

TABLE OF CONTENTS

Page

I. Introduction 213
II. Legislative History 213
III. Actual Application of Procedures to Conclude a Subsequent Arrangement for Reprocessing 222
IV. Conclusion 226

ABSTRACT

This report examines the "timely warning" requirement of the Nuclear Non-Proliferation Act of 1978. The objective is to determine to what extent the application of the timely warning requirement will affect the export of alternative fuel cycle technology - most notably reprocessing.

The legislative history of the relevant section of the Nuclear Non-Proliferation Act is analyzed to determine congressional intent. An analysis of actual consideration of the timely warning requirement is made to show that it has not yet been a serious impediment to nuclear export licensing. The report concludes that the timely warning requirement can be met using alternative nuclear fuel cycles if certain issues are properly addressed in the export licensing process.

I. INTRODUCTION

During the examination of alternative nuclear fuel cycle arrangements, a study of the impact of alternative fuel cycles on the NRC export licensing process was conducted. The study revealed that a major obstacle in implementing an alternative fuel cycle would be the application of the "timely warning" requirement for Subsequent Arrangements involving reprocessing of U.S. origin fuels.

The text of the appropriate section of the Nuclear Non-Proliferation Act (NNPA) is:

> b. With regard to any special nuclear material exported by the United States or produced through the use of any nuclear materials and equipment or sensitive nuclear technology exported by the United States....
>
> (2) the Secretary of Energy may not enter into any subsequent arrangement for the reprocessing of any such material in a facility which has not processed power reactor fuel assemblies or been the subject of a subsequent arrangement therefore prior to the date of enactment of the Nuclear Non-Proliferation Act of 1978 or for subsequent retransfer to a non-nuclear weapon state of any plutonium in quantities greater than 500 grams resulting from such reprocessing, unless in his judgment, and that of the Secretary of State, such reprocessing or retransfer will not result in significant increase of the risk of proliferation beyond that which exists at the time that approval is requested. Among all the factors in making this judgment, foremost consideration will be given to whether or not the reprocessing or retransfer will take place under conditions that will ensure timely warning to the United States of any diversion well in advance of the time at which the non-nuclear-weapon state could transform the diverted material into a nuclear explosive device;

This section is referred to either as Section 303(b)(2) of NNPA or Section 131(b)(2) of the Atomic Energy Act as amended.

II. LEGISLATIVE HISTORY

Several recent reports[1] identify the timely warning requirement as an impediment which, in practical terms, may negate the possibility of large scale commercial reprocessing facilities. The large throughputs associated with these facilities make a strict interpretation of the timely warning requirement impossible to meet. This conclusion is supported by several congressional pronouncements accompanying the consideration and passage of the Nuclear Non-Proliferation Act of 1978. However, this is a conclusion reached on the basis of a stricter interpretation of the requirement than was meant or is being used.

The House report in which the International Relations Committee reported the proposed bill stated that:

> It has long been officially recognized that safeguards would not be effective if their warning of diversion did not come well in advance of the final fabrication of the diverted material into an explosive device. It was understood that safeguards functioned essentially as monitoring devices, not locks, but it was hoped that by warning early enough they might still serve

> to deter diversion by raising in the potential violator's mind the risk of an international response capable of frustrating his final purpose.
>
> As stated previously, warning times of acceptable duration can theoretically be achieved in the case of spent low enriched reactor fuel that has been placed under verified storage in countries not possessing reprocessing facilities. Although weapons usable material contained in such fuel, (sic) the total product is highly radioactive, hard to handle, and therefore at least in part self-securing. Should such material be diverted, the monitoring devices would signal the diversion at a point when the plutonium was still many time-consuming steps away from insertion in an explosive device — perhaps years and almost certainly many months. Thus, it can be seen that security depends as much on the condition of the safeguarded material as on the quality of the safeguard devices themselves.
>
> Conventional reprocessing technologies result in direct access to weapons usable material and therefore do not permit timely warning comparable to the more proliferation resistance situation cited above. In fact, such conventional processes as PUREX were designed specifically to produce high quality plutonium for U.S. weapons and not for application as part of the commercial fuel cycle of a non-nuclear weapon state. It is therefore not surprising that modifications are required in order to provide technologies suitable for use in civil atomic energy programs.[2]

The report of the Senate Committees which reported the bill to the Senate was more instructive in their report:

> It is important to note that the standard of timely warning, the basic concept upon which the entire international safeguards program rests, is strictly a measure of whether warning of a diversion will be received far enough in advance of the time when the recipient could transform the diverted material into an explosive device to permit an adequate diplomatic response. The amount of warning time required will vary (and cannot be defined in terms of a certain number of weeks or months) depending on the type of response which would be needed — i.e., in some cases a bilateral response would be adequate, whereas ain (sic) others a coordinated response by several nations and/or international organizations would be necessary. In addition to determining the amount of warning time required, it will be necessary to determine how much time will actually be available under any specific circumstances.
>
> Some technology covered by section 303(b)(2) would provide a greater warning time than others. Another crucial consideration is the quality of the safeguards in place at the facility — especially the probability that the safeguards would in fact detect a diversion and the rapidity with which such detection would occur. Other factors include whether the nation would have limited access to the material because of multinational control or other barriers, whether the fuel is multinationally owned, and whether the nation has access to any facilities which might be needed to convert the diverted material to a weapons-usable form. Also, if the facility is of such a small size that it would take several months for the facility to produce enough weapons-usable material to make a bomb and the nation does not have access to additional material from other sources, timely warning would probably be possible.
>
> Others factors which may be taken into account in determining whether there will be a significant increase in the risk of proliferation are whether the nation is firmly committed to effective non-proliferation policies and is genuinely willing to accept conditions which would minimize the risks of proliferation, whether the nation has a security agreement or other important foreign policy relationship with the U.S., the nature and stability of the

> recipient's government, its military and security position, and the energy resources available to that nation.
>
> It is important to note that the bill requires that "foremost" consideration be given to the question of timely warning. While this implies that the latter will receive the greatest weight among all factors, there may be circumstances that will suffice and a request may be granted even though timely warning is not present. "Timely warning" cannot be controlling in every case. The Committees do wish to emphasize that in the absence of a clear determination that timely warning will indeed be provided, a strong combination of other factors is necessary to compensate for this weakness in safeguards.
>
> Subsection 303(b)(3) provides that the Secretary of Energy shall attempt to ensure that the standards of subsection 303(b)(2) will also be met with respect to subsequent arrangements for reprocessing in the exempted facilities and related retransfers. The approval of reprocessing in the following facilities would come under subsection 303(b)(3): Windscale (UK), Marcoule and La Hague (France), Eurochemic (Belgium), WAK (FRG), and Tokai-mura (Japan). It should be noted that implementation of the standard described in Subsection 303(b)(2) will depend on the combined judgement of the Secretaries of State and DOE, and should not involve formal rulemaking procedures.[3]

Congress was mindful of the possibility of precluding any reprocessing scheme by a strict reading of the timely warning requirements. Later in the same Senate report recognition of this issue lead to the proposal of an amendment to clarify:

> Subsection (b) is a new provision. It presents one of the most serious difficulties the Executive Branch has with the present version of S. 897. First, it would jeopardize negotiation of new, strict nuclear cooperation agreements since an overly strict interpretation of the "timely warning" standard could rule out all forms of fuel processing necessary for future fuel cycle activities. Second, "timely warning" should not be the sole basis for making determinations concerning the acceptability of subsequent arrangements, taking into account the existence of other factors which must be evaluated. Additional factors of importance include the non-proliferation policies of the countries concerned, and the size and scope of the activities involved. Thirdly, as presently written in S. 897, we are concerned that section 303(b) would give the impression that the U.S. is prejudging the results of the international fuel cycle evaluation by apparently ruling out any form of fuel processing. We should not legislate policies giving such an impression since the serious participation of other countries in this program is dependent upon their perception that the study will result in a fair and open minded evaluation. Finally, the Executive Branch is concerned that the implementation of the standard set forth in paragraph (2) might notwithstanding the intent of the Congress, lead to formal rule-making and litigation. We understand that the words "in his view" are intended to preclude this eventuality.
>
> For the reasons above, and while the Administration fully supports the concept of choosing fuel cycle strategies that maximize timely warning, the Administration strongly opposes retention of section 303(b) in its current form.
>
> We consider it crucial, if the Congress wishes to retain this provision that, as a minimum, subsection 303(b)(2) be revised to read: "The Administrator may not enter into any subsequent arrangement for the reprocessing of any such material in a facility which has not processed power fuel assemblies or been the subject of a subsequent arrangement therefore prior

> to the date of enactment of this Act or for subsequent retransfer to a non-nuclear-weapon state of any plutonium in quantities greater than 500 grams resulting from such reprocessing unless in his view such reprocessing or retransfer shall take place under conditions that will safely secure the materials and that are designed to ensure reliable and timely detection of diversion. In making his judgment, the Administrator will take into account such factors as the size and scope of the activities involved, the non-proliferation policies of the countries concerned and the probabilities that the arrangements will provide timely warning to the United States of diversions well in advance of the time at which the non-nuclear-weapon state could transform the diverted material into a nuclear explosive device; and."[4]

This amendment was never adopted, but indicates that the Carter Administration probably does not read the timely warning requirement as strictly as the sponsors of the bill did initially.

During the debates surrounding the consideration and passage of NNPA, the timely warning concept was a frequently discussed topic. Still no clear definition of timely warning can be extracted.

Initially in the House, Representative McCormack pointed out that the Committee Report included "an unrealistic description of the meaning of the requirement associated with the term timely warning."[5] He went on to press for assurances from the sponsors and floor managers of the bill that a legislative history be established for the relevant section during the amendment process.

During the initial introduction of the Bill to the House the timely warning requirement was defined and redefined more or less consistently with the correspondence to explosives fabrication times. Discussions indicate that the initial thinking in the House was precisely to prohibit the use of currently available reprocessing techniques. Congressman Findley expressed NNPA his view of the requirement:

> Therein lies the danger of reprocessing, which separates plutonium from used reactor fuel, enables a nation to have continuously on hand weapons-usable material. Since a nation, without violating the Non-Proliferation Treaty, may have quietly conducted atomic weapons research, it need only have access to reprocessed plutonium in order to assemble a weapon within a matter of days. In a crisis situation, the temptation to explode a bomb will be great for a nation with the near-weapons capability reprocessing provides.
>
> Present safeguards, when applied to reprocessing, do not, therefore, permit timely warning. Knowing that our nuclear exports have brought a nation only to the verge of atomic weapons capability is not enough. As a responsible supplier we need sufficient warning time to deter the manufacture of a bomb.
>
> Therefore, we must devise safeguards that, when applied to reprocessing, will provide reliable, timely warning. Promising technologies exist which, if pursued, may satisfy this standard. Diluting or mixing plutonium to make it inaccessible are two possibilities. This bill, by defining the standard that safeguards must meet intends to stimulate development of these new technologies. Until that time, we must defer the export of reprocessing facilities.[6]

McCormack indicated his views during the next House discussion of NNPA by stating that:

> It is vitally important that the standard....against which retransfer and reprocessing safeguards are evaluated not leave INFCE participants with the impression that the United States has unilaterally and in advance established a standard in defiance of any concensus that may be reached through INFCE.
>
> As Joseph Nye, Deputy Under Secretary at State testified before Senator Church: ....the INFCE program can be successful only with the participation of other nations, and their meaningful participation depends upon their perception that the program is to be an open and objective study.
>
> This amendment is designed to clearly support what is implicit in the bill; namely, to leave the door open to going ahead with the reprocessing of spent fuel by foreign nations under mutually agreed to conditions; and signal to INFCE participants that the United States will fully participate in and abide by the international concensus on the best course to assure maximum proliferation resistance while preserving international ability to extract the valuable residual energy associated with spent fuel.[7]

Findley was then asked to clarify his concept of timely warning and signs of compromise appear to surface:

> ....the warning time associated with alternative reprocessing technologies would be hard to quantify but the concept represents a continuum, progressing from undesirably short times associated with processes that involve separated plutonium to longer times for processes that retain uranium and most of the fission products present in irradiated spent fuel.
>
> One needs to have warning times that are ample enough to give supplier states or the international community an opportunity to orchestrate an effective response to an act of diversion and to be able to do this, moreover, before the violator is able to transform his stolen material into bombs.
>
> It has always been the hope of the committee that the Secretary of Energy would insist on a warning period that could be measured, however roughly, in months, not weeks or days. Clearly, we aspire to warning times that are as long as possible.
>
> I should add in this connection, however, that once such warning time has been attained, it may be possible to extend timely warning further but only in a way that adds small additional increments of time at successively higher and perhaps prohibitive levels of cost. Thus, the committee recognizes the needs to gage the degree of improvement in warning time that alternative reprocessing technologies provide in light of such considerations.
>
> I would assume that the committee expects the Secretary of Energy to interpret the term "proliferation risk" in a manner consistent with the underlying philosophy of this act. For example, he should not confine his inquiry exclusively to increased proliferation risk in the country performing the reprocessing or receiving the reprocessed product, but should examine, as appropriate under the circumstances, the potential impact of his determinations on other countries as well.
>
> Any substantial diminution in the technical constraints now limiting the ability of a nonnuclear weapon state to fabricate nuclear weapons would amount to a significant increase in the risk of proliferation. Providing a major additional source of weapons usable material, for example, would have this result.
>
> The committee's overall goal is at least to preserve, and where possible, enhance, the somewhat fragile margins of security that prevail today.
>
> I assumed that we are all agreed that the purpose of this provision is not

> to outlaw any kind of fuel processing indefinitely, but rather to assure that when U.S. supplied fuel is processed it will be done within a genuinely secure and safeguardable context.
>
> Should reprocessing become necessary, technologies will be on hand that provide greater security; technologies, in other words, in which the entire world can have greater confidence. It seems to me that that is terribly important not just for international stability, but for the nuclear industry as well.
>
> What we are really saying then is that timely warning helps to provide the world with the reassurance that some margin of security would be retained even if peaceful use guarantees and promises were to be broken.[8]

The tone is more conciliatory to reprocessing interests and constitutes the beginning of the emphasis shifting, to some degree, away from the "device construction" time correspondence and more to technical safeguards limitations and the need for better safeguards methods.

During the initial discussions of the timely warning requirements, Glenn provided the basis for the new modified views on reprocessing:

> Until recent years, non-proliferation efforts were based on an approach that was deemed successful as long as it forestalled the specific manufacture or acquisition of nuclear weapons. It has become clear, however, that this approach is too narrow. Our concerns about proliferation must be broadened to include the capability to quickly procure a nuclear explosive device. The basic reason for this lies in the continuing spread of those types of nuclear technology adaptable to the production of weapons-grade fissionable material.[9]

In later remarks Senator Glenn further pursued a definition for timely warning:

> In reviewing the content of the bill, Mr. President (President of the Senate), I would be remiss if I did not highlight one of the key provisions, namely, the test to be used by the Secretaries of Energy and State in determining whether to approve a subsequent arrangement for reprocessing of U.S. fuel by a nonweapon state. This test provides that a finding of "no significant increase of the risk of proliferation" must precede a decision to approve reprocessing and further that "foremost consideration" must be given to the principle of "timely warning" in making such a finding.
>
> In my earlier remarks, I alluded to this principle, which in its simplified form, states that the effectiveness of safeguards is a function of the amount of time available between a decision by a non-weapon state to divert fissionable material and the fabrication of a nuclear explosive device. If insufficient time exists between those events for an appropriate and effective political, diplomatic, or military response to be made, then "timely warning" is deemed not to be present, and thus effective safeguards are lacking.
>
> The elevation of the "timely warning" principle to statutory status in dealing with the nuclear proliferation problem is, in my view, a very significant step forward in safeguards.[10]

Senator McClure raised several objections to NNPA shortly after that including the use of the time warning requirement:

> One such subsection in particular has been the source of a great deal of confusion and, I believe, future difficulty in our international relations. This is subsection 303(b) which establishes new procedures for the U.S. approvals required in many of our bilateral and multilateral agreements for foreign nations to reprocess or transfer their nuclear wastes. The subsection

> establishes a new statutory standard for such approvals based primarily on the notion of so-called "timely warning" of any diversion activities within a foreign nation involving U.S. fuels. While this section represents the highest of moral values and motivations on the part of the sponsors, it is clear to me that the specific timely warning test will lead to a great deal of diplomatic difficulty for the United States in the future.[11]

Senator Glenn subsequently used the testimony of NRC Commissioner Gilinsky to attempt to bound the timely warning concept:

> The bill before the Committee attempts to correct this safeguards deficiency. Section 303(b)(2) would allow U.S. approval of certain foreign activities involving nuclear explosive material derived from our exports — primarily plutonium — only if we can count on getting warning of attempts to misappropriate it well enough in advance to do something about it. It is entirely reasonable to apply this classic alarm standard to plutonium. Should the Congress decide not to do so, or to apply it in some cases and not in others, it should be clear that in so doing it is dropping the requirement for effective safeguards, relying instead solely on promises that U.S. materials will not find their way into nuclear weapons. Retention of international inspectors in this case can provide little more than cosmetic comfort; there is no deterrent function they can perform should promises be abandoned in the face of real or concocted security threats.
>
> The House Committee on International Relations noted in its report on the bill that warning times for safeguards over plutonium should not be allowed to deteriorate below those now in effect for light water reactors. I find myself in agreement on this point; timely warning is central to safeguards, and we would retreat from our existing warning margins at our peril.[12]

In opening the final session for Senate debate on NNPA Senator Glenn attempted once more to define the requirements of timely warning. He stepped far away from sole consideration of device fabrication time and delineated other factors which may be used to justify reprocessing where a strict reading of timely warning could not be satisfied.

> I think it is important to note that the standard of timely warning, the basic concept upon which the entire international safeguards program rests, is strictly a measure of whether warning of a diversion will be received far enough in advance of the time when the recipient could transform the diverted material into an explosive device to permit an adequate diplomatic response.
>
> The amount of warning time required will vary depending on the type of response which would be needed — that is, in some cases a bilateral response would be adequate, whereas in others a coordinated response by several nations and/or international organizations would be necessary. In addition to determining the amount of warning time required, it will be necessary to determine how much time will actually be available under any specific circumstances. Some reprocessing technology would provide a greater warning time than others.
>
> Another crucial consideration is the quality of the safeguards in place at the facility — especially the probability that the safeguards would in fact detect a diversion and the rapidity with which such detection would occur. Other factors include whether the nation would have limited access to the material because of multinational control or other barriers, whether the fuel is multinationally owned, and whether the nation has access to any facilities which might be needed to convert the diverted material to a weapons-usable form. Also, if the facility is of such a small size that it would take

> several months for the facility to produce enough weapons-usable material to make a bomb and in addition the nation does not have access to additional material from other sources, timely warning would probably be possible.
>
> Other factors which may be taken into account in determining whether a subsequent arrangement for reprocessing will lead to a significant increase in the risk of proliferation are whether the nation is firmly committed to effective non-proliferation policies and is genuinely willing to accept conditions which would minimize the risk of proliferation, whether the nation has a security agreement or other important foreign policy relationship with the United States, the nature and stability of the recipient's government, its military and security position, and whether the nation has any practicable alternatives to reprocessing in meeting its energy needs. In other words, Mr. President, there is nothing in this section of the bill on subsequent arrangements that prohibits, permanently or unconditionally, the reprocessing of spent fuel by other nations.
>
> I repeat that: There is nothing in this section of the bill on subsequent arrangements that prohibits, permanently or unconditionally, the reprocessing of spent fuel by other nations.
>
> It is important to note, however, that the bill requires that foremost consideration be given to the question of timely warning. This implies that the latter will receive the greatest weight among all factors. Although this does not require denial of a request when timely warning is not clearly determinable, the language suggests that in the absence of a clear determination that timely warning will indeed be provided, a strong combination of other factors would be necessary to compensate for this weakness in safeguards. It then follows that a decision to approve reprocessing in the absence of such a clear determination would be an unusual event that should be carefully scrutinized.[13]

Senator McClure restated his uneasiness with the use of the timely warning requirement by stating that NNPA must leave room for reconsideration of the requirement:

> The issue of timely warning is one of the most difficult that we confront, not just in terms of the acceptance or rejection of our efforts by others who are involved in negotiations or dealings with the United States, but also in terms of the techniques by which we can know, and whether or not we can accept assurances, or whether or not we can verify these requirements. The technical questions associated with timely warning, are among the most difficult we have.
>
> I think the sponsors and the floor managers of this legislation would agree that this whole issue of timely warning is one of the most complex and one of the most potentially difficult ones with which we have to deal....Certainly, the United States is in no position to dictate to the rest of the world what the results will be 2, 3, 4 or 5 years from now. We simply do not have that kind of dominance in the market anymore. But, we can have a profound influence on the discussions of these negotiations and whatever the results of those negotiations may be, if they are carefully wrought and reasoned and have international support....I suspect that the Senator from Ohio (Glenn) would agree with me that we are exercising our best judgment now. If our best judgments later indicate a slightly differing result, the Congress can reflect that at that time. Congress does not need to attempt at this time to anticipate all of the results of the negotiating process in those various forums over the next couple of years.[14]

Senator Glenn agreed which left the task of defining timely warning to a case-by-case basis.

> I thank the Senator from Idaho for his comments and I agree with him on this completely in several respects. First, in the difficulty of assessing timely warning. It is an imprecise phrase. We cannot qualify it with specific numbers of so much timely warning because every single case, as the Senator is well aware, varies and has to be subject to scrutiny on its own particular merits or demerits, whichever the case may be.
>
> Yet even realizing that, the difficulty of establishing timely warning, and the whole worldwide network of looking at the nuclear plants around the world, IAEA's look at these plants, nuclear suppliers look at their own and other people's plants, the international fuel cycle evaluation, which the Senator from Idaho referred to, all of these things, base their views on warning time in each individual situation. So warning time might vary in one situation from a matter of a very few days, or perhaps theoretically even hours, as opposed to perhaps years, requiring fabrication of a nuclear weapon, in the situation existing in other countries.
>
> So it is very difficult, and I agree with the Senator from Idaho completely on that.[15]

Concern in the Senate over prejudicing the outcome of INFCE led to the inclusion of an amendment which undercuts the notion that reprocessing is precluded by NNPA.

Senator Dole:

> My concern is that we must show the world that the United States means to negotiate in good faith with other countries and that we are not prejudging the outcome of discussions that require equal participation with other countries.
>
> Mr. President, the amendment I am offering corresponds to wording that is already contained in the House bill.

Senator Percy:

> Mr. President, I first wish to state that S. 897 does not prejudge the results of the international fuel cycle evaluation.
>
> What I wish to do is just ask my distinguished colleague, the author of the amendment, whether his understanding is the same as mine of this amendment. I understand that the amendment, which has been adopted by the House of Representatives, simply underscores the fact that S. 897 does not prohibit reprocessing permanently or unconditionally and that the international fuel cycle evaluation should include a full and fair examination of all relevant technology.

Senator Dole:

> Yes.

Senator Percy:

> That is the proper understanding of the floor manager of the bill. I checked this out with Senator Glenn, and I have no objection to it.

Senator McClure:

> As Senators will recall, the April 7, 1977, Presidential policy statement on nuclear power specifically deferred commercial reprocessing for the near future, but it did not have the effect of a Presidential policy totally in opposition to reprocessing at some point in the future. Therefore, it is valuable to ensure that this statute does not imply and cannot be judicially or administratively construed to have the effect of a congressional statement prohibiting reprocessing.
>
> I think there are domestic political and foreign diplomatic advantages to having the statute include such a disclaimer on any prohibition of reprocessing at this time.
>
> I think the timely warning test in section 303 (Subsequent Arrangements) has been established by this amendment and in identical form as

> that contained in the House bill. I hope that the amendment will be adopted, and I commend my friend from Kansas for having proposed it.

Senator Percy:

> Mr. President, while the bill does not prejudice future choices, it does require, as I am sure we all do, that we must be certain that we do not sanction reprocessing under conditions which would result in a significant increase in the risk of proliferation. With that statement I simply concur with all of the utterances that have been made and assurances given by the distinguished Senator from Idaho, and I am certain that they coincide with the opinions of the distinguished Senator from Kansas.[16]

III. ACTUAL APPLICATION OF PROCEDURES TO CONCLUDE A SUBSEQUENT ARRANGEMENT FOR REPROCESSING

Several retransfers for reprocessing have been approved and at this time the material is being transported to the reprocessing facilities. The two examined here are the retransfers of Japanese spent fuel to the U.K. and to France. Although these reprocessing facilities are "grand-fathered" they still must meet the timely warning requirement.[17]

The process for concluding a subsequent arrangement starts with a form called the MB-10 which is filed with DOE by the transferor and transferee stating the needs for and purpose of the proposed retransfer. This document is used to support the Analysis of Request which is provided by DOE to Congress for the specified waiting period (15 session days) during which Congress can void the proposed Subsequent Arrangement. As a result, it is the analysis of the request which contains the justification for meeting the timely warning requirements. The internal mechanism for final determination of timely warning compliance is a memorandum from the Under Secretary to the Office of International Affairs (OIA) stating that the requirement has been met for the proposed retransfer.[18] OIA then prepares the analysis document for Congress and 15 session days later the subsequent arrangement becomes valid.

The form of an Analysis of Request is to first specify the exact nature of the material being retransferred and the purpose of the retransfer. There are sections discussing IAEA safeguards implementation, non-proliferation issues, and physical need to retransfer spent fuel. There are analyses of section 131 (subsequent arrangement requirements), section 127 (immediately applicable export criteria) and section 128 (full scope safeguards) of the Atomic Energy Act as amended by NNPA. Of particular interest here is the section 131 analysis which includes the timely warning determination:

> The subject reprocessing will occur in the THORP plant planned for construction at Windscale. The Executive Branch has evaluated this particular proposal under Section 131b(2) (timely warning section). Within this framework, the Department of Energy has reached the judgment that the proposed retransfer will not result in a significant increase of the risk of proliferation beyond that which existed at the time that approval was

requested. The Department of State, as required by this Section of the law, has reached this same judgment and ACDA has concurred with this view.

In reaching this judgment, we gave due consideration as to whether we could have timely warning "of any diversion well in advance of the time at which the non-nuclear-weapon state could transform the diverted material into a nuclear explosive device." We believe this judgment is supported, among other factors, by the non-proliferation credentials of the countries involved, where the reprocessing will occur, and the fact that the derived plutonium may not be retransferred to Japan or any other state without explicit U.S. consent.

More specifically, the plutonium separated in the reprocessing facility will remain in the United Kingdom until it is disposed of in accordance with terms that are acceptable to the United States. In cases such as this the United States has been controlling retransfers within the European Community of separated special nuclear material by a commitment from the non-Euratom shipping country:

(1) That the spent fuel will be retained by the processor until it may be reprocessed and that, thereafter, the recovered special nuclear material will be retained by the reprocessor subject to the direction of the shipper. (2) That any direction by the shipper to the reprocessor for the transfer or use of the recovered special nuclear material will be subject to **the prior approval** of the United States.

The non-Euratom shipping country agrees to these conditions based upon the processor's contractual pledge to hold the spent fuel, reprocess it, and then use or transfer the recovered material only in accordance with the shipper's instructions. In the subject case, Japan has assured the United States that it agrees to the above conditions.

Also, the prior approval of the United States would be required for any transfer of the produced material to a country outside Euratom. Such a transfer would constitute a new "subsequent arrangement" pursuant to Section 131 of the Atomic Energy Act and as such would have to be considered on its own merits by the Executive Branch and then the Congress. Thus, the proposed retransfer of Japanese spent fuel to the United Kingdom will not prejudge the U.S. position concerning disposition of the plutonium. While a return to Japan is contemplated by Japan for use in its advanced reactor research program, this will depend on U.S. approval which will only be granted under terms consistent with the provisions of the Non Proliferation Act including Section 131. The United States intends to emphasize this point to the other governments concerned and to underscore that it shall remain the U.S. policy to consider retransfer proposals for reprocessing on a case by case basis. Moreover, we intend to emphasize that our approval of this retransfer in no way constitutes a policy endorsement of the THORP plant. We believe our case by case approach avoids any implication that we are giving any generic endorsement to conventional PUREX reprocessing which could serve to influence non-nuclear weapon states to acquire facilities of a comparable nature, or encourage them to believe that the United States will adopt a relaxed attitude towards subsequent retransfer requests. This case by case approach also enables us to relate our approvals of such retransfers to ongoing developments in the States concerned including the evolution of non-proliferation policies.

Finally, a number of other factors were considered that are relevant to the judgment that the proposed retransfer will not result in a significant increase in the risk of proliferation. In particular, the United Kingdom is a party to the NPT and has developed impressive credentials in fostering rigorous non-proliferation policies. The likelihood that the UK will shift away from such attitudes is judged to be highly remote. Japan also is an NPT party and can be expected to support the development of arrangements that are supportive to non-proliferation. Moreover, the British Foreign Secretary, Mr. Owen, has indicated that the UK intends to take the results of

> the International Nuclear Fuel Cycle Evaluation (INFCE) into account in its detailed planning of THORP to reinforce its non-proliferation policies. Also, it is understood that the THORP facility will be subject to safeguards pursuant to the United Kingdom's voluntary safeguards agreement with the IAEA and to physical security measures meeting the currently applicable international guidelines. Consequently, these factors support a judgment that the subject spent fuel and produced plutonium to be stored in the UK is unlikely to be subject to any diversion by a non-nuclear-weapon state or a terrorist group.[19]

There is no discussion of a quantified warning time and the timely warning requirement is satisifed by the characterization of the United Kingdom as "party to the NPT and has developed impressive credentials in fostering non-proliferation policies." In addition, another Subsequent Arrangement will be necessary to return the separated plutonium to Japan. This, presumably, reserves the right of the U.S. to scrutinize Japan's non-proliferation credentials at a latter date. This may be an inducement to Japan to continue "impressing" the U.S. and clearly qualify for reprocessing under the same characterization.

Several days after the Analysis for Request documents were transmitted to Congress, Joseph Ney delivered testimony to the House International Relations Subcommittee on International Economic Policy and Trade concerning administration policy on approval of Subsequent Arrangements. In his testimony he stated:

> In addition to the requirements of the law, the President has established policy criteria regarding requests for retransfer for reprocessing. Approval of such requests has been on a case-by-case basis when there is clear showing of need (i.e. spent fuel congestion) and, then only provided that the U.S. retains the right of approval over subsequent transfer of the separated plutonium, and the requesting country has made appropriate efforts to expand its spent fuel storage capacity. Three approvals have been made under these criteria since April 1977.[20]

In justifying the satisfaction of the timely warning requirement in the Japanese retransfer he remarked that:

> We believe this conclusion is supported, among other considerations, by the non-proliferation credentials of the countries involved, by where the reprocessing will occur, and by the fact that the derived plutonium may not be returned to Japan or transferred to another country without specific U.S. consent.[21]

Nye later summarized the Administration's policy as approval of retransfers for reprocessing:

> For the interim INFCE period, we will approve retransfer for reprocessing on a case-by-case basis under the following carefully defined conditions:
>
> - Requests involving a clear showing of need (i.e. spent fuel congestion) will continue to be approved on a case-by-case basis if the requesting country has made appropriate efforts to expand its spent fuel storage capacity;
> - Requests not meeting the physical need standard, but involving contracts predating 1977, such as the Kansai request, will be considered for approval on a case-by-case basis if the requesting country is actively cooperating in exploring more proliferation resistant methods of spent fuel disposition and approval will directly further major non-proliferation objectives;

> - We will continue to require prior U.S. approval over the subsequent transfer, including return to the country which has title to the material, of any plutonium resulting from the reprocessing.[22]

The International Relations Committee was sufficiently concerned to question these conclusions but did not reject the proposed retransfer. Several weeks after Nye's testimony Congressman Bingham sent a letter to both Cyrus Vance, Secretary of State, and James Schlesinger, Secretary of Energy, requesting a clarification of Administration policy and expressing concern that the U.S. may approve all such requests.

> Perceptions such as these can have an important, practical impact on the success of our policy. If our standards, like timely warning, appear on the verge of collapse, there will be little incentive for governments and utilities to initiate the kind of fundamental changes necessary for satisfying these standards. Indeed, we believe the temptation to settle on inexpensive and cosmetic revisions will be very great. Given this, U.S. firmness over the prospective use of its sensitive materials seems more necessary than ever as a way of supplying the impetus for genuine fuel cycle and institutional change. As the Administration sometimes perhaps too obligingly points out, U.S. leverage in this capacity is limited; though we would argue that it is much larger — particularly during this initial and formulative phase —than is sometimes supposed. We believe that the cost of taking firm action now should seem slight when viewed in contrast with the costs of trying to conduct policy in a world where scores of states have nuclear arms. But since these latter dangers are more distant and less easily quantifiable, the full weight of the comparison is often lost. This is why a more tangible near-term stimulus will no doubt be required.[23]

Bingham requested that DOE provide the Committee data projecting future retransfer requests, identification of foreign reactors with imminent reracking capacity problems, information on the data used in determining capacity problems, descriptions of major tenants in existing contracts, and identification of possible U.S. sites for foreign spent fuel storage. Possible U.S. storage sites, requests for retransfers pending and new requests likely to be forth coming are the subjects of Annexes A, B, and C attached to this memo.

In his response Dale Myers, then Under Secretary of DOE stated that:

> We found ourselves to be in complete agreement with a number of the points that were made in your thoughtful letter. We believe that they will prove most valuable in improving our review procedures as well as the reports that we submit to Congress on such applications. However, in our view, the decisions that the Administration took on the recent Kansai and TEPCO cases were appropriate, and we do not believe one should infer as a consequence that the United States is now lessening its resolve in the non-proliferation area. On the contrary, we believe that U.S. approval was justified in both cases and, indeed, that a U.S. refusal to accommodate these particular requests could have proven counterproductive to our non-proliferation efforts.
>
> Having said this, however, I should emphasize that it is our intention to continue to bring close scrutiny to bear on such cases so as to assure that U.S. approval only will be given when it is in our non-proliferation interests. Specifically, we intend to continue to review requests for such approvals on a case-by-case basis in accordance with the criteria that have been presented to your Committee. Applications will be approved if they meet the criterion of physical need and if the country is cooperating in expanding its

> storage capacity. Applications not meeting this standard will be considered for approval also on a case-by-case basis by the interested agencies, only if they are to occur pursuant to reprocessing contracts entered into prior to April 1977 and if approval would advance specific, major non-proliferation objectives.
>
> We recognize that these modified criteria create a potential basis for approval of many of the requests we are likely to receive over the next year or so. However, before one concludes that this constitutes an unwise relaxation of U.S. policy, two points must be considered.
>
> First, while approval of all MB-10 requests under pre-1977 reprocessing contracts can potentially be granted under the modified guidelines, such approval is by no means automatic. On the contrary, we intend to give all such requests careful case-by-case review and to look at each application on its merits. Also, when the guideline recognizing preexisting contracts is to be applied, we shall adhere to the stipulation that the U.S. must gain an important non-proliferation benefit from the approval. This factor will be impressed upon each applicable requesting country.
>
> Second, we intend to preserve effective U.S. controls over the disposition of the plutonium produced through such arrangements. Retransfers of plutonium to originating countries, like Japan, will be regarded as new subsequent arrangements and you can be assured that we will give full attention to the standard set forth in Section 131b of the Atomic Energy Act of 1954, as amended.
>
> We cannot, of course, guarantee the success of this overall approach. Nevertheless, it has seemed more promising to us than an alternative of adhering to an uncompromising policy which could create serious tensions with the very nations whose cooperation we need in the non-proliferation area.[24]

IV. CONCLUSION

It is clear that the parameters considered in determining the sufficiency of timely warning, contrary to a literal reading of the NNPA, have little to do with the "device fabrication time" standard as has been widely believed. In fact, it appears that a history of cooperation with the U.S. in fostering non-proliferation objectives is the central factor. This is an obvious response to an inability to meet a strict interpretation of the meaning of timely warning. Congressional objections to this policy have not been forthcoming and it is clear from the legislative history and executive policy surrounding the question of retransfer for reprocessing that the post-INFCE period will be different from the past.

Language used in Congressional debates indicates that reprocessing is expected to be dependent on the necessities of particular cases. Also, that the timely warning requirements is more in the nature of a "best available technology" standard than an absolute measure of fabrication times for explosive devices.

All things considered, it appears from the history and administration of the requirements of NNPA that retransfer for reprocessing will be permitted by the U.S. under conditions which are aimed at assurance, *to the maximum extent feasible,* of strong safeguards. Both the spirit and the letter of NNPA provide that the U.S. will cooperate with nations in further development of nuclear energy technology if they demonstrate sincere concern and appreciation for U.S. non-proliferation objectives.

In fact, the Departments of Energy and State last spring approved several retransfer requests, three for Japan, one for spent fuel from two Swedish reactors, and two for Swiss retransfers. The shipments of spent fuel under these Subsequent Arrangements has already occurred. This fall two more Japanese requests were granted and two Spanish requests have been approved and only await Congress' tacit approval. All of the Japanese requests were based on contracts existing prior to April 7, 1977 and the rest are justified by need for storage capacity.[25]

The device construction time is not referred to in any of these cases. The policy has become not to deny reprocessing (all the above involve French or British reprocessing), but rather to bar transfers of separated plutonium subsequent to reprocessing.

The relationship that large reprocessing throughputs have with device construction times is never an issue and will probably never be one. As a result it must conclude that foreign reprocessing is totally justifiable under the conditions of NNPA.

REFERENCES

1. De Montmollin and Weinstock, "The Goals of Measurement Systems for International Safeguards," presented to the ANS 12/79, pp. 7-8; Mendershausen, "International Cooperation in Nuclear Fuel Services: European and American Approaches," RAND P-6308, 12/78, pp. 15-22.
2. Nuclear Antiproliferation Act of 1977, Report together with additional views reported by the Committee on International Relations, August 5, 1977, House Report No. 95-587, p. 20.
3. Nuclear Non-Proliferation Act of 1977, Report together with additional views to accompany S.897, Report by the Committee on Government Affairs, the Committee on Foreign Relations, October 3, 1977, Senate Report No. 95-467, pp. 11-12.
4. Id., pp. 47-48.
5. Legislative History of the Nuclear Non-Proliferation Act of 1978, H.R. 8638, Publ. L. No. 95-242, prepared by the Congressional Research Service for the Committee on Governmental Affairs, U.S. Senate, Jan. 1979, (remarks of Congressman McCormack, 9/22/77), p. 879.
6. Id. (remarks of Cong. Findley, 9/22/77), pp. 878-79.
7. Id. (remarks of Cong. McCormack, 11/4/77), pp. 858-59.
8. Id. (remarks of Cong. Findley, 11/4/77), p. 862.
9. Id. (remarks of Sen. Glenn, 2/2/78), p. 770.
10. Id. (remarks of Sen. Glenn, 2/2/78), p. 773.
11. Id. (remarks of Sen. McClure, 2/2/78).
12. Id., Statement of Commissioner Gilinsky as quoted at p. 796.
13. Id. (remarks of Sen. Glenn, 2/7/78), pp. 634-35.
14. Id. (remarks of Sen. McClure, 2/7/78), p. 636.
15. Id. (remarks of Sen. Glenn, 2/7/78), p. 637.

16. Id. (floor debate) p. 711.
17. See note 3 and associated text.
18. Personal communication, Michael McDonough, Office of International Affairs, U.S. DOE, 12/13/79.
19. Analysis Request Number RTD/EU(JA)-20 for Retransfer for Reprocessing, 9/22/78, pp. 3-5; this language is echoed almost verbatim in the analysis of France's satisfying the timely warning requirements, see Analysis of Request Number RTD/EU(JA)-21 for Retransfer for Reprocessing, 9/29/78, pp. 3-5.
20. Testimony of Joseph S. Nye, Jr., Deputy to the Under Secretary for Security Assistance, Science, and Technology, before the Subcommittee on International Economic Policy and Trade, House Committee on International Relations, Oct. 3, 1978, p. 4.
21. Id., p. 7.
22. Id., p. 13.
23. Letter from Congressman Bingham and Findley to Cyrus Vance, Secretary of State, November 14, 1978.
24. Letter from Dale D. Myers, Under Secretary to Congressman Bingham, January 26, 1979.
25. Personal communication, Michael McDonough, Office of International Affairs, U.S. DOE, 12/19/79.

Chapter Three

Legal Concerns Arising From Advanced Nuclear Fuel Cycles

Legal concerns arise from the use of advanced fuel cycles under consideration. These concerns stem primarily from the use of fissile nuclear material which can be fashioned into an explosive. Currently no large scale commercial trade in these materials takes place in the U.S., but most advanced fuel cycles will ultimately utilize them.

The first report examines the concept of detecting and locating fissile nuclear material and considers the spiking of nuclear fuels to enhance detectability. After describing the technical capabilities of detection equipment, an analysis of legal concerns such as search and seizure law and due process is presented.

The second report details the various legal implications of spiking of nuclear fuel in order to prevent lethal theft. Common law, statutory law, and legal arguments on liability are discussed at length.

Detection of Special Nuclear Materials at Portal Monitors and Location of Contraband Nuclear Materials: Legal and Technical Problems

John N. O'Brien
NUREG/CR-2217
January 1981

TABLE OF CONTENTS

		Page
I.	Introduction	233
II	The Concepts of Detection and Location	234
III.	Spiking for Detection	236
IV.	Spiking for Location	243
Appendix A:	The Warrant Requirement and Exceptions	260
Appendix B:	The History of Emergency Legislation	264

ABSTRACT

This report examines the issues of how reliably special nuclear materials (SNM) can be detected during attempts to steal it and how recovery techniques initiated because of a confirmed theft may affect civil liberties.

Section II addresses the technical abilities and limitations of detecting SNM under both controlled and uncontrolled conditions. The concepts of "spiking" and shielding are examined.

Section III discusses the legal requirements and technical limits on detecting small quantities of SNM during smuggling attempts. Assessments are made concerning the type of detectors most desirable and which forms of SNM could logically be spiked to enhance their detectability. Administrative and legal restrictions on portal searches and emergency site responses to SNM losses are comprehensively examined.

Section IV examines the activity of searching for and recovering contraband SNM. Methods for searching, sources of difficulty, and estimates of

sensitivity are made. (All data are unclassified.) The legal implications of area and perimeter searches are examined with particular regard to problems of search and seizure law.

I. INTRODUCTION

This report is part of a larger investigation of the various safeguards aspects of alternative nuclear fuel cycles considered in the NASAP exercise. Its purpose is to examine the potential for spiking nuclear materials to enhance their detectability and locatability. The general concepts and administrative constraints on detection and location are also examined.

A. Statement of the Problem

The prime component of any safeguards system for the protection of special nuclear material (SNM) is material accountancy (MA). This involves random and systematic sampling and chemical analysis as well as nondestructive assay to verify the quantity and type of nuclear materials present in a facility. MA is not a preventive tool, however, and is useful only to confirm that material is present or absent. It is a deterrent to diversion or theft of SNM in that once the material is missing the loss will, with some certainty, be made known in a timely fashion.

Because such a discovery of missing SNM may not be in time to prevent theft or diversion, containment and surveillance (C/S) measures are employed to impede unauthorized removal of SNM. C/S measures generally take advantage of passive structural properties of the facilities (e.g., vaults, limited doorway access) and rely on active programs to detect unauthorized movements of SNM as they occur (e.g., criticality monitors, controlled access, doorway monitors). The efficiency of doorway and portal monitoring systems in detecting SNM as it passes through a designated perimeter within which all SNM must be accounted for is integral to the integrity of the C/S system and, therefore, the overall safeguards system.

A further safeguards measure which may function subsequent to the known theft or diversion of SNM is the location, recovery, and return of the material to its authorized location. The exact efficiency of measures to locate contraband SNM is classified; however, estimates of radioactive emissions from various types of SNM and candidate spikants have been compiled and reasonable assumptions concerning locatability can be drawn from these data.

B. Purpose of the Study

NASAP studied various safeguards measures to enhance the protection of nuclear materials in the nuclear fuel cycle from diversion or theft. The concept commonly called "spiking" has been extensively examined in various studies addressing the choice of preferred safeguards measures. However, the wide attention spiking has received is misleading in that only deterrent spiking (lethal levels of radioactivity added to or retained in fuels) received attention in the NASAP study. Two other concepts, detection spiking and location spiking, have been discussed in past literature.

In detection spiking, the level of certain emissions of radioactive materials is raised so that the passage of concealed SNM may be more reliably detected with radiation monitors. Systems designed to do this are called portal or doorway monitors.

Location spiking also raises the emission levels of SNM, but for the purpose of detecting them at distances far greater than in a doorway or portal situation. Ideally, the detection limits for devices used to locate contraband SNM should be sufficient to be effective at distances and under other conditions which appear realistic in terms of a post-theft or diversion search.

The purpose of this study is to examine the potential use of detection and location spiking for nuclear fuels, as well as to examine detection and recovery as activities under U.S. law. Methods suggested in the literature are briefly reviewed and potential plans for their use and administration examined.

C. Scope of This Study

This report is one of several performed as part of the broad task of evaluating generic safeguards variations and specific alternative nuclear fuel cycles which were considered in the NASAP exercise. As such, no further experimentation or data collection is attempted and all data used are extracted from the existing literature. Several authors have suggested the need for further study in the reliability of detection and location spiking and have expressed the view that these measures may enhance nuclear material safeguards. This study addresses those views in the context of considering alternative proliferation-resistant nuclear fuel cycles.

II. THE CONCEPTS OF DETECTION AND LOCATION

A. Looking for Sources

All special nuclear material (SNM) is radioactive and emits either gamma rays or neutrons or both. These radioactive emissions may provide a method for "observing" the presence of SNM by using radiation detectors. The detectors contemplated in this report are designed for surveillance at controlled access points out of an area containing SNM and for locating SNM after it has been removed from the area in an unauthorized fashion. Employment of both these measures is, in effect, a furtherance of the defense-in-depth concept.

The specific types of SNM which are important in the nuclear fuel cycle from a safeguards standpoint are plutonium (Pu), uranium-233 (U^{233}), and uranium-235 (U^{235}).[1] These are the fissile materials which are capable of being fashioned into nuclear fission explosive devices. All these materials emit gamma and neutron radiation which can be observed by radiation detectors with varying efficiencies

They can be "shielded," however, and made more difficult to detect by placing a sufficient quantity of material resistant to passage of neutrons or gamma rays around the SNM, thereby shielding it from observation. Typically, lead may be used. The thickness of the lead sufficient to shield SNM from observation by blocking gamma radiation varies depending on the type of SNM being hidden. U^{235} has the least energy associated with its gamma emissions and, as a result, a quarter inch of lead can reduce its observability via gamma ray detection by a factor of 1000 Pu is not as easily shielded because of its higher-energy gamma emissions, but a one-inch thickness of lead can reduce its gamma emissions by a factor of 100 or more. In the case of U^{233}, it is very difficult to shield gamma radiation because all U^{233} fuels also contain some U^{232} which decays to produce thalium-208 (Tl^{208}) which, in turn, produces extremely high-energy gamma radiation.[2]

An alternative to observing gamma radiation is to observe neutron emissions. Both Pu and U^{233} emit sufficient neutron radiation that they are detectable with radiation detectors. It is possible to shield neutron emissions as well, but the optimal shielding material is borated plastic. Heavy metals, such as lead, do not interdict neutrons while low-density materials such as plastics will slow down and capture most neutrons. Boron, an element which readily absorbs neutrons, will capture the remainder if mixed with a low-density medium like plastic. This type of shielding must be very thick and bulky, however, to be at all effective.[3]

B. Spiking

Spiking is the concept of adding other radioactive materials to SNM in order to enhance its observability even through substantial shielding. As described earlier, the two types of spikants under consideration are gamma emitting and neutron-emitting spikants. These two types will be discussed separately.

1. Gamma-Ray Spikants. Three radioactive substances suggested as gamma spikants are thorium-228 (Th^{228}), cobalt-60 (Co^{60}), and yttrium-88 (Y^{88}).[4]

Th^{228} does not, in itself, increase gamma emissions when added to SNM, but one of its daughter products, Tl^{208}, produces very powerful gamma radiation. However, several days must elapse after purification before enough Tl^{208} is produced from Th^{228} to be effectively observed. A disadvantage is that Th^{228} decay produces harmful alpha radiation which may raise health-physics considerations.

Co^{60} gamma radiation is somewhat less powerful than that produced by Th^{228} decay, but its long half-life is more convenient and it is more readily available than Th^{228}.

The gamma radiation emitted by Y^{88} is more powerful than that by Co^{60}, but its half-life is very short by comparison and it is undetectable after about 100 days.

If U^{232} were added to U^{235} fuels, it would decay to produce Th^{228}. U^{232} is virtually impossible to separate from U^{235} so that it would constitute an unremovable "fingerprint." U^{232}, however, suffers the same disadvantage as Th^{228}. An even greater time must pass, on the order of weeks or months, for sufficient decay to produce sufficient Tl^{208} to be reliably detected by radiation detectors. It should be noted that any aged U^{233} materials will contain enough U^{232} to be observable even through substantial shielding.

In the process stream, Th^{228} may create problems because it is more toxic than the other candidate spikants. This toxicity is due to high alpha emission rates, but since it would add only about a third to the existing alpha radiation from U^{235} and a negligible amount to that of Pu, toxicity may constitute only a minor problem. In process, a more serious concern is that purification may remove Tl^{208} and it would take at least 10 days to reestablish a sufficient concentration for detectability. Co^{60} may volatilize in process, making it difficult to manage. The behavior of Y^{88} in the process stream is not known.[5]

2. Neutron Spikants. Spiking SNM with neutron spikants has two major advantages over gamma-ray spikants: neutron shielding is very bulky and, therefore, more conspicuous than gamma-ray shielding, and moderated thermal neutrons (slowed-down neutrons) are easier to detect against background radiation levels than gamma rays.[6]

Pu emits large quantities of neutrons spontaneously such that addition of a spikant to produce neutron emissions would be superfluous. U^{235}, however, does not produce such a neutron emission so that it may be logical to add a neutron spikant if it is used in the fuel cycle. U^{233} fuels produce a level of gamma radiation sufficient to negate any need for consideration of neutron spiking or observation.[7]

The most promising neutron spikant is californium-252 (Cf^{252}). The addition of Cf^{252} to U^{235} fuels would increase the total reactivity of U^{235} by ~0.1% and it would significantly increase the detectability of neutron emissions.[8]

III. SPIKING FOR DETECTION

A. Regulatory Requirements

The Nuclear Regulatory Commission (NRC) requires in the Code of Federal Regulations that facilities possessing significant quantities of SNM[9] provide physical protection measures in addition to those required for other fixed site facilities.[10] In that set of requirements, NRC provides that:

> Each individual, package, and vehicle shall be searched for concealed special nuclear material before exiting from a material access area unless exit is into a contiguous material access area. *The search may be carried out by a physical search or by use of equipment capable of detecting the presence of concealed special nuclear material.*
>
> Testing and maintenance. Each licensee shall test and maintain intrusion alarms, physical barriers, and other devices utilized pursuant to the

> requirements of this section as follows:
>
> (1) Intrusion alarms, physical barriers, and other devices used for material protection shall be maintained in operable condition.
>
> (2) Each intrusion alarm shall be inspected and tested for operability and required functional performance at the beginning and end of each interval during which it is used for material protection, but not less frequently than once every seven (7) days (emphasis added).[11]

USNRC Regulatory Guide 5.27 provides guidance for licensees in meeting these requirements.

In essence, a doorway monitor is required to be able to detect at least 0.5 g of Pu, 1.0 g of U^{233}, or 3.0 g of U^{235} shielded by at least 3 mm of brass. These sensitivities are not difficult to achieve as long as the shielding used is not greater than the specified amount. However, the use of thicker shielding or of material more effective in shielding than brass may greatly reduce the sensitivity of currently used doorway monitors, which, for the most part, are designed to detect gamma radiation.

B. Effects of Shielding Against Doorway Monitors

Experiments have been performed to examine the effects of shielding certain amounts of SNM for covert removal through a doorway monitor. Assuming the use of gamma-ray detectors and a threshold alarm rate four standard deviations above background gamma radiation,[12] a set of values can be arrived at for concentrations of various spikants which render a given mass of SNM detectable. The concentration of the spikant is inversely proportional to the minimum amount of SNM that the doorway monitor is designed to detect.

Because U^{233} materials will always contain enough U^{232} to generate Th^{228}, it will (after several days) emit sufficiently strong gamma radiation that shielding would be ineffective. Therefore, U^{233} materials are considered sufficiently "spiked" that detection could be adequately performed by observing self-generated gamma radiation.

Given a maximum permissible employee dose rate of 2.5 mr/hr at one foot a 10-g sample of U-235 spiked with Th^{228} would be just detectable through a maximum of ~1 inch of lead. Table 1 gives values for other detection limits and spikants.

Table 1

Detection Efficiency for Shielded Gamma-Ray Spikants[13]

Minimum Detectable Quality of Spiked U^{235} (g)	Thickness of Lead Shielding Necessary for Spikants (in.) Th^{228}	Co^{60}	Y^{88}
10	~1	~3/4	~1/2
100	~2-3/4	~2	~2
1000	~4-1/4	~3-1/4	~3-3/4

The physical dimensions of shielding create an upper limit for an individual concealing it on his person. It is unlikely that a person could carry a lead shield 3 inches thick without detection by an observer. Shielding may be more difficult for neutron spikants since, as discussed earlier, neutron shielding is very bulky and, therefore, more conspicuous than gamma-ray shielding. Plutonium already emits copious amounts of neutrons without any spikant while U^{235} does not. This suggests that U^{235} is a more logical candidate for neutron spiking than Pu.

The high background level of neutrons at facilities processing SNM is a major problem of neutron detection. Using a background level ten times that at Brookhaven National Laboratory in Upton, N.Y, the background at a SNM bulk handling facility may be approximated.[14]

Data indicate that Pu is already adequately "spiked" with its own neutron emitters since less than 100 g of Pu can be detected through six inches of shielding by a neutron detector. U^{235} could be spiked with relatively small quantities of Cf^{252} to give comparable protection.

The shielding material used in collecting these data was polyethylene. Other shielding materials and configurations may possess somewhat different shielding characteristics, but a basic problem in neutron shielding is that neutrons must be slowed down (moderated) in order to be efficiently captured. Polyethylene moderates and captures neutrons, but the use of two materials, one for moderation and one for capture, may increase shielding effectiveness. Once again, the size of the shielding configuration limits concealment such that a more efficient shield than polyethylene is impracticably large.

C. Administration and Legal Restrictions

Normal day-to-day operations call for the use of techniques which amount to a search of all entering and exiting personnel and visual surveillance of personnel while in the facility. The NRC Regulatory Guides suggest that:

> Searching of individuals can be carried out by means of hands-on search ("frisking"), or by means of devices which will detect the presence of weapons and explosives or SNM concealed on the individual, or by a combination of both. The search should be conducted in a manner which (1) provides assurance that firearms, explosives, and other such contraband are not being carried into the protected area and that SNM is not being transported out of a material access area and (2) minimizes inconvenience to the individuals being searched. The use of equipment capable of detecting weapons, explosives, or SNM is usually the preferable form of searching, since the use of detection devices avoid the personal imposition of hands-on search.[15]

The clear preference in avoiding the personal imposition of a physical search is most likely a response to judicial concerns that the "least onerous means" is used to achieve assurance that an individual is not violating access controls. The guide goes on to suggest "airport-type" weapons de tors, in addition to devices to monitor the presence of SNM.[16]

The practice of searching individuals who desire, for one reason or another, entrance to a restricted area is not without precedent. This is one activity which has been widely used to prevent aircraft hijackings[17] and court house violence.[18] Both airport boarding searches and courthouse briefcase inspections have been extensively litigated and found to be reasonable, warrantless searches under the Fourth Amendment.[19] The activities, such as those suggested by the NRC regulatory guides, are somewhat analogous to measures previously litigated and will be examined in that light.

Access controls may include the use of "hands-off" personnel search devices, inspection of packages, use of change rooms, visual surveillance, pat down body searches (frisking), and strip searches including body cavity searches.[20] Only "hands-off" searches and inspection of packages are addressed in this report. In addition, some consideration is given to on-site response to a verified loss, theft, or diversion.

1. "Hands-Off" Personnel Search Devices. The courts have dealt with the constitutional issues concerning the use of a magnetometer, a device which can detect concealed weapons in airports in several different ways, but the use of this type of device has been universally upheld as an "absolutely minimal invasion in all respects of a airline passenger's privacy weighed against the great threat to hundreds of persons if a hijacker is able to proceed undetected."[21]

The courts have gone to the heart of safeguards concerns, stating that "the plane may become a weapon of mass destruction that no ordinary person would have any way of obtaining except through hijacking."[22] The analogy, that SNM is, in effect, a "weapon of mass destruction" that no ordinary person would have any way of obtaining except through a diversion of SNM, is a strong one.

The courts have found the use of magnetometers an "absolutely minimal invasion of privacy...." in which

> There is no detention at all; there is no probing into an individual's private life and thoughts (cites omitted).[23]

A magnetometer is not used surreptitiously because the courts have given weight to the advance notice of passengers in all cases involving airport searches. The NRC Regulatory Guides provide for:

> Posting of a sign in a conspicuous location...to...inform individuals requesting access into the protected area that they will be searched, and that any packages, etc., they wish to take into the protected area will also be searched.[24]

While the use of a warning sign is not contemplated as a tool for obtaining "consent," it does serve to negate any expectation of privacy that an individual may harbor.

The use of a magnetometer is not unlike the use of any mechanical search device, including explosive detectors and SNM detectors. The elements of the search are essentially unchanged with respect to constitutional limitations, regardless of the type of contraband the detection device is directed toward.

Since the use of magnetometers at airports affecting millions of travelers every year has been upheld, there is little basis for asserting that the courts would not lawfully accommodate the extension of the use of a mechanical detection device in the far more limited scope of safeguarding nuclear facilities with no fundamental change in current case law.

2. Inspection of Packages. The NRC guides state that:

> No individual should be allowed to directly carry any package, valise, tool box, or similar hand-carryable item in to the protected area or out of a material access area. Such objects should be handed to an attendant guard or watchman who will check them and pass them into the protected area or out of the material access area.[25]

This type of activity has been upheld in the same context as the use of a magnetometer. In fact, detection devices may be used to screen parcels after inspection for shielding.

The courts have considered the search of carry-on luggage in the airport situation a reasonable search:

> A pre-boarding screening of all passengers and carry-on articles sufficient in scope to detect the presence of weapons or explosives is reasonably necessary to warrant the need....[26]

In the context of an inspection of packages carried into a court house, the need to protect government personnel and property from destruction has been found enough to justify the reasonableness of the search:

> When the interest in protection of government property and personnel from destruction is balanced against an invasion to the entrant's personal dignity, privacy, and constitutional rights, the government's substantial interest in conducting the cursory inspection outweighs the personal inconvenience suffered by the individual.[27]

The intent of the search is also considered germane to the reasonableness:

> The persons whose packages are inspected generally fall within a morally neutral class. Because everyone carrying the enumerated parcels is required to have them inspected, the inspection is not accusative in nature and the degree of insult to the entrant's dignity is minimal. Thus it cannot be said that a finger of suspicion is unfairly or arbitrarily being pointed at an individual as falling within a "highly selective or suspect" group. (Cites omitted).[28]

There is little reason to believe that the courts would view as unreasonable the imposition of inspection of packages and parcels in the much more limited context of facilities containing SNM, when these techniques have been upheld in airport and courthouse contexts.

3. Response to Emergency. The USNRC Regulatory Guides stipulate simply that in the event of an emergency "all individuals should be searched for concealed SNM before being released from the protected area or collection area."[29] No other stance is taken by NRC concerning the scope of the search, which could encompass anything from the use of a mechanical detector to a strip search and body cavity examination. Nowhere in the regulations or guides is interrogation mentioned as a response to a shortage or theft. It has been suggested in the literature that substantial pressure for detention, search, and interrogation of employees may lead to such activities if a shortage is recognized.[30]

The scope of this report is limited to the use of mechanical search devices and, as such, most of these concerns are not addressed here. There is clearly a need for licensee guidance on this problem, however.

D. Conclusions

In the context of an authorized person diverting SNM it must be assumed, for the sake of being conservative, that the diversion occurs incrementally over a period of time. An authorized individual may, for example, take a small quantity of SNM out of a process stream, place it in a prefabricated shielded container, and smuggle the container past a doorway monitor. Over a sufficient period of time a strategic quantity of SNM could be accumulated.

The type and quantity of material diverted depends on the facility in question. The better the quality of material accountancy, the smaller the maximum quantity incrementally diverted must be.

Highly enriched uranium (HEU) would be present at some enrichment facilities and in fuel cycles utilizing HEU fuels. Plutonium would be present in reprocessing facilities, mixed-oxide fuel cycles, and plutonium breeder cycles. U^{233} would be present in reprocessing facilities associated with thorium-based fuel cycles and subsequently in reactor fuel (although it can be denatured). This analysis will be based on the seven alternative nuclear fuel cycles being considered in this phase of study.

The threshold for judging a material to be "detectable" in this discussion is reached when sufficient shielding would be too large to conceal in a portal situation with an observer.

1. Highly Enriched Uranium. Highly enriched uranium, defined as uranium with greater than 20% U^{235}, is relatively impossible to detect in small quantities by gamma-emission observation. One-quarter-inch thickness of lead can effectively shield a few hundred grams of HEU, although it would be very heavy. One half inch of lead shielding would allow HEU in the multi-kilogram range to be successfully smuggled past a doorway monitor.

This suggests that HEU may be a good candidate for the gamma ray spikants suggested (Th^{228}, Co^{60}, and Y^{88}). The higher energy of Th^{228} (2.6 MeV) appears to make it the most attractive except that its half-life is short (~2 years). If that time period corresponds with the maximum residence of the spiked material in the facility in question then spiking with Th^{228} may be desirable. Co^{60} has a longer, and therefore more convenient, half-life (~5 years), but its lower emission energy (~1.2 MeV) would necessitate a larger quantity of spikant. Y^{88} combines a short half-life (~0.3 years) and low energy (~1.8 MeV), making it unsatisfactory.

It may be more desirable to spike HEU with a neutron-emitting spikant.

HEU does spontaneously emit neutrons, but at a rate too low to reliably detect. The addition of Cf^{252} to HEU would make it observable in a portal situation even through bulky shielding and would add to its radioactivity (and, therefore, health-physics problems) by only ~0.1%.

2. U^{233} Fuels. U^{233} fuels which have aged several days since purification emit very strong gamma radiation. The thickness of shielding necessary to render even gram quantities of U^{233} undetectable would be far too large to conceal and would certainly be noticed by the security observer stationed at the portal.

3. Plutonium. Plutonium in a nuclear fuel cycle can have various emission characteristics depending on the burnup of the fuel while in the reactor. However, it can be calculated that a one-inch lead shield could allow 50 to 100 grams of Pu to escape detection by a gamma emissions detector. This suggests that gamma-ray spikants may be desirable. As in the case of HEU, Pu can be spiked with Th^{228} which will render it more detectable.

For neutron detection, no spikant is necessary. Pu emits a copious amount of neutron radiation which is very difficult to shield at a close, controlled range. A 100g quantity of Pu could be detected in a portal situation even through six inches of neutron shielding. It is not credible to assume that six inches of shielding (at minimum, a 12-inch sphere) would be sufficiently inconspicuous to escape observation at the portal.

REFERENCES

1. U^{235} is considered SNM only when it is in a concentration greater than 20%. All references in this report to U^{235} refer to uranium enriched to a 20% or greater concentration.
2. E.V. Weinstock et al., "The Spiking of Special Nuclear Material as a Safeguards Measure," prepared for the U.S. Nuclear Regulatory Commission, BNL-TSO File No. 5.9.1, Sept. 19, 1975, p. II-1.
3. Id., p. II-21.
4. See International Research and Technology Corp., "Modification of Strategic Special Nuclear Materials to Deter Their Theft or Unauthorized Use," prepared for the U.S. Nuclear Regulatory Commission, IRT-378-R, Nov. 6, 1975.
5. Note 2, supra, p. II-5.
6. Id, p. II-22.
7. R.H. Auguston and T.D. Reilly, "Fundamentals of Passive Nondestructive Assay of Fissionable Material", LA-5651-M, Sept. 1974, p.4.
8. Note 2, supra.
9. 10CFR73.60 defines significant quantities as:
   "....uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope), uranium-233, or plutonium alone or in any combination in a quantity of 5,000 grams or more computed by the formula, grams=(grs contained U-235) + 2.5 (grams U-233 + grams plutonium)...."
10. General requirements for physical security at fixed sites not possessing significant quantities of SNM are contained in 10CFR73.40 and 73.50.

11. 10CFR73.60(b),(d).
12. Background gamma radiation varies according to the environment. In a nuclear materials processing facility it may be well above normal levels.
13. Adapted from Weinstock, Note 1, supra, p. II-14.
14. This assumption has not been tested or verified.
15. U.S. NRC Regulatory Guide 5.7B.
16. Id.
17. For example, *United States v. Albarado*, 495 F. 2d. 799 (2d Circ. 1974).
18. For example, *Barrett v. Kunzig*, 331 F. Supp. 266 (M.D. Tenn. 1971) cert. denied, 409 U.S. 914 (1972).
19. Id.
20. Timothy B. Dyk, et al., "Civil Liberties Implications of a Safeguards Program for Special Nuclear Material in the Private Nuclear Power Industry — Report to the Nuclear Regulatory Commission" (Wilmer, Cutler, Pickering, Washington, D.C., 1975), p. 12.
21. Note 17, supra, 495 F. 2d. at 806.
22. Id., p. 802.
23. Id., p. 804.
24. USNRC Reg. Guide 5.7 B-2.
25. USNRC Reg. Guide 5.7 B-2.
26. *United States v. Davis*, 482 F. 2d. 893, 910 (9th Cir. 1973).
27. Note 18, supra, p. 274.
28. Id.
29. U.S. NRC Regulatory Guide, 5.7-4.
30. Note 20, supra, p. 29.

IV. SPIKING FOR LOCATION

A. Methods of Observation

Detection of radioactive emissions in a search outside the facility boundaries is significantly different from portal or doorway detection. Various factors such as changing background radiation, increased source-to-detector distances, and potential lack of control over count rates contribute substantially to greater difficulty in locating contraband nuclear materials.

It is difficult to place a realistic bound on the dimensions of an area search for contraband SNM. The following discussion of possible methods of locating radioactive emissions will be followed by an analysis of search scenarios in order to examine the legal and administrative implications of such a search.

1. Gamma Radiation. Several factors contribute to the difficulty of locating contraband SNM by observing gamma radiation.[31] These include:

- The energy of the emission.
- The self-shielding of the SNM.
- The attenuation of the emission by distance, air, or other intervening materials.
- The background gamma-radiation levels.

- The characteristics of the equipment available.
- The time intervals used in searching.

These factors are examined in the following sections.

a. Self-Shielding and Emission Energy. Nuclear material will absorb some radiation emitted by itself so that, while nuclear reactions which produce gamma rays will be occurring, some of those gamma emissions will never leave the mass of SNM in question. This is referred to as "self-shielding."

Self-shielding can be very significant in affecting the emissions of Pu, actually absorbing most emissions generated in its mass.[32]

b. Attenuation of Gamma Radiation. Contraband SNM will probably be secreted so as to minimize the probability of observation, either visually or with radiation detectors. It must be recognized that air between a source and a detector will by itself attenuate gamma radiation significantly. As other materials are placed to intervene, shielding effects increase dramatically. By placing the source behind 100 cm of concrete, emissions decrease by several orders of magnitude and are commensurately difficult to detect.[33]

c. Background Radiation. In order to alert an observer to the presence of nuclear material, the radioactive source must have an emission sufficiently large to be detectable above normal background radiation. The principal sources of background gamma radiation are radioactive minerals in the ground, radon and daughters in the air, and cosmic radiation. A major problem in a search scenario is that background levels change from one location to another. In general, the higher the background level the more difficult detection becomes.

d. Detector Efficiency. The type of detector dictates actual efficiencies. In general, the efficiency of detection decreases as higher energy emissions are sought.[34]

e. Time Intervals and Search Conditions. An effective search for radioactive sources requires that the time interval for observation at a particular site be of sufficient duration to collect enough emission counts to allow a statistical analysis. The longer the duration, the more accurate the detection system. If an airborne detection system were used, time intervals would necessarily be very short making the results far less reliable. If a normal ground transportation is used (e.g. a van or an automobile), longer intervals are possible.

The objective of the detection system is to identify gamma radiation which is sufficiently greater than the previous background counts as to indicate the existence of some extraneous source. Here, we assume that the previously collected counts contain only background radiation. The smaller the standard deviation of the background counts (e.g., among sample intervals), the less extraneous gamma radiation is necessary for detection. In practice, standard deviations in background when measured from a moving vehicle may be very high, hence reducing the probability of detection.

Data indicate that, if only air intervenes between the source and detector, the energy of the gamma source is not very important. However, as shielding is introduced, high-energy gamma radiation has advantages over lower energies.

f. Potential Gamma-Source Spikants. The literature has suggested four gamma radiation sources as potential spikants: cobalt-60, yttrium-88, cesium-137, and thorium-228.[35]

The higher the specific activity of the spikant, the less of it is necessary for observation purposes. Higher energy emissions are desirable from the standpoint of defeating shielding, and the half-life must be taken into account in that the passage of time will degrade observability at a specific rate.

Y^{88} has the highest specific activity (greatest emission — about 13,500 Ci/g), but its half-life is relatively short (108 days) and emissions are only in the 0.9 and 1.8 MeV range. Co^{60} has a low specific activity (40 Ci/g) and low emission energies (1.2 and 1.3 MeV) and a medium (5.3 year) half-life. Cs^{137} has a long half-life (30 years) but a low energy emission (0.66 MeV) and low specific activity (87 Ci/g). Th^{228} has a high specific activity (822 Ci/g) and a high energy emission (2.6 MeV) but a short half-life (1.9 years).

As is apparent, Y^{88} is desirable over a short term because of its high specific activity, but its activity decreases quickly as time passes. Cs^{137} may have the best potential as a spikant, but its low specific activity and emission energy require that very large quantities be used. Co^{60} has a reasonably long half-life for purposes of spiking, but its low emission energy dictates that relatively large quantities of this spikant would also be necessary. Th^{228} has a relatively short half-life (about seven times greater than Y^{88}), but its high specific activity and much higher emission energy make it attractive as a potential spikant.[36]

2. Neutrons. The observation of neutrons is similar to the observation of gamma radiation, with a few specific exceptions. The source strength of neutrons is not as important, and self-shielding is not significant. Attenuation of neutrons in air is more appreciable than that of gamma radiation.[37]

a. Attenuation of Neutrons. Neutrons emitted from radioactive material have a very high velocity. The oxygen and nitrogen molecules in air are very effective at slowing down fast neutrons. However, neutrons may travel a long distance (~1 km) before becoming thermalized (slowed down to thermal velocities). A thermal (slow) neutron is captured quickly by nitrogen in the air.

If neutron emissions travel about 100 to 300 meters in air most neutrons will still be fast although their energies will be significantly altered.

Calculation of the attenuation of neutrons by concrete is difficult because of the variations in composition. 100 cm of "average" concrete will generally attenuate a neutron flux by about an order of magnitude. This value is approximate, but indicates that concrete can be used to effectively shield neutrons from detection by remote radiation detectors.

b. Neutron Detection Systems. Neutron detection systems look for thermal (slow) neutrons. Since source neutron emissions are fast, some medium must be used at the detector site to moderate (slow down) fast neutrons. Generally this is accomplished with polyethylene which surrounds the actual detection medium. A typical detection medium is boron triflouride (BF_3) which will produce upon a neutron capture, a measurable electric charge in the medium. Neutron detection systems, therefore, will typically observe neutrons by first slowing them down with polyethylene and then by capturing them in a BF_3 medium. A detection system will be set to identify a neutron count rate several times (e.g. four) the standard deviation for successive background counts.

c. Background Radiation. In general, the count rate of background neutron radiation is very small when compared to gamma radiation. This results in a smaller standard deviation for neutron counts than for gamma radiation and, therefore, more accurate measurements.

d. Potential Neutron-Source Spikants. The two neutron spikants suggested in the literature are curium-244 and californium-252. Both elements have high neutron emissions (1.11×10^7 and 2.32×10^{12} neutrons per gram per second, respectively) but their half lives differ significantly (17.6 and 2.65 years, respectively).

3. Methods and Reliability. SNM, stolen and secreted in a realistic way, would be shielded and hidden from sight. If gamma radiation detection were used as a means of recovery, distance would prove an insurmountable barrier to searching a large area expeditiously. Variations in background counts coupled with scenarios involving intervening distance or materials would make detection of moderately shielded SNM difficult, even if spiked. A search scenario must include an assumption that some shielding would be attempted making distance and count-rate intervals the only parameters to be adjusted. As such, in scenarios including buildings and general congestion (e.g., urban environment) it would only be possible to locate contraband SNM by minimizing distances. It can be expected, therefore, that some invasion of privacy would necessarily occur.

Neutrons can be shielded quite easily when there is not consideration of personal concealment. Several feet of water (e.g., a swimming pool) would conceal neutron radiation from detectors. Detectors aimed at observing excessive neutron radiation would benefit as does gamma ray detection from reduced source to detector distances. Either method, therefore, would require, as the exigency increases, greater invasions of privacy.

B. Legal Requirements and Restrictions

1. Jurisdiction and Background. Since the FBI investigates all incidents, including nuclear threats, which involve suspected or actual violations of federal laws, it would have primary jurisdiction and responsibility for directing and coordinating federal operations in the event of hostile actions against nuclear facilities or material and for the recovery of SNM.[38] If required, DOE would support the FBI by providing Nuclear Emergency Search Teams (NEST) responsible for locating and identifying radiation-producing materials. DOE and the Department of Defense (DOD) would work together in many ways, including the DOE/DOD Joint Nuclear Accident Coordinating Center, which exchanges and maintains information related to radiological assistance capabilities and coordinates assistance in the case of incidents involving radioactive materials.

Personnel supporting the recovery plans are organized into NEST teams and include representatives from the DOE laboratories and contractors. Each of these agencies has developed a detailed plan for supporting the teams with ground and airborne detection equipment, for logistic and communications support, and for reinforcement by representatives of the FBI and local law enforcement agencies. In addition to the NEST teams, a wide variety of technical specialists are also available to support an immediate recovery operation.

The foremost problem in recovery activities is the disruption of civil liberties involved in a frantic search for material, which is known only to be in a non-particular area (i.e., a certain city block or even a city itself). Integral to the implications of the entire recovery issue is a decision as to which doctrinal legal authority (and, therefore, legal procedure) the recovery operation is performed under. There seem to be three general doctrines of authority that recovery operations could fall under: national security, ordinary crime, and emergency. Each authority carries its own restraints and freedoms in a response to a criminal activity. It is questionable whether recovery activities could fall completely under the rubric of protecting health and safety, because of the clear criminal nature of a theft of SNM — unless the SNM was believed to be missing because of an innocent mistake. The literature does not suggest that innocent mistakes are to be assumed, however, considering the consequence of a successful diversion.[39]

Regardless of the authority assumed for recovery operations, it is difficult to imagine a wide-scale search operation which would not result in a general suppression of some constitutional rights. The right most likely to be violated is freedom from unreasonable search and seizure, both with and without warrants or due process.

Two other areas of concern can be raised: the voluntary or involuntary media suppression of the recovery operation, and the possibility of martial law and potential evacuations. These considerations lie outside the scope of this report, but must be weighed in any final analysis.

The legal authorities (i.e., national security, ordinary crime, and emergency) must be examined separately, because the outcome of judicial review of recovery activities may depend on which authority is invoked.

2. Legal Authority.

a. National Security. The elements of national security require that a warrant must be obtained for a search unless the theft is initiated by an individual who is an agent of or acting in collaboration with a foreign power. The thrust of court decisions dealing with this is that a foreign agent's dwelling could be entered and/or his telephone tapped without first obtaining a warrant.[40]

If a recovery operation is instigated because of concern that another nation is actually attempting to subvert or threaten the United States Government, then drastic measures could most certainly be taken. The most widely noted statement by the Supreme Court, granting authority for administrative powers during such a period, is the decision supporting a curfew on and the detention of Japanese-Americans during World War II. During that period, the Commanding General of the Western Command, United States Army, directed that all persons of Japanese ancestry should be excluded from a "military area." This area encompassed the home of the petitioner, a Japanese-American who had knowingly violated the order. The Supreme Court stated at that time:

> We are unable to conclude that it was beyond the war power of Congress and the Executive to exclude those of Japanese ancestry from the West Coast war area at the time they did. True, exclusion from the area in which one's home is located is a far greater deprivation than constant confinement to the home from 8 p.m. to 6 a.m. Nothing short of apprehension by the proper military authorities of the gravest imminent danger to the public safety can constitutionally justify either.[41]

Two important facts are worth noting here, however. First, the action which is justified above was taken pursuant to a declared state of war. Congress had, in effect, given approval to actions embodied in Executive Order No. 9066. On the basis of Executive Order No. 9066,[42] several military orders, such as the one noted above, were held to be justifiable intrusions upon civil liberties. In the event of a recovery operation, it is not clear if the Executive would be upheld in actions such as relocation of populations, in the absence of a Congressional mandate, even if foreign involvement could be shown.

Second, the decisions upholding relocation of Japanese-Americans have been widely criticized from many points of view. It is possible that if a similar situation arose again, the courts and society in general would be more sensitive to considerations of civil liberties. However recovery operation, in the face of foreign involvement, would be an action with wide public support. Another important factor is that the individuals affected in a recovery operation would not be a racial class, but a broad class of individuals whose safety is genuinely in danger.

It is not clear what a recovery operation would entail, but it is unlikely to be more intrusive than the relocation of Japanese-Americans during World War II If there is foreign involvement and imminent danger of a nuclear incident, it is likely that, in view of its history, the courts would uphold intrusive recovery actions.

b. Ordinary Crime. There will be overwhelming pressure to search expeditiously if a successful theft of SNM occurs. The Supreme Court's simple dictum that the courts must "balanc(e) the search against the invasion which the search entails,"[43] has led to differing views of what is or is not reasonable in time of criminal crisis.

In 1974, the San Francisco police detained and questioned blacks, in absence of specific grounds, during the hunt for the perpetrators of the "Zebra murders." Federal District Court Judge Alfonso J. Zirpoli granted an injunction forbidding these activities, even though many murders had occurred and all that was known was that the suspects were black.[44] The precedent relied on by Judge Zirpoli was a 1966 Baltimore case where the police had searched over 300 private dwellings — without probable cause or warrants — most of them occupied by blacks, to find two blacks they believed had killed one police officer and wounded another during a liquor store robbery. In enjoining such conduct, the court observed that this type of operation was not likely to produce the suspects.[45]

On the other hand, a federal court in New York upheld the search without a warrant of an individual's apartment. The search did not fit any of the exceptions to the warrant requirement enumerated by the Supreme Court. The situation in this case may loosely fit the fact pattern of a recovery operation. The day after four major New York City buildings were struck by explosions police arrested an individual with dynamite bombs that they believed to be intended for the destruction of Army property. Shortly before the arrest, the police searched the apartment of a friend of the individual for the alleged purpose of seeking other explosives or information indicating the location and time of other explosions. The court held the search lawful because "the consequences feared by the FBI had to be considered in the atmosphere of seven terrifying explosions which had recently occurred in the City of New York."[46] Of course, this case entailed the search only of one person's apartment, but nonetheless, the court justified an otherwise unreasonable search by balancing it against the occurrence of "terrifying explosions."

At the crux of the recovery issue, if treated as ordinary crime, is the applicability of the warrant requirement and the particularity requirements of a warrant. If evidence procured by a means which violates either the warrant requirement or the particularity requirement, the evidence is not admissible in a criminal proceeding of any kind.

(1) The Warrant Requirement. The warrant requirement and its exceptions are outlined in Appendix A. The applicability of the warrant requirement to recovery operations is not clear, because of a lack of a similar historical fact pattern. Of course, the absence of information concerning recovery operations necessitates a speculative view.

The Supreme Court has found the warrant requirement to be applicable to searches and inspections performed for public health and safety. The criminal nature of a health and safety inspection was not found to be insubstantial enough to completely dispense with the warrant requirement:

> It is surely anomalous to say that the individual and his private property are fully protected by the Fourth Amendment only when an individual is suspected of criminal behavior.[47]

The warrant requirement, if the recovery operation is conducted as a criminal investigation, seems to be applicable. There is little case law which indicates that the judiciary would fully defer from a search of this nature, regardless of the scope, unless it is an emergency as discussed below.

(2) The Particularity Requirement. The Fourth Amendment states that:

> No Warrants shall issue, but upon probably cause, supported by oath or affirmation, and particularly describing the place to be searched, and the persons or things to be seized.[48]

This mandate displays the constitutional framers' absolute opposition to "general warrants" or "writs of assistance." The purpose of the Fourth Amendment, as described earlier, "is to safeguard the privacy and security of individuals against arbitrary invasions by government officials."[49] General warrants are thought to violate this tenet by leaving the decision to invade a particular person's privacy to the unsupervised discretion of a police officer.

The Supreme Court historically held that the warrant must be particular enough to allow the officer, "with reasonable effect (to) ascertain and identify the place intended."[50] The Supreme Court, in 1967, announced a test for the reasonableness of an inspection for health and safety purposes. First, the purpose of the inspection programs is to prevent the "development of conditions which are hazardous to public health and safety;"[51] second, the only test of the reasonableness of a search is to "balanc(e) the need to search against the invasion the search entails;"[52] third, applying the balancing test, the public interest in abatement of dangerous conditions justifies the issuance of warrants aimed at entire areas where "it is doubtful that any other canvasing technique would achieve acceptable results."[53]

This has lead some to conclude that the courts would be willing to sacrifice the particularity requirement, to a degree, in order to maintain some level of judicial control over the search.[54] This may be the only method available to the judiciary in the event of a massive, sweeping search for stolen SNM. It is somewhat doubtful that such a search would be declared unlawful or be enjoined in light of the dangers involved.[55]

In absence of a legislative statement or foreign involvement, the recovery operation must be viewed as an ordinary criminal investigation. This leaves it up to the judiciary to accept or reject the loss of Fourth Amendment rights as a tradeoff against a possible nuclear explosion or dispersal of toxic radiological agents. It is difficult to imagine the courts enjoining a recovery operation in light of the possible consequences.

c. Emergency Power. The Supreme Court has upheld the suppression of constitutional rights in emergency situations. The courts have ruled that emergency exceptions are constitutional for seizure, without due process, of tubercular cattle[56] and unwholesome food,[57] for the enforcement of the compulsory smallpox vaccination program[58] and health quarantine,[59] for collection of the internal revenue of the United States,[60] for protection against economic disaster of a bank failure,[61] and for protection of the public from misbranded drugs.[62]

The Supreme Court has outlined what the requirements of an emergency situation must be in order to justify a suppression of constitutionally guaranteed rights.

- The action must be directly necessary to secure an important governmental or general public interest.
- There has to be a special need for very prompt action.
- The state must keep strict control over its monopoly of legitimate force: the person initiating the seizure must be a government official responsible for determining, under a narrowly drawn statute, that it [the action] was necessary and justified with particular instance.[63]

The first requirement is not illusive. The recovery of stolen SNM is most definitely "an important governmental and public interest." The second requirement is satisfied because there is a "special need for very prompt action."

Only the third requirement of a narrowly drawn statute and a designated responsible official is absent in a recovery operation. The history of "emergency legislation" contained in Appendix B is informative in how this requirement may be satisfied.

Warrantless searches outside of a legislative scheme are most often justified through the emergency doctrine: instances when police action is called for and time is of the essence. The scope of an emergency search is limited to the extent of the emergency which initiated it. During an emergency search authorities have the right to seize any evidence in plain view.

The emergency doctrine emerged in 1948 when the Supreme Court allowed that, under exceptional circumstances, authorities may dispense with the need for a warrant. The search in question must be shown to be absolutely necessary. The timeliness of the search and the need to avoid delay are very important since it is the immediate need to search which justifies the exception to the warrant requirement.

There are five broad categories of circumstances when warrantless emergency search is legal: (1) fire emergencies, (2) hot pursuit, (3) loss or destruction of evidence, (4) report of noise or suspicious odor, and (5) report of crime or injury.[64] Only hot pursuit and report of crime or injury are discussed here.

(1) Hot Pursuit. A fleeing felon can be followed by pursuing authorities

into a building which he has just entered.[65] This doctrine is somewhat limiting in that a warrantless search after the arrest can be made only for weapons used in the crime or against authorities. The Supreme Court has further stated that the warrant requirement does not require authorities to delay an investigation if delay would gravely endanger their lives or the lives of others. Courts have rejected warrantless searches beyond that. For example, the courts rejected the application of the hot pursuit doctrine when a defendant was arrested in his house and the arresting authorities searched his attic on the pretense of looking for snipers.[66]

(2) Report of Injury or Crime. Warrantless crime scene searches can be conducted only when there is reason to believe that there may be loss or destruction of evidence.[67] There is no exception to the warrant requirement predicated on the seriousness of the crime. The courts have allowed authorities the right to make a "walk through" search of premises to check for victims or potentially dangerous persons still present. When a person is reported mysteriously missing, warrantless room-to-room searches of hotels and other business premises have been allowed.[68]

C. Direct Constitutional Impacts

1. The Fourth Amendment Concerns. The reasonableness of a search is the controlling factor in whether the search is held legal or illegal. While the primary objective of a recovery operation would be the recovery of the stolen SNM, it seems that once the SNM is recovered, it should be admissible as evidence to be used against those who stole it. The test for reasonableness is laid out by the Court:

> Unfortunately there can be no ready test for determining reasonableness other than by balancing the need to search against the invasion the search entails.[69]

With this test in hand, a two-pronged approach to the problem could be taken. A recovery operation may present an unprecedented "need to search" which could only render the search reasonable. The all-or-nothing approach used by the courts, which makes any contraband found in a lawful search admissible regardless of its relation to the reason for the search, may be outmoded because of the presence of a potential or real need to search as great as the need to search for stolen SNM. Several commentators have suggested that if evidence unrelated to the recovery operation were turned up, (i.e., contraband which is not SNM) it may be legislatively made inadmissible in a criminal proceeding. This would have the effect of lessening "the invasion the search entails" by protecting "third-party" interests.[70] This does not eliminate the tremendous invasion of privacy a recovery operation could present to third parties, however. It could be argued forcefully that the "expectation of privacy" would be far less in an emergency search for stolen SNM since, presumably, most people would favor the recovery of stolen SNM and, in fact, welcome measures aimed at locating it.

The desirability of excluding evidence not related to the recovery operation is great. The courts would not find themselves making a choice between finding the search reasonable (allowing individuals innocent of nuclear theft, but guilty of non-related crimes, to be tried on the basis of a search conducted for safeguards reasons) and finding it unreasonable (making prosecution of the suspected thieves difficult because the inadmissibility of evidence of their theft — the recovered SNM). The only precedent for finding evidence secured in a legal search inadmissible is that of evidence found in a manner inconsistent with the particularity of the search that has been laid out by the court:

> The scope of the search must be strictly tied to and justified by the circumstances which rendered its initiation permissible (cites omitted.) In other words, it is, and indeed for preservation of a free society must be, a constitutional requirement that to be reasonable *the search must be as limited as possible commensurate with the performance of its functions* (emphasis original.)[71]

While contraband other than SNM may be found, the "scope" of the search may not be violated since a small parcel of SNM may be difficult to find and, therefore, a thorough search may be required. Perhaps the courts will find that the fruits of such a search must also be reasonably "tied to and justified by the circumstances which rendered its [the search] initiation permissible." Of course, this suggestion amounts to a drastic change in the doctrines of search and seizure, but a drastic change may be necessary.

Such a change in the rules of criminal evidence would better be initiated through legislation than case law.

2. Due Process Concerns. The due process requirements of the constitution require that no person is to be deprived of life, liberty, or property without an opportunity to be heard in defense of his rights. This constitutional requirement can be circumvented if certain conditions exist. These conditions, outlined above,[72] are a compelling interest, special reason for prompt action, and statutory authority for the intrusion given to a designated official.

NRC lacks the statutory authority and the designated official. If NRC were to take steps toward fulfilling these requirements, a more orderly recovery operation with fewer consequences could most likely be expected.

D. Potential Scenarios

The aspects of a recovery operation which may affect civil liberties are distinct from other nuclear safeguards activities in two respects. First, they may never be used. Those activities selected in a recovery operation only exist as plans in the unlikely event of theft or loss of SNM. Second, they present the greatest potentials for altering civil liberties generally. In the event of a successful theft, unprecedented activities may be necessary to prevent great destruction. For these reasons, methods of changing planned recovery activities through research and development of search techniques should be ongoing. If all nuclear material could be absolutely and easily located at all times — through the use of techniques such as radioactivity scans — wholly different and possibly less onerous activities might be possible. This report also considers the possibility of spiking radioactive material for purposes of detection and location.

Since response plans are not made public, the activities speculated upon must contain the most intrusive elements of a recovery operation, otherwise, the full, potential impact of recovery operation may not be clear. These include area searches, perimeter searches, search of pedestrians, and vehicle searches.

1. The General Legal Characteristics of a Search for Contraband SNM.

a. Area Searches. If a quantity of contraband SNM were known only to be within an area of only a few blocks, pressure to thoroughly search the dwellings in that area would be tremendous. Barton, in addressing the problems presented by an area search, suggests that:

> It is...quite likely that even in a nuclear emergency, such a search (or an area warrant) would be struck down.
>
> Nevertheless, in airport search cases, a perceived overwhelming necessity dictated a change in the law. And public opinion would probably support such a change in the law. If the courts were to expand the emergency exception to permit area searches during nuclear emergency, the implication would be much greater freedom for area searches in any riot or terrorist blackmail situation. If, instead, the courts were to weaken the probable cause or particularity requirements for the issuance of warrants, the implication could be to expand general search powers enormously.[73]

This statement fairly represents the doctrinal choice which would be presented to the courts if many dwellings were entered in an uncertain effort to recover a missing quantity of SNM. Declaring the search unlawful may activate tort liability for officers conducting the search,[74] but this problem is minimized by the Court's ruling that "good faith and probable cause" are acceptable defenses in such cases.[75]

In absence of any further legislation or rule-making on recovery operations, the courts' choices in dealing with a recovery process are limited:

- Declare the search unconstitutional and attempt to define what circumstances or statutes might make a recovery search acceptable.
- Expand the emergency exception in search and seizure requirements to allow for warrantless searches in emergency situations involving a risk as great as that in a nuclear incident.
- Require a warrant which would lessen both the probable cause requirement and particularity requirement of a search warrant.

The impact of the search for recovery of stolen SNM could, most probably, be lessened if NRC were to establish how evidence should be treated and publicly designate a government official to be in charge of the search. Of course, the search itself would still be onerous, but there would be no impetus for the courts to rule on its validity if no prosecutions were sought. If prosecutions of the indicted thieves of the recovered SNM were the only prosecutions sought, the court would have to rule on the admissibility of the contraband SNM as evidence. Perhaps the statutes protecting SNM could be amended to allow less difficult prosecution in absence of the stolen SNM as evidence. In any event, if many prosecutions were sought on the basis of contraband seized during the search, but not related to the recovery operation, the courts would almost certainly rule the search unconstitutional.

No questions are raised here concerning the forces that would be involved in the search or the tactics that would be used. These issues are not directly related to civil liberties but must, nonetheless, be decided in advance of a recovery operation. The courts have shown a clear preference for prior planning and accountability.

In the event of a widespread area search requiring entry into dwellings, it may not be possible to fulfill this requirement. There are two options if the courts were to accommodate this activity. The emergency exception to the warrant requirement could be expanded to include a nuclear materials recovery operation, or an area warrant could be judicially granted relaxing both the particularity requirement and the probable cause requirements.

The implications of either option are far-reaching. If the emergency exception were expanded, warrantless searches might be permitted in other emergency situations which are potentially less dangerous than a nuclear safeguards breach (i.e., riots, demonstrations). If the particularity and probable cause requirements were relaxed, a constitutional requirement explicitly condemning such searches would be directly contravened. Either option requires a fundamental change in the law of search and seizure which would have a direct impact on civil liberties.

b. Perimeter Searches. Since a thorough perimeter search can lessen the overall onerousness of a recovery operation, by allowing time for sensitive radiation detectors to arrive, a perimeter search is an alternative to an area search without mechanical detectors. In light of this, it may be advisable to plan recovery operations in such a manner as to first implement a perimeter search. Here, we presume that the civil liberties impacts of a perimeter search are less onerous than those of an immediate area search conducted without radiation detectors designed for such searches.

In order to isolate the area in which the stolen SNM is believed to exist, authorities may order a sweeping search of automobiles and pedestrians. There are two activities represented here: one is the search of pedestrians and the other is the search of automobiles.

(1) Search of Pedestrians. If contraband SNM were known to be within a certain area (e.g., a city block), a great deal of pressure would exist to search all persons leaving that area. Devices exist for this purpose. Handheld personnel monitors can be used in the same way that handheld magnetometers are used to search persons who activate the portal magnetometer

at airports.[76] The availability and exact sensitivity are classified secret national security information.

If an emergency were perceived, there might not be time to obtain handheld detection devices. In that case, a "frisk" of all individuals departing the area suspected of containing contraband SNM would be necessary.

"Stop and frisk" cases which have appeared before the Supreme Court have held that the authority of a police officer to frisk without a warrant is restricted to a search for weapons which may endanger the officer:

> There must be narrowly drawn authority to permit a reasonable search for weapons for the protection of the police officer, where he has reason to believe that he is dealing with an armed and dangerous individual, regardless of whether he has probable cause to arrest the individual for a crime.[77]

On the other hand, the Supreme Court has acknowledged that:

> The Fourth Amendment does not require police officers to delay in the course of an investigation if to do so would gravely endanger their lives or the lives of others.[78]

There is little doubt that the malevolent use of contraband SNM would "gravely endanger...the lives of others." The presence of an individual in an area known to contain contraband SNM may serve as the functional equivalent of probable cause for a search. If so, the fact that an individual is not in his home and is mobile becomes important. The "emergency" warrant exception can be based on the threat of loss of evidence:

> When there is probable cause to search and it is impractical...to get a search warrant, then a warrantless search may be reasonable.[79]

If the contraband SNM were known to be within a certain area, it could be contained there only by a perimeter search. In containing the contraband SNM, mechanical detectors could be obtained in the short period between containment and search, which would be allowed by a perimeter search. It seems doubtful that the courts would hold a personal search at a perimeter station unreasonable, but the courts have made it clear that the decision depends heavily on the circumstances of the particular instance.

Case law has indicated that a physical search of pedestrians could be justified by the extraordinary "need to search" in the event of theft or loss of SNM. A search administered uniformly to all persons exiting the controlled area would more likely be held lawful than one conducted arbitrarily. The search would be more acceptable if its scope was restricted, to as great a degree as possible, to the object sought. For an obvious example, a body cavity search would certainly be unreasonable if the SNM is in a form which must be kept in a large container (i.e., Pu^{239} in the liquid nitrate form which is too large to conceal in a body cavity).

(2) Search of Vehicles. Vehicle searches can be conducted with a mechanical hand-held detector.[80] The availability of these detectors to authorities conducting the search is very important. Technologies for searching for contraband SNM in vehicles at checkpoints are classified secret national security information and, therefore, cannot be discussed here.

By and large, the same doctrines applying to personal searches in a perimeter search program apply to vehicle searches. The Supreme Court has intimated that a search of vehicles, constitutes less of an invasion than a search of a home because an automobile may be searched:

> Where it is not practical to secure a warrant because the vehicle can be quickly moved out of the locality...in which the warrant must be sought.[81]

Since the need to secure the contraband SNM is great and a perimeter search will probably lessen the overall obtrusiveness of the search ultimately by providing containment until mechanical detectors can be obtained, vehicle perimeter search techniques are not likely to be found unreasonable.

As in pedestrian searches, a vehicle perimeter search is an alternative to an area search where there are no mechanical detectors. The exception to the warrant requirement for automobile searches has already been established so that no fundamental change in case law would be required. While this exception would be somewhat broadened by relaxing the already relaxed probable cause requirement for vehicle searches, the civil liberties implications of a search of vehicles exiting a specific and limited area are not great.

E. Conclusions

If a diversion or theft of SNM occurred it can be assumed that drastic measures would be taken to locate and recover the contraband material. There is not much in the literature relating to the specifics of such a search since most details remain classified. An operation aimed at recovery would certainly involve at least kilogram quantities of SNM. This would probably be easy to conceal in such a way as to shield the SNM from detection over any appreciable distance.

1. Highly Enriched Uranium. Highly enriched uranium by itself has relatively low gamma and neutron emission levels, which would make HEU essentially unobservable if shielded at all. A search for unspiked HEU using radiation detectors would have to include entry into areas normally not subject to searches, bringing the warrant requirement into question. For example, 30 kg of HEU could be successfully hidden from mechanical observation by secreting it in a basement sump well under one or two feet of water. This conclusion can be reached by simple, well-known physical calculations.

If HEU were spiked with either a gamma or neutron spikant it would be more observable, but even then it could be shielded. This is especially true if the perpetrator has taken measures to quickly deposit the contraband HEU in a shielded holding place.

Th^{228} would probably be the most desirable gamma spikant because of its high energy emissions. Gamma spikants suffer from one large problem. Detectors moving from location to location seeking extraneous gamma radiation will register significant variations in background levels and, therefore, long count intervals and accurate background data must be available. This represents a sizable problem since both conditions are difficult to meet, particularly in the context of an expeditious search.

In any event, to be observable for the purposes of location, HEU may require the addition of a very high-energy gamma source, perhaps at lethal spiking levels. Even then, however, effective shielding is certainly possible.

For a neutron spikant, the emission energy is not as important as the rate of emission. Even with a high count rate, concrete or water are very effective shields. In fact, placing the contraband SNM at the bottom of a pool or small lake would make its neutron emissions impossible to observe.

2. Uranium-233. Uranium-233 reactor fuels will contain some U^{232} which will generate radioisotopes producing very high-energy gamma radiation. The high-energy emission from U^{233} fuel will actually approximate lethal spiking, making shielding necessary to prevent lethal exposures. Given that the material must be shielded anyway, it is reasonable to assume that additional shielding will render the contraband U^{233} unobservable by radiation detectors.

3. Plutonium. Plutonium emits both gamma radiation and neutrons, each of which is observable with radiation detectors. Neither is of sufficient strength that simple shielding measures would permit observation over distance. Pu could be spiked to enhance gamma and/or neutron emissions, but in either case simple water or concrete shielding could interdict emissions to render the contraband Pu unobservable at long distances.

4. General Conclusions Concerning a Search for Contraband SNM. Spiking of HEU and Pu could significantly increase the likelihood of locating contraband materials by mechanical devices. U^{233} is already sufficiently radioactive that addition of a spikant would be superfluous.

However, any emissions used for detection could be easily shielded forcing the search for contraband material to include entry into dwellings and trespassing onto what would most likely be private property.

The legal requirement of a search warrant citing specifically the particular premises to be searched would be impossible to meet, and such an operation would certainly require some fundamental change in judicial case law concerning search and seizure.

REFERENCES

31. T.J. Connolly, in Weinstock, Note 2, supra, p. III-3.
32. Id., using T. Rockwell (ed.) "Reactor Shielding Design Manual," U.S. AEC Report TID-7004, 1956.
33. Id., using A.E. Profio and G.C. Huth, "Remote Sensing of Plutonium by the Law Energy Scattered Flux," Nuclear Technology, Vol. 26, July 1975, pp. 340-351; E.P. Blizard (ed.), Reactor Handbook, Vol. III, Part B, "Shielding," Interscience Publishers, 1962.
34. Id., using S.H. Vegors et al., "Calculated Efficiencies of Cylindrical Radiation Detectors," IDO-16370, Sept. 1958.

35. Id., pp. III-13-17.
36. Thorium-228 is not in itself a spikant, but its daughter product, thallium-208, produces high energy emissions once in equilibrium.
37. Note 2, supra, pp. III-17-22.
38. Atomic Energy Act as amended, Sec. 221 b.
39. See Generally Dyk, Note 20, supra; John H. Barton, "Intensified Nuclear Safeguards and Civil Liberties," NRC Contract No. AT-49-24-0190, 1975.
40. *Zweibon v. Mitchel,* 516 F.2d. 594, 823.(D.C. Cir. 1975) (*en banc*).
41. *Korematsu v. United States,* 323 U.S. 214, 217-18 (1944).
42. 7 Fed. Reg. 1407.
43. *Camara v. Municipal Court,* 387 U.S. 523, 536-37 (1967).
44. *Williams v. Alioto,* No. C-74-0866-ACW (N.D. Cal. April 25, 1974).
45. *Lankford v. Gelston,* 364 F.2d. 197 (4th Cir. 1966).
46. *United States v. Mellville,* 309 F. Supp. 829, 832 (S.D.N.Y. 1970).
47. *Camara,* Note 43, supra, p. 530.
48. U.S. Constitution, Amend. IV.
49. *Camara,* Note 43, supra, p. 528.
50. *Steele v. United States,* 267 U.S. 498, 503 (1925).
51. *Camara,* Note 43, supra, p. 535.
52. Id., pp. 536-37.
53. Id.
54. Ayres, "Policing Plutonium: The Civil Liberties Fallout," Harvard Civil Rights-Civil Liberties Law Review, Vol. 10, 1975, p. 420.
55. The Supreme Court has made it clear that domestic security surveillance programs were overbroad relative to the dangers they sought to avert, but this attitude probably would not extend to clear cut cases of extreme emergency. For example see *U.S. v. United States District Court,* 407, U.S. 297, 324 (1972).
56. *Kroplin v. Trauz,* 119 Ohio St. 610 (Ohio S. Ct. 1929).
57. *North American Cold Storage Co. v. City of Chicago,* 211 U.S. 306 (1908).
58. *Jacobson v. Massachusetts,* 197 U.S. 11 (1905).
59. *Compagnie Francaise de Navigation a Vapeur v. Louisiana State Board of Health,* 186 U.S. 380 (1902).
60. *Phillips v. Commissioner,* 283 U.S. 589 (1930).
61. *Fahey v. Mallonee,* 332 U.S. 245 (1946).
62. *Ewing v. Mytinger & Casselberry, Inc.* 339 U.S. 594 (1949).
63. *Fuentes v. Shevin,* 407 U.S. 67, 91 (1972).
64. Search and Seizure Law Report, Vol. 7, No. 7, July 1980, p.1.
65. *Warden v. Hayden,* 387 U.S. 294 (1967).
66. *U.S. v. Carter,* 522 F.2d.666 (D.C. Cir. 1975).
67. *Mincey v. Arizona,* 437 U.S. 385 (1978).
68. *State v. Hardin,* 518 P.2d. 151 (Nev. 1974).
69. *Camara,* Note 43, supra, pp. 536-37.
70. "Legislative response to *Zucker v. Stanford Daily,*" Committee Report by the Committee on Civil Rights, the Record of the Ass'n of the Bar of the City of New York, Vol. 35, Oct. 1980, pp. 415-417; Dyk, Note 20, supra, p. 105; Barton, Note 39, supra, p.23.
71. *U.S. v. Albarado,* 495 F.2d. 799, 807 (2nd Cir. 1974).
72. Notes 56-62 and accompanying text.
73. Barton, Note 39, supra, p. 24.

74. Suit brought under 42 U.S.C. 1983 allows a Federal tort action for illegal arrest and search, *Monroe, v. Pape,* 365 U.S. 167 (1961).
75. *Pierson v. Ray,* 386 U.S. 547 (1967); On the general inadequacy of possible criminal and tort liability, as deterrents for police violations of constitutional rights, see W. LaFave, Arrest 411-27 (1965).
76. W.E. Kunz, et al., "Hand-held Personnel and Vehicle Monitor," Los Alamos Scientific Laboratory, presented at the Institute of Nuclear Materials Management Annual Meeting, 6/18-20/75, p.246.
77. *Terry v. Ohio,* 392 U.S. 1, 27 (1968).
78. *Warden v. Hayden,* 387 U.S. 294, 298-99 (1967).
79. *Chiniel v. California,* 395 U.S. 752, 773 (1969).
80. Note 76, supra.
81. *Carroll v. United States,* 267 U.S. 132, 153 (1925).

APPENDIX A
THE WARRANT REQUIREMENT AND EXCEPTIONS

Intrusions into the physical privacy of individuals have traditionally been analyzed by the courts in terms of the Fourth Amendment, which provides that people have the right "to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures...."[1]

The Supreme Court has interpreted the purpose of this amendment to "safeguard the privacy and security of individuals against arbitrary invasions by government officials."[2] To protect this right against unreasonable search and seizures, the Fourth Amendment requires that a search can only be conducted pursuant to a warrant issued "upon probable cause, supported by oath or affirmation, and particularly describing the place to be searched, and the persons or things to be seized."[3]

The reasonableness of a search is based on balancing the "need to search against the invasion which the search entails."[4] This balancing is to be undertaken by a "neutral and disinterested magistrate," rather than by an executive officer whose "duty and responsibility are to enforce the laws, to investigate, and prosecute."[5]

There are several well-defined exceptions to the warrant requirement before a search can be executed, involving situations in which exigencies make it imperative to proceed without a warrant.[6] These recognized exceptions are: search incident to arrest,[7] stop and frisk,[8] the automobile or moving vehicle,[9] the doctrine of hot pursuit,[10] the seizure of evidence or contraband that is subject to removal or destruction,[11] and emergency seizure exception.[12] In addition, a search may be made pursuant to a valid consent,[13] or when evidence is in plain view, if the officer is otherwise justified in his position.[14]

There are, however, two different types of searches. These are criminal searches and civil searches.[15] A criminal search connotes hostility by the searching officer toward the individual whose privacy is invaded in that the ultimate goal of the search is a criminal prosecution. It is the "probable cause" requirement of the Fourth Amendment which is meant to protect the individual from such hostile intrusions. The Fourth Amendment protection against unreasonable searches and seizures has been extended beyond criminal searches to searches and inspections conducted by administrative and regulatory agencies.[15] These intrusions are "less hostile" than the typical policeman's search for the fruits and instrumentalities of crime.[17] They are deemed "quasi-criminal" because "most regulatory laws...are enforced by criminal processes."[18] These activities, called civil searches, are not aimed at seeking out criminal activities.

The position of the Supreme Court, with respect to the applicability of the warrant requirement to civil searches provided a strong basis for believing that most civil searches do fall under the warrant requirement.[19] The Court has stated:

> The Fourth Amendment interests at stake in these inspection cases are (not) merely "peripheral." It is surely anomalous to say that the individual and his private property are fully protected by the Fourth Amendment only when the individual is suspected of criminal behavior.[20]

The Court has cited, with approval, the dissenting statements from prior cases holding civil searches outside the warrant requirement. "The Fourth Amendment...has a much wider frame of reference than mere criminal prosecutions."[21]

It is the individual's interest in privacy which the Fourth Amendment protects, and that would not appear to fluctuate with the "intent" of the invading officers.[22]

The problem is that the fact patterns of cases dealing with the civil search questions are not void of suspect criminal activity. The Court recognized that these cases involve regulatory laws which "are enforced by the criminal processes."[23] This lack of a clear case involving a pure civil search indicates that there is no discrete dichotomy between civil and criminal searches in terms of the applicability of a warrant requirement.[24] For this reason an examination of elements of civil and criminal cases is needed.

The regulation of warrantless criminal searches is based upon two fundamental rules of reasonableness:[25] first, the requirement of probable cause, second, the existence of exigent circumstances.[26]

> No amount of probable cause can justify a warrantless search or seizure absent "exigent circumstances."[27]

There is a difficulty, however, in applying the probable cause required to a case involving a civil search. Probable cause requires that:

> The facts and circumstances within [an individual's] knowledge of which they had reasonable trustworthy information [be] sufficient in themselves to warrant a man of reasonable caution in the belief that an offense has been or is being committed.[28]

For civil searches the Supreme Court has ruled that "if a valid public interest justifies the intrusion contemplated, then there is probable cause to issue a suitably restricted search warrant."[29] The advantage of this approach is that it "neither endangers the time-honored doctrines applicable to criminal investigations nor makes a nullity of the probable cause requirement in this area."[30] It follows in the case of civil searches that the probable cause test differs from that applied to criminal searches only in that the search must be justified by a "functional equivalent of probable cause."[31]

The Court has approached the civil search as an activity bearing the same standard as a criminal search — that "reasonableness is...the ultimate standard."[32]

The two-pronged approach to ascertain the reasonableness of a warrantless search is applicable to civil searches if probable cause can be couched in a "valid public interest"[33] and exigent circumstances can be established which make attaining a warrant impractical.

The court has not been wholly consistent in applying this two-pronged test, which includes a new formulation of probable cause.[34] In a recent decision concerning roving automobile border searches for aliens, the search in question was miles away from the border, and despite the similarities with the fact patterns in other cases, four justices applied the traditional probable cause test finding the search unreasonable for lack of probable cause. Four dissenting justices, recognizing that the "traditional (criminal) probable cause test was inapplicable, dispensed with the probable cause test altogether and adopted a reasonableness standard "sufficiently flexible to authorize the search involved...."[35] Justice Powell concurred in the case finding the search unreasonable, using the logic of previous cases, holding that "there may exist a constitutionally adequate equivalent of probable cause to conduct roving vehicular searches in border areas."[36] Powell, however, made no determination of whether probable cause did exist. Instead he based his decision on the lack of exigent circumstances.[37]

In another case, where the new formulation of probable cause was not consistently applied (decided on the same day as the case noted above), Justice Powell joined in the majority view, which found that the search of "the trunk of an automobile, which the officer reasonably believed to contain a gun, was vulnerable to intrusion by vandals,...was not unreasonable."[38] In the view of the dissenting Justices, the reasonableness of the search was conceded in that a valid public interest of this nature "may establish probable cause to search...."[39] In this case, therefore, the Court unanimously held that the valid public interest test applied a probable cause, while the minority held that there was a lack of exigent circumstances. The majority based its opinion on the reasonableness test without exigent circumstances, holding that the search "was not unreasonable solely because a warrant had not been obtained."[40]

The inconsistency lies in the fact that in the first case the dissenting judges would have dispensed with the probable cause test, while in the second, the majority dispensed with the requirement of exigent circumstances.

Even the determination of whether exigent circumstances exist is not clear as shown in another case where four justices found exigent circumstances in the same fact pattern in which four dissenting justices could not.[41]

An alternative test has been used which is simply to consider the "reasonableness" of the search. When considering the reasonableness of airport searches,[42] the courts have mainly based their opinions on Justice Powell's suggestion that probably cause be dispensed with altogether and a standard be adopted which is "sufficiently flexible to authorize the search involved."[43]

This "reasonableness" test has not been clearly enunciated by the Court, so that its use as a rationale for more intrusive techniques for access control than "hands off" inspection of individuals and packages is questionable. Since the courts have found some airport mechanical search techniques simply "reasonable," there should be no problem using the same mechanical techniques in more limited situation of access to areas containing SNM and other nuclear facilities.

It appears that more intrusive nuclear safeguards access controls should be rationalized, both from the standpoint of nontraditional (civil) probable cause and the existence of exigent circumstances.

A final factor to be considered is the "expectation of privacy." The Supreme Court has stated that "a person has a constitutionally protected reasonable expectation of privacy."[44] It would most likely be held that an employee or visitor should not be allowed to harbor an expectation of privacy where the privacy is violated by access controls.

REFERENCES

1. U.S. Constitution, Amend. IV.
2. *Camara v. Municipal Court,* 387 U.S. 523, 528 (1967).
3. U.S. Constitution, Amend. IV.
4. *Camara,* Note 2, supra, pp. 536-37.
5. *United States District Court,* 407 U.S. 297, 324 (1972).
6. *Coolidge v. New Hampshire,* 403 U.S. 443, 455 (1971); *McDonald v. United States,* 335 U.S. 451, 456 (1948).
7. *United States v. Robinson,* 414 U.S. 218 (1973).
8. *Terry v. Ohio,* 392 U.S. 1 (1968).
9. *Chambers v. Maroney,* 399 U.S. 42 (1970); *Carroll v. United States,* 267 U.S. 132 (1975); *Untied States v. Connolly,* 479 F. 2d. 930, 934-35 (9th Cir. 1973) cert. denied, 414 U.S. 897 (1974).
10. *Warden v. Hayden,* 387 U.S. 294, 298-99 (1967).
11. *Schmerber v. California,* 384 U.S. 757, 770-71 (1966); *Chapman v. United States,* 365 U.S. 610, 615 (1961); *United States v. Blake,* 484 F. 2d 50, 53-56 (8th Cir. 1973).
12. *United States v. Goldstein,* 456 F. 2d. 1006, 1009 (8th Cir. 1972), cert. denied, 416 U.S. 943 (1974).
13. *Schneckloth v. Bustamarte,* 412 U.S. 218 (1973).
14. *United States v. Haden,* 397 F. 2d. 460, 465 (7th Cir. 1968), cert.denied, 396 U.S. 1027 (1970).

15. Melinda Roberts, "The Emergency Doctrine: Civil Search and Seizure and the Fourth Amendment," 43 Fordam L. Rev. 571, 572 (1975).
16. *United States v. Biswell,* 406 U.S. 311 (1972); *Camara v. Municipal Court,* 387 U.S 523 (1967); Note, "Inspections by Administrative Agencies: Clarification of the Warrant Requirement," 49 Notre Dame Law 879 (1974).
17. *Camara,* Note 2, supra, p. 530.
18. Id.
19. Id., p. 531.
20. Id., p. 530.
21. *Frank v. Maryland,* 359 U.S. 360. 377 (1959) (dissenting option) overruled, *Camara v. Municipal Court,* 387 U.S. 523 (1967).
22. *Abel v. United States,* 362 U.S. 217, 255 (1960) (dissenting option) cited with approval in *Camara v. Municipal Court,* 387 U.S. 523, 530 (1967).
23. *Camara,* Note 2, supra, p. 531.
24. Roberts, "Emergency Doctrine," pp. 574-75.
25. Id., p. 577.
26. *Coolidge v. New Hampshire,* 403 U.S 443 (1971).
27. Id., p. 468.
28. *Carroll v. United States,* 267 U.S. 132, 162 (1925).
29. *Camara,* Note 2, supra, p. 539.
30. Id.
31. *Almeida - Sanchez v. United States,* 413 U.S. 266, 277 (Powell, J., concurring).
32. *Camara,* Note 2, supra, p. 539.
33. Id.
34. *Almeida - Sanchez,* Note 31, supra.
35. Id., p. 289 (dissenting opinion).
36. Id., p. 279.
37. Id., p. 285.
38. *Cady v. Dombrowski,* 413 U.S. 433, 448 (1973).
39. Id., p. 454 (dissenting opinion).
40. Id., p. 448.
41. *Cardwell v. Lewis,* 417 U.S. 583 (1974).
42. *United States v. Bell,* 464 F. 2d. 667 (2d Cir. 1974); *United States v. Lopez,* 328 F. Supp. 1077 (E.D. N.Y. 1971); *United States v. Epperson,* 454 F. 2d. 769 (4th Cir. 1972); *United States v. Davis,* 482 F. 2d 893 (9th Circ. 1973).
43. *Almeida - Sanches,* 413 U.S. at 289; also *Cady v. Dombrowski,* Note 38, supra, p. 439.
44. Note 5, supra.

APPENDIX B
THE HISTORY OF EMERGENCY LEGISLATION

In 1897 a Connecticut court ruled that conditions could exist which would cause an intrusion on the liberty of some individuals. The case was in reference to a proposed railroad line and the seizure of the land (eminent domain) was at issue. The State court ruled that:

> Public necessity...is that urgent, immediate public need arising from exist-

> ing conditions which, in the judgement of the legislative, justifies a disturbance of private rights that otherwise might be legally exempt from such interference. The term [public necessity], is, therefore, a relative one.[1]

In 1908, the Supreme Court ruled on the seizure of unfit food without a prior hearing. The Court couched its decision in the state's right to protect the lives and health of its citizens.

> The right to so seize is based on the right and duty of the state to protect and guard, as far as possible, the lives and health of its inhabitants, and that it is proper to provide that food which is unfit for human consumption should be summarily seized and destroyed to prevent the danger which would arise from eating it.[2]

In 1934 the Supreme Court made a clear statement on the suppression of civil liberties in an emergency situation:

> When the provisions of the Constitution, in grant or restriction, are specific, so particularized as not to admit of construction, no question is presented. Thus, emergency would not permit a State to have more than two Senators in the Congress, or permit the election of the President by a general popular vote without regard to the number of electors to which the States are respectively entitled, or permit the States to "coin money" or to "make anything but gold and silver coins a tender in payment of debts." But where constitutional grants and limitations of power are set forth in general clauses, which afford a broad outline, the process of construction is essential to fill in the details.[3]

The Supreme Court, however, made a strong statement in the same case on limitations and activities during an emergency:

> Emergency does not create power. Emergency does not increase granted power or remove or diminish restrictions imposed upon power granted or reserved. The Constitution was adopted in a period of grave emergency. Its grant of power to the Federal Government and its limitations of the power of the States were determined in light of the emergency and they were not altered by emergency. What power was thus granted and what limitations were thus imposed are questions which have always been, and always will be, the subject of close examination under our constitutional system. While emergency does not create power, emergency may furnish the occasion for exercise of power. "Although an emergency may not call into life a power which has never lived, nevertheless emergency may afford a reason for the exertion of a living power already enjoyed" (cites omitted). The constitutional question presented. embraces the particular exercise of it in response to particular condition. Thus, the war power of the Federal Government is not created by the emergency of war, but it is a power given to meet that emergency. It is the power to wage war successfully and thus it permits the harnessing of the entire energies of the people in a supreme cooperative effort to preserve the nation. But even the war power does not remove constitutional limitations safeguarding essential liberties.[4]

In 1939, a New York court suggested that "emergency legislation" is an integral step in legislative progression in the tradition of common law, to provide for societal needs which an ever more complex society presents:

> Almost every legal innovation has been the product of "emergency" — a condition that deviates from antecedent experience and for which the usual forms of law seem inadequate to serve public order. Such conditions or emergencies, step by step, gave stimulation to the creations, to new writs and to the new plans of common law during all its vital development. The

> statutory "emergency" of the last decade in this country has frequently been a legislative fiction, but such fictions to provide treatment for new conditions are in the best tradition of the common law. A declaration of emergency by a legislative body under recent legislative practice is usually a recognition that new conditions require new treatment under regulations that might be and frequently were long continued by successive enactments from time to time. It was inevitable that these new devices of legislative action, having once been accepted as "emergency" legislation and having met the test of experience would in time, and where successful in practice, be accepted as common and legitimate fields of permanent legislation.[5]

In 1966, Congress legislated that states could not apply new voting regulations until the regulations were scrutinized by federal authorities to determine whether their use would violate the Fifteenth Amendment. The Supreme Court commented that:

> This may be an uncommon exercise of Congressional power..., but the Court has recognized that exceptional conditions can justify legislative measures not otherwise appropriate.[6]

The Court went on to cite decisions which allowed government to suppress some constitutional rights because of public necessity or emergency.

In 1967, the Supreme Court intimated that emergency situations could necessitate a suspension of the warrant requirement:

> Since our holding emphasizes the controlling standard of reasonableness, nothing we say today is intended to foreclose prompt inspection, even without a warrant, that the law has traditionally upheld in emergency situations.[7]

The Court in the same case, qualified its position to a degree, declaring that in order to determine the reasonableness of a search:

> ...it is obviously necessary first to focus upon the governmental interest which allegedly justifies official intrusion upon the constitutionally protected interest of the private citizen. For example, in a criminal investigation, the police may undertake to recover specific stolen or contraband goods. But that public interest would hardly justify a sweeping search of an entire city conducted in the hope that these goods might be found. Consequently, a search for these goods, even with a warrant, is "reasonable" only when there is "probable cause" to believe that they will be uncovered in a particular dwelling."[8]

Emergency situations have recently been qualified by the Circuit Court of the District of Columbia:

> ...This case raises a question about the way the Government should operate when responding to a crisis. Neither the term "national security" nor "emergency" is a talisman, the thaumaturgic invocation of which should, ipso facto, suspend the normal checks and balances on each branch of Government. Our laws were not established merely to be followed only when times are tranquil. If our system is to survive, we must respond to even the most difficult of problems in a matter consistent with limitations placed upon the Congress, the President, and the Courts by our Constitution and laws.[9]

From this history, it seems likely that the courts, in a recovery operation, would weigh the public interest in recovering stolen SNM against the invasion upon constitution rights which the recovery operation entails. In order to make any assertion as to what the courts would do, each activity must be assessed in terms of the public interest and what intrusions will occur. This analysis must necessarily be vague because of the speculative nature of a recovery operation.

REFERENCES

1. *In re Shelton St. Ry. Co.*, 38A. 362, 363 (Ct. 1897).
2. *North American Cold Storage Co. v. City of Chicago*, 211 U.S. 306, 315 (1908).
3. *Home Bldg, Assn. v. Blaisdell*, 290 U.S. 398, 426 (1934).
4. Id. pp. 425-426.
5. *Noyes v. Erie & Wyoming Farmers Co-op. Corp.*, 10 N.Y.S. 2d 114, 121 (N.Y. 1939).
6. *South Carolina v. Katzenbach*, 383 U.S. 301, 334 (1966).
7. *Camara v. Municipal Court*, 387 U.S. 523, 539 (1967).
8. Id., p. 535.
9. *Algonquin SNG, Inc. v. Federal Energy Administration*, 518 F.2d. 1051, 1062 (D.C. Cir. 1975).

The Possible Legal Consequences of Protective Radioactive Spiking of Nuclear Fuel

Jerry J. Cadwell

NUREG/CR-1047
February 1980

TABLE OF CONTENTS

Page
I. Protective Radioactive Spiking of Nuclear Fuel 271
II. The Context in Which Spiking Could Be Challenged and Defended 272
III. Defending Spiking as "Necessary" 274
IV. Can the NRC Justify Spiking as Required for the "Common Defense and Security" of the United States? 278
V. Is Spiked Nuclear Material a "Trap" or a "Dangerous Device"? 280
VI. Spiking Used To Prevent a Dangerous Felony 285

ABSTRACT

"Spiking" of fresh nuclear reactor fuel with a radioactive material has been proposed to inhibit the domestic theft and processing of the fuel into materials suitable for making a nuclear bomb. The proposed spiking would expose terrorists attempting to process or handle the nuclear fuel without proper shielding to lethal or near-lethal doses of radiation.

The intentional use of a lethal device to protect property from theft has been addressed by various courts and is the subject of some statutory and case law. The principal argument against spiking as a proper legal activity, according to the economic analysis theory proposed by Professor Posner of the University of Chicago Law School, would be that the economic and social costs of the theft of special nuclear material would not outweigh any legal or social costs associated with spiking and, hence, spiking could not be justified by an economic argument. This conclusion is reached when one considers the value of the SNM at stake, its location, the warnings given to the thief, the deadliness of the SNM, the character of the conflicting activi-

ties (spiking versus theft of SNM), the thief's care or negligence, and the cost of avoiding theft by other means.

Several sections of the Atomic Energy Act of 1954, as amended, indicate that the NRC could justify spiking on the basis of a need to preserve the "common defense and security of the United States." However, opinions given by the NRC General Counsel regarding the NRC's lack of capability to instigate an employee clearance program based on general "common defense and security" are used to indicate that spiking could not be justified unless specific congressional authorization is given.

Using common law and modern variations of the common law, it is determined that spiking, because it is done with the intent to injure a thief, could be considered a "trap" or dangerous device. Various cases are cited to show that an owner of a chattel (such as spiked nuclear fuel) could not lawfully set a trap to inflict death because a trap cannot discriminate between an unlawful intent and a lawful intent. Furthermore, traps tend to inflict death and destruction which, if the owner were present, could not lawfully be inflicted.

In a number of early cases consideration was given to the question of removing the "trap" aspect of spring guns and other dangerous instrumentalities by giving proper notice. In general, notice does not relieve the owner of the responsibility or liability for manslaughter or murder if a thief is killed.

The objection to spiked fuel as constituting a trap may be partially overcome by arguing that the theft of spiked nuclear fuel would be a felony, specifically a "dangerous felony," and thus entitled to protection by the use of deadly force. If the theft of spiked fuel is considered a dangerous felony, then attending guards would be allowed the use of deadly force to prevent or terminate a felony. If spiking is considered a part of the deadly force used by the guards, then justification exists for spiking.

Because of the potential for large-scale destruction and loss of life incident to a theft of fuel, it is difficult to predict the extent to which courts would follow their normal procedure and allow arguments by analogy. The best prediction is that the courts would adopt an economic social theory (such as posed by Professor Posner) used in the last 15 years in environmental cases, would consider applicable common law, and as a result would disapprove spiking for use in United States commerce.

I. PROTECTIVE RADIOACTIVE SPIKING OF NUCLEAR FUEL

The term "spiking," as used in this report, refers to the proposed incorporation of radioactive material in nuclear fuel for the purpose of inhibiting unauthorized use of nuclear fuel. Unauthorized use includes theft of the material and (after theft) the possession and processing of the material into concentrations and materials suitable for use in making a nuclear bomb.[1] The special nuclear materials (SNM) in the nuclear reactor fuel, for which protective spiking is being considered, are those isotopes of plutonium and uranium capable of use in making nuclear explosive devices.[2]

There are several techniques for spiking and several reasons for considering each technique. The spiking methods include the three techniques of adding radioactive material to fresh reactor fuel before it is processed into fuel rods, subjecting the newly processed reactor fuel to irradiation before it is shipped, and placing radioactive sleeves or other mechanisms on or near the new fuel before the fuel is shipped to the user.[3]

The purpose of spiking is to provide lethal or near-lethal doses of radiation to deter domestic terrorists from stealing reactor fuel. The consequence of the use of spiking in international shipments is beyond the scope of this report. This report deals with the possibility of spiked fuel being required for U.S. domestic use. A secondary purpose of spiking is to increase the difficulty of converting reactor fuel into the proper form for use in nuclear weapons by making it necessary to process the stolen material behind radiation barriers with special and very expensive remote equipment.[4] Spiking may also degrade the performance of any nuclear explosive device made from the stolen material.[5] The probability of locating and recovering stolen material might also be enhanced by spiking if the contained radioactivity is instrumentally detectable from reasonable distances.[6]

REFERENCES

1. W. Meyer, et al., "The Homemade Nuclear Bomb Syndrome," Vol. 18, Nuclear Safety, July-August 1977.
2. For identification of special nuclear material and the particular schemes which have been considered for spiking, see E.V. Weinstock, "The Spiking of Special Nuclear Materials as a Safeguards Measure," Vol. I, Brookhaven National Laboratory, Technical Support Organization, September 19, 1975.
3. Id.; "The Spiking of Special Nuclear Materials as a Safeguards Measure," Volume 2, IRT-378-R, prepared for Brookhaven National Laboratory, November 6, 1975; J.E. Selle, "Chemical and Physical Considerations of the Use of Nuclear Fuel Spikants for Deterrence," ORNL/TM-6412, October 1978; J.E. Selle et al., "Practical Consideration of Nuclear Fuel Spiking for Proliferation Deterrence," ORNL/TM-6483.
4. J.E. Selle, Note 3, supra.

5. E.V. Weinstock, Note 3, supra, Chapter II.
6. Edward Straker, "Material Radiation Criteria and Non-Proliferation," SAI 01379-507-LJ, January 8, 1979; see previous report in this chapter.

II. THE CONTEXT IN WHICH SPIKING COULD BE CHALLENGED AND DEFENDED

Spiking could be challenged in a court of law if the challenger can show that he has received an injury of the type recognized by courts as compensable. Several sources of lawsuits could be envisioned arising from the activity of spiking nuclear fuel. Since the primary reason for spiking nuclear materials is to prevent their theft, it may be reasonable to expect that the most common challenge to spiking would come from the thief's survivors asking for money damages and criminal charges as compensation for the thief's death. There is a line of court cases allowing a thief to recover compensation for injury incurred during a theft. This right of the thief is given recognition in *McKinsey v. Wade*[1] where the court stated "a thief does not forfeit all rights including the right to live."

A more remote injury might be that to a third person injured by radiation as a result of an accident or the successful theft of spiked fuel. In this instance, the legal theory of recovery for damages would probably be based on negligence, with the injured third person claiming that the owner of the spiked fuel could or should have foreseen the injury and was negligent in spiking the fuel and caused the foreseeable injury. This argument has possible merit, but is not pursued in this report because the possibility of third-party injury is thought to be relatively remote and would most likely fail to have a court-required causal connection with the spiking activity. Even if a negligence claim were brought against the owner of the spiked fuel, the economic arguments (to follow) would be appropriate for defending the use of spiked fuel.

There is also the possibility that the use of spiked fuel may be considered by courts as an inherently hazardous activity which causes "strict" liability for serious harm done to persons or property irrespective of fault of the fuel owner. The subject of strict liability is outside the scope of this report.

The arguments that follow represent those which might be used by attorneys for the plaintiff and defendant in such a case. It is not clear which would prevail. Parts of some of the arguments take the form of "justification." In many areas of the law, such as justifiable homicide, a "justification" is recognized for an activity that, strictly speaking, is not legal or desirable. Although justifiable and, therefore, permitted, the activity in question is not authorized or legal; it is merely granted an exception to the general rule.

Defenses are arguments used to persuade the court that there are good and sufficient reasons for allowing the challenged activity, in this case spiking. The first defense of spiking to be considered is based on the economic argument that spiking is necessary when the consequences of a theft of SNM are compared with those societal interests which may seek protection by legal arguments against spiking. The second type of defense, called common law, is based on judge-made law in the form of court decisions. By reviewing the court decisions made by judges who have thoughtfully considered similar situations, one can get a general idea of what would happen if a new case were brought into court.

The "law and economics" argument is relatively new, having become a subject of serious interest in about 1959[2] when, according to Professor Posner, legal scholars such as Calabresi, Becker, and Coase began to write on this topic. Up to that time the courts had traditionally allowed only common law arguments where defenses are made by arguing that the present case is, by analogy, the same as a previously decided case and that the two cases (the new and the old) should be decided in the same way. This method (known by the Latin term *stare decisis*) uses legal precedent set by former cases to assure that the courts treat similar situations in similar ways so that a thread of predictability and fairness prevails. Economic arguments (which sometimes urge a departure from common law precedents) are increasingly being viewed with favor by the courts.

When an economic argument is used to demonstrate to the court that spiking is "necessary" or provides the best balance when personal injury to the thief and the social and economic costs are weighed, the efficacy of spiking must be demonstrated. The efficacy of spiking becomes an issue when an attempt is made to show that society will benefit socially and economically from the use of spiking. For the purposes of this report and in order to argue both for and against spiking, it is assumed that spiking will be an effective deterrent. However, a study done by Straker[3] can be interpreted as casting doubt on the degree of deterrence to theft that spiking provides. In addition, Weinstock[4] has stated that "it is likely that greater security could be purchased...by increasing the conventional security measures. In terms of monetary cost, the cost of spiking seems to be excessive compared with the cost of additional physical protection."[5]

A circular argument can be made that a law suit from a thief could arise only when the spiked fuel actually accomplished its goal of injuring the thief. Given that, the argument of economic benefit would always be reached because the very fact of a law suit complaining of injury to a thief is evidence of the efficacy of spiking.

The remainder of this report consists of arguments based on the assumption that spiking can be shown to have a deterrence to theft.

REFERENCES

1. *McKinsey v. Wade*, 136 Ga. 109, 200 S.E. 2d 30 (Ga. App. 1975).

2. Richard A. Posner, "Some Uses and Abuses of Economics in Law," University of Chicago Law Review, Vol. 46, 1979, p. 283.
3. Edward Straker, "Material Radiation Criteria and Non-Proliferation," 01379-507-LJ, January 8, 1979.
4. E.V. Weinstock, "The Spiking of Special Nuclear Materials as a Safeguards Measure," Vol. I, Brookhaven National Laboratory, Technical Support Organization, Sept. 19, 1975.
5. Id.; IRT, "The Spiking of Special Nuclear Materials as a Safeguards Measure," Vol. 2, November 1975.

III. DEFENDING SPIKING AS "NECESSARY"

One of the more modern defenses which an attorney would use to defend spiking should it be challenged in a court of law would be the argument that the use of spiking was "necessary" when the possible consequences of a theft of special nuclear material are compared with those societal interests sought to be protected by legal arguments against spiking.

In his article, "Killing or Wounding To Protect a Property Interest,"[1] Professor Posner of the University of Chicago Law School has argued that many recent court decisions on questions similar to that of the legality of spiking have rested ultimately upon an economic basis. These cases usually do not couch their decisions on a stated economic basis; however, the reasoning used in the decision is, in fact, economic.

> Some people express shock at the idea of weighing personal injury and death in the same balance with purely economic costs and benefits, but it is done all the time. Individuals who work at hazardous jobs for premium pay are exchanging safety for other economic goods. Where life is taken or injury inflicted in an involuntary transaction, such as an automobile accident, society often attempts to approximate the loss in monetary terms. It goes without saying that the task of approximation is an extremely difficult one. Some dimensions of the loss — such as anguish to family and friends — cannot even be approximated by the methods available to the courts and are, therefore, usually ignored. But is it out of the question to ban all hazardous activities on these grounds?[2]
>
> These activities reinforce the point made in an early case, *Bird v. Holbrook*[3], that neither blanket permission nor blanket prohibition of spring guns and other methods of usual deadly force to protect property interests is likely to be the rule of liability that minimizes the relevant costs. What is needed is a standard of reasonableness that permits the courts to weigh such considerations as the value of the property at stake, its location (which bears not only on the difficulty of protecting it by other means, but also on the likelihood of innocent trespass), what kind of warning was given, the deadliness of the device (there is no reason to recognize a privilege to kill when adequate protection can be assured by a device that only wounds), the character of the conflicting activities, the trespasser's care or negligence, and the cost of avoiding interference by other means....[4]

Posner, who is the leading proponent of the law and economics method, has further suggested seven criteria which he considers to be important if one is attempting to justify killing or wounding to protect a property interest. A court would decide for itself what the relative importance of these criteria were and what additional criteria would be considered. These seven criteria are not equal in importance nor are they complete. They can, however, be very instructive.

The seven proposed criteria are the following: the value of the property at stake, its location, what kind of warning was given, the deadliness of the device, the character of the conflicting activities, the trespasser's care or negligence, and the cost of avoiding theft by other means.

A. The Value of the Property at Stake

The purely commercial value of reactor fuel material is not very high, when compared to values of the interest society has in preventing the material from being used to make an explosive device. This economic consideration is one of Posner's criteria to eliminate those cases where the protection of a property interest of small value causes a loss of life. Some experts even assert[5] that the manufacturing and shipping costs of spiking, when compared with its marginal deterrent effect, make spiking an economic burden that can not be justified. The protection of nuclear fuel by the use of spiking probably would not be allowed in light of society's health and safety interest.

B. The Location of the Spiked Material

The difficulty of protecting SNM by means other than spiking depends on the location of the spiked fuel and the likelihood of innocent trespass. The difficulty of protection and the location of the SNM must be weighed against each other in terms of economic costs and benefits.

The location of spiked fuel varies; it may be found in a new fuel fabrication plant, in transit on public roads, in use in a reactor, and in reprocessing plants where it is reprocessed into reusable reactor fuel. In each case, the likelihood of innocent trespass would, because of the presence of heavy armed guards and the type of shipping containers used for spiked fuel,[6] be highly unlikely.

As to the difficulty of protecting the SNM by other means regardless of its location, the primary objectives of spiking reactor fuel are (1) to cause injury to the thief sufficient to prevent him from processing the reactor fuel into an explosive device; (2) if not to injure the thief, then to slow his progress by forcing him to process the fuel by use of remote devices behind heavy shielding; and (3) to a very minor degree, depending on the spikant used, to diminish the explosive ability of the device finally built.

Without repeating other work done on this subject,[7] it can be said that the difficulty of protecting fuel by means other than spiking, regardless of the fuel's location, is not great. It seems that the argument that spiking is necessary or economically justifiable because of the fuel's location cannot be sustained, because the SNM is heavily guarded and the difficulty of protecting fuel by other means is small.

C. What Kind of Warning Was Given? Was It Adequate?

Nuclear fuel could not be stolen unless the persons committing the theft were knowledgeable and determined. New spiked reactor fuel in transit would probably be shipped inside massive spent-fuel shipping containers which are about 5 feet in diameter and about 15 to 18 feet long, weighing from 20 to 75 tons.[8] In addition, these shipping containers would be marked with U.S. Department of Transportation placards indicating that the material being shipped was radioactive. Fuel not in transit would be protected by facility physical protection and material control and accounting procedures.

As to notice about the level of injury which the thief would receive from the fuel, there may be none. However, it is common knowledge (which can be imputed to the thief) that radioactive material is dangerous. It would be very difficult to reach any fuel without some notice that radioactive material was present. The knowledge that material is radioactive, even without the knowledge of the level of the radioactivity or its potential capacity for injury, should provide the warning required for this test.

D. The Deadliness of the Device

In a complete economic argument, the deadliness of the device must be considered so that the likelihood of injury can be compared with the likelihood of social (economic) benefit. The spiking levels proposed are considered to be lethal or near lethal to those individuals who are within 3 feet of an unshielded fuel element for one hour; therefore, the unshielded fuel must be considered deadly. However, the fuel is normally shielded while in transit such that it is not deadly unless the shipping cask is intentionally (and laboriously) opened. The deadliness of the spikant can be measured with suitable instruments, but is not detectable with any of the five human senses.

An argument can be made that the spiking material is not deadly unless the shipping cask is intentionally and knowingly broken open. This type of argument, joining the deadliness of the device to its accessibility, was rejected in a recent Iowa case[9] where damages were awarded to a burglar who broke into a boarded up house, opened an interior door (which was braced shut), and was seriously injured by a shot from a spring gun set by the absentee land owner. Case law indicates that the deadliness of a device cannot be measured by its remoteness to the thief at the beginning of the crime. By analogy, spiking can be said to be deadly, even though contained inside a shipping cask or guarded facility.

E. The Character of the Conflicting Activities

The activity of spiking nuclear fuel is designed to prevent or deter theft of SNM and subsequent production of a nuclear explosive device. The production and use (or threat of use) of a nuclear explosive device would be an extremely disruptive activity and very expensive in terms of social and economic costs. An additional cost of spiking nuclear fuel would be that borne by utility ratepayers due to increased costs of handling fuel which is more radioactive than it would be without the spiking.

The activity of theft and the potential use of SNM by terrorists offer no economic benefits to society. The economic effects of theft would be costs which are only detrimental. On the basis of only this particular analysis, spiking would probably be permissible.

F. The Trespasser's Care or Negligence

In the theft of nuclear fuel, the trespasser would be intermeddling with a chattel which, during transit, would be protected by armed guards, marked with signs and encased in a large strange-appearing shipping cask. If a thief could be shown to be negligent in the process of stealing the spiked fuel, then the court could limit the recovery which he or his survivors could receive for his injury. Negligence is a term of art which, put simply, means that the thief did something a reasonably prudent man would not have done, which contributed to thief's injury. If the thief assumed the risk, that is, he actually recognized and understood the risk of injury and voluntarily chose to assume that risk, then he may also be barred from a court recovery for his injury. The thief's negligence would arise only if he attempted to remove the fuel from the shipping cask and steal it without the protective shield provided by the cask. Since the thief's activity is a hazardous one, some commentators have suggested that the thief assumes the risk of any negligence. However, this argument is not well received and is, according to Posner,[10] an argument which can be debated endlessly.

In some cases it has been maintained that the thief's negligence or assumption of risk will not bar a court recovery for his injuries. In *Marquis v. Benfer*[11] where two broken locks allowed an innocent plaintiff with no criminal intent to enter a house and be injured by a spring gun, the court refused to hold that the injured plaintiff assumed the risk of being injured or was negligent. The court found that even though the injured person should have had knowledge that he was somewhere where he was not supposed to be, because he had removed two broken locks, he was not negligent, did not assume the risk, and that the property owner was liable for the injury caused by the spring gun.

G. The Cost of Avoiding Theft by Other Means

The other means of avoiding theft are to increase the physical protection and to use fuel cycles which do not involve SNM at all or, at least, to use SNM in a form which is not attractive for theft.

In monetary terms, the cost of spiking seems excessive[12] compared with the cost of additional physical protection. For U.S. domestic purposes it seems that methods less expensive than spiking can be employed.

In summary, it appears that a general economic argument could not be used to justify spiking. As pointed out earlier, if the courts are to accept an economic argument at the expense of erosion of accepted historical common law doctrine, there must be strong evidence of the efficacy of spiking.

REFERENCES

1. Richard A. Posner, "Killing or Wounding to Protect a Property Interest," Journal of Law and Economics, Vol. 14, 1971, p. 201.
2. Id., p. 212.
3. *Bird v. Holbrook,* 4 Bing 628, 130 Eng. Rep. 911 (Com. Pl. 1828).
4. Note 1, supra, p. 214.
5. E.V. Weinstock, "The Spiking of Special Nuclear Materials as a Safeguards Measure," Brookhaven National Laboratory, Technical Support Organization, September 19, 1975, Chapt. 8-9.
6. "USDOE Shipments of Nuclear Fuel and Waste: Are They Really Safe?," DOE/EV-0004, October 1977.
7. Note 5, supra, Vol. 1.
8. Note 6, supra, p. 5.
9. *Katko v. Briney,* 183 N.W. 2d 657 (Iowa 1971).
10. Note 1, supra, p. 213.
11. *Marguis v. Benfer,* 298 S.W. 2d 601 (Tex. Civ. App. 1956).
12. IRT, "The Spiking of Special Nuclear Materials as a Safeguards Measure," November 1975, Vol. 2.

IV. CAN THE NRC JUSTIFY SPIKING AS REQUIRED FOR THE "COMMON DEFENSE AND SECURITY"[1] OF THE UNITED STATES?

A review of the Atomic Energy Act of 1954, as amended, along with the United States Code would reveal the following sections dealing with the use of "common defense and security."

> It is therefore declared to be the policy of the United States that:
> The development use and control of atomic energy shall be directed so as to make the maximum contribution to the general welfare, subject at all times to the paramount objective of making the maximum contribution to the common defense and security....[2]

The Congress of the United States makes the following findings concerning the development, use and control of atomic energy.[3]

> The development utilization and control of atomic energy for military and for all other purposes are vital to the common defense and security.[4]
>
> The processing and utilization of source, byproduct and special nuclear material must be regulated in the national interest and in order to provide for the common defense and security and to protect the health and safety of the public.[5]
>
> Funds of the United States may be provided for the development and use of atomic energy under conditions which will provide for the common defense and security and promote the general welfare.[6]

> A program for Government control of the possession, use and production of atomic energy and special nuclear material, whether owned by the Government or others so directed as to make the maximum contribution to the common defense and security and the national welfare and to provide continued assurance of the Government's ability to enter into and enforce agreements with nations or groups of nations for the control of special nuclear materials and atomic weapons.[7]

A reading of these above provisions from the Atomic Energy Act of 1954, as amended, would tend to convince the reader that spiking of nuclear fuel could be justified, if said to be required for the common defense and security of the United States. However, it is not clear that spiking could be justified in such a straightforward manner.

A similar question of justification based on a common defense and security was addressed in the public rule making hearings held by the NRC on "Authority for Access to or Control of Special Nuclear Material," Docket No. RM-50-7 (1979). Specifically, a legal question arose with regard to whether a clearance program for employees at light water reactor facilities, to protect against loss or diversion of SNM, could be justified as being in the interest of common defense and security. A review of that proceeding sheds light on the spiking problem.

Leonard Bickwit, Jr., General Counsel of NRC, said in a letter to the NRC commissioners:

> A clearance program for LWRs [Light Water Reactors] thus presents two critical legal questions. First, can such a program be based on the need to protect against loss or diversion of SNM in the interest of the common defense and security?
>
> The answer to the first question is clearly no. Nowhere in the rule making record is there any indication that the proposed [clearance] rule is designed to protect against loss or diversion of SNM at LWRs. There was an effort made to relate reactor sabotage to the national defense. While this arguably ties the proposed program to the common defense and security, it does not tie the proposed program to loss or diversion of SNM.[8]

Bickwit's position illustrates that in spite of the general language of the Atomic Energy Act of 1954 regarding the common defense and security, the NRC counsel did not find it general enough to justify imposition of a clearance program for LWR personnel. NRC counsel instead looked for specific congressional authorization to implement the personnel program.

By analogy, the determination of spiking as "necessary" to provide for the common defense and security would probably require specific authorization. A memorandum from Peter L. Strauss, (then) General Counsel of NRC to Commissioner Gilinsky regarding the clearance program further emphasizes the need for specific authorization.

> The Commission's defense would begin by noting that the language of the statute is not explicitly limited in this fashion. The statute empowers us to require clearances for those engaged in designated activities involving "quantities of special nuclear material which in the opinion of the Commission are important to the common defense and security...." Thus if the Commission could clearly show a connection between the quantities of

> special nuclear material present in an hypothetically sabotaged reactor and the common defense and security, it would appear to be within the language of the statute. To me, this connection seems strained. At the least, I would expect the courts to look beyond the statutory language to the legislative history to ensure that Congress' intent is being followed. The courts would be reluctant to assume that Congress intended to give the Commission a carte blanche in defining where it needed clearance programs.[9]

It would appear that spiking of reactor fuel in the general interest of common defense and security could not be justified, although there is a possibility legal justification could be resolved if spiking is done to prevent the loss or diversion of any special nuclear material[10] for only those reactor fuels containing sufficient quantities of SNM to produce an explosive device.

REFERENCES

1. See definition 42 USCA 2014(g) or Section 11g of the Atomic Energy Act of 1954, as amended.
2. 42 USCA 2011(a).
3. 42 USCA 2012(a).
4. 42 USCA 2012(a).
5. 42 USCA 2012(d).
6. 42 USCA 2012(g).
7. 42 USCA 2013(c).
8. Memorandum from Leonard Bickwit, Jr., General Counsel to Chairman Hendrie and Commissioners Gilinsky, Kennedy, Bradford, and Ahearne entitled, "Discussion Paper to Assist Commission in the Matter of Clearance Rule for SNM (SECY-79-319)," September 11, 1979. (NRC Public Document Room, Docket RM-50-7), p. 12.
9. Memorandum from Peter L. Strauss, General Counsel to Commissioner Gilinsky entitled, "Legal Analysis of Security Clearance Programs," February 2, 1977, p. 4 attachment to Memorandum from Leonard Bickwit to Chairman Hendrie, (NRC Public Document Room, Docket RM-50-7), Note 8, supra.
10. Atomic Energy Act, Section 161 i.(2) as amended by Public Law 93-377.

V. IS SPIKED NUCLEAR MATERIAL A "TRAP" OR A "DANGEROUS DEVICE"?

A. Definition of a "Trap" or a "Dangerous Device"

In *Crosby v. Savannah Electric Company*,[1] it was held that the doctrine of mantrap rests upon the theory that "...the owner is expecting a trespasser or a licensee and has prepared the premises to do him injury." In *Wilder v. Gardner*,[2] the owner set a spring gun or trap to prevent depredation of his property by humans or animals. The owner expected trespassers and deliberately set a trap designed to do them injury. In this case it was held that such a device may be considered a mantrap if the court can find or infer that the owner had knowledge of the existence of a dangerous condition coupled with a conscious indifference to the consequences and a deliberate intent to inflict injury is inferrable.

In *Central of Georgia R. Co. v. Ledbetter,*[3] it was held that "[T]o the licensee as to the trespasser, no duty arises of keeping the usual condition of the premises up to any given standard of safety, except that they must not contain pitfalls, mantraps and things of that character."

In *Louisville & Nashville R. Co. v. Young,*[4] a trap was defined as a dangerous condition hidden with sufficient cover to obscure it or to render it unobservable to one who approaches it.

In *State v. Green*[5] it was held that for a person to be excused from inflicting injury or causing death to a trespasser or intermeddler of chattels, that person must show circumstances such as to make it reasonable to believe he was in danger of losing his life or suffering dangerous bodily harm and that he himself so believed at the time of the incident. A trap or dangerous device can not distinguish between benign and malevolent intent, whereas a person is judged to be able to make this distinction.

Fowler V. Harper and Fleming James, Jr. in The Law of Torts, Volume 2, Section 27.3, pages 1440-1441, said:

> The possessor of land may not arrange his premises intentionally so as to cause death or serious bodily harm to a trespasser.The possessor may of course take some steps to repel a trespass. If he is present he may use force to do so, but only that amount which is reasonably necessary to effect the repulse. Moreover, if the trespass threatens harm to property only — even the theft of property — the possessor would not be privileged to use deadly force, he may not arrange his premises so that such force will be inflicted by mechanical means. If he does, he will be liable even to a thief who is injured by such device.

The Restatement of Torts, Section 85, page 180, treats this problem slightly differently.

> The value of human life and limb, not only to the individual concerned, but also to society, so outweighs the interest of a possessor of land in excluding from it those whom he is not willing to admit thereto that a possessor of land has,....no privilege to use force intended or likely to cause death or serious harm against an other whom the possessor sees about to enter his premises or meddle with his chattel, unless the intrusion threatens death or serious bodily harm to the occupiers or users of the premises....A possessor of land cannot do indirectly and by a mechanical device that which, were he present, he could not do immediately and in person. Therefore, he cannot gain a privilege to install, for the purpose of protecting his land from intrusions harmless to the lives and limbs of the occupiers or users of it, a mechanical device whose only purpose is to inflict death or serious harm upon such as may intrude, by giving notice of his intention to inflict, by mechanical means and indirectly, harm which he could not, even after request, inflict directly were he present.

In *Simpson v. State,*[6] the court stated that

> The secrecy and frequency of the trespass would not justify the owner in concealing himself, and with a deadly weapon taking the life, or grievously wounding the trespasser, as he crept stealthily to do the wrong intended. What difference is there in his concealing his person, and weapon, and inflicting unlawful violence, and contriving and setting a mute, concealed

> agency or instrumentality which will inflict the same, or it may be greater, violence? In each case the intention is the same, or it is to exceed the degree of force the law allowed to be exerted. In the one case, if the trespasser came not with an unlawful intent — if his trespass was merely technical — if it was a child, a madman, or an idiot, carelessly, thoughtlessly entering and wandering on the premises, the owner would withhold all violence. Or, he could exercise a discretion, and graduate his violence to the character of the trespass. The mechanical agency, is sensitive only to the touch; it is without mercy, or discretion; its violence falls on whatever comes in contact with it. Whatever may not be done directly cannot be done by circuitry and indirection. If an owner, by means of spring guns or other mischievous engines planted on his premises, capable of causing death or of inflicting great bodily harm on ordinary trespassers, does cause death, he is guilty of criminal homicide.

B. The Concept of Trap or Dangerous Device as Applied to Spiking

Spiking "...involves the use of a spikant in the fuel to provide a gamma flux of sufficient intensity to induce death after a very short exposure time."[7] As stated by Weinstock, "Thus, for example, the same radioactive spikant that improves detection at close range will...at a much higher level, kill an unprotected person who comes too close to the material."[8] Other, more recent reports talk in terms of injuring rather than killing a person who approaches the material too closely.[9]

Spiked fresh reactor fuel material would have many of the radioactive attributes of spent fuel discharged from a nuclear reactor with, however, one major difference. For the spiked fuel it could be said that "the owner is expecting a trespasser...and has prepared the premises to do him injury."[10] The addition of a spikant to deter theft has the element of intent to injure or kill those not deterred. It is this particular aspect of spiking — its use to intentionally kill or injure a thief, and the results of pursuing this objective — that gives spiked fuel its special distinction and makes spiked material different from ordinary radioactive material. Most crimes require some specific voluntary act with an intention to produce a specified result. It may be said that an action is done intentionally if one acts "purposely" with a conscious object to engage in conduct of that nature and to act "knowingly" as to the nature of his conduct if he is aware that his conduct is of that nature.[11] Adding a spikant purposely with conscious knowledge of the nature of the danger created, which danger did not exist before, knowing that any thief will be killed or seriously injured, may create the basis for civil or criminal liability.

From these discussions it can be seen that the distinguishing features of a trap or dangerous device as it may apply to spiking are that in spiking, as in a trap, there is a clear intent of injuring or killing a thief by the radiation emitted, and that the danger is not readily apparent to a thief or trespasser to the chattel, in this case, spiked fuel.

From the foregoing arguments, one could reasonably conclude that a shipment of spiked fuel was a "trap" or "dangerous device." This would be true even for a thief because, as the court said in a case involving a boy killed by an explosive installed by the owner to prevent theft, "a thief does not forfeit all rights including the right to live."[12]

C. The Arguments Against Considering Spiked Nuclear Fuel as a Trap or Dangerous Device

1. Recapture of Chattels. The right to use force to recapture a chattel differs from the right to defend the chattel in the first place. Having lost momentary control of the chattel, a limited right to retake the chattel by force has been recognized. This privilege to use force has been restricted to those extreme cases where the emergency justifies the risk of the breach of the peace.[13] On the basis of this argument, the use of force by guards attempting to recapture the fuel shipping cask (a chattel) may justify the use of spiking.

2. Removal of the "Trap" Aspect of Spiking by the Use of Adequate Notice. Spiked nuclear fuel, by virtue of its ominous shipping cask, the presence of guards, and signs proclaiming the nature of the danger, may give adequate warning of the dangerous nature of the fuel inside. In the cases which have dealt with "notice" of a trap it was decided that the owner is liable for the trap action even though adequate notice is given and the thief has actual knowledge of the presence and dangerous nature of the trap. "Notice, warning or the knowledge of the maintenance of a spring gun or similar device has been held not to constitute a complete defense to a criminal prosecution arising out of the death or injury caused by the device, or to constitute no defense [by the trap gun setter to prevent liability] at all."[14]

In *State v. Childers,*[15] a conviction for unlawfully shooting with intent to wound was upheld despite the fact that the farmer, who maintained a spring gun in a melon field, posted signs at both ends of the field warning of the spring gun. The signs were found by the jury to not constitute a warning.

In *State v. Green,*[16] two brothers entered a house protected by a spring gun. One brother knew that the house had a "dynamite" trap and warned the other brother. The brother who disregarded the notice or knowledge of the presence of a trap was killed, and the trap gun setter was convicted of manslaughter despite the thief's actual knowledge that some hazard or trap was on the premises.

In *State v Ban,*[17] the court held that the presence of a danger sign outside a cabin giving notice of the presence of a spring gun inside the cabin was immaterial. An earlier 1882 federal case, *United States v. Gilliam,*[18] expressed a contradictory view. Gilliam held that where no notice of the setting of a spring gun is given, the party setting it is responsible to the same extent as if he had been present and fired the gun himself, but that where notice is given, the one injured is deemed to have brought the calamity upon himself and, if killed, to have been his own executioner.

In *State v. Marfaudelle,*[19] a tenant knew the landlady was snooping in his apartment. The tenant warned the landlady not to disturb a trunk because it contained a spring gun. The landlady did not heed the warning and opened the trunk in the tenant's absence and was killed by the spring gun. The court refused to accept the tenant's offer to prove he had warned the landlady of the spring gun. The court held that such notice or warning did not constitute a defense unless it was brought home to the deceased in such a manner that her act in opening the trunk would be a deliberate attempt on her part to take her own life. However, one author has said that:

> ...if the dangerous device is not customary, it would seem that at least as far as concerns responsibility to a person injured while trespassing, the owner must take at least all reasonable steps to bring home notice of its use to all those persons whom he has reason to expect to trespass upon his property. Unless such notice is given, the device can have no deterrent effect; and the failure to give such a notice, if it be deliberate, tends to show that the purpose in installing it is not merely to prevent intrusion but in part at least to injure such persons as may intrude.[20]

This same author cites an early 1828 English case[21] which held that an owner is privileged to use a dangerous and unusual device if the injury it is intended or likely to inflict is less than death or serious bodily harm and is not disproportionately great as compared with the value of the property or property interest which the device is designed to protect. In addition, a reasonably sufficient warning of its use must be brought home to all those likely to intrude and come in contact with the device. In this case, a plaintiff who was trespassing on the defendant's garden in search of his fowl, was injured by a spring gun which the defendant had set therein without any warning of its presence. The court held that the plaintiff should recover for his injuries. In the opinion of Chief Justice Best who took part in the referenced case and in a similar and earlier decision of *Ilott v. Wilkes,*[22] the absence of notice was of principal importance, as showing that the spring guns were not set for the purpose of "deterring" trespassers, but "for the purpose of doing injury to anyone who might trespass upon his garden."

Only early 19th century cases have dealt with the issue of notice for traps or dangerous devices; no modern cases seem to have dealt with this issue. Thus, on the basis of early case law, it can be said that liability for spiked reactor fuel (if considered as a dangerous device or a trap) cannot be avoided by providing notice to any would-be thief of the dangerous propensity of the fuel.

REFERENCES

1. *Crosby v. Savannah Electric Co.*, 114 Ga. App. 193, 198, 150 S.E. 2d 563, 569, (1966).
2. *Wilder v. Gardner,* 39 Ga App 608, 147 S.E. 911 (1929).
3. *Central of Georgia R. Co. v. Ledbetter,* 46 Ga App 500, 504 168 S.E. 81, 83 (1933).
4. *Louisville & Nashville R. Co. v. Young,* 112 Ga App 608, 145 S.E. 2d 700 (1965).

5. *State v. Green,* 118 S.C. 279, 110 S.E. 145, 19 ALR 1431 (1921).
6. *Simpson v. State,* 59 Ala 1, 31 Am Rep 1 (1877).
7. J.E. Selle, "Chemical and Physical Considerations of the Use of Nuclear Fuel Spikants for Deterence," ORNL/TM-6412, p. 1.
8. E.V. Weinstock, "The Spiking of Special Nuclear Material as a Safeguards Measure," Vol. 1, September 19, 1975.
9. Edward Straker, "Material Radiation Criteria on Non-Proliferation," SAI 01379-507-LJ, January 8, 1979.
10. *Crosby v. Savannah Electric Co.,* 114 Ga. App. 193, 198, 114 S.E. 2d 563, 569.
11. Lafave and Scott, *Handbook on Criminal Law* (1972), p. 198.
12. *McKinsey v. Wade,* 136 Ga. 109 200 S.E. 2d 30 (Ga. App. 1975).
13. Prosser, Law of Torts (4th Edition, 1971), p. 118.
14. "Use of Setgun, Trap, or Similar Device on Defendant's Own Property," 47 ALR 3d 646.
15. *State v. Childers,* 133 Ohio St. 508, 14 NE2d 767 (1938).
16. *State v. Green,* 118 SC 279, 110 SE 145 (1921).
17. *State v. Ban,* 11 Wash 481, 39 P 1080 (1895).
18. *United States v. Gilliam,* 25 Fed Cas 1319, No. 15, 205a (1882).
19. *State v. Marfaudelle,* 48 Wash. 117, 92 P. 939 (1907).
20. Bohlen and Burns: "The Privilege to Protect Property by Dangerous Barriers and Mechanical Devices," Yale Law Journal, Vol. 35, 1926, p. 530.
21. *Bird v. Holbrook,* 4 Bing. 628 (1828 C.P.) cited in note 31, Note 20, supra.
22. *Ilott v. Wilkes,* 3 B & Ald 304 (K.B., 1820).

VI. SPIKING USED TO PREVENT A DANGEROUS FELONY

A. Classification of Theft of Spiked Fuel as a Felony

A felony is defined in two different ways. Some states provide that any crime punishable by death or imprisonment in a state prison is a felony, and any other crime (punishable by fine or imprisonment in a local jail or both) is a misdemeanor.[1]

Less commonly, a felony is defined as dependent not on the place of imprisonment, but on the length of imprisonment. This latter definition used by the federal government provides that any crime punishable by death or imprisonment for more than one year is a felony and any other crime is a misdemeanor.[2]

Section 57 of Atomic Energy Act of 1954 makes theft of SNM a felony by stating that "Unless authorized by a general or specific license issued by the Commission...no person may transfer or receive in interstate commerce, transfer, deliver, acquire, own, possess, receive possession of, or title to, or import into or export from the United States any special nuclear material." This section of the Atomic Energy Act is codified in 42 U.S.C.A. § 2077. The violation of 42 U.S.C.A. § 2077 is given in 42 U.S.C.A. § 2272 as not more than $10,000 or by imprisonment for not more than 10 years or both.

In addition, the theft of a fuel shipment would be a felony if it violated Section 223 of the Atomic Energy Act codified in 4 U.S.C.A. § 2273 which provides for a fine of not more than $5000 or imprisonment of not more than two years for willful violation of Atomic Energy Act of 1954.

In addition to violating the Atomic Energy Act of 1954, the theft of fuel material would be a felony if it violated the following several sections of the U.S. Code:

- 18 U.S.C.A. § 659. Embezzlement or theft of goods in interstate shipment. Not more than $5000 fine or imprisonment for not more than ten years or both (if value of property taken is over $100).
- 18 U.S.C.A. § 832. Transportation of radioactive material by passenger car or vehicle (49 U.S.C.A. §1472(h) by air and 46 U.S.C.A. § 170 by water) in violation of ICC regulations. $1000 fine and imprisonment for not more than 1 year or both unless there is a death or bodily injury resulting from a violation of this section in which case the penality is not more than $10,000 or imprisonment of not more than 10 years or both.
- 18 U.S.C.A. § 2117. Breaking or entering carrier facilities with intent to commit larceny. $5000 fine or not more than ten years' imprisonment or both.
- 18 U.S.C.A. § 2314. Interstate transportation of stolen goods whose value is over $5000. Fine not more than $10,000 or imprisonment for not more than ten years or both.

Since the spiked fuel would be private property,[3] it probably would not qualify for the several codified conspiracy and robbery[4] offenses against the United States.

One could also argue that the theft of SNM is the type of felony that would justify the use of deadly force. Most modern jurisdictions[5] limit the use of deadly force to prevent or terminate commission of dangerous felonies (those felonies involving a substantial risk of death or serious bodily harm, e.g., murder, voluntary manslaughter, mayhem, kidnapping, arson, burglary of a dwelling, robbery, and forceable rape). If the owner of the spiked fuel could maintain that theft of SNM is a dangerous felony or could justify the use of deadly force if had he been present, he might be able to argue successfully that the use of spiking as a deadly trap is also justified.

B. The Theft of Spiked Fuel as a Dangerous Felony

The current concept of a "dangerous felony" developed as a modification of the historical common law concept that all felonies were of equal degree because they were all punishable by death. At common law only a few narrowly defined crimes were classified as felonies. Many modern felonies such as income tax evasion, antitrust violation, selective service violation, and embezziement do not involve a crime which "creates a substantial risk the person arrested will cause death or serious bodily harm if his apprehension is delayed"[6] and are not deadly felonies. Only seven states; Delaware, Hawaii, Kentucky, Maine, Nebraska, North Carolina, and Texas[7] have adopted the model Penal Code's dangerous felony approach for the arrest of nonviolent felons. Thirty-seven states have justification statutes which limit the use of deadly force by police officers to effect arrest,[8] and twenty-four states codify the common law by providing that deadly force may be used to arrest any felony suspect.[9]

The common law would justify the use of deadly force in situations where the interest protected is more important than the life of the person who threatens it.[10] The common law did not undertake to balance the various interests at stake by weighing the victim's life against the interest which he threatened, but referred instead to the type of conduct in which the victim was engaged. Generally, the conduct must have involved an attempt to commit a felony against the actor, his property or society in general. Thus the law of justifiable homicide was based not on the reasonableness of the force used by the actor, but on the nature of the activity which the force was designed to prevent.[11]

On the basis of this common law rationale, the theft of reactor fuel could be classified as a "dangerous" felony, thus warranting the use of deadly force in the form of spiking to prevent the theft. This would be the result of weighing the "nature of activity" of stealing SNM and the possible resultant construction of a nuclear explosive device against the protective activity of spiking the material.

The potential illicit uses of the stolen enriched fuel, which include the fabrication of an explosive device that may cause death and destruction to many people, would seem to qualify the theft of spiked fuel as a dangerous felony.* However it cannot be said with complete assurance that theft of reactor fuel would be a dangerous felony.

C. Common Law "Use of Deadly Force" Argument to Justify Spiking

Some of the arguments for and against spiking of fuel involve the common law concepts that have developed regarding the use of deadly force to protect property.[12] Deadly force concepts could be used to argue that if deadly force is permitted to protect reactor fuel, then spiked fuel should be allowed because the deadly force aspect of spiking is no worse or may even be part of the privileged use of deadly force. To pursue the argument further,

---

*Certain other criminal activities appear to have this same status. Consider for instance the crimes of adding biological or chemical agents to domestic water supplies; sabotage and subsequent collapse of hydroelectric dams; intentional train derailment of tank cars of chlorine gas; sabotage of liquid natural gas ships while in harbor.

if guards can be excused for subjecting a thief to possible death or serious bodily harm by shooting at him to prevent or terminate a dangerous felony, would not the use of spiking, with adequate warning in the presence of guards, be similarly excused for exposing the thief to possible death or serious bodily harm?

The concurrent or contemporaneous use of spiking as part of the deadly force permitted guards to prevent or terminate a dangerous felony may be unjustifiable in light of recent cases and judicial trends.[13] In three recent cases (1977, 1976), California limited the use of deadly force by police officers in fleeing felon cases.[14] In these cases, the officer's privilege of using deadly force was deemed appropriate "only if the felony is a forcible and atrocious one which threatens death or serious bodily harm or there are other circumstances which reasonably create a fear of death or serious bodily harm to the officer or other person."[15] However, this limitation may not exclude the use of deadly force for the prevention of the theft of spiked fuel because the theft of fuel containing bomb grade nuclear material (even if spiked) would probably be a dangerous felony.

Even if theft of spiked fuel is considered a dangerous felony, the peace officer's privilege to use deadly force may not be in effect because the guards protecting the spiked fuel may not be peace officers. They are more likely to be private citizens employed to work as guards. As observed by an Arizona Court in 1977 in *State v. Bar,*[16] "serious inroads have been made in the authority of private persons to use deadly force to arrest for *any* felony" (emphasis added).

The definition of the theft of fuel containing bomb grade material as a dangerous felony would seem to be the key to this bootstrap theory of allowing the use of spiking as a concurrent continuation of the deadly force used by the guards. However, this is an unsettled area of the law and as such this concept should not be relied upon alone as justification of the use of spiking.

REFERENCES

1. LaFave and Scott, *Criminal Law*, West Publishing Co., 1972, p. 26.
2. 18 USCA 1.
3. 42 USCA 2073 and the Atomic Energy Act of 1954 as amended section 53 c.(1).
4. 18 USCA 371 (Conspiracy to commit offense against U.S.); 18 USCA 2112 (Robbery of personal property belong to U.S.); 18 USCA 641 (Theft of government property); 18 USCA 659 (Theft or embezzlement from any transportation facility of any goods in interstate or foreign commerce); 18 USCA 2117 (Breaking or entering carrier facilities).
5. Note 1, supra, p. 406.
6. See generally the 1962 American Law Institute's Restatement of the Law proposed for its Model Penal Code.

7. Comment, "Deadly Force to Arrest: Triggering Constitutional Review," Harvard Civil Rights-Civil Liberties Law Review, Vol. 11, 1976. p. 369.
8. Id.
9. Id.
10. "Justification for the Use of Force in Criminal Law," Stanford Law Review, 1961, p. 566.
11. Id. p. 572.
12. See generally Steven Day, "Shooting the Fleeing Felon: State of the Law," Criminal Law Bulletin, Vol. 14, 1978, p. 285.
13. Perkins, *Perkins on Criminal Law* (2nd Edition, 1969) p. 985.
14. *Peterson v. Long Beach,* 72 Cal App 3d 852, 140 Cal Rptr. 401 (1977); *Kortum v. Alkin,* 69 Cal App. 3d 325, 138 Cal. Rptr. 26 (1977); *Long Beach Police Officers Ass'n v. Long Beach,* 61 Cal. App. 3d 364, 132 Cal. Rptr. 348 (1976).
15. *Kortum v. Alkin,* 69 Cal. App. 3d 325, 334, 138 Cal. Rptr. 26, 31 (1977).
16. *State v. Bar,* 115 Ariz. App. 346, 565 P. 2d. 526 (1977).

Chapter Four

Ranking Nuclear Fuel Cycles

Both of the reports in this chapter represent an attempt to arrive at a ranking method rather than to determine conclusively a single "best," most safeguardable, fuel cycle. The complex and subjective nature of safeguards measures and threats prevents attainment of the latter goal. Both reports are aimed at providing a procedure for distinguishing between nuclear fuel cycles, dependent on which safeguards and non-proliferation factors are considered the most important by a "ranker." Although both reports give a hierarchy of safeguardability, the hierarchy in each report represents an example of a ranking based on the judgments of the authors; neither claims to be objectively correct.

It is hoped that this chapter will reveal the difficulty of generating an absolute ranking of nuclear fuel cycles according to any complex set of criteria. The reports do describe methods for examining, at least, those trade-offs associated with one fuel cycle over another.

A Suggested Ranking For Selected Alternative Fuel Cycles

Jerry J. Cadwell

NUREG/CR-1052
February 1980

TABLE OF CONTENTS

	Page
I. Introduction	293
II. General Description of the Ranking Method	293
A. Approach	293
B. The Choice of Ranking Criteria	294
III. Conclusions	297
References	300
Appendix A: List and Description of Fuel Cycles	301
Appendix B: Ranking Based on Simple Score Totals	303
Appendix C: Ranking Based on Criteria Interdependence	305
Appendix D: Modified Ranking Based on Criteria Interdependence	308
Appendix E: DOE Interim Management Directive 6104-A	311

ABSTRACT

This report describes a ranking of 19 Non-Proliferation Alternative Systems Assessment Program (NASAP) fuel cycles according to ease of safeguardability.

Eight different safeguards criteria were used to evaluate the applicability of the current safeguards practices for each of the fuel cycles.

Four different ranking techniques gave the same three fuel cycles as easiest to safeguard. These cycles were the light water reactor cycle (LWR) once-through, the LWR high burn-up once-through, and the high temperature gas cooled reactor (HTGR) once-through.

I. INTRODUCTION

The Non-Proliferation Alternative Systems Assessment Program (NASAP) being conducted by the U.S. Department of Energy includes the task of evaluating the nuclear safeguards required for each fuel cycle.

The U.S. Nuclear Regulatory Commission has commissioned Brookhaven National Laboratory to review the given fuel cycles* and, as part of this task, to rank them to indicate the relative difficulty of safeguarding each fuel cycle and the relative significance of the safeguards issues.

An earlier Brookhaven report[1] discussed the technical safeguards issues for each of the alternative fuel cycles. A second Brookhaven report,[2] discussed the licensing and regulatory problems which the individual fuel cycles would encounter.

Using these two reports as the source and description of safeguards problems, a comprehensive matrix was developed wherein each fuel cycle was ranked for each safeguards problem according to the severity of the problem. Here, severity is defined as a combination of the difficulty, feasibility and, to a very limited degree, cost of safeguards.

The safeguards problems chosen for evaluation were those encountered in the traditional areas of safeguards such as physical protection, transportation concerns, material control and accounting, and resistance to sabotage/dispersal, as well as difficulty of converting the SNM to bomb material, applicability of current inspection and enforcement practice, ease of recovery of stolen SNM, and finally, applicability of current safeguards regulatory schemes. This ranking is preliminary and is amplified and improved in the report following in this chapter.

II. GENERAL DESCRIPTION OF THE RANKING METHOD

A. Approach

With few exceptions, the fuel cycles considered are far from fully developed; the applicability and reliability of certain safeguards techniques remain untested. The relative evaluation or ranking of specific safeguardability within and among fuel cycles is therefore a more subjective process than would be desired ideally. Recognizing this problem, ranking criteria and approaches were chosen in such a way that readers may substitute their own individual evaluations and arrive at their own overall ranking.

The eight criteria selected are discussed in Section II.B. Each of the 19 fuel cycles was evaluated against each of the eight criteria. Each cycle-criterion combination was evaluated on a three-level basis: "High" indicating that safeguards techniques exist or may be easily emplaced; "Moderate" meaning that some problems exist, but successful development of tech-

---

*See Appendix A for list of fuel cycles.

niques is reasonably assured; or "Low" where severe safeguards problems exist or difficult developmental programs must be undertaken. Commonly, a 1 to 10 ranking has been used in such evaluative approaches. For this study, however, a three-level evaluation was considered to be more consistent with the level of technical development and the necessity for subjectivity mentioned earlier.

After completing each of the cycle/criterion evaluations, a combinatorial method was chosen to allow the eight individual criteria evaluations for a given fuel cycle to be condensed into a single figure giving the overall ranking of candidate fuel cycles. This combinatorial process would normally require weighting decisions, for example, the physical protection aspects of safeguarding may be twice as important, or of equal importance, or only half as important as material control and accounting aspects. Consideration of the eight criteria reveals the difficulty of assigning objectively derived weighting factors.

The three combinatorial methods applied are described briefly in Section III and details are presented in Appendices B, C, and D. While the methods differ from one another in detail, the same cycle/criteria data served as input to all three. It is not surprising, therefore, that the final cycle rankings are essentially the same regardless of the combinatorial method chosen.

The ranking approach outlined above was chosen with due deliberation after making a literature search[3] for rankings done on similar data. Only one ranking study was revealed which pertained directly to this subject.[4] Other attempts to rank fuel cycles have been made. Appendix E shows a U.S. Dept. of Energy (DOE) Interim Management Directive of Dec. 22, 1977, which lists SNM according to its relative degree of attractiveness (i.e., attractive to an adversary wishing to make an explosive device). Appendix F is a table[5] developed by the Office of Technology (OTA) for their "Nuclear Proliferation and Safeguards" study for the Congress of the United States which is also referenced in a General Accounting Office Report.[6]

One of the techniques[7] used for ranking is to solicit opinions from experts and to tabulate the results. A similar technique has played a role in the ranking approach used here. The individual cycle/criterion evaluations grew out of intense discussions among many safeguards experts.

It is again stressed that this ranking approach is highly subjective, and readers of this report are urged to apply their own perceptions to the cycle/criterion evaluations and/or to the combinatorial method to determine acceptance of the final cycle ranking.

B. The Choice of Ranking Criteria

Choosing the criteria is a major step in the ranking procedure. The criteria were chosen to be, insofar as possible, traditional safeguards classifications conceptually familiar to those in the field. They are:

- difficulty of converting to weapons material
- resistance to sabotage or dispersal
- applicability of current material control and accounting practices
- applicability of current physical protection practices
- applicability of current transportation practices
- applicability of current inspection and enforcement practices
- ease of SNM recovery by safeguards personnel after theft
- applicability of current safeguards regulatory schemes

While each of these criteria is important to domestic safeguards, experts would certainly disagree as to their relative importance (or weighting). Relationships between criteria also compound the weighting difficulty. For example, the level of physical protection required in a given fuel cycle is certainly related to the difficulty of converting the fuel to weapons material.

Each of the criteria is briefly described below; the rationale for selecting "High," "Moderate" or "Low" is outlined. It is to be remembered that, within this rating context, "High" is the most desirable rating from the standpoint of safeguardability, "Low" the least.

Application of these ranking criteria requires an understanding of the various fuel cycles. These fuel cycles have been described in detail in an earlier report by Weinstock,[8] and no detailed description of them is given here.

1. Difficulty of converting to weapons material. This category considers the SNM availability and the difficulty of converting the material to a nuclear explosive device (inverse of material attractiveness). The presence of unspiked material suitable for explosive fabrication within a fuel cycle leads to a "Low" rating. If such material is spiked with fission products or Co^{60} or is otherwise unsuitable for explosive fabrication, it is granted a "High" (i.e., safeguardable rating.) SNM containing U^{232} is given a "Moderate" rating.

2. Resistance to sabotage or dispersal. There is no apparent reason, at least at this stage of appraisal, to consider any one of the reactors in the NASAP studies to be appreciably different in terms of sabotage or dispersal risk from any other. Certain fuel cycles do, however, present added sabotage risks when viewed in their entirety (e.g., those cycles involving reprocessing as compared to once-through cycles.) This rating factor thus is based solely upon the non-reactor facilities within a given cycle.

3. The adequacy of current material control and accounting practices. This criterion was used to reflect the usual sampling, analytical, testing, and other complications that a fuel cycle might create. The principal source of problems in this area was the use of a spikant.

4. Adequacy of current physical protection practices. This criterion was selected in an attempt to identify those fuel cycles which would require more physical protection than is provided for the current LWR fuel cycle. This category may be especially subjective.

5. Adequacy of current transportation practices. This criterion was used to highlight the problems of transporting 1) large volumes of SNM, 2) spiked fuel, and 3) SNM material easily converted to material usable in a weapons device.

The transportation of large volumes of SNM was viewed as a problem of scale even if current safeguards procedures and practices are applicable. This problem of scale arises at some subjectively determined point where the sheer magnitude and frequency of transportation become a matter of concern. The LWBR Seed Blanket fuel cycle, because of the nature of the fuel used, is considered to be in such a category, as is the LWBR high-enriched prebreeder which requires the transportation of fissile uranium to bulk storage.

Fuel spiked with a material other than U^{232} is rated favorably, but if the fuel is spiked with U^{232} only, the spiking protection is considered to be only "Moderate."

If the material being transported is pure Pu or another material easily converted to explosives, the applicability of transportation practice is considered to be "Moderate," even though the current civilian transportation practice, which deals with pure Pu, is considered to be effective and more than adequate. Ranking a cycle as "Moderate" when transportation of pure SNM is required penalizes any cycle that uses pure SNM. A good argument can be made that it is not the frequency of shipments of SNM that is important but rather the degree of protection that each shipment receives. For purposes of this ranking it is thought that the increased frequency of shipments could (like advertising) make subnational adversary groups more aware of the possibility of theft and would, therefore, tend to increase the probability of theft.

6. Adequacy of current inspection and enforcement practices. This criterion was added to rank the difficulties expected during required NRC inspections. It is assumed that spiking to any degree would impede inspection efforts. Spiking with U^{232} or pre-irradiation after fabrication drew a "Moderate" rating for a fuel cycle while a hard gamma spike brought a "Low" rating.

7. Ease of SNM recovery by safeguards personnel after theft. This criterion is considered less important than the other categories. It is listed here in an attempt to illuminate one asset of spiking and to discriminate between fuel cycles which ship pure SNM and those which ship SNM only in spent fuel. The fuel cycles which were ranked "Low" were those with high-enriched, unspiked new fuel and those with SNM in unspiked makeup fuel.

8. Applicability of current safeguards regulatory schemes. For this criterion a spiked fuel cycle received a "Low" rating because of questions of legal liabilities which might arise from spiking.[9]

III. CONCLUSIONS

Nineteen representative fuel cycles were ranked according to eight criteria for safeguardability (Figure 1). Since most differences between the fuel cycles for any one criterion were modest, a three-class "High," "Moderate," or "Low," ranking proved appropriate to indicate these differences.

Of all the safeguards issues, spiking and the presence of pure SNM in the fuel cycle had the most pronounced effect. Without resorting to a numbered and weighted ranking, it is readily apparent that, from the standpoint of safeguardability, the highest ranking fuel cycles were the LWR once-through (cycle 1.1) and LWR high burnup once-through (cycle 1.2), followed by the HTGR once-through (cycle 4.1). After these three fuel cycles, the hierarchy among the remaining fuel cycles is less clear.

Appendices B, C, and D briefly describe three numerical rating techniques which are used to rank the safeguardability of each fuel cycle. The method of Appendix B assigns a number 0, 1, and 2 to "High," "Moderate," and "Low" ratings, and then sums the eight criteria values for each fuel cycle to obtain its total score. Note that this is equivalent to assigning an equal weight to each criterion. Using this method, the same three fuel cycles mentioned above (LWR 1.1, 1.2, and HTGR 4.1) receive the lowest score (i.e., appear to be the most easily safeguarded.) The LWBR high-enriched prebreeder (cycle 2.5), the LWBR seed-blanket (2.6), the GCFR with U-Pu/Th spiked recycle (cycle 5.1), the LMFBR U-Pu spiked recycle (6.3), and the LMFBR with spiked Th-Pu/Th (cycle 6.4) received the highest numerical scores (poorest ranking) indicating significant questions of safeguardability. The remaining cycles occupy intermediate ranking positions.

The method presented in Appendix C uses the same individual criterion/cycle rating inputs as did the Appendix B method. The original eight criteria are reduced to five, however, by combining certain of the original criteria in an attempt to quantify their interdependence. Again, the fuel cycle scores, based now on the five reduced criteria, are totaled and cycle rank determined. The results are similar to those obtained by the Appendix C method; the same three cycles appear to be "best", and the "worst" Appendix C cycles also receive high numerical scores (poor ranking) by the Appendix C approach. The order at the "worst" end is somewhat different, however, with other cycles (1.3, 6.2, and 6.3) forming the "worst" group.

The somewhat more complex ranking method outlined in Appendix D again points to the same "best" cycles. And, again, cycles 2.5, 2.6, 5.1, 6.3, and 6.4 appear among the "worst." Other cycles ranking poorly by the Appendix D method are the LWR with U^{235}-Pu-spiked recycle (cycle 1.3) and the Shippingport Type 1 LWBR (cycle 2.2); these last cycles are also ranked low by the methods of Appendices B and C.

In summary, then, cycles 1.1, 1.2, and 4.1 appear to offer the fewest safeguards problems; cycles 1.3, 2.5, 5.1, 6.3, and 6.4 appear to present the

RANKING OF NASAP FUEL CYCLES

	LWR				LWBR SHIPPING PORT		LWBR BACKFIT		LWBR HIGH CONVERTER	
	ONCE THROUGH	HI BURNUP ONCE THROUGH	U235 PU SPIKED RECYC	U233 TH RECYCLE	PRE BREEDER	BREEDER	PRE BREEDER	BREEDER	PRE BREEDER	SEED BLANKET BREEDER
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	2.6
DIFFICULTY OF CONVERTING TO WEAPONS MATERIAL	HIGH	HIGH	PU present for makeup purposes can be alleviated by International Fuel Cycle Center (IFCC) LOW	U233 and U238 present with about 50% U-233. Bomb manufacture possible-with high bulk and weight HIGH	High enriched(a) uranium depends on makeup requirements. LOW	Mixed U-235 and U-233 About 80% HEU IFCC alleviates U232 spike. MODERATE	High enriched(a) uranium depends on need for makeup LOW	High enriched uranium Mixed U-235 and U-233 80% HEU IFCC alleviates. U232 spike MODERATE	High enriched(a) uranium LOW	Mixed U-235 and U233 About 67% HEU U232 spike MODERATE
RESISTANCE TO SABOTAGE OR DISPERSAL	Reference cycle HIGH	HIGH	Presence of reprocessing PU and spiking MODERATE	Presence of reprocessing MODERATE	Presence of reprocessing and possible U233 dispersal MODERATE	Presence of reprocessing and possible U233 dispersal MODERATE	Presence of reprocessing and possible U233 dispersal MODERATE	Presence of reprocessing and possible U233 dispersal MODERATE	Presence of reprocessing and possible U233 dispersal MODERATE	Presence of reprocessing and possible U233 dispersal MODERATE
APPLICABILITY OF CURRENT MC&A PRACTICE	HIGH	HIGH	Use of cobalt 60 impedes sample analysis & material accounting. MODERATE	Use of cobalt 60 and presence of U232 impedes sample analysis and material accountability MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE
APPLICABILITY OF CURRENT PHYSICAL PROTECTION PRACTICE	HIGH	HIGH	More physical protection required at fuel fab facility MODERATE	More physical protection required at fuel fabrication facility MODERATE	More physical protection required at reprocessing and fuel fab facility MODERATE	More physical protection required at reprocessing and fuel fab facility MODERATE	More physical protection required at reprocessing and fuel fab facility MODERATE	More physical protection required at reprocessing and fuel fab facility MODERATE	More physical protection required at reprocessing and fuel fab facility MODERATE	More physical protection required at reprocessing and fuel fab facility MODERATE
APPLICABILITY OF CURRENT TRANSPORTATION PRACTICE	HIGH	HIGH	PU required for makeup Additional SNM material will require transportation(c) MODERATE	PU and makeup material will require transportation MODERATE	U-233, PU & makeup material will require transportation MODERATE	80% HEU MODERATE	HEU present may require(d) makeup Storage of 80% U-235 required MODERATE	Mixed U235 & U233 80% HEU MODERATE	93% HEU makeup from enrichment facilities required Both store 37% fissile-U LOW	67% HEU Makeup from U233 storage required Large amounts of U233 & lesser amounts of U235 require shipment LOW
APPLICABILITY OF CURRENT INSPECTION AND ENFORCEMENT PRACTICE	HIGH	HIGH	Presence of spikant impedes inspection LOW	U232 spike present MODERATE	U232 spike present MODERATE	U232 spike present MODERATE	U232 spike present MODERATE	U232 spike present MODERATE	U232 spike present MODERATE	U232 spike present MODERATE
EASE OF SNM RECOVERY BY SAFEGUARD PERSONNEL AFTER THEFT	SNM only in spent fuel HIGH	SNM found only in spent fuel HIGH	Spiking helps to locate HIGH	New fuel has U233 with radioactive U232 MODERATE	Only spent fuel has SNM Makeup probably requires HEU MODERATE	Spent and recycled fuel has SNM U232 spiked MODERATE	Only spent fuel has SNM. Makeup probably requires HEU MODERATE	Spent and recycled fuel has SNM MODERATE	U235 in new fuel LOW	U233 in new fuel LOW
APPLICABILITY OF CURRENT SAFEGUARDS REGULATORY SCHEMES	This is considered the reference system HIGH	HIGH	Spiking and reprocessing raise serious issues LOW	HEU use with recycled spiked PU Spiking raises serious issues MODERATE	Storage problems GESMO-like safeguards problems MODERATE	GESMO-like safeguard problems MODERATE	GESMO-like safeguard problems MODERATE	GESMO-like safeguard problems MODERATE	GESMO-like safeguards problems MODERATE	GESMO-like safeguard problems MODERATE

NOTE: High means good for safeguards.
IFCC means International Fuel Cycle Center

Figure 1

REVISION 1

HWR	HTGR		GCFR	LMFBR				
ONCE THROUGH	ONCE THROUGH	DENATURED U233/TH	U-PU/TH SPIKED RECYCLE	U-PU/U RECYCLE HOMOGENEOUS	U-PU/U SPIKED RETRO-HOMO	U-PU/TH SPIKED RETRO-HOMO	TH-PU/TH SPIKED	DENATURED U233/TH
3.0	4.1	4.2	5.1	6.1	6.2	6.3	6.4	6.[illegible]
HIGH	HIGH	PU LOW	PU makeup IFCC alleviates LOW	PU in MOX MODERATE	PU in MOX IFCC alleviates MODERATE	PU for makeup in MOX IFCC alleviates MODERATE	PU with TH in makeup IFCC alleviates MODERATE	U 233 25% for makeup has U232 spike HIGH
HIGH	HIGH	HIGH	Reprocessing (can be sabotaged) Shipment of PU (can be sabotaged) Shipment of PU (can be stolen and dispersed) MODERATE	Reprocessing (can be sabotaged) Shipment of PU (can be sabotaged) Shipment of PU (can be stolen and dispersed) MODERATE	Reprocessing (can be sabotaged) Shipment of PU (can be sabotaged) Shipment of PU (can be stolen and dispersed) MODERATE	Reprocessing (can be sabotaged) Shipment of PU (can be sabotaged) Shipment of PU (can be stolen and dispersed) MODERATE	Reprocessing (can be sabotaged) Shipment of PU (can be sabotaged) Shipment of PU (can be stolen and dispersed) MODERATE	HIGH
On line refueling causes accounting problems MODERATE	Storage of fuel sticks without fuel element causes loss of identity MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE	Presence of U232 causes material accountability & sample analysis problems Preirradiation req. MODERATE	HIGH	Preirradiated fuel HIGH	Presence of U232 causes some material accountability & sample analysis problems Preirradiation used MODERATE	Presence of U232 & thorium daughters cause some material accountability & sample analysis problems MODERATE	Presence of U232 causes material accountability & sample analysis problems MODERATE
HIGH	More physical protection required at fuel fabrication MODERATE	HIGH	More physical protection required for fuel fabrication MODERATE	More physical protection required for fuel fabrication MODERATE	More physical protection required for fuel fabrication MODERATE	More physical protection required for fuel fabrication MODERATE	More physical protection required for fuel fabrication MODERATE	HIGH
HIGH	HIGH	Makeup material requires U233 transport MODERATE	PU in MOX from storage Relatively high quantities of MOX shipped MODERATE	PU storage required Transport of fresh fuel containing PU required Large amounts involved if no IFCC LOW	PU storage required Large SNM quantities required to be shipped if no IFCC MODERATE	Requires makeup from another cycle Large SNM quantities required to be shipped if no IFCC MODERATE	Require makeup from another cycle Large quantities of SNM required to be shipped if no IFCC MODERATE	25% U233 required from another cycle. Presence of U232 provides spikant for fresh fuel MODERATE
Online refueling LOW	HIGH	Mixture of PU, U233 and TH causes measurement problems. MODERATE	Presence of spikant impedes inspection LOW	HIGH	Presence of spikant impedes inspection LOW	Presence of spikant impedes inspection LOW	Presence of spikant impedes inspection LOW	U232 spike MODERATE
Only spent fuel has SNM HIGH	Only spent fuel has SNM HIGH	PU in storage LOW	Blanket has U233 with U232 spike. Other SNM is in spent fuel Unspiked SNM is in makeup LOW	MOX (PU-U) in recycled fuel and in storage LOW	Spiked MOX HIGH	PU in makeup LOW	PU in makeup LOW	U233 U232 in makeup fuel MODERATE
Safeguarding heavy water may be a problem. LOW	Storing of fuel rods after burning off the graphite block may be a problem. Minimum SNM in spent fuel HIGH	Many GESMO like safeguards issues are present. LOW	Additional licensing of preirradiation facility required. Many GESMO-like safeguards issues are present. Spiking raises serious issues. MODERATE	MODERATE	Additional licensing of preirradiation facility required Spiking raises serious issues MODERATE	Additional licensing of preirradiation facility required Spiking raises serious issues MODERATE	Many unknowns LOW	Many unknowns MODERATE
							NASAP ranking Aug 79 Colburn	

greatest safeguards difficulties. The remaining cycles occupy intermediate positions.

REFERENCES

1. Weinstock, E.V. and Keisch, B., "Technical Safeguards Issues for Alternative Fuel Cycles," NUREG/CR-1048, BNL-NUREG-25557, August 9, 1979.
2. J.J. Cadwell, "Safeguards Licensing Problems Which Could Restrain Implementation of NASAP Fuel Cycles," NUREG/CR-1051, Feb. 19, 1980.
3. DOE/RECON Information System," Citations from the DOE Energy Data Base: Comparative Evaluations of Fuel Cycles," Bibliographic Computer Search conducted by Computer Science Division of Union Carbide Corporation, Nuclear Division.
4. R.N. Anderson et al., "Methodology for Comparative Evaluation of Nuclear Fuel Reprocessing Techniques for Advanced Low Proliferation Risk Fuel Cycles," Brookhaven National Laboratory, BNL-23312, 1977.
5. "Nuclear Proliferation and Safeguards," Office of Technology Assessment, OTA-E-48, 1977, p. 34.
6. "Quick and Secret Construction of Plutonium Reprocessing Plants: A Way to Nuclear Weapons Proliferation?,"Comptroller General of the United States, EMD-78-104, October 6, 1978.
7. Note 4, supra.
8. Note 1, supra.
9. J.J. Cadwell, "The Possible Legal Consequences of Protective Radioactive Spiking," NUREG/CR-1047, Nov. 30, 1979.

APPENDIX A

List and Description of Fuel Cycles

NASAP Reactor/Fuel Cycle Systems For NRC Review

1.0 Light Water Reactors(1)

1.1 PWR-OT: standard PWR using 3% low-enriched uranium oxide fuel achieving 30 MWD/kg burnup; once-through fuel cycle with spent fuel sent to long-term storage.(2)

1.2 PWR Mod-OT: PWR using 3% low-enriched uranium oxide fuel modified to achieve 50 MWD/kg average burnup, and other means to decrease uranium requirements; spent fuel is sent to long-term storage.

1.3 PWR-U/Pu spiked recycle: PWR using 3% low-enriched uranium oxide fuel and self-generated recycle fuel of co-processed uranium and plutonium oxide; the recycle fuel is spiked or pre-irradiated.(3)

1.4 LWR-DU(3)/Th: PWR using 12% U^{233}/thorium oxide fuel; the spent fuel is reprocessed to recover the U^{233}/U^{238} mixture which is recycled after blending with additional U^{233} to 12%; Pu is sold for spiked recycle.

2.0 Light Water Breeder Reactors(1)

2.1 Prebreeder, Shippingport Type I: PWR using 20% enriched UO_2-ZrO_2-CaO/ThO_2 fuel; the spent fuel is reprocessed to recover U^{233} which is stored for use in LWBR; Pu is stored.

2.2 Breeder, Shippingport Type I: same as 2.1 except it uses U^{233}/thorium oxide fuel which is reprocessed to recover U^{233} for recycle as spiked fuel.(3)

2.3 Backfit Prebreeder: standard PWR using 15% enriched uranium oxide/thorium oxide fuel; the spent fuel is reprocessed to recover U^{233} which is stored for use in LWBR; Pu is stored.

2.4 Advanced Breeder: standard PWR except modified for tight lattice, hexagonal fuel bundle and thoria control rods; using U^{233}/thorium oxide fuel which is reprocessed to recover U^{233} for recycle as spiked fuel.(3)

2.5 HEU Backfit Prebreeder: standard PWR using 93% enriched uranium oxide/thorium-oxide fuel; PWR-type fuel bundles with poison control rods; non-fissioned U^{235} and bred U^{233} recovered and accumulated for startup of LWBR.

2.6 Breeder, seed-blanket type: seed consists of UO_2-ThO_2 pellets, blanket of ThO_2 pellets; initially fueled with HEU (mixture of non-fissioned U^{235} and bred U^{233}) recovered from HEU Backfit Breeder, eventually self-sustained by bred U^{233}; ThO_2 and poison control rods.

3.0 Heavy Water Reactors(1)

3.1 HWR DU(5)-OT: CANDU-type HWR using 1.2% slightly enriched uranium oxide fuel; plant designed for 1300 MWe, 2200 psi reactor coolant pressure; spent fuel is sent to long-term storage.

4.0 High Temperature Gas-Cooled Reactors(1)

4.1 HTGR DU(5)-OT: 20% enriched uranium-thorium oxycarbide particle fuel; the spent fuel is sent to long-term storage.

4.2 HTGR DU(3)/Th: 12% enriched U^{233}/thorium oxycarbide particle makeup fuel; spent fuel is reprocessed to recover the U^{233} and recycle it after denaturing to 12%; Pu is stored.

5.0 Gas-Cooled Fast Breeder Reactors(1)

5.1 GCFR U-Pu/Th spiked recycle: uranium-plutonium oxide homogeneous core and thorium oxide blanket; core and blanket reprocessed; core is coprocessed U and Pu subsequently pre-irradiated(3); the U^{233} is recovered and sold as denatured fuel.

6.0 Liquid Metal Fast Breeder Reactors(1)

6.1 LMFBR U-Pu/U recycle: standard U-Pu oxide homogeneous core, uranium oxide blanket; core and blanket reprocessed separately; core is coprocessed U and Pu; blanket is co-processed U and Pu with excess Pu used for LWRs and LMFBRs.

6.2 LMFBR U-Pu/U, spiked recycle: same as 6.1 except co-processed U/Pu is pre-irradiated.(3)

6.2.1 Heterogeneous core design

6.2.2 Homogeneous core design

6.3 LMFBR U-Pu/Th spiked recycle: uranium-plutonium oxide core and thorium oxide blanket; same as 6.2 except U^{233} is recovered from blanket fuel and sold as denatured fuel; Pu makeup from LWRs.

6.3.1 Heterogeneous core design

6.3.2 Homogeneous core design

6.4 LMFBR Th-Pu/Th, spiked recycle: thorium-plutonium oxide homogeneous core and thorium oxide blanket; core and blanket reprocessed separately; recovered Pu is recycled to LMFBR core; Pu is co-processed with thorium and pre-irradiated(3); the U^{233} is recovered and sold as denatured fuel.

6.5 LMFBR DU(3)-Th/Th: denatured U^{233} mixed with thorium oxide fuel in homogeneous core and thorium oxide in blanket; core and blanket reprocessed separately; recovered U^{233} is denatured and sold; recovered plutonium is mixed with uranium and pre-irradiated and sold.

Footnotes for Appendix A

(1) Enrichment, reprocessing, Pu conversion, Pu fabrication, Pu storage and U^{233} fabrication in secure locations.

(2) For reference only.

(3) To a radiation level of 1000 rad/hr at 1 meter from a fuel bundle when loaded into the reactor 6 months after fuel fabrication.

APPENDIX B

Ranking Based on Simple Score Totals

In this simplest ranking approach, the individual cycle/criterion ratings of Figure I were interpreted numerically:

High = 0
Moderate = 1
Low = 2

and entered into a revised Table B-1. The eight ratings were totaled for each cycle to arrive at cycle scores. The cycle ranking ("best" to "worst") was then derived based on the assumption that the lowest score indicates the fewest potential safeguards difficulties:

Cycle No.	Score	
1.1	0	("Best)
1.2		
4.1	2	
3.0	5	
6.5	7	
1.4 2.4 6.1	8	
2.1 2.3 6.2	9	
1.3 2.2 4.2	10	
2.5 2.6 6.3 6.4	11	
5.1	12	("Worst")

Table B-1

Simple Ranking Scores

Fuel Cycle Number	Criteria* A	B	C	D	E	F	G	H	Total Score
1.1	0	0	0	0	0	0	0	0	0
1.2	0	0	0	0	0	0	0	0	0
1.3	2	1	1	1	1	2	0	2	10
1.4	1	1	1	1	1	1	1	1	8
2.1	2	1	1	1	1	1	1	1	9
2.2	2	1	1	1	2	1	1	1	10
2.3	2	1	1	1	1	1	1	1	9
2.4	1	1	1	1	1	1	1	1	8
2.5	2	1	1	1	2	1	2	1	11
2.6	2	1	1	1	2	1	2	1	11
3.0	0	0	1	0	0	2	0	2	5
4.1	0	0	1	1	0	0	0	0	2
4.2	2	0	1	1	1	1	2	2	10
5.1	2	1	1	1	1	2	2	2	12
6.1	1	1	0	1	2	0	2	1	8
6.2	1	1	1	1	1	2	0	2	9
6.3	1	1	1	1	1	2	2	2	11
6.4	1	1	1	1	1	2	2	2	11
6.5	1	0	1	1	1	1	1	1	7

---

*Criteria Key:

A - Difficulty of Converting to Weapons Material
B - Resistance to Sabotage or Dispersal
C - Applicability of Current MC&A Practices
D - Applicability of Current Physical Protection Practices
E - Applicability of Current Transportation Practices
F - Applicability of Current Inspection and Enforcement Practices
G - Ease of SNM Recovery by Safeguards Personnel After Theft
H - Applicability of Current Safeguards Regulatory Schemes

APPENDIX C

Ranking Based on Criteria Interdependence

Certain interdependences exist among the criteria. An attempt, admittedly very simplified, was made to generate combined criteria based on these interdependences. For example, the availability of fuel cycle material to a potential illicit user is dependent on the ranking in at least four criteria: MC&A practice, physical protection practice, transportation practice, and ease of recovery. The safeguards adequacy in each of these four areas modifies the effect of the weapons conversion criteria. For example, the degree of availability certainly becomes more critical, from a weapons point of view, if the fuel cycle material can be readily converted to weapons material.

Using this approach, three new "condensed" criteria were generated:

I ("Weapons") = $A(C+D+E+G)$*

II ("Sabotage") = $B(D)$

III ("Dispersal") = $B(C+D+E)$

Two of the criteria, F-inspection and enforcement practices and H applicability of current regulatory schemes, were considered to be independent.

To give equal weight to the five criteria (three condensed and two independent), it is necessary to normalize the condensed criteria formulations. Thus:

$$I = A(C+D+E+G)/8$$

$$II = B(D)/2$$

$$III = B(C+D+E)/6$$

$$IV = F$$

$$V = H$$

The ratings A through H presented in Table B-1 were substituted in the above equations and the values of I through V calculated; these are tabulated and summed in Table C-1. The resultant cycle ranking is

---

*See Criteria Key, Table B-1.

Cycle No.	**Score***
1.1 1.2 4.1	0 ("Best")
6.5 6.1	2.5-2.63
1.4 2.4	3.5
2.1 2.3 3.0 4.2	4.0-4.25
2.2 2.5 2.6	4.42-4.67
1.3 6.2 6.3 6.4	5.375-5.75
5.1	6.25 ("Worst")

---

*Cycles with nearly identical scores have been grouped.

Table C-1

Interdependence Ranking Scores

Fuel Cycle Number	Condensed Criteria* I	II	III	IV	V	Total Score
1.1	0	0	0	0	0	0
1.2	0	0	0	0	0	0
1.3	0.75	0.5	0.5	2	2	5.75
1.4	0.5	0.5	0.5	1	1	3.5
2.1	1.0	0.5	0.5	1	1	4.0
2.2	1.25	0.5	0.67	1	1	4.42
2.3	1.0	0.5	0.5	1	1	4.0
2.4	0.5	0.5	0.5	1	1	3.5
2.5	1.5	0.5	0.67	1	1	4.67
2.6	1.5	0.5	0.67	1	1	4.67
3.0	0	0	0	2	2	4.0
4.1	0	0	0	0	0	0
4.2	1.25	0	0	1	2	4.25
5.1	1.25	0.5	0.5	2	2	6.25
6.1	0.63	0.5	0.5	0	1	2.63
6.2	0.375	0.5	0.5	2	2	5.375
6.3	0.63	0.5	0.5	2	2	5.63
6.4	0.63	0.5	0.5	2	2	5.63
6.5	0.5	0	0	1	1	2.5

---

*Condensed Criteria Key

I - "Weapons" = A(C+D+E+G)/8

II - "Sabotage" = B(D)/2

III - "Dispersal" = B(C+D+E)/6

IV - "I&E" = F

V - "Regulations" = H

Note/Criteria A through H are defined in Table B-1.

APPENDIX D

Modified Ranking Based on Criteria Interdependence

The overall ranking scheme described here is intended to do two things: (a) to derive one final or resultant ranking from a number of initial or contributory rankings, and (b) to quantify the "arbitrariness" or "imprecision" in this final ranking. This arbitrariness arises from the fact that the several rankings, each deriving from the consideration of a single criterion, may be and probably are to some extent inconsistent; fuel cycle A is ranked above fuel cycle B in one criterion, but the reverse is true in another. The greater the inconsistency in the initial rankings, the more arbitrary is the final result. The analyst should be aware not only of the final ranking, but also of its imprecision when using this datum.

Conceptually, the ranking scheme may be described as occurring in three steps:

(1) A "score" is defined which measures the extent to which any given ranking of fuel cycles is consistent with the initial rankings in each of the criteria. The exact definition of this score is as follows: If there are N fuel cycles and C criteria, the score is a sum of 1/2 CN(N-1) terms, one for each pair of fuel cycles in each of the criteria. The value of the term is -1 if the pair of fuel cycles appears in the same order in the ranking for that criteria as in the given ranking, -1 if the order is reversed, and zero if the pair is ranked equivalently.

(2) The ranking with the highest score is taken to be the final or resultant ranking. The procedure to find this ranking should be carried out with a computer algorithm; since time constraints prohibited this approach, we used a heuristic, manual approach in this preliminary application.

(3) The scores of other possible rankings are examined to determine if there are other rankings which are as good, or nearly as good, as this optimal ranking, or if this optimal ranking is really unique. If many rankings are essentially as good as the optimal one, we have a high degree of arbitrariness or imprecision. If the contrary is true we have a more definitive result. These results are displayed in the form of histogram-type graphs, one for each fuel cycle. The x-axis of these graphs represents location in the ranking: for 19 fuel cycles, the x-axis is numbered from one to 19. The value of the function displayed on each graph is the highest score of any ranking which contains the fuel cycle under consideration at each particular rank. Thus, the histogram for a given fuel cycle will peak at that value on the x-axis corresponding to the rank of the fuel cycle in the optimal ranking found in (2); a sharply peaked histogram indicates that this ranking is

relatively unique (precise) while a flat histogram indicates that the fuel cycle could have been ranked in a number of locations and still be reasonably consistent with the initial rankings in each of the categories.

The initial rankings chosen for input to this procedure were derived from the five columns headed "Condensed Criteria" in Table C-1 because it is assumed in the definition of the "score" above that each of the categories is of essentially equal importance.

The following ranking results from the calculation in step 2 above:

Fuel Cycle

1.1 }
1.2 } ("Best")
4.1 }

6.5

3.0

6.1

1.4 }
2.4 }

4.2

2.1 }
2.3 }

6.2

6.3 }
6.4 }

1.3

2.2

5.1

2.5 }
2.6 } ("Worst")

Bracketed cycles yielded the same optimal score.

While the cycle ranking is the major purpose of this report, the histogram construction described in Step 3 above has the potential for yielding additional information relating to the degree of precision in the ranking. Only a few of these histograms have been prepared, primarily to illustrate the technique; two are shown in Figure D-1. If future study serves to reduce the subjectivity of the criteria selection and the rating within each criterion, this histogram construction step may play a significant role in establishing the precision of cycle ranking.

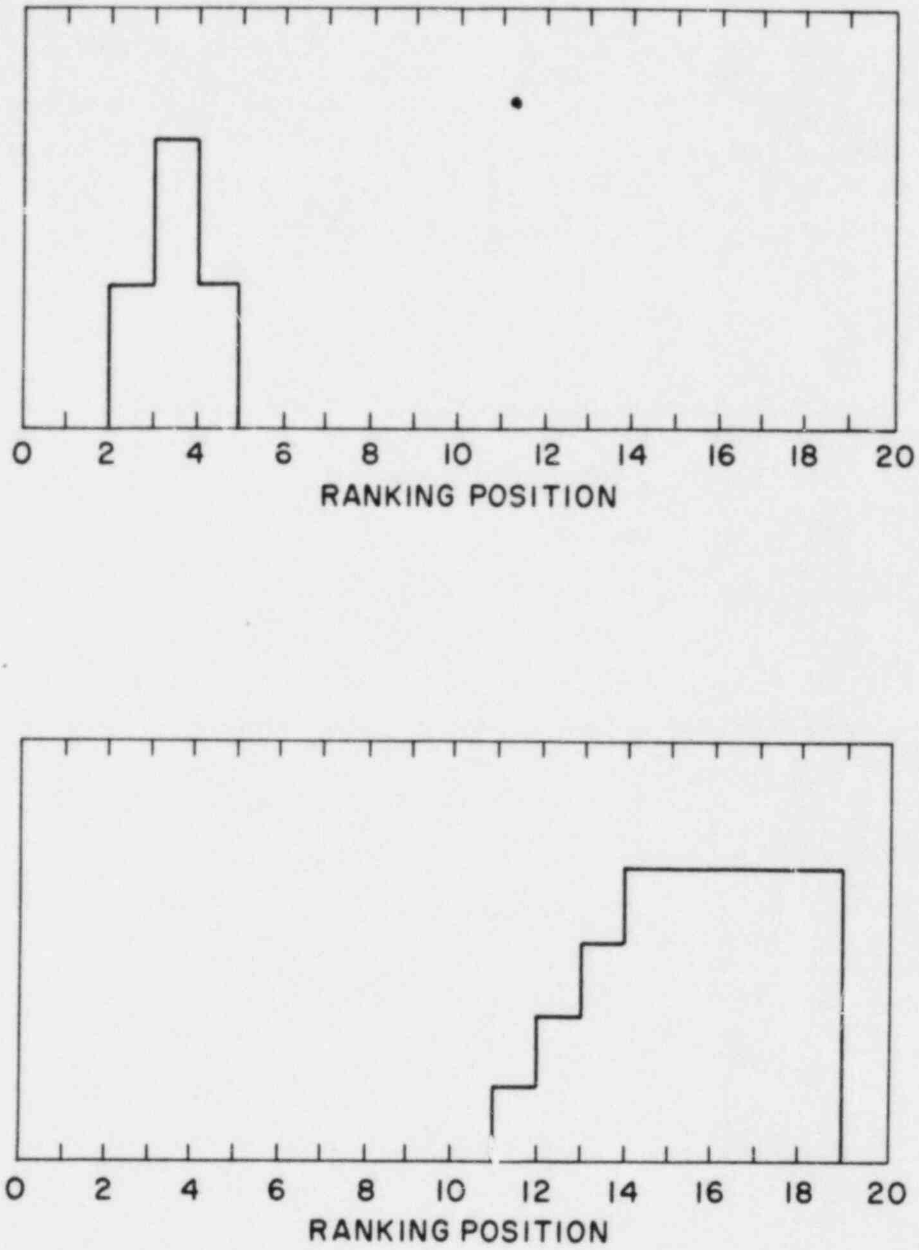

0
2
4
6
8
10
12
14
16
18
20
RANKING POSITION
0
2
4
6
8
10
12
14
16
18
20
RANKING POSITION

Figure D-1

APPENDIX E

DOE Interim Management Directive

IMD NO. 6104-A **21** **December 22, 1977**

	Effort to Effect Weapons Use	Examples of Material Types From Table IV	Relative Degree of Attractiveness *
(1)	Direct nuclear weapons use.	1-4	100
(2)	Requires, as a minimum, some shaping effort prior to use. The materials may contain minor amounts of impurities and alloying agents which would not preclude direct nuclear weapons use after shaping.	5-11	50
(3)	Requires some chemical conversion effort prior to shaping/use efforts.	12-14	20
(4)	Requires some purification effort prior to chemical conversion/shaping/use efforts.	15-21	10
(5)	Requires extensive purification effort prior to chemical conversion/shaping/use efforts.	22	1

Example Ranking of SNM According to Possible Attractiveness for Diversion

1. Assembled Pu Weapons Components
2. Assembled U^{235} Weapons Components
3. Pu Machined Weapons Parts
4. U^{235} Machined Weapons Parts
5. Pu Metal (buttons, rods, pieces, etc.)
6. U^{233} Metal
7. U^{235} Metal
8. Pu Oxides
9. U^{233} Oxides
10. U^{235} Oxides

11. U^{235} Carbides
12. Nirate Crystals and Nitrate Solutions of Pu, U^{233}, and U^{235}
13. Pu, U^{233}, and U^{235} Solutions Other Than Nitrate
14. Compounds of Pu, U^{233}, and U^{235} Other Than Those Listed in Items 8-12 Above
15. Pu Alloys
16. U^{233} Alloys
17. U^{235} Alloys
18. Pu Fuel Elements and Assemblies
19. U^{233} Fuel Elements and Assemblies
20. U^{235} Fuel Elements and Assemblies
21. Pu, U^{233}, and U^{235} High-Grade Recoverable Scrap
22. Pu, U^{233}, and U^{235} Low-Grade Recoverable Scrap (Process Residues)

---

*The maximum attractiveness index is 100. This index is inversely proportional to the effort for weapons use. In all cases, it is assumed that fissile materials are present in amounts above those listed for material Categories I and IA in Table II.

A Suggested Ranking For Seven Selected Fuel Cycles

B. Keisch

October 1980

TABLE OF CONTENTS

		Page
I.	Introduction	315
II.	Rating Basic Features	315
III.	Major Rating Categories	321
IV.	Unweighted Ranking	322
V.	Weighting of Major Rating Categories	323
VI.	Generation of Weighted Rankings	324
VII.	Results	325
VIII.	Conclusions	330
References		331
Appendix A		332
Appendix B		334

ABSTRACT

This report describes a ranking of only 7 Non-Proliferation Alternative Systems Assessment Program (NASAP) fuel cycles according to safeguard and non-proliferation issues. By narrowing the scope of investigations more detailed rankings can be made.

Twelve basic features are combined into five major categories and used to evaluate the technical issues with respect to safeguards issues. The issues of practicality and proliferation resistance are addressed in this report and a weighting is applied to the various factors.

A computer-assisted ranking method was used to assess possible ranking orders and to denote potential ambiguities therein. Only the HTGR (medium enriched, once-through) cycle and the LMFBR (U-Pu/Th spiked

recycle) appeared to be unambiguous in ranking ("best" and "worst," respectively). A large degree of subjectivity remains as an important factor in ranking these cycles.

I. INTRODUCTION

The U.S. Nuclear Regulatory Commission has commissioned Brookhaven National Laboratory (BNL) to devise a ranking method for a set of selected fuel cycles and to apply the method. The previous, similar report included all 21 cycles as described in the Preliminary Safety and Environmental Information Documents which treat the NASAP fuel cycles.[1] The previous report is frequently referenced here. Information used in that task was taken from a work in which the technical safeguards issues were described.[2]

For further study, a selection of a subgroup of seven cycles was made by BNL as (a) representative of most of the safeguards issues and (b) relatively practical choices. A list and brief description of the cycles selected appear in Appendix A.

Differences in philosophy between the present ranking and that described previously[3] include consideration of aspects of non-proliferation and practicality which were not included before. As will be seen, the method described here depends upon a subjective ordering procedure with respect to certain pertinent features, the combining of such features into general attributes, and the weighting of the importance of those attributes. Ultimately, a computer program yields a "best" ranking order and also graphically illustrates any potential ambiguities in the position of each cycle in the order.

As an outgrowth of the previous study,[2] rankings published elsewhere were considered, but most were not directly applicable to the present case. Reference 2 describes a number of such rankings[4] to which might be added one more.[5] The latter is an attempt at formally quantifying proliferation risks, but it is not clear whether the highly mathematical treatment presented is applicable to this highly subjective subject. Further, the presentation only deals with proliferation risks and, thus, is not directly useful for domestic safeguards purposes.

The utility of any method for ranking of the fuel cycles, including the present one, must be tempered by the lack of detail, lack of experience, and general subjectivity of the judgments involved. At this time, the method itself may thus be of more interest than the outcome of its application.

II. RATING BASIC FEATURES

In the process of ranking the seven fuel cycles considered here, twelve basic features were chosen as described below. In the following section these features are combined into five major categories.

The numerical values given for any of the features are strictly a function of ordering. That is, the best cycle, of the seven, for any one feature is assigned a score of 1; the worst, a score of 7. Ties share the score for the tied positions. For example for any given feature, if cycle "b" is considered "best" and cycle "f" is considered worst, they are assigned a score of 1 and 7, respectively, and the others, cycles "a," "c," "d," "e," and "g" are each assigned a score of 2+3+4+5+6/5 or 4. Obviously this system does not take into account great disparities in quality. That is, no further allowance is made if, for example, the difference between best and second best is great while the difference between second best and worst is small. The twelve basic features are:

A. Commercialization

This feature is a measure of how close to practice any particular cycle is. Throughout this presentation, the numbers identifying the fuel cycles are those to be found in Appendix A and corresponding to the number given in references 1 through 3. For the seven cycles chosen the scores for commercialization are:

Cycle	Score	Explanation
1.3	1	Very similar to presently operating systems
2.3	4.5	Experimental
2.4	4.5	"
4.1	4.5	"
4.2	4.5	"
6.1	2	Under construction
6.3	7	Exists only as a conception

B. Proliferation Deterrence

This feature is a measure of the degree of proliferation deterrence offered by the cycle. In a sense, it is also a measure of whether or not material in the fuel cycle exists which is both divertable by the plant operator and is weapons usable. "Protection" such as spiking and/or coprocessing is not considered to be of much value for proliferation deterrence. Hence, such protection has importance only in the sense of international safeguards and only for facilities in non-weapons states. For purposes of this rating, the presence of undenatured U^{233} and plutonium are considered equivalent and detrimental. For the seven cycles the scores for Proliferation Deterrence are:

Cycle	Score	Explanation
1.3	3	Separated Pu present
2.3	6	Separated Pu and undenatured U^{233} present
2.4	3	Undenatured U^{233} present
4.1	1	Pu present only in spent fuel
4.2	6	Separated Pu and undenatured U^{233} present
6.1	3	Separated Pu present
6.3	6	Separated Pu and undenatured U^{233} present

C. "Inherent" Protection against Sabotage and/or Theft

This feature is meant to include protection methods such as spiking and coprocessing which have value only in consideration of subnational theft and, hence, only for domestic safeguards. Unprotected SNM is an obvious liability, but so is the presence of spikant materials, such as Co^{60}, which are potentially hazardous through possible theft followed by dispersion. The use of sensitive technologies such as reprocessing is considered an extra vulnerability to sabotage.

Cycle	Score	Explanation
1.3	7	Reprocessing, Co^{60} spikant, Pu in recycled fuel
2.3	5	Reprocessing, Pu storage
2.4	2	Reprocessing
4.1	1	Spent fuel only
4.2	5	Reprocessing, Pu storage
6.1	3	Reprocessing, Pu in recycled fuel, coprocessed Pu in storage
6.3	5	Reprocessing, Pu in storage

D. Quantity of Weapons Usable Material

This feature is intended as a measure of the quantity of weapons usable material present for a reference level of energy production (0.75 GWe-yr). The accessibility is not taken into account here except that material requiring enrichment is considered inaccessible. Numbers are kg/0.75 GWe-yr, are rounded, and include only main streams or caches.

Cycle	Score	Explanation
1.3	4	160 Pu (clean in separation plant) + 330 Pu (with U and Co^{60} in sep. plant) + 300 fissile Pu in fuel
2.3	3	250 U^{233} (storage) + 90 Pu (storage)
2.4	5.5	1500 U^{233} (in recycle and fuel)
4.1	1	60 U^{233} and 60 Pu (in spent fuel only)
4.2	2	200 U^{233} (in reprocess) + 70 Pu (storage)
6.1	5.5	1300 fissile Pu (in recycle) + 240 Pu (storage)
6.3	7	1800 Pu (in fuel with pre-irradiation) + 400 U^{233} (in reprocessing)

E. Quality of Weapons Usable Material

This feature is meant to be a measure of the suitability of weapons usable material. That is, how little (or how much) effort is required to prepare diverted or stolen material prior to building a weapon. Enrichment is generally considered not a viable procedure for this purpose. However, it is recognized that, for international safeguards considerations, a nation bent on diversion through enrichment would have an easier route if, for example, medium-enriched U^{235} were present than if only low-enriched or natural material were available. The entries under "explanation" only include the "best" material available in the cycle. The score, however, reflects the nature of other material as well.

Cycle	Score	Explanation
1.3	6	Clean Pu in separation plant
2.3	7	Highly enriched U^{233} and clean Pu
2.4	2	Highly enriched U^{233} in separation plant
4.1	1	"Heat-spiked" Pu only in spent fuel
4.2	5	Highly enriched U^{233} in separation plant and Pu in storage
6.1	3	Coprocessed Pu in recycle
6.3	4	Highly enriched U^{233} in separation plant and coprocessed Pu in cycle

F. "Inherent" Protection of Weapons Usable Material

This feature is meant to be a measure of protective methods applied to weapons usable material only (compare with C, above). It includes features such as spiking and coprocessing. The scores reflect a judgment of efficiency of the protective methods used.

Cycle	Score	Explanation
1.3	4	Mostly coprocessed and spiked or in plant
2.3	7	None for sensitive material in storage
2.4	2	Denaturing
4.1	1	In spent fuel only
4.2	3	Mostly denatured or in spent fuel, but some in storage
6.1	6	Coprocessing
6.3	5	Mostly pre-irradiated

G. Physical Protection

This feature is meant to be a measure of the ease of applying physical protection methods to the vulnerable parts of the cycle. Except for cycle 4.1 (once-through HTGR), there is probably little or no difference among the cycles.

Cycle	Score	Explanation
1.3	4.5	—
2.3	4.5	—
2.4	4.5	—
4.1	1	Spent fuel in great bulk
4.2	4.5	—
6.1	4.5	—
6.3	4.5	—

H. Material Control and Accounting

This feature is meant to reflect the degradation of quality in the measurement (assay) methods used for accounting purposes which may result because of the presence of high radiation fields or "unusual" material or situations.

Cycle	Score	Explanation
1.3	7	Spiking degrades nondestructive assay methods
2.3	4.5	Thorium and U^{232} present
2.4	4.5	" " " "
4.1	2	Element identity possibly lost in pre-storage conversion
4.2	4.5	Thorium and U^{232} present
6.1	1	No unusual problems
6.3	4.5	Thorium and U^{232} present

I. Transportation

This feature reflects the quantity and quality of sensitive material required to be shipped.

Cycle	Score	Explanation
1.3	6	SNM to storage, Co^{60} spikant to plant, reprocessing to fabrication
2.3	4	SNM to storage, enrichment to fabrication, reprocessing to enrichment
2.4	2	Reprocessing to fabrication
4.1	1	Spent fuel only in large bulk
4.2	5	SNM to and from storage, reprocessing to fabrication
6.1	3	Coprocessed SNM to storage, reprocessing to fabrication
6.3	7	Denatured SNM to and from storage, SNM to preirradiation, reprocessing to fabrication

J. Ease of Recovery after Theft

This feature reflects the enhanced detectability of spiked fuel and the role that this might play in the recovery of concealed stolen material. Also bulkiness of material may also make such material more difficult to conceal effectively.

Cycle	Score	Explanation
1.3	2	Co^{60} spiking helps
2.3	5	U^{232} helps somewhat
2.4	5	U^{232} helps somewhat
4.1	1	Highly radioactive spent fuel in great bulk
4.2	3	U^{232} helps somewhat; great bulk
6.1	7	Coprocessing only
6.3	5	U^{232} helps somewhat

K. Inspection and Enforcement

This feature is intended as a measure of how certain characteristics of the fuel cycles impinge on the inspection process. For example, the effect of spiking may limit access to material or the measurement verification process, particularly when nondestructive assay methods are involved, as they often are, for verification purposes.

Cycle	Score	Explanation
1.3	3	Spiking
2.3	5	U-Th mixtures (U^{232} "spike")
2.4	5	" " "
4.1	2	Possible lost identity in preparing for storage
4.2	5	U-Th mixtures (U^{232} "spike")
6.1	1	Coprocessing only
6.3	7	U-Th mixtures (U^{232} "spike") and preirradiation facility.

L. Requirements for New Regulations (Domestic Only)

This feature represents an evaluation of the need for new regulations to cover any unusual features in the cycles. The explanations below reflect these features. Score estimates are purely subjective assessments of the complexities involved. In some cases, ratings are made relative to the difficulties encountered in the Generic Environmental Statement on Mixed Oxides (GESMO) licensing proceedings.

Cycle	Score	Explanation
1.3	6	Spiking and coprocessing
2.3	3	GESMO-like
2.4	3	GESMO-like
4.1	1	Protecting identity during pre-storage processing
4.2	3	GESMO-like
6.1	5	Coprocessing
6.3	7	Spiking, coprocessing, and pre-irradiation

III. MAJOR RATING CATEGORIES

In the previous section, twelve basic features were defined for which scores were alloted for each of the seven cycles. These basic features are, however, related to one another in complex ways. Also, there are certain more general issues to which the basic features are also related. In this section, five general issues are defined. For each of these general issues there are a number of basic features which are combined. Some basic features are judged common to more than one issue. For example, physical protection is an important feature of the issues dealing with weapons, sabotage and dispersal, regulation, and practicality. For each issue the scores developed in the previous section are totaled, feature-by-feature, and normalized by dividing by the total number of features included in the issue. No attempt is made to weight the importance of each feature.

A. Weapons

The following features are included: Weapons Usable Material Quality, Quantity of Weapons Usable Material, "Inherent" Protection of Weapons Usable Material, Ease of Recovery After Theft, Physical Protection, and Transportation. These features were chosen because they are related to the question of how readily suitable weapons material can be diverted or stolen. Note that material control and accounting is excluded from this issue (as here defined) because its impact is mainly to detect theft or diversion and not to prevent it. Broadly speaking, of course, the risk of detection can be a deterrent, but here this effect is judged of secondary importance and, hence, excluded. With similar reasoning, a number of other basic features can be connected with this issue, but only the above six are used.

B. Sabotage and Dispersal

The basic features are "Inherent" Protection Against Sabotage and/or Theft, Ease of Recovery after Theft, Physical Protection, and Transportation. Note that there is a certain similarity between "Inherent" Protection Against Sabotage and/or Theft and "Inherent" Protection of Weapons Usable Material.

These basic features are an example wherein the score is different for a different application of otherwise similar attributes. By making this distinction, and incorporating each particular feature only into the appropriate issue, the influence on the ranking of any such differences is fairly represented.

C. Proliferation Resistance

The basic features are Proliferation Deterrence, Quantity of Weapons Usable Material, Material Control and Accounting, and Inspection and Enforcement. The feature "Quality of Weapons Usable Material" was omitted because it is somewhat similar to "Proliferation Deterrence," the premise being that the presence of any quality of weapons-usable material is detrimental.

D. Regulatory Requirements

The basic features are Requirements for New Regulations, Inspection and Enforcement, Transportation, Physical Protection, and Material Control and Accounting.

E. Practicality

The basic features are Commercialization, Transportation, Physical Protection, and Material Control and Accounting. The inclusion of the latter three is intended to represent the pressures of licensing requirements on the commercialization process.

IV. UNWEIGHTED RANKING

Table 1 shows a summary of the scores for all the cycles for the five issues as described in section III and the overall total score. For convenience, the cycles are listed in ranking order by overall score with "best" first.

The order obtained in this way is comparable to the order in which these seven cycles appear among the 19 ranked in a previous report.[2] Table 2 summarizes that effort and includes the three methods discussed there. The only difference expecially noteworthy is the relative location of cycle 1.3 in the previously published rankings and that given in Table 1. This difference may be partly explained by the inclusion of certain criteria in the present work (e.g. "Practicality") and also the differences in scoring methods as well as a degree of subjectivity. However, as discussed below, even the resulting difference is not of major impact.

Table 1

UNWEIGHTED RANKING SCORES

Scores

Cycle	Weapons	Sabotage/ Dispersal	Proliferation Resistance	Regulations	Practicality	Total
4.1	1.00	1.00	1.50	1.40	3.45	8.35
6.1	4.83	4.38	2.63	2.90	2.28	17.02
2.4	3.50	3.38	4.50	3.80	4.23	19.41
1.3	4.42	4.88	4.25	5.30	2.61	21.46
4.2	3.75	4.38	4.38	4.40	4.56	21.47
2.3	5.08	4.63	4.63	4.20	4.44	22.98
6.3	5.42	5.38	6.13	6.00	6.45	29.38

Table 2

UNWEIGHTED RANKING ORDERS

	This Work	Reference 2*		
	Table 1	Appendix F	Appendix G	Appendix H
"Best"	4.1	4.1	4.1	4.1
	6.1	6.1 ⎫	6.1	6.1
	2.4	2.4 ⎭	2.4	2.4
	1.3	2.3	2.3 ⎫	4.2
	4.2	1.3 ⎫	4.2 ⎭	2.3
	2.3	4.2 ⎭	1.3 ⎫	6.3
"Worst"	6.3	6.3	6.3 ⎭	1.3

---

*Brackets indicate equivalence in rank. Appendices B,C, and D of the first report in this chapter are equivalent to Appendices F,G, and H, respectively, of Reference 2.

V. WEIGHTING OF MAJOR RATING CATEGORIES

The importance of each rating category to any ranking is obviously not equivalent. For example, such a feature as a need for modification of the existing regulations is not as detrimental as the quantity of weapon-suitable material that is available. The former can be altered by some "political" process while the latter constitutes a real, and probably unalterable, physical attribute.

Furthermore, whether the ranking is considered for purposes of domestic safeguards or as a means of deterring proliferation will also have some bearing on the relative importance of the categories. Therefore, two safeguards modes are discussed separately.

A. Domestic Safeguards

For domestic safeguards purposes, of the five major categories, the two most important are judged to be those titled "Weapons" and "Sabotage and Dispersal." The category "Proliferation Resistance" is judged to be of least concern. The remaining two categories "Practicality," and "Regulatory Requirements" are judged to be 3rd and 4th in importance, respectively. To apply these judgments for weighting purposes, these five categories are scored by a method similar to that used for each basic feature (Section II). Thus the category weighting factors, for domestic applications, are:

Category	**Weighting Factor**
Weapons	1.5
Sabotage and Dispersal	1.5
Practicality	3
Regulatory Requirements	4
Proliferation Resistance	5

It is intended that the weighting factors be used by dividing the score achieved by each cycle for each category by the appropriate factor prior to totalling the resulting scores for the cycles. No attempt is made to judge the "separation" of importance between adjacent categories by assignment of these weighting factors. However, in the computer program used to calculate rankings, a means to adjust the "spread" of weighting is available (see below).

B. International Safeguards

For purposes of non-proliferation, the order of importance for the five categories are somewhat different. The "Weapons" category is still most important. However, "Sabotage and Dispersal" is slightly downgraded while "Proliferation Resistance" is elevated in importance so that these two are considered equivalent. Thus, the category weighting factors, for international safeguards, are:

Category	Weighting Factor
Weapons	1.5
Sabotage and Dispersal	2.5
Proliferation Resistance	2.5
Practicality	4
Regulation Requirements	5

VI. GENERATION OF WEIGHTED RANKINGS

Once the overall, subjective, judgments have been made for the basic features of each cycle (Section II), for the manner in which the basic features are combined into Major Rating Categories (Section III), and for the weight to be given to each Category (Section V), overall scores for each cycle can be readily calculated and the cycles could be then ranked by these overall weighted scores. Further, this could be accomplished for both Domestic and International applications by selecting the appropriate weighting scheme. Because of the inevitable imperfections in the judgment process, one should also attempt to qualify the results by ascertaining (1) with fixed judgments, how definitive is the particular ranking order that was determined and (2) what effect will alterations in judgments have on the ranking order. To ascertain the former requires the use of a computer program which also will make the latter more readily determined as well.

Appendix H of Reference 2 (Appendix D of the first report in this chapter) describes a method which derives "a resultant ranking from a number of initial or contributory rankings" and qualifies "the 'arbitrariness' or 'imprecision' in this final ranking." "Imprecision" in a final ranking may result if, for any pair of cycles, one is "better than the other in one category" and "worse in a second category."

The scheme described in Reference 2 is as follows:

(1) A score is defined which measures the extent to which any given ranking of fuel cycles is consistent with the rankings in each of the categories. If there are N fuel cycles and C categories, there are N! possible rankings. For each of these possible rankings the score is a sum of 1/2 CN(N-1) terms, one for each pair of fuel cycles in each of the categories. The value of a term is +1 if, for the pair of fuel cycles considered, the order of the pair is the same in the ranking as in the category. The value of the term is -1 if that order is reversed, and zero if the pair is equivalent.

(2) The ranking with the highest score is taken to be the resultant or "best" ranking.

(3) A compilation of the score for all N! rankings may be examined to find rankings that are "as good" or "nearly as good" as the "best" ranking. This can be conveniently accomplished by preparing a histogram for each cycle in which, for each position in the order (along the x axis), one plots the highest score among those rankings in which the cycle appears in that position. A histogram that is sharply peaked indicates a relatively precise ranking for that cycle. A "flat" histogram indicates that the particular cycle is not precisely located in the rankings.

In Reference 2, the author dealt with 19 fuel cycles and the number of possible rankings was approximately 1.2×10^{17}. The task of determining scores for all of these was impossible.

Thus, a "heuristic, manual approach" was employed. In the present case, considering only 7 cycles, there are 5040 possible rankings. This number was easily handled with a computer program (Appendix B).

This computer program accomplishes the following:

(1) Asks the user whether "domestic" or "international" weighting is required.

(2) Asks the user if the "spread" of the weighting is to be controlled. (The choice of "spread" allows the user to fix the relative worth of the category weighting factors instead of the order only. The value chosen is the ratio of the weighting factor for the "most" important category to that for the "least" important. Scaling for the intermediate factors is automatic.)

(3) Computes scores for all 5040 (seven factorial) possible rankings based on the rankings that are built in to the program and records the scores in a floppy disc file for further use.

(4) Produces hard copy histograms for all seven of the fuel cycles.

(5) Lists the rankings having scores that are equivalent to at least 90% of the best score.

VII. RESULTS

For the seven cycles under consideration here, the computer program was run for both domestic weighting and international weighting with the following results:

A. Domestic Weighting

The program was run with no control over the spread of the weighting factors (see section VI) so that the spread was 3.3.

The ranking achieving the best score (57.5) was:

"Best" 4.1
2.4
6.1
4.2
1.3
2.3
"Worst" 6.3

From examination of the histograms and the rankings achieving almost as good a score, (97% of the best score), the brackets were added to the above listing to indicate "close" decisions. Thus, only the placement of the "best" and the "worst" cycle were "definitive."

The seven histograms are shown in Figs. 1-7 and one can see the very slight distinctions in the placement of, for example, cycle 1.3 in 5th or 6th positions. On the other hand, cycles 4.1 (20% enriched U^{235} Th once-through) and 6.3 (LMFBR U-Pu/Th spiked recycle) are distinctively first and last, respectively.

B. International Weighting

The program was run with the spread of the weighting factors set at 3 (roughly comparable to the Domestic run above).

The ranking achieving the best score (43.3) was:

"Best" 4.1
2.4
6.1
4.2
1.3
2.3
"Worst" 6.3

This ranking turns out to be the same as the best ranking with domestic weighting. And, as in the latter case, examination of the rankings achieving almost as good a score (99% of the best score) indicates the near equivalence of the bracketed cycles above. The histogram for the seven cycles generated with international weighting are shown in Figs. 8-14. Again the "best" and the "worst" cycles are well defined while the others are not.

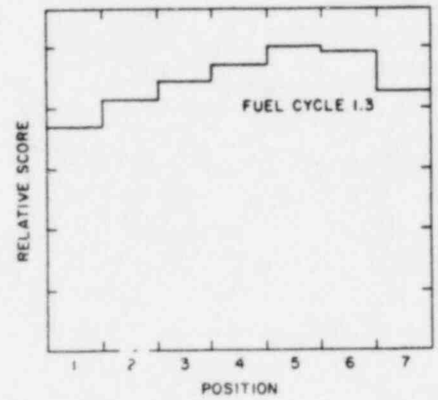


Figure 1

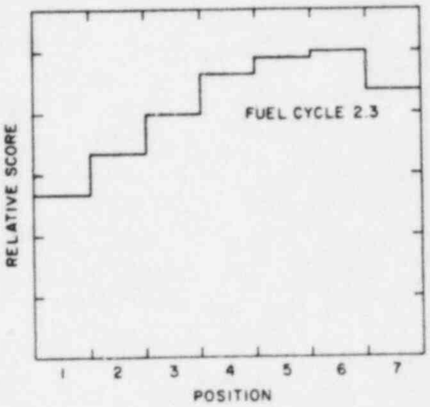


Figure 2

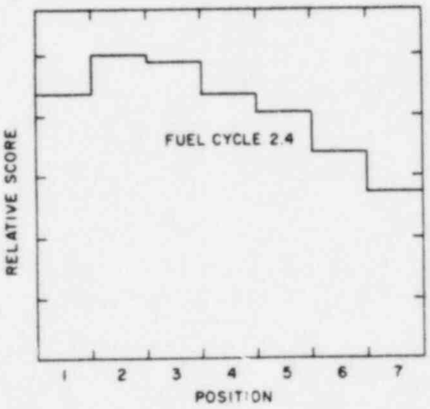


Figure 3

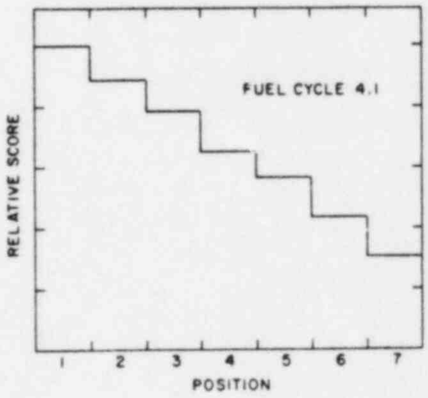


Figure 4

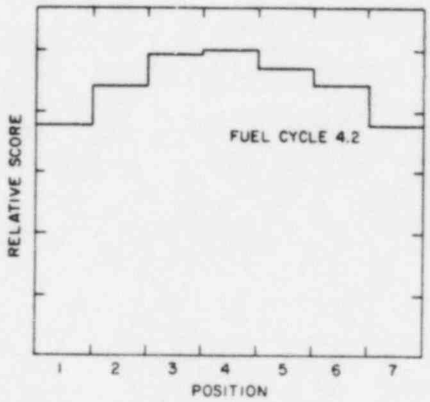


Figure 5

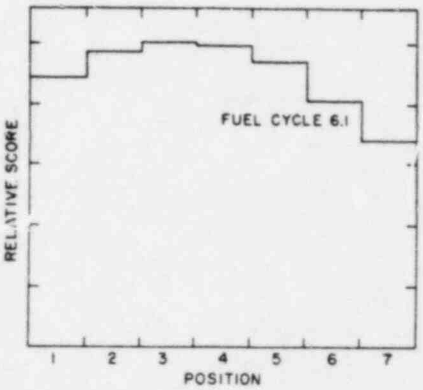


Figure 6

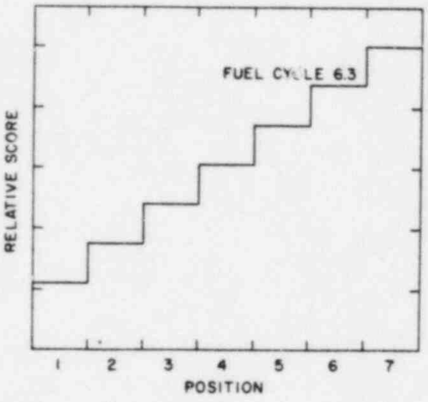


Figure 7

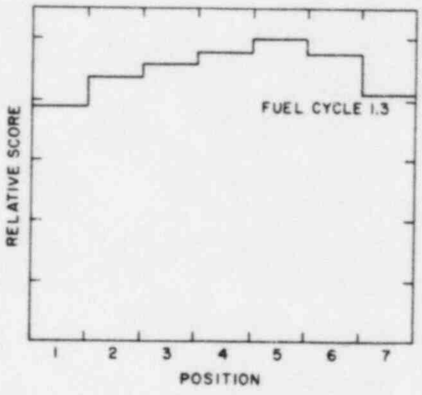


Figure 8

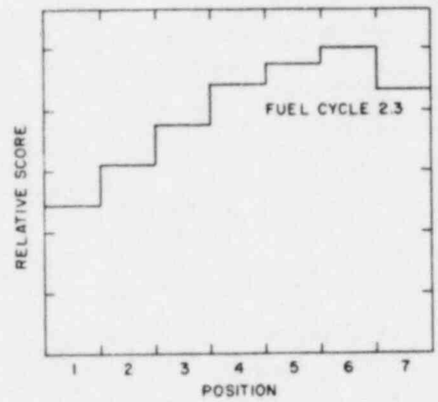


Figure 9

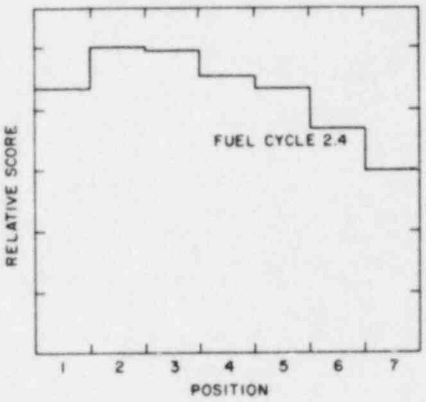


Figure 10

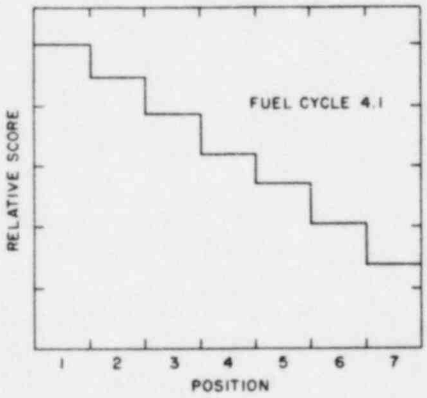


Figure 11

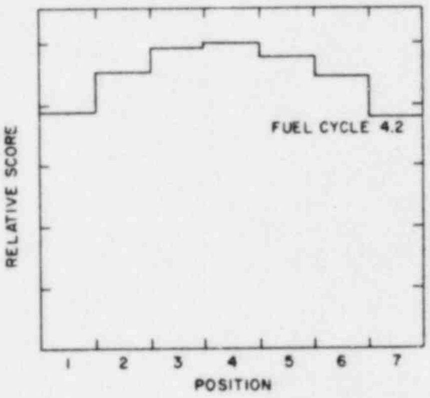


Figure 12

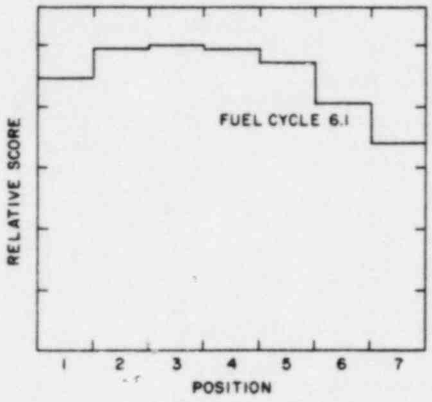


Figure 13

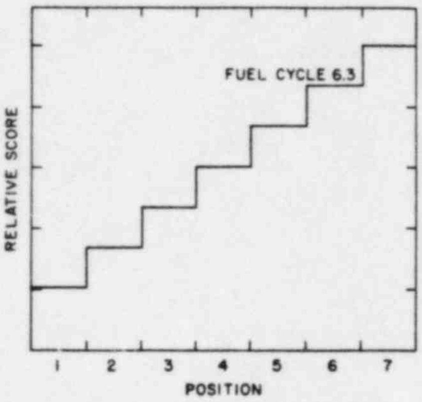


Figure 14

C. Effects of Weighting

While the "best" ranking order is the same for both weighting modes, there are subtle differences in the distinctiveness of the order. For example, the positions for cycles 2.4, 6.1 and 4.2 are less distinct for international than for domestic weighting. However, it cannot be emphasized too strongly that the ultimate basis for any of these results is the subjective assignment of numeric values based on judgments of ordering and weighting. Thus one should be mainly concerned with the method described here rather than the specific results.

VIII. CONCLUSIONS

The general features of the rankings for the seven cycles considered here are quite similar to those reported previously. Picking out the seven from the 19-cycle rankings of the previous work results in the same "best" (cycle 4.1) and "worst" (cycle 6.3) cycles as in the present work (except that one ranking method of the previous work ("Modified Ranking Based on Criteria Interdependence") places cycle 1.3 just below cycle 6.3). The ordering of the middle five cycles is similar to those derived here. Slight differences in the ranking order are not surprising since the methods are only slightly different and the criteria used are also only slightly different. On the other hand, the overall similarities that result are probably because the most important criteria are the same for both methods and slight alterations in ordering the basic features do not change the overall rankings much if at all. The computer program enables one to show that this is so by repeating the run with slight changes.

Clearly, more precise rankings and more sophisticated systems of ranking are inappropriate at this time considering the lack of hard information available for these cycles. In order to refine the judgments involved in these methods, there would have to be considerable actual experience with certain concepts involved in the cycles. There has, for example, been very little useful experience with coprocessing or spiking.

Economics is one important factor that has not been considered in these rankings. Without doubt, from the safeguards point of view, once-through cycles, such as 4.1, are intuitively "better." All the rankings, here and in the previous work, bear this out. It is clear then, that one important reason to consider any of the more complex cycles at all would be an economic one, i.e., that the cost of fuel would be so high as to justify the use of more complex systems which would be more difficult and more expensive to safeguard.

REFERENCES

1. PSEID, (7 Volumes), U.S. DOE, DOE/NE-0003/1 through 7, January 1980.
2. E.V. Weinstock and B. Keisch, "Technical Safeguards Issues for Alternative Fuel Cycles," NUREG/CR-1048, BNL-NUREG-51182, January 3, 1980.
3. J.J. Cadwell, "A Suggested Ranking for Selected Alternative Fuel Cycles," NUREG/CR-1052, BNL, February 20, 1980. (Presented, in somewhat modified form, as the first report in this Chapter).
4. R.N. Anderson et al., "Methodology for Comparative Evaluation of Nuclear Fuel Reprocessing Techniques for Advanced Low Proliferation Risk Fuel Cycles," BNL 23312 (1977); Office of Technology et al., "Nuclear Proliferation and Safeguards," 1977, p. 34; Comptroller General of the United States, "Quick and Secret Construction of Plutonium Reprocessing Plants: A Way to Nuclear Weapons Proliferation?" EMD-78-104, October 6, 1978.
5. P. Silvennionen and J. Vira, "An Approach to Quantitative Assessment of Relative Proliferation Risks for Nuclear Fuel Cycles," Technical Research Centre of Finland, unpublished, 1979.

APPENDIX A

NASAP Reactor/Fuel Cycle Systems* For Ranking In The Present Study

1.0 Light Water Reactors**

1.3 PWR-U/Pu spiked recycle: PWR using 3% low-enriched uranium oxide fuel and self-generated recycle fuel of co-processed uranium and plutonium oxide; the recycle fuel is spiked or pre-irradiated.***

2.0 Light Water Breeder Reactors**

2.3 Backfit Prebreeder: standard PWR using 15% enriched uranium oxide/thorium oxide fuel; the spent fuel is reprocessed to recover U^{233} which is stored for use in LWBR; Pu is stored.

2.4 Advanced Breeder: standard PWR except modified for tight lattice, hexagonal fuel bundle and thoria control rods; using U^{233}/thorium oxide fuel which is reprocessed to recover U^{233} for recycle as spiked fuel.***

4.0 High Temperature Gas-Cooled Reactors**

4.1 HTGR DU(5)-OT: 20% enriched uranium-thorium oxycarbide particle fuel; the spent fuel is sent to long-term storage.

4.2 HTGR DU(3)/Th: 12% enriched U^{233}/thorium oxycarbide particle makeup fuel; spent fuel is reprocessed to recover the U^{233} and recycle it after denaturing to 12%; Pu is stored.

6.0 Liquid Metal Fast Breeder Reactors**

6.1 LMFBR U-Pu/U recycle: standard U-Pu oxide homogeneous core, uranium oxide blanket; core and blanket reprocessed separately; core is co-processed U and Pu; blanket is co-processed U and Pu with excess Pu used for LWRs and LMFBRs.

6.3 LMFBR U-Pu/Th spiked recycle: uranium-plutonium oxide core and thorium oxide blanket; same as 6.1 except co-processed U/Pu is pre-irradiated*** and U^{233} is recovered from blanket and sold as denatured fuel; Pu makeup from LWRs.

6.3.1 Heterogeneous core design

---

*Numbering is retained from previous listing of systems,[1] for easy identification.

**Enrichment, reprocessing, Pu conversion, Pu fabrication, Pu storage and U^{233} fabrication in secure locations.

***To a radiation level of 1000 rad/hr at 1 meter from a fuel bundle when loaded into the reactor 6 months after fuel fabrication.

REFERENCES

1. E.V. Weinstock and B. Keisch, "Technical Safeguards Issues for Alternative Fuel Cycles," NUREG/CR-1048, BNL-NUREG-51182, January 3, 1980 in the next Chapter.

APPENDIX B

Computer Programs

The following pages contain a listing of the programs written for use on the Hewlett-Packard 9845. It is written in an enhanced BASIC. The second part of the program generates the 7! possible rankings as 5040 string variables. These were written to a binary file called "SEVEN" which is read into the main program.

In the main program, lines 30 to 70 contain the ranking orders for the 5 major categories. The subroutines following line 620 contain the weighting factors. Examples are also given in the subroutines for means to handle equivalent rankings within the categories although they are not used as the program now stands. Line 310, which is here shown as a comment, can be used to create a file for saving the scores for the 5040 rankings.

Although the program is not very complex, a long time is required to run it. (One estimate is on the order of 15 hours.) This is because of the large number of possible ranking orders. If a larger number of cycles, even eight, were considered, the time would become totally unmanageable. One could, however, be less rigorous by making a decision which would eliminate from consideration all cycles not ranking the "best" cycle first.

The output, which is generated in a relatively short time near the end of the total running time consists of seven histograms and list of rankings having scores within 90% of the best score.

```
        80 / 11 / 20                    Ranker

10     OPTION BASE 1
20     DIM Score(5040),Rank$(5040)[7],Rankcat$(5)[7],Yplot(7)
30     Rankcat$(1)="4351627"
40     Rankcat$(2)="4356217"
50     Rankcat$(3)="4615327"
60     Rankcat$(4)="4632517"
70     Rankcat$(5)="6143257"
80     LINPUT "INTERNATIONAL OR DOMESTIC RANKING? (I OR D)",Wtype$
81     INPUT "ENTER WEIGHTING SPREAD IF DESIRED. (0 = NONE)",Sprda
82     IF Sprda=0 THEN 90
83     IF Wtype$="D" THEN Sprd=(5-1.5*Sprda)/(Sprda-1)
84     IF Wtype$="I" THEN Sprd=(5-Sprda)/(Sprda-1)
90     FREAD "SEVEN:F8",Rank$(*)
100    FOR Ranknumb=1 TO 5040
110    FOR Cycle=1 TO 7
120    FOR Cycle2=1 TO 7
130    IF Cycle=Cycle2 THEN Nextcycle2
140    FOR Cat=1 TO 5
150    Equiv=0
160    ON Cat GOSUB Cat1,Cat2,Cat3,Cat4,Cat5
170    IF Equiv=1 THEN Nextcat
180    A=POS(Rank$(Ranknumb),VAL$(Cycle))
190    B=POS(Rankcat$(Cat),VAL$(Cycle))
200    C=POS(Rank$(Ranknumb),VAL$(Cycle2))
210    D=POS(Rankcat$(Cat),VAL$(Cycle2))
220    IF SGN(A-C)=SGN(B-D) THEN Scoretemp=Scoretemp+1/Factor
230    IF SGN(A-C)<>SGN(B-D) THEN Scoretemp=Scoretemp-1/Factor
240 Nextcat:    NEXT Cat
250 Nextcycle2:    NEXT Cycle2
260    NEXT Cycle
270    Score(Ranknumb)=Scoretemp
280    DISP Ranknumb,Scoretemp
290    Scoretemp=0
300    NEXT Ranknumb
310 !  FCREATE "Scores:F",200
320    FPRINT "Scores:F",Score(*)
330    ! *************************
340    FOR Cycle=1 TO 7
350    MAT Yplot=ZER
360    FOR Position=1 TO 7
370    Scoretemp=-200
380    FOR Ranknumb=1 TO 5040
390    IF POS(Rank$(Ranknumb),VAL$(Cycle))<>Position THEN Nextranknumb
400    IF Scoretemp>Score(Ranknumb) THEN Nextranknumb
410    Scoretemp=Score(Ranknumb)
420 IF Bestscore>Score(Ranknumb) THEN 470
430 IF Bestscore=Score(Ranknumb) THEN Counter=Counter+1
```

```
440   IF Bestscore<Score(Ranknumb) THEN Counter=0
450   Bestscore=Score(Ranknumb)
460   Bestrank=Ranknumb
470 Nextranknumb:  NEXT Ranknumb
480   Yplot(Position)=Scoretemp
490   NEXT Position
500   GOSUB Plot
510   NEXT Cycle
520   GOSUB Date
521   IF Wtype$="I" THEN Type$="INTERNATIONAL"
525   IF Wtype$="D" THEN Type$="DOMESTIC"
530   PRINT PAGE,Month;"/";Day,LIN(1),"RANKINGS ACHIEVING BEST SCORES",LIN(1),Ty
pe$;" WEIGHTING",
531   IF Sprd<>0 THEN PRINT "WEIGHTING SPREAD IS ";Sprda,
532   PRINT LIN(2)
540   FOR Ranknumb=1 TO 5040
550   IF Score(Ranknumb)>=.9*Bestscore THEN GOSUB Printout
560   NEXT Ranknumb
570   EXIT GRAPHICS
580   PRINTER IS 16
590   PRINT PAGE,"FINISHED"
600   DISP "FINISHED"
610   STOP
620   ! ************** SUBS ****************
630 Cat1:  IF Wtype$="D" THEN Factor=1.5+Sprd
635   IF Wtype$="I" THEN Factor=1+Sprd
640   GOTO 690
650   IF (Cycle=6) AND (Cycle2=7) THEN Equiv=1
660   IF (Cycle=7) AND (Cycle2=6) THEN Equiv=1
670   IF (Cycle=2) AND (Cycle2=5) THEN Equiv=1
680   IF (Cycle=5) AND (Cycle2=2) THEN Equiv=1
690   RETURN
700 Cat2:  IF Wtype$="D" THEN Factor=1.5+Sprd
705   IF Wtype$="I" THEN Factor=2.5+Sprd
710  ! GOTO 760
750   IF ((Cycle=5) OR (Cycle=6)) AND ((Cycle2=5) OR (Cycle2=6)) THEN Equiv=1
760   RETURN
770 Cat3:     IF Wtype$="D" THEN Factor=5+Sprd
775      IF Wtype$="I" THEN Factor=2.5+Sprd
780 ! IF ((Cycle=4) OR (Cycle=6)) AND ((Cycle2=4) OR (Cycle2=6)) THEN Equiv=1
790 ! IF ((Cycle=2) OR (Cycle=5)) AND ((Cycle2=2) OR (Cycle2=5)) THEN Equiv=1
800   RETURN
810 Cat4:  IF Wtype$="D" THEN Factor=4+Sprd
815   IF Wtype$="I" THEN Factor=5+Sprd
820   GOTO 860
830   IF ((Cycle=4) OR (Cycle=6)) AND ((Cycle2=6) OR (Cycle2=4)) THEN Equiv=1
840   IF ((Cycle=2) OR (Cycle=3) OR (Cycle=5)) AND ((Cycle2=2) OR (Cycle2=3) OR
(Cycle2=5)) THEN Equiv=1
850   IF ((Cycle=1) OR (Cycle=7)) AND ((Cycle2=1) OR (Cycle2=7)) THEN Equiv=1
860   RETURN
```

```
870 Cat5:  IF Wtype$="D" THEN Factor=3+Sprd
875   IF Wtype$="I" THEN Factor=4+Sprd
880   GOTO 910
890   IF ((Cycle=2) OR (Cycle=3) OR (Cycle=6) OR (Cycle=7)) AND ((Cycle2=2) OR (
Cycle2=3) OR (Cycle2=6) OR (Cycle2=7)) THEN Equiv=1
900   IF ((Cycle=1) OR (Cycle=5)) AND ((Cycle2=1) OR (Cycle2=5)) THEN Equiv=1
910   RETURN
920 Plot:  !
930   PRINTER IS 16
940   PRINT Yplot(*)
950   Ymax=0
960   FOR I=1 TO 7
970   IF Ymax<Yplot(I) THEN Ymax=Yplot(I)
980   NEXT I
990   PRINTER IS 13,"GRAPHICS"
1000  GRAPHICS
1010  LOCATE 20,120,20,100
1020  SCALE 0,7,0,1
1030  AXES 1,.2
1040  MOVE 0,0
1050  FOR I=1 TO 7
1060  Y=Yplot(I)
1070  IF Y<0 THEN Y=0
1080  DRAW I-1,Y/Ymax
1090  DRAW I,Y/Ymax
1100  NEXT I
1110  LORG 5
1120  FOR I=0 TO 6
1130  MOVE I+.5,-.1
1140  LABEL USING "D";I+1
1150  NEXT I
1160  MOVE 3.5,-.2
1170  LABEL USING "K";"POSITION"
1180  LDIR PI/2
1190  MOVE -.3,.5
1200  LABEL USING "K";"RELATIVE SCORE"
1210  LDIR 0
1220  MOVE 5.5,.8
1230  ON Cycle GOSUB One,Two,Three,Four,Five,Six,Seven
1240  LABEL USING "K";"FUEL CYCLE "&A$
1250  PRINTER IS 0
1260  PRINT PAGE,LIN(5)
1270  DUMP GRAPHICS
1280  RETURN
1290 One: !
1300  A$="1.3"
1310  RETURN
1320 Two: !
1330  A$="2.3"
1340  RETURN
```

```
1350 Three: !
1360  A$="2.4"
1370  RETURN
1380 Four: !
1390  A$="4.1"
1400  RETURN
1410 Five: !
1420  A$="4.2"
1430  RETURN
1440 Six: !
1450  A$="6.1"
1460  RETURN
1470 Seven: !
1480  A$="6.3"
1490  RETURN
1500 Printout: !
1510  Printnumb=Printnumb+1
1520  PRINTER IS 0
1530  PRINT PROUND(Score(Ranknumb),-1);
1531  IF Score(Ranknumb)=Bestscore THEN PRINT " (BEST SCORE)",
1532  PRINT LIN(1)
1540  FOR I=1 TO 7
1550  ON VAL(Rank$(Ranknumb)[I,I]) GOSUB One,Two,Three,Four,Five,Six,Seven
1560  PRINT A$
1570  NEXT I
1580  PRINT "--------------------------------------",LIN(2)
1590  IF INT(Printnumb/5)=Printnumb/5 THEN PRINT PAGE
1600  RETURN
1610 Date: !
1620 OUTPUT 9;"R"
1630  ENTER 9;Month,Day
1640  RETURN
```

```
       80 / 2 / 12                    7Fact_

10     OPTION BASE 1
20     DIM Rank$(5040)[7]
21     Rankingnumb=1
30     FOR I=1 TO 7
40     FOR J=1 TO 7
41     IF I=J THEN Nextj
50     FOR K=1 TO 7
51     IF (I=K) OR (J=K) THEN Nextk
60     FOR L=1 TO 7
61     IF (I=L) OR (J=L) OR (K=L) THEN Nextl
70     FOR M=1 TO 7
71     IF (I=M) OR (J=M) OR (K=M) OR (L=M) THEN Nextm
80     FOR N=1 TO 7
81     IF (I=N) OR (J=N) OR (K=N) OR (L=N) OR (M=N) THEN Nextn
90     FOR P=1 TO 7
100    IF (I=P) OR (J=P) OR (K=P) OR (L=P) OR (M=P) OR (N=P) THEN Nextp
110    Rank$(Rankingnumb)=VAL$(I)&VAL$(J)&VAL$(K)&VAL$(L)&VAL$(M)&VAL$(N)&VAL$(P)
120    Rankingnumb=Rankingnumb+1
130 Nextp.  NEXT P
140 Nextn:  NEXT N
150 Nextm:  NEXT M
160 Nextl:  NEXT L
170 Nextk:  NEXT K
180 Nextj:  NEXT J
190 Nexti:  NEXT I
200     PRINTER IS 0
210     FOR R=1 TO 5040 STEP 9
211     FOR I=0 TO 8
220     PRINT Rank$(R+I);" ";
221     NEXT I
222     PRINT LIN(1)
230     NEXT R
240     PRINTER IS 16
250     END
```

Chapter Five

TECHNICAL SAFEGUARDS ISSUES FOR ALTERNATIVE FUEL CYCLES

E.V. Weinstock and B. Keisch
NUREG/CR-1048, BNL NUREG-51182
January 1980

TABLE OF CONTENTS

		Page
I.	Introduction	345
II.	Description of Alternative Fuel Cycles	355
III.	Generic Safeguards Issues	378
IV.	Analysis of Individual Fuel Cycles	423
V.	Summary and Conclusions	434

ABSTRACT

Twenty-one alternative fuel cycles proposed under the Non-Proliferation Alternative Systems Assessment Program (NASAP) of the Department of Energy have been reviewed, on behalf of the Nuclear Regulatory Commission, for technical safeguards issues and problems that might affect regulation and licensing. The approach adopted was to identify generic features, common to two or more fuel cycles, and assess these independently of the fuel cycles in which they are involved. Then the individual fuel cycles were reviewed in order to identify additional unique features — i.e., those associated with a single fuel cycle, only.

The generic issues identified were the use, storage, and transportation of strategic special nuclear material (SSNM), the use of radiation barriers as a protective measure for SSNM, co-processing, the use of U^{233}/Th fuels, denaturing, the use of heavy water as a moderator, the storage of spent fuel and waste, and international fuel service centers.

Four variations of spiking were assessed with respect to their effect on accountability and verification, availability of suitable spikants, effect on health, safety, and economics, appropriateness of proposed radiation dose

rate criteria, effectiveness as a safeguards measure, and so on. These variations of spiking have the advantage of protecting the SSNM during all or some parts of the fuel cycle, but complicate it and also increase costs. Requiring radiation barriers to protect SSNM would also conflict with the "ALARA" philosophy. However, the disadvantages of spiking and its variations has to be balanced against the chief advantage of a considerable increase in the protection of strategic special nuclear material.

Coprocessing of plutonium-uranium appears feasible, but could probably not be adopted in existing reprocessing plants, meaning a delay of at least ten to fifteen years before its commercial introduction.

The use of U^{233}*/Th fuels would have a strong effect on accountability methods. There is little experience with high burnup, high* U^{232} *fuels, nor with mixtures of uranium, plutonium, and thorium. The performance of isotope dilution mass spectrometry as an accountability tool in plants reprocessing spent fuels containing both* U^{233} *and* U^{235} *would be degraded.*

The breeding of plutonium in denatured fuels poses additional safeguards problems. To counteract the tendency of reactors using repeated recycle of denatured fuels to "drift" towards increased plutonium and decreased U^{233} *production, it may be necessary to provide some highly enriched* U^{233} *or* U^{235} *makeup fuel. Restrictions on the use of denatured* U^{233} *fuels in dispersed reactors should be essentially no greater than for LEU(*U^{235}*) fuels.*

The use of heavy water in HWRs raises the question of accountability for heavy water. There are additional development needs for this purpose.

Long-term storage of spent fuel and waste is under NRC regulatory authority. The most significant safeguards problem would derive primarily from international rather than domestic safeguards considerations, since neither spent fuel nor high level waste is attractive to terrorists but the former, at least, is subject to IAEA safeguards.

International fuel service centers raise, primarily, institutional issues. The exact nature and composition of such centers would have an important bearing on their effectiveness.

The appearance of large quantities of weapons-usable material in all the fuel cycles except the once-through LWR, HWR, and HTGR using low enriched uranium would necessarily raise all the safeguards issues identified in the safeguards supplement to GESMO with respect to use, storage, and transport of SSNM. Some of the techniques discussed may reduce some problems, but not eliminate them.

A few of the fuel cycles involve problems not arising in the others. Two of the three prebreeders for the LWBR fuel cycle use selective dissolution to separate residual U^{235} *from bred* U^{233}*. Contamination of the* U^{235} *by* U^{232} *may prevent this. The larger number and small size of the fuel elements for HWRs, together with on-line refuelling procedure, make accountability for* *spent fuel difficult. Spent fuel from once-through HTGRs may require some processing to separate the fuel particles from the graphite matrix and thus the identity and discrete nature of the fuel element would be lost and item counting for accountability would no longer suffice. In LMFBRs, spent fuel is stored under sodium, making it difficult to verify inventories.*

The following general conclusions are drawn:

(1) only the once-through systems are free of the safeguards problems associated with strategic special nuclear material;

(2) all other fuel cycles involve the use of SSNM somewhere in the fuel cycle;

(3) international fuel service centers not containing reactors eliminate routine shipments of bulk SSNM for all fuel cycles except for a few, but do not eliminate shipments of SSNM in fresh fuel assemblies;

(4) power-generating international fuel service centers in which all reactors burning SSNM are co-located eliminate all routine shipments of SSNM in any form with a few exceptions;

(5) international fuel service centers are not necessarily more secure than dispersed facilities against on-site subnational diversion or sabotage;

(6) spiking or its variations, alone or in combination, could substantially decrease the vulnerability of all fuel cycles to diversion, but would not eliminate the need for material accountability or for physical protection against sabotage;

(7) with or without spiking and/or international fuel service centers, the residual vulnerabilities of all fuel cycles, except denatured ones, involving the breeding and recycling of SSNM, are similar and would require similar protection measures;

(8) because of the long lead time for the introduction of any of the proposed fuel cycles there is adequate time to resolve the safeguards technical problems.

I. INTRODUCTION

In April, 1978, NRC asked the Technical Support Organization (TSO) of Brookhaven National Laboratory to perform "a preliminary analysis and assessment of the safeguardability of the various alternative fuel cycles being studied by the Department of Energy." As part of this project, a series of reports have been prepared.[1-6] This section is an outgrowth of a preliminary report submitted to NRC.[7]

This section identifies and, to the extent possible within the limited time and resources allotted to the project, assesses technical safeguards issues associated with the proposed alternative fuel cycles, so that their impact on safeguards regulation can be judged. The fuel cycles considered are a slightly expanded version of the set submitted by DOE to NRC in attachments to letters from E.J. Hanrahan of DOE to N. Haller of NRC, dated August 7, September 1, 1978, and February 13, 1979. The complete set is shown in Table 1.-1 and is described in more detail in part 2 of this report. Although other fuel cycles were considered under the Non-Proliferation Alternative System Assessment Program, they are not included in this project.

A chart of the fuel cycles showing, in shorthand style, their principal distinguishing characteristics is presented in Table 1.-2. This may be used by those wishing to avoid the rather detailed descriptions in part 2, and as a handy quick reference for the discussions in parts 3 and 4.

As may be seen, the number of fuel cycles, including minor variations, comes to twenty-one. This is a very large number either to comprehend or to analyze in any detail. The scheme adopted, therefore, is to identify certain safeguards features common to two or more fuel cycles and identify and discuss the issues associated with these, independently of the specific fuel cycles. This is done in part 3. Then, in part 4, both the particular generic issues and the specific issues uniquely associated with each fuel cycle are identified and the latter are further discussed. In this way repetition is reduced to a minimum, although not eliminated altogether.

In part 4, frequent reference is made to the safeguards supplement to GESMO.[8] ("Generic Environmental Statement on the Use of Recycle Plutonium in Mixed-Oxide Fuel in Light Water Cooled Reactors.") This is done to avoid having to repeat the complete analysis of safeguards issues, problems, and proposed solutions appearing in that report in connection with the recycle of plutonium in light water reactors. Obviously, this would be beyond the resources allocated for this study. Moreover, since the same principal safeguards issues (except for the dispersal hazards of plutonium) are raised by the appearance in any fuel cycle of substantial quantities of strategic special nuclear material (SSNM), essentially the same "solutions" (i.e., safeguards measures) as those considered in GESMO would be applicable in these cases.

Table 1.-1.

NASAP Reactor/Fuel Cycle Systems for NRC Review

1.0 Light Water Reactors[a]

1.1 PWR-OT: standard PWR using 3% low-enriched uranium oxide fuel achieving 30 MWD/kg burnup; once-through fuel cycle with spent fuel sent to long-term storage.[b]

1.2 PWR Mod-OT: PWR using 3% low-enriched uranium oxide fuel modified to achieve 50,000 MWD/MT average burnup, and other means to decrease uranium requirements; spent fuel is sent to long-term storage.

1.3 PWR-U/Pu spiked recycle: PWR using 3% low-enriched uranium oxide fuel and self-generated recycle fuel of co-processed uranium and plutonium oxide; the recycle fuel is spiked or pre-irradiated.[c]

1.4 LWR-Denatured U^{233}/Th: PWR using 12% U^{233}/thorium oxide fuel; the spent fuel is reprocessed to recover the U^{233}/U^{238} mixture which is recycled after blending with additional U^{233} to 12%; Pu is sold for spiked recycle.

2.0 Light Water Breeder Reactors[a]

2.1 Prebreeder, Shippingport Type I: PWR using 20% enriched UO_2-ZrO_2 CaO/ThO_2 fuel; the spent fuel is reprocessed to recover U^{233} which is stored for use in LWBR; Pu is stored.

2.2 Breeder, Shippingport Type I: same as 2.1 except it uses U^{233}/thorium oxide fuel which is reprocessed to recover U^{233} for recycle as spiked fuel.[c]

2.3 Backfit Prebreeder: standard PWR using 15% enriched uranium oxide/thorium oxide fuel; the spent fuel is reprocessed to recover U^{233} which is stored for use in LWBR; Pu is stored.

2.4 Advanced Breeder: standard PWR except modified for tight lattice, hexagonal fuel bundle and thoria control rods; using U^{233}/thorium oxide fuel which is reprocessed to recover U^{233} for recycle as spiked fuel.[c]

2.5 HEU Backfit Prebreeder: standard PWR using 93% enriched uranium oxide/thorium-oxide fuel; PWR-type fuel bundles with poison control rods; non-fissioned U^{235} and bred U^{233} recovered and accumulated for startup of LWBR.

2.6 Breeder, seed-blanket type: seed consists of UO_2-ThO_2 pellets, blanket of ThO_2 pellets; initially fueled with HEU (mixture of non-fissioned U^{235} and bred U^{233}) recovered from HEU Backfit Breeder, eventually self-sustained by bred U^{233}; ThO_2 and poison control rods.

3.0 Heavy Water Reactors[a]

3.1 HWR Denatured U^{235}/OT: CANDU-type HWR using 1.2% slightly enriched uranium oxide fuel; plant designed for 1300 MWe, 2200 psi reactor coolant.

4.0 High Temperature Gas-Cooled Reactors[a]

4.1 HTGR Denatured U^{235}/OT: 20% enriched uranium-thorium oxycarbide particle fuel; the spent fuel is sent to long-term storage.

4.2 HTGR Denatured U^{233}/Th: 12% enriched U^{233}/thorium oxycarbide particle makeup fuel; spent fuel is reprocessed to recover the U^{233} and recycle it after denaturing to 12%; Pu is stored.

5.0 Gas-Cooled Fast Breeder Reactors[a]

5.1 GCFR U/Pu/Th spiked recycle: uranium-plutonium oxide homogeneous core and thorium oxide blanket; core and blanket reprocessed; core is co-processed U and Pu subsequently pre-irradiated;[c] the U^{233} is recovered and sold as denatured fuel.

6.0 Liquid Metal Fast Breeder Reactors[a]
- 6.1 LMFBR U/Pu/U recycle: standard U/Pu oxide homogeneous core, uranium oxide blanket; core and blanket reprocessed separately; core is coprocessed U and Pu; blanket is co-processed U and Pu with excess Pu used for LWRs and LMFBRs.
- 6.2 LMFBR U/Pu/U, spiked recycle: same as 6.1 except co-processed U/Pu is pre-irradiated.[c]
  - 6.2.1 Heterogeneous core design
  - 6.2.2 Homogeneous core design
- 6.3 LMFBR U/Pu/Th spiked recycle: uranium-plutonium oxide core and thorium oxide blanket; same as 6.2 except U^{233} is recovered from blanket fuel and sold as denatured fuel; Pu makeup from LWRs.
  - 6.3.1 Heterogeneous core design
  - 6.3.2 Homogeneous core design
- 6.4 LMFBR Th-Pu/Th, spiked recycle: thorium-plutonium oxide homogeneous core and thorium oxide blanket; core and blanket reprocessed separately; recovered Pu is recycled to LMFBR core; Pu is co-processed with thorium and pre-irradiated;[c] the U^{233} is recovered and sold as denatured fuel.
- 6.5 LMFBR Denatured U^{233}/Th/Th: denatured U^{233} mixed with thorium oxide fuel in homogeneous core and thorium oxide in blanket; core and blanket reprocessed separately; recovered U^{233} is denatured and sold; recovered plutonium is mixed with uranium and pre-irradiated and sold.

---

[a] Enrichment, reprocessing, Pu conversion, Pu fabrication, Pu storage and U^{233} fabrication in secure locations.

[b] For reference only.

[c] To a radiation level of 1000 r/hr at 1 meter from a fuel bundle when loaded into the reactor 6 months after fuel fabrication.

Table 1.-2.

Summary of Fuel Cycle Characteristics

CLASS	LWR	LWR	LWR	LWR	HWR	HTGR	HTGR
Type Designation	U^{235} Once Through	U^{235} High Burn-up, Once Through	U^{235}/Pu Spiked Recycle	U^{233}/Th Recycle	Once Through	Once Through	Denatured U^{233}/Th Recycle
Fuel	3% U^{235} in U	4.3% U^{235} in U	a) 3.2% U^{235} b) 2.8% Pu in U	11% U^{233} in U + Th	1.2% U^{235} + Th	20% U^{235} in U	12% U^{233}
Blanket	—	—	—	—	—	—	Th (fertile particle)
Spent Fuel & Disposition	~0.8% U^{235} ~1% Pu, Stored	~0.8% U^{235} ~1% Pu, Stored	a) all Pu to recycle, 1% U to storage b) all U/Pu (coprocessed) spiked with Co^{60} to recycle	7% U^{233}, 1% U^{235} in U (29% U), 0.4% Pu, Pu spiked with Co^{60} and stored, U^{233} to recycle, Th stored	0.1% U^{235} + 0.6% Pu	3% U^{233} + 2% U^{235} in U+Th+ 1.3% Pu	3% U^{233} + .3% U^{235} + 1.2% Pu, store Pu, store U
Blanket-Product & Disposition	—	—	—	—	—	—	88% U^{233} in U + Th, store Th, denature & recycle U
Chemical Processing	None	None	Purex & modified purex (coprocessing)	Thorex	None	None	Purex (fissile particle), Thorex (fertile particle)
Storage (SNM)	Spent fuel elements ~1% Pu & ~0.8% U^{235}	Spent fuel elements ~1% Pu & ~0.8% U^{235}	1% U^{235}	Pu (Co^{60} spike)	Spent fuel ~0.1% U^{235} ~0.8% Pu	Spent fuel 3% U^{233} + 2% U^{235} + Th + 1.3% Pu	Pu, 3% U^{233}

SNM Make Up Required	3% U^{235} in U (fresh fuel)	4.3% U^{235} in U (fresh fuel)	3.2% U^{235} in U	50% Fissile U^{233} in U	1.2% U^{235} (fresh fuel)	20% U^{235} (fresh fuel)	10% U^{233}
Radiation Barriers ("Spiking, etc.)	None	None	Co^{60} in recycled Pu	Co^{60} in stored Pu, U^{232} in recycled U^{233}	None	None	U^{232} in stored & recycled U^{233}

Note: The meaning of enrichment percentages given in the Table are, in most cases, clear. However, in a few cases, they may be ambiguous. Generally, uranium enrichments are given in terms of % of the stated isotope in terms of uranium only. Plutonium "enrichment" is given as a percentage of the total heavy metal. Plutonium content is given as total plutonium unless specifically indicated as "fissile" plutonium.

Table 1.-2. (Cont'd)

Summary of Fuel Cycle Characteristics

CLASS	GCFR	LWBR	LWBR	LWBR	LWBR	LWBR	LWBR
Type-Designation	U/Pu/Th Spiked Recycle	Type I Pre-breeder	Type I Breeder	Backfit Pre-breeder	Backfit Advanced Breeder	High Enrichment Backfit Prebreeder	Seed-Blanket Breeder
Fuel	14% fissile Pu in U (preirrad.)	20% U^{235}	82% U^{233} + 4% U^{235} in U	16% U^{235}	75% U^{233} in U + Th	93% U^{235} + 9% U^{233} + Th	54% U^{233} + 9% U^{235} + Th
Blanket	Th	Th (separable pellets)	–	Th (separable pellets)	–	–	–
Spent Fuel & Disposition	13% fissile Pu in U, coprocessed & recycled	14% U^{235} & 1% Pu, Recycle U, store Pu	81% U^{233} (same as fresh fuel) + Th, Recycle U & Th + add fresh Th	7% U^{235} + 1.4% Pu, store Pu, recycle U	75% U^{233}, Recycle U & Th + add fresh Th	40% U^{233}, 34% U^{235}, store U & store Th	54% U^{233}, 8% U^{235} + Th, recycle U + Th, add Th
Blanket-Product & Disposition	U^{233} + Th, U^{233} denatured & stored, Th stored	93% U^{233} in U + Th, Th to storage, store U^{233}	–	90% U^{233} in U + Th, store U^{233}, store Th	–	–	–
Chemical Processing	Purex-core Thorex-blanket	Purex-core Thorex-blanket	Thorex	Purex-fuel Thorex-blanket	Thorex	Thorex	Thorex
Storage (SNM)	12% U^{233}	Pu & U^{233}	–	90% U^{233} (with U^{232} spike)	–	74% fissile U^{233} (with U^{232} spike)	–

SNM Make Up Required	20% fissile Pu in U	Re-enrichment of residual U^{235} fuel	—	Re-enrichment of residual U^{235} fuel	—	93% U^{235} (fresh fuel)	67% U^{235}
Radiation Barriers ("Spiking, etc.)	U^{232} in stored U^{233} & preirradiate recycled fuel	U^{232} in stored & recycle U^{233}	U^{232} in recycled U^{233}	U^{232} in stored U^{233}	U^{232} in recycled U^{233}	U^{232} in stored U^{233}	U^{232} in recycled U^{233}

Note: The meaning of enrichment percentages given in the Table are, in most cases, clear. However, in a few cases, they may be ambiguous. Generally, uranium enrichments are given in terms of % of the stated isotope in terms of uranium only. Plutonium "enrichment" is given as a percentage of the total heavy metal. Plutonium content is given as total plutonium unless specifically indicated as "fissile" plutonium.

Table 1-2. (Cont'd)

Summary of Fuel Cycle Characteristics

CLASS	LMFBR	LMFBR	LMFBR	LMFBR	LMFBR	LMFBR	LMFBR
Type-Designation	U/Pu/U (Homogeneous)	U/Pu/U (Spiked Heterogeneous)	U/Pu/Th (Spiked Homogeneous)	U/Pu/Th (Spiked Heterogeneous)	U/Pu/Th (Spiked Homogeneous)	Th/Pu/Th (Spiked Homogeneous)	Denatured U^{233}/Th (Homogeneous)
Fuel	12% fissile Pu in U	15% fissile Pu in U	12% fissile Pu in U	16% fissile Pu in U	12% fissile Pu in U	14% fissile Pu in Th	10% U^{233} in U
Blanket	U	U	U	Axial-U, inner radial-Th	Th	Th	Th
Spent Fuel & Disposition	12% fissile Pu in U, coprocess U + Pu, recycle with some blanket material	14% fissile Pu in U, coprocess, U + Pu, recycle with some from blanket	12% fissile Pu in U, coprocess, recycle U/Pu with addition from blanket	15% fissile Pu combined with axial blanket (1% Pu), partially coproc. U/Pu recycled to fuel, U as diluent for U^{233} from blanket	12% fissile Pu in U, coprocessed, recycled	U^{233} (4%) + 9% fissile Pu (14% total Pu) in Th, coprocess Pu/Th recycle, combine U^{233} with blanket, store excess Th	6% U^{233} in U + 4% Pu, dilute Pu with depleted U store, recycle U^{233} (with U^{232} spike)
Blanket-Product & Disposition	2% Pu in U, part coprocess. Pu & U & part recycle to feed, recycle U to blanket, add depleted U	2% Pu in U, part coprocess, part recycle U/Pu, preirrad. & store remainder, recycle U to blanket, add depleted U	2% Pu in U, part coprocess, part recycle U/Pu, part pre-irrad. U/Pu & store, recycle separated U	U^{233} (with U^{232} as spike) diluted with U from core & stored. Store Th	2% U^{233} in Th, denature separated U^{233} & store (with U^{232} spike). Store Th	2% U^{233} in Th, combine U^{233} with that from core, denature & store (with U^{232} spike). Store Th	2% U^{233} in Th, recycle (with U^{232} spike), store Th

Chemical Processing	Purex	Purex	Purex	Purex (core & axial blanket) Thorex inner & radial	Purex (core) Thorex (blanket) blankets)	Thorex	Purex (core) Thorex (blanket)
Storage (SNM)	17% fissile Pu in U	Pre-irradiated 20% Pu	Pre-irradiated 20% Pu	Denatured 12% U^{233} (with U^{232} spike)	Denatured 12% U^{233} (with U^{232} spike)	Denatured 12% U^{233} (with U^{232} spike)	18% fissile Pu in U
SNM Make Up Required	—	—	—	20% fissile Pu in U	20% fissile Pu in U	20% fissile Pu in Th	25% U^{233} in U
Radiation Barriers ("Spiking, etc.)	None	Pre-irradiate stored Pu & fuel	Pre-irradiate stored Pu & fuel	U^{232} in stored U^{233}, pre-irradiate fuel	U^{232} in stored U^{233}, pre-irradiate fuel	U^{232} in stored U^{233} & Th^{228} daughters in fuel	U^{232} in recycled fuel

Note: The meaning of enrichment percentages given in the Table are, in most cases, clear. However, in a few cases, they may be ambiguous. Generally, uranium enrichments are given in terms of % of the stated isotope in terms of uranium only. Plutonium "enrichment" is given as a percentage of the total heavy metal. Plutonium content is given as total plutonium unless specifically indicated as "fissile" plutonium.

One generic issue raised by the NASAP fuel cycles, namely radioactive spiking and its variations, has been considered in greater detail here than in GESMO (although considerable use is made of a BNL study of this subject performed in support of GESMO — see part 3). This is because many of the NASAP fuel cycles depend very heavily on this device to counter the objections raised to the widespread commercial use of SSNM. Also, detailed consideration of this subject was specifically requested in the appendix to the Preliminary Safety and Environmental Information Documents[9] (PSEIDs), of which seven have appeared at the present writing (see the list of references at the end of part 2 for the individual titles). Occasionally, these are supplemented by reference to other documents. The information in the PSEIDs is not always complete or consistent; one important example is that the methods of providing radiation barriers for the protection of SSNM, as proposed in the descriptions of the individual fuel cycles, are not always the same as those proposed in an appendix devoted to this subject and attached to all PSEIDs, nor is it demonstrated in some of the fuel-cycle descriptions that the radiation dose rates achieved by the methods proposed there meet the criteria of the appendix. These discrepancies and omissions are noted in the detailed discussions of parts 3 and 4.

Another difficulty with the material supplied is that, for the most part, it treats the fuel cycles as though they were mature, isolated entities. In actuality, of course, there will be a long transition period before any fuel cycle reaches equilibrium and, in fact, due to technical improvements, new developments, changing economic conditions, and so on, it may be doubted whether any fuel cycle will ever reach equilibrium. During this prolonged transitional phase there will be symbiotic links between different fuel cycles, the plutonium from one, for example, being used to produce U^{233} for another. It is our understanding that an eighth volume in the series of PSEIDs was to contain scenarios for the evolution of the various fuel cycles, but it was not received in time for inclusion in this report.

The present report is also limited to an analysis of the domestic safeguards issues, only, arising in the various fuel cycles. Questions related to proliferation resistance (e.g., the relative difficulty of further enriching U^{233}- and U^{235}-bearing fuels) were not considered.

REFERENCES

1. O'Brien, "Institutional Problems Associated with a Domestically Sited Multinational Fuel Cycle Facility," reprinted in Chapter One.
2. Cadwell, "The Possible Legal Consequences of Protective Radioactive Spiking of Nuclear Fuel," reprinted in Chapter Three.
3. O'Brien, "Impacts of Alternative Nuclear Fuel Cycles as the US/IAEA Safeguards Agreement," reprinted in Chapter One.
4. O'Brien, "Export Licensing Problems Associated with Alternative Nuclear Fuel Cycles," reprinted in Chapter Two.

5. Cadwell, "A Suggested Ranking for Selected Alternative Fuel Cycles," reprinted in Chapter Four.
6. Cadwell, "Safeguards Licensing Problems Which Could Restrain Implementation of NASAP Fuel Cycles," reprinted in Chapter Two.
7. John N. O'Brien and E.V. Weinstock, "Safeguards for Alternative Fuel Cycles," informal BNL report, October 26, 1978.
8. NUREG-0414, "Safeguarding a Domestic Mixed Oxide Industry Against a Hypothetical Subnational Threat," U.S. Nuclear Regulatory Commission, May 1978.
9. "Preliminary Safety and Environmental Information Document," Department of Energy, NASAP 78-12, April 1979, Vol. 1-7.

II. DESCRIPTION OF ALTERNATIVE FUEL CYCLES

NASAP has issued descriptions of the fuel cycles it is submitting to NRC for assessment. These are contained in the Preliminary Safety and Environmental Information Documents (PSEIDs), of which seven[1-7] have been issued as of the present writing. The first six of these describe primarily the reactors in the fuel cycles, and the seventh the other elements of the fuel cycles (fabrication plants, reprocessing plants, waste disposal, etc.). In these volumes the fuel cycles are treated as they would exist in isolation from each other, in equilibrium. Since in actuality they would evolve from existing cycles, and since more than one new fuel cycle might evolve (just as now there are both light and heavy water reactors), it is likely that, for many years to come, portions of old and new fuel cycles will exist simultaneously and, possibly, in symbiosis with each other. To the extent possible, and where it affects safeguards, this will be noted in the safeguards part of this section. An eighth volume in the PSEID series is in preparation[8] but was not received in time for inclusion in this analysis.

Brief descriptions of the reactor cycles (more detailed for the less familiar LWBR cycles) and the various fuel cycle facilities, emphasizing the various fuel types, follow. These are based on the descriptions in the PSEIDs, supplemented where necessary by information from other sources.[9,10] For details the reader is referred to these documents.

2.1. Reactor Cycles

2.1.1. Light Water Reactors. Four different designs for light-water reactors (actually, PWRs only) are considered under NASAP.

2.1.1.1. "Standard" Once-through PWR using LEU (U^{235}) Fuel. This design is essentially what is used today in PWRs. It is used as a reference to which the other designs are compared. Burnup is 30,000MWD/Te.

2.1.1.2. Once-through PWR using LEU (U^{235}) Fuel with Extended Burnup. This design is similar to the previous one except that the burnup of the fuel is increased to ~50,000 MWD/Te and only one-fifth of the core is replaced at each annual refuelling. The higher burnup is compensated for by a somewhat higher fuel enrichment (~4%, compared with ~3% in the reference design).

2.1.1.3. PWR using LEU (U^{235}) Fuel and Spiked, Self-Generated U/Pu Recycle Fuel. This is essentially the type of reactor considered in the Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light-Water-Cooled Reactors (GESMO),[9] except that the recycled plutonium is co-processed with uranium and spiked with Co^{60} to provide a radiation barrier against theft or seizure. Makeup fissile requirements are provided by fresh LEU fuel.

2.1.1.4. PWR using Denatured U^{233}/Th Fuel, with Recycle of U^{233}. The fresh fuel consists of mixed uranium-thorium oxides, the uranium being enriched to 12% in U^{233}. Uranium recovered from the spent fuel is supplemented by highly enriched U^{233} from an external source (not specified), mixed with fresh thorium, and recycled. Recovered thorium is stored for at least 10 years after reprocessing. Recovered plutonium is spiked and stored in a "secure" center. The source of the initial U^{233} for the reactor is also not specified. At equilibrium the U^{233} concentration in the uranium is about 1300 ppm.

Selected characteristics of these four designs are shown in Table 2.1-1, prepared from data in the PSEID.[1]

2.1.2. Light-Water Breeder Reactors.

2.1.2.1. Prebreeder and Breeder Reactors Based on Shippingport LWBR Type I Modules. In this concept, both the prebreeder and the breeder use fuel modules similar to those in the Shippingport LWBR reactor. Each module consists of a hexagonal annular blanket region filled by a moveable hexagonal seed region. Each of these regions is filled by an array of Zircaloy-clad fuel rods or pins, somewhat like those used in ordinary light-water reactors. Reactivity is controlled by moving the seed within the blanket, thus changing the neutron leakage and the proportion of neutrons absorbed in fertile material. Since neutron poisons are not used for control, the conversion ratio can be quite high.

In the pre-breeder, the uranium is "moderately" enriched ($< 20\%$ U^{233}) and is in the form of an annular pellet containing UO_2, ZrO_2, and CaO in a ternary solid solution. The interior of these pellets is filled with a cylindrical ThO_2 pellet. This arrangement is called a "duplex" pellet. Rods may contain additional ThO_2 pellets in the axial blanket regions at top and bottom. Seed and blanket regions contain similar types of pellets, but the average uranium fraction of the heavy metal in the blanket is less than that in the seed region.

The fuel pellets in the breeder are composed either of a binary solid solution of ThO_2 and UO_2, highly enriched in U^{233}, or of pure ThO_2. The

Table 2.1.-1.

Selected Characteristics of Alternative LWR Designs. In all cases, total reactor power is 3817 MW, net electric 1344 MW.

	Standard Once-Thru LEU PWR	High Burnup Once-Thru LEU PWR	PWR with Spiked U/Pu Recycle	Denatured U^{233}/Th PWR
Burnup, MWD/MTHM[a]	30,390	50,650	30,390	33,390
Core Composition	LEU oxide	LEU oxide	LEU/Pu mixed oxide	U^{233}-U^{238}/ Th mixed oxides
Core Fuel, Spiked or Denatured	No	No	Spiked	Denatured
Excess Fuel, Spiked or Denatured	None	None	None	Pu, Spiked (88 kg/yr)
Total Heavy Metal, BOEC,[b] kg	101,580	100,653	101,615	92,446
Initial U Enrichment[c]	2.2%(U^{235})	2.5%(U^{235})	2.2%(U^{235})	12%(U^{233})
Fissile Inventory, BOEC,[b] kg	2443	2994	3146	2793
Number of Fuel Assemblies	241	241	241	241
Total Heavy Metal/Assembly, kg	426	426	426	389
Total Weight/Assembly, kg	650	650	650	594
Amount of Pu/fresh assembly, kg	0	0	~20[d]	0
Refueling Interval, yrs.	1	1	1	1
Fraction of Core Replaced per Refueling	1/3	1/5	1/3	1/3
Radiation Dose Rate from Spent Fuel, r/hr[e]	20,000	77,000	Not Calc.	Not Calc.
Number of Rods per Assembly	236	236	236	236
Active Length of Rod, in.	150	150	150	150
Outer Diameter of Rod, in.	0.382	0.382	0.382	0.382

[a] Metric tons of heavy metal.

[b] Beginning of equilibrium cycle.

[c] Average over all assemblies.

[d] Pu-bearing assemblies only, typical value (may vary from ~15 to >20 according to indeterminate design factors, number of cycles occurred, etc.).

[e] At 90 days and 1 meter from assembly, in air.

initial U^{233} is produced in the prebreeder, but at equilibrium the breeder is expected to be self-sustaining.

The core in both the prebreeder and the breeder, in the reference design, would consist of an array of 109 seed-blanket modules of the type just described surrounded by 54 reflector-blanket modules of pure ThO_2 of various shapes. The pertinent characteristics of the reactors and the fuel are shown in Table 2.1-2, adapted from reference 3.

Present plans call for replacing the entire core of the pre-breeder every three years, in a single reloading. The breeder would be refueled on the more conventional schedule of 1/3 of the core each year. The fuel from the prebreeder would be reprocessed in such a way as to separate the thorium (and the bred U^{233}) from the uranium in the annular pellets. This is done by a selective dissolution. The burned uranium is then sent to a Purex reprocessing stage and the thorium and bred U^{233} to a Thorex stage, for recovery of the

Table 2.1.-2

Selected Characteristics of Pre-Breeder and Breeder Based on Shippingport LWBR Type I Modules.

	Pre-Breeder[a]	Breeder[a]
Reactor Thermal Output, MWt	2026	2026
Net Electric Power Output, MWe	721	711
Average Discharge Burnup,[a] MWD/MTHM[b]	11,200	10,100
Initial Core Loading, kg		
Heavy Metal[a]	148000	164000
Fissile Fuel	4388	3528
Fuel Type	Duplex Pellets: UO_2-ZrO_2-CaO annulus with ThO_2 core	Binary Mixture: UO_2-ThO_2
Core Height, cm[a]	213	213
Number of Modules[a]	109	109
Mass of Heavy Metal per Module, kg[a]	1360	1505
Initial Fissile Loading per Module, Fresh Fuel, kg	40.3(U^{235})	32.4(U^{233})
Equivalent Diameter, cm[a]	478	478
No. of Pins per Assembly[c]	619/444	325/444
Overall Assembly Length, cm	366	366
Cladding Outside Diameter, mils[c]	306/571.5	419/571.5
Cladding Wall Thickness, mils[c]	22/27.75	21/28
Cladding Material	Zircaloy-4	Zircaloy-4
Fissile Enrichment, Fresh Fuel, %[d]	20%(U^{235})	84%(U^{233}) 3%(U^{235})
Fissile Enrichment, Discharged Fuel, %[d]	14%(U^{235})	81%(U^{233}) 4%(U^{235})

[a] Excluding axial and radial reflectors.

[b] Metric tons of heavy metal charged.

[c] First number refers to seed, second to blanket rods.

[d] At equilibrium.

fissile material. After separation of the U^{233}, the thorium is stored for at least 10 years before recycling it, to allow the excess Th^{228} (from U^{232}) to decay. The recovered residual uranium from the Purex process, which still has a U^{235} enrichment of 14%, is sent to an enrichment plant for re-enrichment to 20% and eventual recycle. As discussed elsewhere, this may be prevented by U^{232} contamination; if so, it will be necessary to supply highly-enriched uranium (>20% U^{235}) for makeup, with obvious safeguards implications. The recovered U^{233} is stored until enough has accumulated to start up a breeder reactor (in about 10 years), and the plutonium, of which 96 kg is produced per year, is stored indefinitely.

2.1.2.2. Light-Water Backfit Prebreeder Supplying Advanced Breeder. This concept differs from the preceding one in several respects, detailed below.

The prebreeder is designed to be backfitted into present PWR vessels without extensive redesign of the plant. The fuel elements would resemble those in conventional PWRs, rather than the seed-blanket modules of the Shippingport type. The fuel itself would consist of thorium dioxide pellets alternating with duplex pellets with a thorium dioxide insert of the type discussed earlier, except that the annulus would be made of pure UO_2, enriched to 16% in the isotope U^{235}. Reactivity control would be by standard poison rods and borated water.

The "advanced" breeder for this concept would require a specially designed plant and would more closely resemble that based on the Shippingport design, in that the fuel modules would be hexagonal and the core would be surrounded by thorium oxide reflector-blanket assemblies. However, in place of movable seed modules, the advanced breeder would have thorium oxide control-rod "fingers" dispersed throughout the fuel bundles, in a manner similar to that of the poison rods in a conventional PWR. Additional control would be provided by poison rods and by boron in the water. The breeder would be fueled by uranium highly enriched in U^{233} (>82%), produced in the pre-breeder. One third of the core of both the prebreeder and the breeder would be replaced each year.

As in the previous concept, the residual uranium in the UO_2 pellets (initial U^{235} enrichment 15-16%, discharge enrichment ~7%) is separated from the bred uranium in the ThO_2 pellets by selective dissolution and sent to Purex processing. The recovered uranium is returned to an enrichment plant for re-enrichment and recycle and the plutonium (~90 kg/year) is stored. U^{233} is recovered by the Thorex process and stored until enough has been accumulated for the initial core of the breeder (~10 years). The U^{232} concentration in the bred uranium is expected to be ~2500-4500ppm.

Pertinent characteristics of this concept are shown in Table 2.1.-3, which should be compared with Table 2.1.-2. Note that the power of the reference design is different from that of the reactor described in Section 2.1.2.1.

2.1.2.3. Light-Water Backfit Prebreeder and Seed-Blanket Breeder System. The last of the light-water breeder reactor concepts proposed under NASAP differs from the previous two primarily, as far as safeguards is concerned, in that the prebreeder would use highly enriched U^{235} fuel and produce U^{233}, while the breeder, in the initial stages, would use a mixture of all the uranium isotopes (i.e., including non-fissioned U^{235} and bred U^{233}) recovered from the fuel discharged from the prebreeder. As

Table 2.1.-3.

Selected Characteristics of Light Water Backfit Prebreeder and Advanced Breeder

	Prebreeder	Breeder
Reactor Thermal Output, MWt	3800	2900
Net Electric Power Output, MWe	1295	1035
Average Discharge Burnup, MWD/MTHM[a,b]	34,800	10,100
Initial Core Loading, kg		
Heavy Metal[a]	89,800	235,000
Fissile Fuel	3,680	4,498
Fuel Type	ThO_2 pellets & duplex pellets with UO_2 annulus ThO_2 core	Binary solid solution, UO_2-ThO_2
Core Height, cm[a]	363	366[a]
Number of Assemblies or Modules	205	157[a]
Mass of Heavy Metal per Assembly or Module, kg[a]	438	1497
Initial Fissile Loading per Assembly or Module, kg	18	29
Equivalent Diameter of core, cm	353	427[a]
No. of Pins per Assembly[c]	264	288/99
Overall Assembly Length, cm	449	497[a]
Cladding Outside Diameter, mils[c]	379	571/530
Cladding Wall Thickness, mils[c]	23.5	28/35
Cladding Material	Zircaloy-4	Zircaloy-4
Fissile Enrichment, Fresh Fuel, %	15.7(U^{235})	4.6(U^{235}) 77(U^{233})
Fissile Enrichment, Discharged Fuel, %	6.8(U^{235}) 90 (U^{233})	5.4(U^{235}) 74 (U^{233})

[a] Excluding axial and radial reflectors.

[b] Megawatt-days per metric ton of heavy metal charged.

[c] First number refers to seed, second to blanket rods.

breeder operation continues and approaches a self-sustaining condition, the percentage of U^{233} relative to U^{235} would gradually increase.

The backfit prebreeder would be based on the Combustion Engineering Company System 80 reactor plant. The fuel assemblies would be similar in geometry to those of a standard PWR (i.e., a square array of rods with a number of guide holes for control rods.) The fuel would consist of pellets composed of a binary solid solution of UO_2 and ThO_2, the uranium enrichment being 93% U^{235}. Reactivity control would be provided by a combination of neutron-absorbing rods, boric acid solution, fixed burnable poisons, and volume control. One third of the core would be replaced each year.

The breeder core would be fueled with seed-blanket modules. The fuel in the seed rods would consist of UO_2-ThO_2 pellets, and that in the blanket rods of ThO2 pellets. Reactivity control would be via movable ThO_2 rods and poison rods dispersed throughout the seed regions, and boron dissolved in the water. The entire core would be replaced as a batch every 2.5 years, for reprocessing and recovery of the uranium. In the initial stages, at least, the recovered uranium would be supplemented by makeup highly enriched U^{233} (90.8% fissile) from storage. At equilibrium, makeup uranium would be 67% fissile.

Selected characteristics of the reactor are shown in Table 2.1.-4.

Table 2.1. 4.

Selected Characteristics of Light Water Backfit Prebreeder and Seed-Blanket Breeder System

	Prebreeder	Breeder
Reactor Thermal Output, MWt	3817	2993
Net Electric Power Output, MWe	1300	1000
Initial Core Loading, kg		
Heavy Metal[a]	93,507	171,504
Fissile Fuel	3088[b]	5622[c]
Average Seed Discharge Burnup, MWd/MTHM[d]	33,961	15,300
Fuel Type	Binary UO_2-ThO_2	Binary UO_2-ThO_2
Core Height, cm[e]	381	366
Number of Assemblies	241	169
Mass of Heavy Metal per Assembly, kg[a]	388	1015
Initial Fissile Loading per Assembly, kg	12.8	33.3
Equivalent Diameter of core, cm	373	405
No. of Pins per Assembly[f]	236	459
Overall Assembly Length, cm	450	513
Cladding Outside Diameter, mils	382	440
Cladding Wall Thickness, mils	25	27.5
Cladding Material	Zircaloy-4	Zircaloy-4
Fissile Enrichment, Fresh Fuel, %	93(U^{234}	8.6(U^{235}) 54 (U^{233})
Fissile Enrichment, Discharged Fuel, %	34(U^{235}) 40(U^{233})	8.4(U^{235} 54 (U^{233})

[a] Not including axial and radial reflectors.

[b] Fissile load for initial cycle of the pre-breeder.

[c] Fissile load for initial cycle of the breeder as supplied by the mixed-oxide pre-breeder.

[d] Megawatt-days per metric ton of heavy metal charged.

[e] Excluding axial reflectors.

[f] Average number of pins.

2.1.3. Heavy Water Reactors. A single alternative heavy water reactor design has been proposed under NASAP. It is based primarily on the standard Canadian CANDU 600 design, with modifications to increase the power and burnup. The standard design has a net electrical power output of 600 MW, uses natural uranium for fuel, and has an average fuel burnup of 7500 MWD/MTU; the NASAP design has a net electrical power of 1260 MW, uses 1.2%-enriched uranium, and has an average fuel burnup of 20,000 MWD/MTU. The higher-than-natural enrichment is needed to permit higher burnups. The reactor is both moderated and cooled by heavy water, but the coolant and moderator are separated so that the latter is at a relatively low temperature (200°F) and pressure. As in all CANDUs, the reactor is refuelled "on-line" — that is, during operation — by means of remotely operated refuelling machines. The fuel cycle mode is once-through.

Selected characteristics of the proposed design are shown in Table 2.1.-5.

Table 2.1.-5.

Selected Characteristics of High-Burnup HWR

Reactor Thermal Power, MW	4029
Net Electrical Power, MW	1260
Average Burnup, MWD/MTU	19,750
Fuel Cycle	Once-Through
Fuel Composition	UO_2
U^{235} Enrichment, %	1.2
Core Loading, kgU	166,056
Refueling Interval	Continuous
Fraction of Core Replaced/yr	1/3
Total No. of Fuel Bundles	8,880
Mass of Uranium/Bundle kg	18.7
Total Weight of Fuel Bundle, kg	23
Length of Fuel Bundle, in.	19.5
Outer Diameter of Rod, in.	0.515
No. of Rods per Bundle	37
Radiation Dose Rate/Fuel Bundle, r/hr*	303
D_2O Inventory	
Coolant, MT	402
Moderator, MT	395

*At 1 meter in air, after 90 days cooling.

2.1.4. High Temperature Gas-Cooled Reactors. Two HTGR designs have been considered under NASAP: a once-through design using 20% U^{235}-enriched fuel and thorium, and a recycle design using 12% U^{233}-enriched fuel and thorium. The reactors are graphite moderated and reflected and helium cooled. The fuel elements consist of hexagonal graphite prisms or blocks drilled with holes along their length to accommodate the fuel. The latter is in the form of graphite sticks containing coated fuel particles. These are of two types: fissile and fertile. The fissile particles have three coatings of pyrolytic graphite and one of silicon carbide surrounding a UO_2 kernel, while the fertile particles have only two coatings of pyrolytic graphite over a thorium carbide kernel (the former type is called a "TRISO"-coated and the latter a "BISO"-coated particle). Both designs are for a net reactor electrical power of 1332 MW.

2.1.4.1. Once-Through Medium Enriched HTGR. The once-through HTGR uses uranium enriched to 20% in U^{235} as fuel. One quarter of the core is replaced each year by fresh fuel. Spent fuel is ultimately shipped to permanent geological storage.

2.1.4.2. Recycle Medium-Enriched HTGR. This reactor differs from the previous one primarily in recycling the bred U^{233}. Since it is not a breeder it requires an external source of U^{233} for make-up fuel. The spent fuel is reprocessed to recover the bred U^{233}, which is then denatured to an enrichment of 12% by the addition of depleted uranium and, before refabrication, supplemented by 12% U^{233}-enriched uranium from the external source. The U^{232} content of the bred uranium is about 400 ppm; however, this number will depend on the source of the thorium, and may be substantially higher. Recovered thorium is stored for 10 years before reuse, fresh or decayed thorium being used for reloads. Plutonium, also recovered from the spent fuel, is stored.

Obviously, the reactor requires an external source of U^{233} not only for make-up but for the initial loadings (including at least a couple of initial reloads), unless it is intended to start up with MEU, HEU, or Pu fuel.

Selected characteristics for the two designs are shown in Table 2.1.-6.

2.1.5. Gas-Cooled Fast Breeder Reactor. The gas-cooled fast-breeder reactor design developed for NASAP uses a homogeneous plutonium-uranium mixed-oxide core and thorium oxide axial and radial blankets. U^{232} recovered from the blanket is denatured by the addition of depleted uranium and stored for use in other reactors. Plutonium and uranium from the core are coprocessed, mixed with makeup plutonium and uranium from "secure" storage, pre-irradiated after fabrication in assemblies, and recycled into the reactor. Recovered thorium is stored for 10 years before reuse, and new or decayed thorium is fabricated into fresh blanket elements.

Selected characteristics of the reactor are shown in Table 2.1.-7.

2.1.6. Liquid-Metal Fast Breeder Reactors. NASAP is proposing five major alternatives for the design of liquid-metal fast breeder reactors and their associated fuel cycles, plus two minor variations. These are summarized briefly below.

2.1.6.1. "Standard" LMFBR with Homogeneous U/Pu Core and U Blanket. The core is composed of depleted uranium oxide mixed

Table 2.1.-6.

Selected Characteristics of Alternative HTGR Designs

	Once-Through MEU HTGR	Recycle MEU HTGR
Net Electric Power, MWe	1332	1332
Fresh Fuel Enrichment	20%(U^{235})	12% (U^{233})
Average Discharge Burnup, MWD/MTHM	130,000	48,000
Initial Core Loading		
Heavy Metal, kg	40,760	56,340
Fissile Material, kg	1798	1798
Refueling Material, yrs.	1	1
Fraction of Core Replaced/yr	1/4	1/3
Number of Fuel Elements	~5000	~5000
Average Initial Fissile Loading per Element, kg	~0.3(U^{235})	~0.3(U^{233})
Total Mass of Fuel Element, kg	100	119
Height of Fuel Element, in.	31.2	31.2
Minimum Width, in.	14.2	14.2
Radiation Dose Rate from Spent Fuel Element, r/hr[*]	~5000	~5000

[*] At 1 meter, in air, 90 days after cooling.

Table 2.1.-7.

Selected Characteristics of Alternative Gas-Cooled Fast Breeder Reactor

Reactor Thermal Power, MW	3290
Net Electrical Power, MW	1200
Average Discharge Burnup, MWD/MTHM	81,000
Core Composition	$(Pu,U)O_2$
Blanket Composition	ThO_2
Core Loading	
Heavy Metal, kg	33,560
Fissile Fuel, kg	4,439
Refueling Interval, yrs.	1
Fraction of Core Replaced/yr.	1/3
Fraction of Blanket Replaced/yr.	1/4
Number of Core Assemblies	253
Mass of Pu/Fresh Assembly, kg	17.6
Number of Pins/Assembly	324
Outer Diameter of Pins, in.	0.315
Overall Assembly Length, in.	176

with plutonium oxide and has two enrichment zones (enrichment in this case being defined as total fissile/total heavy metal in region). The two are 10 and 14% fissile. The blanket is depleted uranium oxide. Core and blanket fuel elements are processed separately. The plutonium and uranium from the core are coprocessed and supplemented by additional coprocessed plutonium and uranium from the blanket to replace burned plutonium and uranium. Excess coprocessed uranium and plutonium from the blanket is placed in "secure" storage for eventual supply of other reactors. Make-up depleted uranium is supplied from an external source.

2.1.6.2. LMFBR with Heterogeneous U/Pu Core and U Blanket, Pu Fuel Spiked. The major differences between this and previous design are that this one has both an internal and an external (axial plus radial) blanket, only one enrichment zone (15% fissile), and all plutonium recovered from it is both coprocessed and "spiked" by pre-irradiation in a separate reactor. That is, both the plutonium fed back into the core and that stored or sold for use in other reactors are pre-irradiated.

2.1.6.3. "Standard" LMFBR with Homogeneous Core and Spiking. This design is identical to that described in design #1 above except that all plutonium is spiked by pre-irradiation, as in design #2.

2.1.6.4. LMFBR with Spiked U/Pu Core, U Axial Blanket, and Th Internal and Radial Blanket. In this design there are two enrichment zones in the core (averaging ~16% fissile of equilibrium), fueled with U/Pu oxides; the axial blanket consists of UO_2, while the internal and radial blankets are made of ThO_2. Coprocessed mixed oxides from the core and axial blanket are returned to the core after addition of makeup plutonium and uranium from an external source and pre-irradiation. Bred U^{233} is stored after it is denatured by the addition of U^{238} either from the core, axial blanket, or external source. New thorium is used for the internal and radial blankets, while discharged thorium, after separation of the contained U^{233}, is stored. The external source of Pu is not specified but presumably comes from the reprocessing of spent denatured LWR fuel.

2.1.6.5. LMFBR with Spiked Homogeneous U/Pu Core, Th Blankets. This is identical with design #3 except for the substitution of ThO_2 for the UO_2 in the axial and radial blankets. Core and blanket assemblies are processed separately, plutonium and uranium from the core are coprocessed and supplemented by makeup uranium and plutonium from "secure" storage, and U^{233} recovered from the blanket is denatured by the addition of depleted uranium and sent to "safe" storage. Core assemblies are pre-irradiated. Blanket elements are made from new thorium and the recovered thorium is sent to storage for 10 years before re-use.

2.1.6.6. LMFBR with Homogeneous Spiked Pu/Th Core and Th Blanket. The plutonium and part of the thorium recovered from the core are supplemented by makeup plutonium and thorium from "secure" storage and refabricated into core assemblies. There are two enrichment zones averaging 10% fissile at equilibrium. The spiking is provided by the daughter products of Th^{238} (mostly from U^{232} decay) present in the recycled thorium. The rest of the thorium from the core is mixed with that recovered from the blanket and stored for 10 years before reuse. The U^{233} recovered from the core and blanket is denatured with depleted uranium and sent to "secure" storage. Blanket assemblies are fabricated from new thorium.

2.1.6.7. LMFBR with Denatured U^{233} Core and ThO_2 Blanket. The core contains two enrichment zones fueled with UO_2 enriched to 10% in U^{233}, on the average. Blankets are composed of ThO_2. Core and blanket are processed separately. Denatured U^{233} recovered from the core is supplemented by highly enriched U^{233} recovered from the blanket and 25% enriched U^{233} from an external source for recycle. Plutonium recovered from the core is diluted with depleted uranium to an "enrichment" of 20% and sent to "secure" storage. Recovered thorium is sent to storage for 10 years and fresh or decayed thorium is used for blanket fabrication.

Selected characteristics of the various designs are given in Table 2.1.-8. Net electric power of all designs is 1000 MW. Total heavy metal and fissile inventories are given for the beginning of equilibrium cycle (BOEC). The total heavy metal inventory includes the heavy metal in the blankets. The fissile inventory is given either for the core (C in the table) or for the entire reactor (T), depending on the data available in the references. It does not include U^{235}. The enrichments given are defined as fissile plutonium plus U^{233} divided by total heavy metal in the region. The fissile mass (excluding U^{235}) per driver assembly is obtained by dividing the fissile inventory at BOEC by the number of driver assemblies, and is therefore somewhat high for those designs for which only total fissile inventories (i.e., including those in both core and blankets) were available.

It will be noted that the last four of these require an external source of fissile material to compensate for bred U^{233} sent to storage or as fuel to other reactors. In the first three of these cases, the external makeup is plutonium (which could come, for example, from the reprocessing of spent denatured LWR fuel). In the fourth case the external makeup is U^{233} (~25% fissile). In the actual situation there will be links between reactors of various kinds, and the nature of these links will change with time. Two possible symbiotic systems, specifically, are considered:

- System A, in which design #5 (spiked $(Pu,U)O_2$ core with ThO_2 blanket) supplies U^{233} for design #7 (denatured LMFBR).
- System B, in which design #6 (spiked $(Pu,Th)O_2$ core, ThO_2 blanket) supplies the U^{233} for design #7.

Times to reach equilibrium differ drastically for these two systems. Thus, the $(Pu,U)O_2/ThO_2$ breeder of System A requires at least twelve years to produce enough excess U^{233} to fuel the denatured reactor, while the $(Pu,Th)O_2/ThO_2$ breeder in System B requires only five years, approximately.

Table 2.1.-8.

Selected Characteristics of Alternative LMFBR Designs
In all cases, reactor thermal power is 2740 MW and net electric power 1000 MW.

	1	2	3	4	5	6	7
Core Type	Homogeneous	Heterogeneous	Homogeneous	Heterogeneous	Homogeneous	Homogeneous	Homogeneous
Average Discharge Burnup,[a] MWD/MTHM	61,100	56,300	61,100	56,800	62,000	59,500	57,500
Core Composition	$(Pu,U)O_2$	$(Pu,U)O_2$	$(Pu,U)O_2$	$(Pu,U)O_2$	$(Pu,U)O_2$	$(Pu,Th)O_2$	UO_2
Internal Blanket Composition	None	UO_2	None	ThO_2	None	None	None
Axial Blanket Composition	UO_2	UO_2	UO_2	UO_2	ThO_2	ThO_2	ThO_2
Radial Blanket Composition	UO_2	UO_2	UO_2	ThO_2	ThO_2	ThO_2	ThO_2
Core Fuel, Spiked or Denatured	Pu,No	Pu, Spiked[f]	Pu, Spiked[f]	Pu, Spiked[f]	Pu, Spiked[f]	Pu, Spiked[g]	U^{233}, Denatured
Excess Fuel, Spiked or Denatured	Pu,No	Pu, Spiked[f]	Pu, Spiked[f]	U^{233}, Denatured	U^{233}, Denatured	U^{233}, Denatured	Pu,No
Inventory, BOEC[b]							
Total Heavy Metal, kg	85,200	112,367	85,200	109,112	79,800	87,700	106,500
Fissile, kg[c]	3464(T)	4525(C)	3464(T)	4853(C)	3526(T)	4192(T)	3675(T)
Core Fissile Enrichment[d]							
Inner Zone, %	10.24	18.9	10.24	20.5	9.86	11.82	8.11
Outer Zone, %	14.36	(Single zone)	14.36	19.4	15.08	17.67	11.77
Number of Assemblies							
Drivers, Zone 1	150	270	150	222	150	150	150
Drivers, Zone 2	102		102	48	102	102	102
Internal Blanket	0	121	0	121	0	0	0
Control	19	30	19	30	19	19	25
Radial Blanket	198	318	198	138	198	198	198

Fissile Content per Driver[e] Assembly, kg	13.8	16.8	13.8	18.0	14.0	16.6	14.6
Refueling Interval, yrs.	1.25	1	1.25	1	1.25	1.25	1.5
Driver Residence Time, yrs.	2.5	3	2.5	3	2.5	2.5	3.0
Radial Blanket Res. Time, yrs.	3.7-6.2	6	3.7-6.2	6	3.7-6.2	3.7-6.2	4.5-7.5
Number of Pins per Driver Assembly	271	271	271	271	271	271	271
Active Length of Driver Pin, in.	48	48	48	48	48	48	48
Length of Axial Blanket, in.	28	28	28	28	28	28	28
Outer Diameter of Driver Pin, in.	0.29	0.31	0.29	0.31	0.31	0.31	0.34

---

[a] Megawatt days per metric ton of heavy metal.

[b] Beginning of equilibrium cycle.

[c] Total (T) or Core (C).

[d] (Pu^{239} + Pu^{241} + U^{233}) ÷ Heavy metal in core region.

[e] Total or Core fissile mass at BOEC ÷ Number of driver assemblies.

[f] By pre-irradiation.

[g] By mixing with recovered Th.

2.2. Fuel Cycle Facilities

A large number of alternative fuel cycle facilities being considered under NASAP are described in reference (7). Only those that are actually used in the fuel cycles previously described are summarized below. The numbering scheme is similar to that used in the PSEID and in the material flow diagrams for the various reactor cycles.

2.2.1. Reprocessing. All fuel cycles except the once-through ones require the reprocessing of either uranium or thorium fuels or both. Under the NASAP program only variations of the Purex and acid Thorex processes are considered. In all cases, the plutonium and thorium are converted to oxides for storage, while the uranium is converted to an oxide, a nitrate, or a hexafluoride, or to gel microspheres (for eventual feed to a vibratory or sphere-pac fabrication process). The uranium product may or may not be denatured. Conversion facilities are considered to be part of the reprocessing plant.

For details of the process see reference (7). In the brief summaries below only the nature of the feed and product is considered.

2.2.1.1. Purex Processes. Five Purex processes are described in the PSEID but only four are used in the fuel cycles considered. In all cases the plutonium is stored as either PuO_2 or as $(Pu,U)O_2$ powder, and the uranium as UF_2, UNH, or UO_2.

2.2.1.1.1. Purex 1. Purex 1 is the standard or reference Purex process in which spent uranium or MOX fuel is processed and purified and separated uranium and plutonium are produced. The model plant has a design throughput of 1500 Te/yr of heavy metal.

2.2.1.1.2. Purex 2. Purex 2 is similar to Purex 1 except that the products are separated uranium and a co-processed mixture of uranium and plutonium. The oxide mixture may consist of powder or of gel microspheres, depending on the fuel type required. The process may also be operated (and is so postulated for some cycles) so that no pure uranium is produced.

2.2.1.1.3. Purex 4. Purex 4 is identical with Purex 2 except that the coprocessed, converted product is pre-irradiated for storage. Note that this implies the irradiation of on the order of 100-200 tonnes of mixed plutonium and uranium oxides in bulk form per year in a special reactor.

2.2.1.1.4. Purex 5. Purex 5 is identical with Purex 2 except for the introduction of a spikant (e.g., Co^{60}) into the process stream at the point at which the uranium and plutonium are separated from the fission products. The products would be a highly radioactive mixture of uranium and plutonium oxides and a pure uranium compound.

2.2.1.2. Thorex Processes The Thorex process was developed for the reprocessing of uranium-thorium spent fuels. The presence of substantial quantities of plutonium, as a third component, requires modification of the original process. The uranium product in the processes described below is in the form of UO_2 powder or gel micro-spheres. Plutonium is stored as the oxide, and thorium is stored for 10-20 years, also as the oxide, to allow excess Th^{228}, from the decay of U^{232}, to decay before reuse.

2.2.1.2.1. Thorex 1. Thorex 1 has been developed for spent fuels containing uranium and thorium only and would have to be modified for those containing significant quantities of plutonium in addition (as from denatured U^{232}/Th fuel cycles). The uranium and thorium are separated first from the fission products and then from each other. The purified U3233 and attendant uranium isotopes are converted to UO_2 or gel microspheres and the thorium to ThO_2. The former is recycled as needed while the latter is stored. Trace amounts of plutonium are routed to high-level waste.

2.2.2.1.2. Thorex 3. Thorex 3 is a modification of Thorex 1 designed for the reprocessing of three-component spent fuels containing uranium, plutonium, and thorium and the production of purified, separated streams of each, as oxides. The U^{233} is denatured by the addition of U^{238} before storage or use, the PuO_2 is stored as is until needed, and the ThO_2 is stored for 10-20 years before reuse.

2.2.2.1.3. Thorex 7. The Thorex 7 process is designed for three component fuels, also, but the U^{233} and residual U^{235} are denatured with U^{238} in situ and the plutonium is spiked with Co^{60} after purification. The spiked plutonium and denatured uranium are stored as oxides until needed and the thorium as ThO_2 for 10-20 years before reuse.

2.2.2. Fabrication. The PSEID for fuel cycle facilities discusses four options, Fab. 1, 2, 3, and 4, for the fabrication of the various fuels required by the alternative cycles. The classification scheme is based on the physical and radiation characteristics of the fuel. The first three options are for the fabrication of sintered oxide pellets; the fourth, for the manufacture of fuels using microspheres.

The feed material for either of these two physical classes (sintered oxide pellets and microspheres) may have low gamma and alpha activity (e.g., low-enriched U^{235} fuels), low gamma and high alpha activity (e.g., plutonium-bearing fuels), or high gamma activity (e.g., U^{233}-bearing fuels). In the first case, operations and maintenance may be carried out by direct contact with the material; in the second, operations may be performed remotely but maintenance directly; in the fourth, both operations and maintenance have to be carried out remotely.

Model plant capacities for LWR fuel fabrication are assumed to be 520 and 480 metric tons of heavy metal (MTHM) per year for fresh and recycle fuels, respectively. For HTGR fuel fabrication plants, the corresponding capacities are 260 and 480 MTHM/yr, respectively.

A very brief description of the four fabrication options follows.

2.2.2.1. Fab. 1. Fab. 1 is the standard process by which low-enriched, natural, or depleted uranium oxide is sintered into pellets for LWR, HWR, LWBR, and LMFBR fuels. Being a contact process, it is suitable only for fuels with low gamma and alpha activity, such as U^{235}, U^{238}, and thorium fuels.

2.2.2.2. Fab. 2. Fab 2 is similar to Fab 1. except that it is performed remotely with low gamma-active, high alpha-active fuels such as those containing plutonium. Maintenance is performed by direct contact.

2.2.2.3. Fab. 3. Fab. 3 is similar to Fab 1. except that it is remotely operated and maintained. It is used for highly gamma-active fuel such as those containing U^{233} (i.e., U^{232} and its daughters) or a spikant like Co^{60}.

2.2.2.4. Fab 7. Fab 7 is used for the production of microsphere-based fuels, such as those used in HTGR's or in the Sphere-pac process, in which several different size spherical fuel particles are vibratorily compacted to a high density in fuel rods. The latter is especially suitable for remote fabrication and maintenance, as would be required for recycle U^{233} or spiked fuels.

The four classes of fuel fabrication and the fuel forms to which they apply are shown in Table 2.2.-1.

2.2.3. Waste Disposal Schemes. The PSEID for nuclear fuel cycle facilities[7] lists and describes six options for "waste disposal." Actually, three of these provide interim storage rather than permanent disposal, and of these, two are for purified concentrated fuel materials not ordinarily considered wastes. The options are as follows:

2.2.3.1. Waste Disposal 1: Interim Storage of Spent Fuel Away from Reactors (AFR's). The proposed model facility would store spent fuels at least five years old in a water-cooled basin. Capacity is assumed to be 5000 metric tons of heavy metal, expandable in increments of 1000 MT to 15,000 MT. Maximum receipt rate would be 2000 MT/yr, and it would be ready to begin operating in 1983. It would be capable of storing LWR, HWR, or HTGR fuel from reactors operating in a once-through or recycle mode. HTGR fuel, consisting of graphite blocks, would have to be double-encapsulated to prevent direct contact with the water.

Fuel would ultimately be shipped from the AFR to a permanent storage site or to a reprocessing plant.

2.2.3.2. Waste Disposal 2: Geologic Disposal of Spent Fuel. Waste disposal option 2 provides for the geologic disposal of spent fuel, and therefore is applicable only to once-through cycles.

The baseline repository is assumed to have a capacity for 62,000 and 36,600 MTHM in the form of PWR and BWR assemblies, respectively, at the reference burnup. Because of the higher burnup of HTGR fuels and their combustible nature, it might be necessary to burn the graphite and store only the fuel particles, in a suitable matrix, in cannisters. All fuel will have cooled for at least 10 years since discharge, before being shipped to the repository.

Table 2.2.-1.

Fuel Fabrication Options

Option	Fuel Form
Fab 1	Pellets[a] 1. U^{235}/O_2 2. $U^{235}/O_2/CaO/ZrO_2/ThO_2$ 3. ThO_2 4. $(U^{235},Th)O_2$
Fab 2	Pellets[b] 5. $(U^{235},Pu)O_2$ 6. $(Pu,Th)O_2$
Fab 3	Pellets[c] 7. U^{233}/O_2 8. U^{233}/ThO_2 9. U^{235}/PuO_2-spiked
Fab 7	Microspheres[a] 10. $(U^{235},Th)OC$ 11. ThO_2 Microspheres[c] 12. U^{233}/O_2

[a] Low gamma and alpha activity; contact operation and maintenance.
[b] Low gamma, high alpha activity; remcte operation, contact maintenance.
[c] High gamma activity; remote operation and maintenance.

Operations would include receiving cannistered fuel assemblies from AFR's, overpacking damaged cannisters, decontaminating cannisters if necessary, and depositing the cannisters in the repository.

Because of uncertainties in the behavior of the stored fuel and also in the possible future need for reprocessing, it is necessary for the fuel to be stored retrievably for some period of time: a minimum of 5 years for observing the behavior of the fuel and 25-100 years for demand contingencies. This means that the fuel will be accessible during those periods and therefore of importance to international safeguards.

2.2.3.3. Waste Disposal 3: Interim Storage of Plutonium. A number of the U^{233}/Thorium cycles produce plutonium as a by-product; these include the light-water denatured U^{233}/Th cycle, the Shippingport Type I (U^{233}/Th) prebreeder, the backfit prebreeder, and the HTGR denatured U^{233} (or U^{235})/Th cycle. The amounts of plutonium per year range from approximately 60 kg for the HTGR cycle to 100 kg for the backfit prebreeder.

Interim storage for this plutonium therefore must be provided.

The scheme proposed by NASAP is that described in the Barnwell Applicability Study.[11] It involves the storage of up to 30,000 kg of plutonium as the oxide in a maximum of 1000 pressure vessels each with a capacity of 32 kg of Pu. The pressure vessels are stored in holes in a borated concrete floor slab. Facilities include a receiving station, a cannister-filling station in a loading cell, a decontamination room, a loadout room where the cannisters (each containing up to 8 kg of Pu) are loaded into the pressure vessels (up to four cannisters per vessel), and the storage vault. A fork-lift transports the shielded pressure vessels to their appropriate locations in the vault.

2.2.3.4. Waste Disposal 4: Interim Storage of U^{233}. Two of the LWBR cycles, namely the Shippingport Type I pre-breeder and the backfit pre-breeder, require the interim storage of U^{233}. The proposed storage facility would have a capacity of 20 metric tons of U^{233}, probably in the form of an aqueous nitrate solution. A variety of critically safe storage containers is feasible: thin slab tanks, annular vessels, cylinders, etc. Neutron absorbers might also be used. The preferred approach apparently is to store the solution, at a uranium concentration of 375 g/liter, in 10-liter plastic bottles of the kind used to store plutonium nitrate solution; these would be placed inside a stainless steel pressure vessel which in turn would be placed inside two 55-gallon drums welded end-to-end. The preference for storage as a nitrate solution rather than as an oxide powder is based on the relative ease of processing the solution to remove the highly radioactive daughter products of U^{232} just before fabricating the recycle fuel.

2.2.3.5. Waste Disposal 5: Shallow Land Disposal of Low-Actinide Waste. Waste from effluent treatment in the fabrication of low-enriched, natural, or depleted uranium, or thorium fuels, (e.g., in breeder blankets) is considered low-actinide waste. As defined here, most of it consists of contaminated calcium fluoride from the effluent-air scrubber systems. It would be disposed of in shallow on-site trenches which are then backfilled. This material has no safeguards interest.

2.2.3.6. Waste Disposal 6: Geologic Disposal of Actinide Waste. The geologic storage of radioactive waste was originally conceived for the disposal of wastes from the processing of spent reactor fuels, and only recently for the permanent storage of unprocessed spent fuel (see Section 2.2.3.2. above). Because of the low concentration of SNM in this waste, the intense radioactivity from the fission products, and the insolubility of the vitrified product, this material is of minimum interest to safeguards.

2.2.4. Transportation. Volume VII, "Fuel Cycle Facilities," of the PSEID considers the transportation requirements for fresh, spent, and spiked fuel and for solidified high-level and actinide waste for the NASAP fuel cycles.

Table 2.2.-2 summarizes the quantities of such materials to be trans-

Table 2.2.-2.

Transportation of Fuel, Part A
(Per 0.75 GWe-yr)

		LWR				HWR	GCFR	HTGR	
		Once Through	Improved Once Thru	Spiked Recycle	U^{233} Recycle	Once Through	U/Pu/Th Recycle	Once Through	$U^{233,235}$/ Th Recycle
FRESH	HM,Tonnes	27	16	18	25	44	20	5	14
FUEL	Trucks	5	3	3	4.5	12	19	16	45
	SSNM, kg[a]	—	—	—	U^{233},[c] 317	—	—	—	—
SPENT	HM,Tonnes	27	16	27	25	44	8	5	5
FUEL	Trucks	60	36	60[b]	54	74	20	158	158
	SSNM, kg[a]	Pu,246	Pu,180	Pu,490	Pu,94	Pu,270	Pu,1566	Pu,58	Pu,75
SEPARATE	HM,Tonnes	—	—	—	—	—	20	—	9
BLANKET	Trucks	—	—	—	—	—	50	—	250
MATERIAL	SSNM, kg[a]	—	—	—	—	—	U^{233}, 426	—	U^{233}, 201
SPIKED	HM,Tonnes	—	—	9	—	—	0.4	—	—
FUEL	Trucks	—	—	21[b]	—	—	21	—	—
	SSNM, kg[a]	—	—	Pu,265	—	—	Pu,1665	—	—
	"spikant"	—	—	Co^{60}	—	—	Pre-irrad.	—	—
TOTAL	HM,Tonnes	54	32	54	50	88	48	10	28
TRAFFIC	Trucks	65	39	84[b]	60	86	110	174	453
	SSNM, kg[a]Pu 246	190	755	94	270	3230	58	75	
	U^{233}, kg	—	—	—	317	—	426	—	201

[a] SSNM includes, Pu, 12% U^{233}, 20% U^{235}.

[b] Using shipping containers of current design.

[c] Make-up material.

Table 2.2.-2.

Transportation of Fuel, Part B
(Per 0.75 GWe-yr)

		LWBR					
		Shippingport		Backfit		High Enriched	Seed-Blanket
		Prebreeder	Breeder	Prebreeder	Breeder	Prebreeder	Breeder
FRESH	HM,Tonnes	88	115	23	106	24	172
FUEL	Trucks	9	12	2.3	11	No Data	No Data
	SSNM, kg[a]	—	—	—	—	U^{235},980	U^{235},680[b] U^{233},4300
SPENT	HM,Tonnes	88	115	23	106	24	172
FUEL	Trucks	65	77	53	70	No Data	No Data
	SSNM, kg[a]	Pu,96 U^{233},436	U^{233},1720	U^{233},252 Pu,192	U^{233},1550	U^{235},269 U^{233},320	U^{235},670 U^{233},4300
TOTAL	HM,Tonnes	176	230	46	212	48	344
TRAFFIC	Trucks	74	89	55	81	No Data	No Data
	SSNM, kg[a], Pu	96	—	92	—	—	—
	SSNM, kg[a], U^{233}	436	1720	252	1550	320	8600
	SSNM, kg[a], U^{235}	—	—	—	—	1250	1350

[a] SSNM includes, Pu, 12% U^{233}, 20% U^{235}.

[b] Includes some make-up material.

Table 2.2.-2.

Transportation of Fuel, Part C
(Per 0.75 GWe-yr)

		LMFBR						
		Homogeneous U/Pu/U	Heterogeneous U/Pu/U Spiked	Homogeneous U/Pu/U Spiked	Heterogeneous U/Pu/Th Spiked	Homogeneous U/Pu/Th Spiked	Homogeneous Th/Pu/Th Spiked	Homogeneous U^{233}/Th
FRESH	HM,Tonnes	28	24	17	23	15	17	40
FUEL	Trucks	27	23	16	22	15	16	40
	SSNM, kg[a]	Pu,1845	—	—	—	—	—	U^{233},1200[b]
SPENT	HM,Tonnes	11	11	11	18	12	12	13
FUEL	Trucks	46	29	28	47	30	31	33
	SSNM, kg[a]	Pu,1730	Pu,700	Pu,560	Pu,2230	Pu,1740 Pu,1572	U^{233},467	Pu,532
SEPARATE	HM,Tonnes	17	24	17	16	15	17	17
BLANKET	Trucks	25	62	44	41	38	43	42
MATERIAL	SSNM, kg[a]	Pu,350	Pu,512	Pu,350	U^{233},404	U^{233},315	U^{233},307	U^{233},252
SPIKED	HM,Tonnes	—	12	11	12	11	12	—
FUEL	Trucks	—	30	29	30	29	31	—
	SSNM, kg[a]	—	Pu,2340	Pu,1845	Pu,2500	Pu,1850	Pu,1300	—
	"spikant"		Pre-irrad.	Pre-irrad.	Pre-irrad.	Pre-irrad.	Th^{228} daughters	
TOTAL	HM,Tonnes	56	71	56	69	53	58	70
TRAFFIC	Trucks	98	144	117	140	112	121	115
	SSNM, kg[a]	3925	3552	2755	4730	3500	3870	532
	Pu U^{233}	—	—	—	404	315	307	1452

[a] SSNM includes, Pu, 12% U^{233}, 20% U^{235}.

[b] Includes some make-up material.

ported for all the cycles so as to present a comparative overview of the traffic in fuel and in SSNM. The table provides data on a 0.75 GWe-year basis and gives metric tonnes of heavy metal, number of truckloads, and kilograms of SSNM for this quantity of energy produced. The categories of material shipped are: fresh fuel and blanket material, spent fuel, separate blanket material (after irradiation), and spiked fuel. The total traffic is also given for each cycle.

No figures are given for the transport of bulk materials, either from processing plant to fabrication plant or from processing to storage, or for the transport of waste materials or spikants (e.g., Co^{60}). One implication, therefore, is that processing plants and fabrication facilities are co-located. If they were not, there would obviously be additional transportation requirements.

In addition we herein ignore waste materials, both those that do not contain significant quantities of SNM (e.g., high-level wastes from plant reprocessing) and those that do (e.g., waste material from fabrication plants) as well as SNM or SSNM materials to be stored. Some of the proposed cycles include pre-irradiation of the latter, which, although details are not specified, might involve additional transportation requirements.

In spite of the above omissions, the table clearly shows the range of transportation requirements for the proposed cycles. Heavy metal tonnage varies by a factor of more than 30, numbers of truckloads by a factor of more than 10, and quantity of SSNM by a factor of more than 150.

2.2.5. International Fuel Service Centers. The use of international fuel service centers (IFSC's) to minimize proliferation and domestic safeguards risks has been studied under NASAP.[7,11] Both power-generating and non-power-generating centers were considered. A power-generating center is one which contains power reactors as well as certain fuel-cycle facilities (reprocessing plants, fabrication plants, interim spent fuel storage facilities, and waste management facilities), while non-power generating centers contain only the fuel cycle facilities. The on-site power reactors are those in which fresh SSNM is used; they also produce fissile material (Pu or U^{233}) which is denatured or spiked for use in dispersed reactors, or else recycled internally. In most cases the on-site reactors will be fast breeders, although some cases involving thermal reactors (e.g., advanced converters) were also considered. The dispersed reactors are all thermal reactors of more or less conventional design, operating on low-enriched uranium, denatured uranium-thorium, or spiked mixed oxide (plutonium-uranium) fuels, although one unconventional reactor type, a spectral shift design (SSCR), is an alternative.

Enrichment plants and permanent waste disposal facilities are not included in the IFSC's.

A selected set of the cases considered is shown in Table 2.2.-3. The second, third, and fourth columns show the type, number, and deployment time (to equilibrium) of the on-site reactors (all reactors are assumed to be of the 1000-MWe size). The fifth and sixth columns give the type and number of dispersed reactors (also 1000-MWe each) served by the center (and, in turn, serving it). The abbreviations SSCR, DNF, and MOX-S stand for spectral shift converter reactor, denatured fuel, and spiked mixed-oxide fuel, respectively. The total number of reactors, on-site and dispersed, is given in the last column.

All the cases shown in Table 2.2.-3 are of the power-generating type except the last, C.1, which contains only fuel-service facilities. The reprocessing plant is assumed to have a capacity of 1500 MTHM/yr (except for two cases considered in Ref. 11, which had a capacity of 500 MTHM/yr) and the fabrication plant consists of as many 200-MTHM/yr lines as needed to provide the required capacity. The area of power-generating centers is determined by a waste-heat dissipation requirement of at least 1 acre/MWe, so that the largest center is at least 25,000 acres in area. Because of the large number of reactors at the site, overall construction times (deployment times)

Table 2.2.-3.

NASAP International Fuel Service Center (IFSC) Cases

Case	In-IFSC Reactors		IFSC Development Time (yr)	Off-IFSC Reactors		Total No. of Reactors Serviced
	Type	GWe		Type	GWe	
A.1	LWR (Pu/Th)	10	22	LWR (LEU) LWR (DNF/Th)	41 9	60
A.2.a	LMFBR (Pu/Th)	9	22	LWR (LEU) LWR (DNF/Th)	26 23	58
A.2.b	LMFBR (Pu/Th)	9	33	LWR (LEU) SSCR (DNF/Th)	17 36	62
A.2.c.1	LMFBR (Pu/Th)	6	13	LWR (LEU) HWR (DNF/Th) LWR (DNF/U)	14 15 6	41
A.2.c.2	LMFBR (Pu/Th) (Pu/U Core)	8	13	HWR (DNF/Th)	23	31
A.2.d	LMFBR (Pu/Th)	21	24	LMFBR (DNF/Th) LWR (DNF/U)	32 16	69
A.2.e	LMFBR (Pu/Th)	10	21	LWR (LEU) HTGR (DNF/Th)	29 29	68
A.3	LMFBR (Pu/U)	25	33	LWR (MOX-S)	25	50
B.1	LWR (Pu/U)	19	19	LWR (LEU)	39	58
B.2	LWR (Pu/U)	12	13	LWR (DNF/Th; U^{233} recycle)	54	66
B.3	HTGR (Pu/Th)	14	16	LWR (LEU) LWR (DNF/U)	53 3	70
C.1	(Fuel Service Only)	—	19	LWR (LEU) LWR (MOX/S)	39 19	58

are very long — up to 33 years. During this time there are thousands of construction workers on-site (peak force 7,500-10,000), and the operating personnel are also numbered in the thousands.

All sensitive activities except the enrichment of uranium are carried out in the centers. Weapons-useable plutonium and uranium are processed and used here, but only spiked or denatured fuels are sent off-site. Spent fuel from the dispersed reactors is sent to the IFSC after a 6-month cooling period.

The ownership and/or management of the center is assumed to be multinational in character.[11]

REFERENCES

1. Preliminary Safety and Environmental Information Document, (PSEID), Vol. I, Revision 1, "Light Water Reactors," DOE, NASAP 78-12, April 1979.
2. PSEID, Vol. II, Rev. 1, "Heavy Water Reactors," DOE, April 1979.
3. PSEID, Vol. III, Rev. 0, "Light-Water Breeder Reactors," DOE, January 1979.
4. PSEID, Vol. IV, Rev. 1, "High-Temperature Gas-Cooled Reactors," DOE, April 1979.
5. PSEID, Vol. V, Rev. 1, "Gas-Cooled Fast Reactor," DOE, April 1979.
6. PSEID, Vol. VI, Rev. 1, "Liquid-Metal Fast Breeder Reactors," DOE, April 1979.
7. PSEID, Vol. VII, Rev. 0, "Fuel-Cycle Facilities," DOE, Jan. 1979.
8. PSEID, Vol. VIII (to be published).
9. "Preconceptual Design Study of Proliferation Resistant Homogeneous Oxide LMFBR Cores," General Electric Co., GEFR-00392, Nov. 1978.
10. "Preconceptual Study of Proliferation Resistant Heterogeneous Oxide Fueled LMFBR — Final Report," Vols. 1 and 2, Westinghouse Electric Corp., Nov. 1978.
11. "International Fuel Service Center Study," Burns and Roe Industrial Services Corp., draft in progress, May 1979.

III. GENERIC SAFEGUARDS ISSUES

In this part, a number of safeguards features common to two or more of the proposed fuel cycles are discussed. The issues they raise are identified and, within the limitations of time and resources allotted to this study, analyzed for their impact on domestic safeguards and regulatory operations. Since the emphasis is on the regulatory process, solutions are offered only in general terms. None of the technical problems seem insurmountable, especially in view of the long lead time required for the development and deployment of most of the fuel cycles, during which appropriate solutions may be pursued.

The issues discussed in this chapter include:

- The Use of SSNM
- Radiation Barriers
- Coprocessing

- The Use of U^{233}/Th Fuels
- Denaturing
- The Use of Heavy Water as a Moderator
- Storage of Spent Fuel and Waste
- Storage of U^{233} and Plutonium in Bulk
- International Fuel Service Centers
- Transportation

The use of radiation barriers is discussed at considerably greater length than the others because it is the most controversial of the proposed measures and raises the largest number of safeguards issues.

In a following part, additional features, not covered above and specific to particular cycles, will be presented and discussed.

3.1. The Use of SSNM. A number of proposed alternative cycles require strategic special nuclear materials (SSNM) as a makeup material for fuel fabrication. Table 3.1.-1 lists these cycles and the materials used in them. The quantities shown are taken from the flow sheets in the approp-

Table 3.1.-1.

SSNM Makeup Material

Fuel Cycle	Material	Quantity of SSNM (kg/0.75 GWe-yr)
LWR		
U^{233}/Th Recycle	50% U^{233}	317
LWBR[a]		
High-Enriched Prebreeder	93% U^{235}	980[b]
Seed-Blanket Breeder	67% (U^{233}+U^{235})	97
GCFR	20% Fissile Pu (with U)	178[c]
LMFBR		
Hetero., U/Pu/Th	20% Fissile Pu (with U)	208[c]
Homo., U/Pu/Th	20% Fissile Pu (with U)	100[c]
Th/Pu/Th	20% Fissile Pu (with Th)	666 (991 Total Pu)
U^{233}/Th	25% U^{233}	320

[a] In addition, the Shippingport and Backfit Prebreeders call for re-enrichment of cycled ura- In view of the potential U^{232} contamination of this material, it is likely that SSNM material will be needed for fuel makeup in these LWBRs as well. See part 4.

[b] The proposed scheme also includes the transfer of SSNM (40% U^{233} and 34% U^{235}) from reprocessing to storage (589 kg/.75 GWe-yr).

[c] Fissile Pu only. Estimate based upon inconsistent data. Total Pu not estimated.

riate volumes of the PSEID. Since there are inconsistencies in these documents, these quantities should be considered approximate. The amounts of SSNM vary from ~ 100 kg/0.75 GWe/yr to approximately ten times that much.

These materials are not produced by the fuel cycle in which they are to be used. Hence, they are either transported to the fabrication facility from an outside source or, if the system is located at an "International Fuel Service Center," another process that produces such material might be the source of supply (see Sections 2.2.4. and 3.10.). (In the case of the LWBR high-enriched prebreeder, however, the source of 93% U^{235} would be an enrichment plant not co-located with the fabrication facility.)

The safeguards issues involved in the use of these materials are similar to those raised in the GESMO,[1] which was limited to a discussion of plutonium in mixed-oxides. That study found that the safeguards problems for mixed-oxides were essentially quantitative rather than qualitative in nature (except for the toxic risk of Pu in dispersal devices) as compared with the safeguards of high enriched uranium currently in effect.

The order of magnitude of SSNM use in the cycles considered here, if a majority of U.S. nuclear energy production involved these cycles, is similar to that projected in the GESMO for plutonium in mixed-oxides. It may therefore be assumed that, as in that case, a statement presenting "a detailed and comprehensive analysis of the environmental impacts of potential diversions of special nuclear materials and of alternative safeguards programs to protect the public from such a threat"[1] would have to be prepared before any of these fuel cycles could be approved by NRC. Obviously, it is beyond the scope of the present report to perform such a detailed analysis, but it can be noted that, for the fuel cycles listed in Table 3.1.-1, essentially the same issues would be raised as were for the LWR mixed-oxide fuel cycle.

3.2. Radiation Barriers. In a number of the NASAP fuel cycles it is proposed to use radiation barriers as a safeguards measure to protect strategic special nuclear material. The purpose would be to make the material both more difficult to seize or divert, and more difficult to convert into a nuclear explosive (by increasing the resources, the skills, and the time required to do so). The radiation barrier would therefore serve both to deter and to delay. To achieve these goals, the dose rates have to be high enough to pose a substantial potential hazard to unprotected persons in the immediate vicinity of the materials. A number of important technical, regulatory, and licensing issues are raised by this concept. These are discussed below. The discussion will be based on studies related to this subject that have been performed in the past few years.[1-7]

3.2.1. Radiation Levels. An important question is what radiation levels are required to achieve the desired purpose. This depends on the motivation, resourcefulness, and skill of the adversary, as well as on the resources he is able and willing to commit to the task. What would deter a terrorist might not deter a government, and some terrorists might be more easily deterred or less resourceful than others. These considerations have led to a very wide range of suggested radiation levels, which are usually expressed as roentgens (or rads, or rems(r) — the terms will be used interchangeably here) per hour at some standard distance such as 1 meter or 1 foot from the fissile material.

Table 3.2.-1, from Vol. 2 of reference 3, provides some perspective on the choice of radiation levels. In reference 3 a dose rate of 1000 r/hr at 1 meter from a 1 kg sample of plutonium was considered to be a minimum deterrent to theft by a terrorist (reference 3 was concerned only with domestic safeguards). Values on this order of magnitude have also been suggested in more recent studies. However, reference 3 also suggested that much higher dose rates — between 10,000 and 100,000 r/hr — might be required under certain circumstances. This was based on the possibility that any terrorist group capable of building a nuclear explosive would also be knowledgeable enough to take measures to reduce the danger of working with the stolen

Table 3.2.-1.

Effects on Individuals of Various Total Body Doses of -Rays*

Total Body Dose (r)	Effects
< 25	No likely acute health effects.
25-100	No acute effects other than temporary blood changes.
100-200	Some discomfort and fatigue, but no major disabling effects. Chances of recovery excellent.
200-600	Entering lethal range (LD-50 ~ 500 Rads). Death, if it occurs, within several weeks. Some sporadic, perhaps temporary disabling effects (nausea, vomiting, diarrhea) within hour or two after exposure. Unlikely to be completely disabling in first few hours.
600-1,000	Same as above, except that death within 4-6 weeks highly probable.
1,000-5,000	Death within week or two practically certain. Disabling effects within few hours of exposure more severe than above, but only sporadically disabling.
5,000-10,000	Death within about 48 hours. Even if delivered in less than one hour, does not cause high disability for several hours, except for sporadic intense vomiting and diarrhea. Convulsing and ataxia likely after several hours.
10,000-50,000	Death within a few hours or less. Complete incapacitation within minutes, if delivered in that time.

*From reference 3.

material — e.g., by quickly transferring it, after seizure, to shielded casks, by using long manipulators and shadow shielding, and so on; also, that dedicated terrorists might be willing to expose themselves to lethal doses (from Table 3.2.-1, the LD-50 acute dose is ~ 500 r) to accomplish their ends. For these reasons, it might be necessary to incapacitate them before the material could be transferred to a shielded enclosure. From Table 3.2.-1, an almost immediately disabling dose is in the neighborhood of 10,000 to 50,000 r, requiring the very high dose rates mentioned above.

These dose rates are very high compared with those that NRC, in its regulations, evidently has regarded as sufficient to deter potential diverters of strategic special nuclear material. This may be inferred from 10 CFR 73.6(b),[8] which specifically exempts from the physical protection provisions of Part 73 special nuclear material not readily separable from other radioactive material and having an unshielded dose rate of 100 r/hr at a distance of 3 feet from any accessible surface. A similar exemption is suggested in the IAEA publication INFCIRC/225.[9] The NRC exemption was motivated entirely by considerations of domestic safeguards, according to R.G. Page of NRC,[10] who participated in the original selection of this dose rate. The threshold level was based on a study performed by the regulatory authorities (then part of the Atomic Energy Commission) in the period 1961-1962, the object of which was to determine the maximum radiation level to which workers in the nuclear energy field should be allowed to be exposed, regardless of how short the duration of exposure might be. The value chosen at that time was 100 r/hr, and in the late 1960's the committee formulating 10 CFR 73.6(b) adopted the same value on the basis of a "judgment call."[10] The IAEA simply followed NRC's lead.

The minimum levels proposed by NASAP are shown in Table 3.2.-2, from Appendix A, attached to each of the PSEIDs. Candidate methods for achieving these levels are listed in Table 3.2.-3, also from Appendix A. The different methods will be discussed below. It will be noted that mechanically attached sources are proposed as an alternative to intimately mixed sources.

The levels for mixed-oxides in the second column of Table 3.2.-2 are roughly comparable to 1000 r/hr at 1 meter from 1 kg of Pu, at least for thermal fuels, for which the ratio of Pu to heavy metal is less than 0.1. The minimum levels for fuel assemblies, 10 r/hr, seem low, but reflect the longer exposure time required to divert them and extract the plutonium or HEU. It must also be kept in mind that at a more practical working distance of 1 foot, the dose rates are almost an order of magnitude higher than at 1 meter. These levels are high enough that it is felt that no government capable of developing its own nuclear weapons would expose its workers to them without protection — i.e., without providing shielding and remote operating equipment, thus achieving the intended delay and increased commitment of resources. An additional point is that, if the fuel assemblies were fabricated from spiked or partially processed material meeting the criteria for bulk materials in Table 3.2.-2, the dose rates from an assembly would in fact be much higher than 10 r/hr at 1 meter.

If the incorporation of radiation barriers were to be required by NRC regulation, it would be necessary to specify the minimum acceptable levels and duration of these levels for the various forms of SSNM encountered in the fuel cycle. From what has been said, it is clear that there is no wholly objective way to set these levels, since for any practicable level it is always possible to postulate protective measures within the capability of some hypothetical terrorist group (a judgment concerning the adequacy of a given radiation barrier for purposes of non-proliferation would probably lie outside NRC's authority). It follows, then, that whatever level is set by NRC would have to be based on informed judgment. However, regardless of the specific choice of level, the mere fact that it is high enough to threaten life or health will raise certain issues that must be considered by the NRC; these are among the topics discussed below.

Table 3.2.-2.

Types of SNM and Candidate Radiation Levels

Type	Fuel Material	Minimum Radiation Level During 2-Year Period (r/hr at 1 meter)	
		Mixed[a]	Mechanically Attached[b]
1	PuO_2, HE UO_2 powder or pellets[c]	1,000 per kg HM	10,000/kg HM
2	PuO_2-UO_2 and HE UO_2-ThO_2 powder or pellets[c]	100 per kg HM	10,000/kg HM
3	LWR, LWBR, or HTGR recycle fuel assembly (including type 2 fuels)	10 per assembly	1,000 per assembly
4	LMFBR or GCFR fuel assembly (including type 2 fuels)	10 per assembly	1,000 per assembly

[a] Radioactive material intimately mixed in the fuel powder or in each fuel pellet.

[b] Mechanically attached sleeve containing cobalt-60 is fitted over the material container or fuel element and locked in place (hardened steel collar and several locks).

[c] High-enrichment uranium (HEU) is defined as containing 20% or more uranium-235 in uranium, 12% or more of uranium-233 in uranium, or mixtures of uranium-235 and uranium-233 in uranium of equivalent concentrations.

3.2.2. Methods of Producing a Radiation Barrier. Four methods have been proposed by NASAP, in Appendix A of the PSEIDs, for producing a radiation barrier. These are (1) spiking, which is the addition of radioactiv-

Table 3.2.-3.

Candidate Methods and Radiation Levels for Spiking Fuel Materials

Type	Fuel Material	Minimum 2-year radiation level (r/hr at 1 meter)	Process	Minimum initial radiation level (r/hr at 1 meter)
1	PuO_2, HE UO_2 powder or pellets	1,000 per kg HM	Cobalt-60 addition	1,300 per kg HM
2	PuO_2-UO_2 and HE UO_2/ThO_2 powder or pellets	100 per kg HM	Cobalt-60 addition	130 per kg HM
			Fission-product addition (ruthenium-106)	400 per kg HM
3	LWR, LWBR, or HTGR recycle fuel assembly	10 per assembly	Cobalt-60 addition	13 per assembly
			Fission-product addition (ruthenium-106)	40 per assembly
			Pre-irradiation (40 MWd/MT)	1,000 (30 days) per assembly
4	LMFBR or GCFR fuel assembly	10 per assembly	Cobalt-60 addition	13 per assembly
			Fission-product addition (ruthenium-106)	40 per assembly
			Pre-irradiation (40 MWd/MT)	1,000 (30 days) per assembly

ity to the fuel materials at some stage of the nuclear fuel cycle; (2) partial processing of spent fuel, in which some portion of the fission products are retained in the recovered plutonium; (3) pre-irradiation, in which fabricated fuel assemblies are exposed to a neutron flux before being shipped to the power reactor; and (4) mechanically attached sources. In addition, the description of certain fuel cycles includes pre-irradiation of bulk fuel materials prior to storage but this process appears to be impractical. Sometimes the term spiking will be used in a generic sense to mean any of these schemes.

In the first three methods, the radioactivity is intimately mixed with the fuel material; in the fourth, it is not. The first three methods therefore protect the fuel against diversion by the recipient nation as well as against diversion or seizure by terrorists or by third nations (e.g., while in transit through the territory of the third nation). The fourth method, though presumably effective against terrorists and third-nation attack, would be ineffective against the recipient nation, since in the natural course of events it would detach the sources before using the fuel.

Spiking and partial processing also have the advantage that they occur early in the fuel cycle; in fact, under partial processing the plutonium never appears unaccompanied by intense radiation, while spikants can be added during or immediately after reprocessing. Under pre-irradiation the materials are unprotected up to the fuel-assembly stage. Sources may be attached to containers of bulk materials or fuel rods while they are in storage or in transit, but during processing these fuel forms would be unprotected by radiation.

On the other hand, spiking and partial processing would interfere seriously with fuel fabrication, while pre-irradiation and attached sources would not. Obviously, the different methods have different advantages and disadvantages which would have to be weighed carefully by NRC in determining which, if any, should be adopted.

The individual methods are discussed in the following.

3.2.2.1. Spiking. Important regulatory issues specific to spiking as the method of providing the radiation barrier are:

(1) whether suitable candidates for spikants exist, suitability being defined in terms of availability, chemical, physical, and radioactive properties, and cost, and

(2) the possible necessity to safeguard the spikant itself.

3.2.2.1.1. Choice, Availability, and Cost of Spikant. A set of criteria was adopted in Vol. 2 of Reference 3 to screen potential candidates for spikants. Neutron emitters were ruled out for lethal spiking because impracticably large quantities would be required. For gamma-ray emitters the criteria were that (1) the half-life be between 1 and 50 years, (2) the γ-ray energy be at least 1 Mev, (3) the gamma-ray yield for energies of at least 1 Mev be at least 25%, and, (4) the candidate be either a fission product with a significant yield or be produced by capture in an isotope with a natural abundance of at least 10% and a thermal capture cross section of at least 1 barn.

In the above study, the nuclide that was available in the largest quantities at reasonable cost and that satisfied these criteria was Co^{60}, produced by thermal neutron capture in Co^{59}. Other studies[4-6] have come to similar conclusions on the basis of more detailed consideration of chemical, thermodynamic, and mechanical properties. These studies also suggested ruthenium-106 and cerium-144, separated from the fission-product stream and added, at a later stage, to the plutonium product, but this is a special case of fission-product retention or partial processing, which is discussed below. These studies also suggested the possibility of combining Co^{60} addition with fission-product retention, to make up for the short half-lives of Ru^{106} (368 days) and Ce^{144} (285 days).

Co^{60} could be recycled by recovering it during the reprocessing of spiked fuel, but it probably could not be co-processed with the fuel but would have to be recovered from the high-level waste stream and added to the product at a later stage. This would probably require a major modification of an existing LWR reprocessing plant, such as the one at Barnwell.

At the proposed spiking levels, the addition of Co^{60} is not expected to affect adversely the properties of the fuel. Most of its compounds have melting points well above temperatures used for sintering and therefore are not expected to volatilize during this process. However, experimental work would have to be performed to verify the behavior of the additive during processing and its compatibility with the fuel.

The availability and cost of the spikant are important considerations. Estimates of the production rate required by the year 2000 can be based on nuclear power projections for the U.S., the schedule for plutonium recycle in a given reactor following start-up (assuming that all reactors reach equilibrium self-generated recycle as soon as possible), the amount of plutonium recycled per year per reactor, and the amount of the spikant required per kilogram of plutonium to produce the desired radiation levels.

The dose rate from a 1-curie point source of Co^{60} at a distance of 1 meter is, approximately, 1.4 r/hr. Then, neglecting self-absorption (which should be small), the amount of Co^{60} required to produce a dose rate of 1000 r/hr at a distance of 1 meter from a 1-kilogram mass of plutonium as the oxide is 720 Ci. At equilibrium self-generated recycle the total amount of Pu recycled per year in a 1000-MWe PWR operating at an average load factor of 0.75 is ~ 555 kg (see Figure 2.1.-3). The buildup to this value takes approximately 20 years and begins at about four years after reactor startup. For calculational purposes the actual buildup can be replaced by a step function rising abruptly to full equilibrium value at eight or nine years after reactor start-up. The amount of plutonium recycled in the year 2000 is then equal to the amount of plutonium that would be produced per year by the reactor population projected for the period 1991-1992 if all the reactors were on equilibrium self-generated recycle. A recent projection for the U.S.,[11] linearly interpolated, gives ~ 170 GWe at this time (average of low and high estimates). The total amount of Co^{60} needed to spike the recycle Pu in the year 2000 is then

$$\frac{720\ \text{Ci Co}^{60}}{\text{kg Pu}} \times \frac{555\ \text{kg Pu}}{\text{GWe-yr}_{(\text{effective})}} \times 170\ \text{GWe} = 70\ \text{MCi Co}^{60}$$

Without interfering significantly with the weapons program, the three large production reactors at the Savannah River Laboratory could each produce ~ 8 MCi Co^{60}/yr, or a total, say, of 25 MCi/yr for all three.[12] This would have to be increased by roughly a factor of 3 to supply the needs for the year 2000, an increase that could probably be accommodated if some reduction in the rate of production of weapons material were permitted. If Co^{60} were recovered from previously spiked spent fuel, the production requirements could be reduced; however, as noted above, methods of recovering it from the fission-product waste stream would have to be developed and incorporated into the design of the reprocessing plants that would be in existence by then.

The cost of the Co^{60} would depend on the specific activity. Higher specific activities mean smaller amounts of accompanying Co^{59}, which is a neutron absorber, and therefore smaller effects on the reactivity and the burnup of the fuel. At a specific activity of 200 Ci Co^{60}/g Co and a concentration of 0.7 Ci Co^{60}/g Pu, it may be estimated, from calculations by Gorrell,[12] that the plutonium concentration in MOX fuel in a light water reactor would have to be increased by about 0.7% relative. It would appear to be possible to produce megacurie quantities of Co^{60} at a specific activity of ~ 200 Ci/g at a cost of $0.50-$1 per Ci[3] (1975 dollars), or at a total production cost in the year 2000 of $35-70 M (also 1975 dollars). The cost of production of the spikant would therefore not appear to be a major factor. Any other spikant (except for cesium, which would be unsuitable because of the volatility of its compounds) would probably cost more.

On the basis of the foregoing, it may be concluded that neither the availability nor the cost of the spikant would be a major factor in the licenseability of a spiking scheme using Co^{60}, provided the necessary measures were undertaken to expand the present production capacity by a factor of about 3 by the year 2000.

3.2.2.1.2. Safeguarding of Spikant. It was estimated in the previous section that, for total plutonium recycle spiked with Co^{60}, an annual production of ~ 70 MCi of Co^{60} would be required by the year 2000, on the basis of present nuclear power projections. As noted in reference 3, the Co^{60} would itself pose a considerable hazard to the public and to workers. At a level of 1 Ci of Co^{60}/g of Pu, a 5-MT/day LWR reprocessing plant could have as much as 1.5×10^7 Ci in storage at one time. The uniform dispersal of 1% of this over one square mile would produce a surface dose rate on the order of 1 r/hr.[3] Although such a uniform dispersal over so large an area is barely conceivable and is used here only for illustrative purposes, it is clear that dispersal could significantly contaminate substantial areas.

The consequences of a dispersal of spiked plutonium oxide were also estimated in reference 3. For the postulated weather conditions and population density it was found that a complete dispersal of 1 kg of plutonium as the oxide, spiked at the level of 1 Ci of Co^{60} per g of Pu, would cause approximately two more long-term lung cancers than the dispersal of the same quantity of unspiked plutonium.

It is therefore possible that both shipments (which could involve megacurie quantities) and stores of Co^{60} would have to be protected. However, in a report considering the relative risks and consequences of theft or sabotage involving large quantities of radiological materials,[24] Co^{60} was not considered to be an important problem. The reason given is that high γ-ray emitters are too dangerous and inconvenient for terrorists to handle considering the prospects of either breaching or carrying off a heavy cask and the complex manipulation required for the efficient manufacture of an aerosol with effective physical, chemical, and radiological properties.

Most likely the cobalt would be produced by irradiation in production reactors like those at the Savannah River Laboratory and shipped to the reprocessing or fabrication plant as the metal, the form in which it is normally irradiated and in which it is relatively nondispersable. At the processing plant it could be stored as the metal until actually needed, and then converted to the compound (e.g., nitrate or oxide) suitable for addition to the fuel. All storage and processing would probably have to take place in vital areas.

It may be concluded that, before requiring spiking, NRC would have to compare the additional safeguards hazards and protective measures (as well as additional hazards to health and safety in normal operations and under accident conditions) with those of other approaches.

3.2.2.2. Partial Processing. One method of providing a radiation barrier is to retain certain of the fission (or activation) products during the processing of spent fuel for recovery of the plutonium and uranium. A possible variation would be to separate the desired fission products and add them to the product at a later stage. These schemes are called, variously, partial processing, low decontamination, and fission-product retention.

Partial processing has been used for the reprocessing of spent EBR-II fuels. However, it was considered specifically as a safeguards measure for LWR fuels in references 2, 4, 5, and 6, and for LMFBR fuels under the process name CIVEX.[13]

Some of the fission products that have been considered are ruthenium-106, zirconium-95, and cerium-144; these have half lives of 368 days, 65 days, and 285 days, respectively. Zr^{95} has too short a half life to be useful unless the plutonium is recovered, refabricated, and inserted into the reactor within a very short time after discharge. The other two fission products permit longer delays in recycling, but exclusive reliance on them would eliminate a large quantity of long-cooled fuel from recycling and therefore possibly involve an unacceptable economic penalty. The relatively low emission rate of high-energy gamma-rays by the Ce^{144}-Pr^{144} decay chain and the small fraction of cerium that can be co-processed with the product (3-5%)[6] make this choice less desirable than that of the ruthenium. Ru^{106} therefore appears to be the most likely candidate, and is favored in most of the studies.

Even reliance on Ru^{106} would eliminate the protection of much of the older accumulated spent fuel from recycling, however, and might impose stringent scheduling requirements on the recycle of recovered plutonium. In reference 2, the criterion was adopted that the dose rate at 1 meter from a 5 kg sample of plutonium should be at least 5000 r/hr. Neglecting self shielding this is equivalent to the 1000 r/hr criterion for the dose rate from 1 kg, in

Table 3.2.-2. However, reference 2 concluded that such a dose rate could not be maintained beyond 200 days after discharge from the reactor. Lowering the minimum acceptable dose rate to 100 r/hr, in accordance with 10 CFR 73.6(b), would extend this time by approximately three years, so that at least $3^1/_2$-4 years might be allowed to elapse before recycling of the plutonium; actually, the allowable time might even be longer, provided that the plutonium were refabricated into assemblies before this, since the criterion for assemblies is less strict than that for bulk materials (see Table 3.2.-2). Some provision would have to be made for situations in which either the refabrication or the insertion of the recyle fuel into the power reactor failed to meet the necessary deadlines; or else, as suggested in references 4, 5 and 6, a "duplex" spiking scheme, in which Co^{60} is used to supplement the Ru^{106}, might be required.

A number of questions would still have to be resolved before partial processing could be adopted; these include uncertainties in the retention fraction of the fission products, their possible volatilization during the conversion or fuel fabrication process, effects on fuel properties (e.g., sinterability), etc. Considerable experimental work would have to be done to establish the proper flowsheet conditions.[4] Major modification of existing reprocessing plants (e.g., Barnwell) would have to be undertaken, and new plants would have to be specifically designed for this purpose. This is in addition to the time and effort required to develop new remote fabrication, handling, accountability, and inspection techniques (see below). Clearly it would be years — at least ten, and probably a good deal longer — before any such scheme could be adopted on a commercial scale. This is also true of Co^{60} spiking.

3.2.2.3. Pre-Irradiation. Pre-irradiation of fabricated fuel assemblies before they are shipped to the power reactor would be one way to avoid some of the severe disadvantages of the previous two methods of providing a radiation barrier, such as remote fabrication and maintenance, degradation of accountability methods, increased attractiveness to saboteurs, and so on. A detailed paper study of the feasibility of pre-irradiation has been performed by Pflasterer and Deane;[7] the present discussion will be based on that work.

The concept adopted for the pre-irradiation facility (PIF) was that of a thermal-spectrum, water-moderated and cooled, self-driven reactor — i.e., one driven by the fuel elements to be irradiated. The irradiation criterion for the assemblies was that the dose rate 3 feet from the assembly be greater than 250 r/hr up to 180 days after discharge. The reactor was to be capable of irradiating 600 LMFBR fuel assemblies per year. It was estimated that a burnup of 300 MWD/Te would provide the necessary radiation field, or about 0.3% of the 100,000 MWD/Te maximum burnup in LMFBR fuel, but ~ 1% of the maximum burnup of an LWR fuel element; the scheme is being proposed only for LMFBR fuel, however.

The proposed design calls for the irradiation of 72 assemblies at a time in a 100-MW$_{th}$ reactor. Refueling would occur every 3 to 4 weeks and is estimated to require 2.5 days. Assembly power during irradiation would be approximately 1 MW on the average. Irradiated assemblies would be shipped to the power reactors in shielded casks 30 to 60 days after irradiation.

The great advantage of the pre-irradiation scheme is that it would not interfere with the fabrication, quality control, or accountability of the fuel at the fabrication plant. The disadvantages it shares with the previous two methods are the remote handling required for the fresh fuel assemblies to prepare them for use (e.g., during preparations for shipment to and receipt at the power reactor, inspection and storage, and insertion into the reactor) and the use of heavy shielded casks for shipment. It also has the disadvantage that it protects only the form of the fuel least vulnerable to diversion or seizure, namely the fabricated assemblies, which are discretely countable, massive, and require chemical processing to recover the plutonium from them. The more vulnerable bulk powders and pellets would have to be protected during the fabrication process by conventional safeguards.

The most expensive feature of the pre-irradiation scheme is the pre-irradiation facility itself (see section on the costs of the different methods). It is also the most problematic from the licensing point of view. Because it is a thermal reactor driven by fast-reactor fuel assemblies, and must allow for a variety of assembly designs to service different LMFBR's, it has certain unique problems. It has a large excess reactivity, a marginally adequate control system, a large positive void co-efficient under certain conditions, and large thermal flux gradients between assemblies, resulting in large uncertainties in the calculation of design parameters. Design modifications could alleviate some of these problems, though possibly at greater cost. One example would be to irradiate fewer assemblies at a time, which would reduce the excess reactivity but at the same time reduce the throughput and increase the cost. Critical experiments could provide some of the more-difficult-to-calculate design parameters, but at the expense of increased cost and delay.

The size, and therefore cost, of the pre-irradiation facility could be reduced if the lower dose-rate criterion proposed by NASAP, 10 r/hr at 1 meter from an assembly for at least two years, were adopted. Unfortunately, reference 7 does not present the decay of the radiation levels beyond 180 days after exposure (which is quite different than for spent fuel, since the shorter irradiation times in the pre-irradiation facility accentuate the shorter-lived activities), but a rough estimate of the amount by which the pre-irradiation exposure could be reduced by adopting the NASAP criterion is a factor of 2 to 3.

The licensability problems of the pre-irradiation facility design suggest that the development of a commercial facility would take at least ten to fifteen years. This includes time for designing, constructing, and performing the critical experiments, proof-testing of pre-irradiated fuel assemblies, and designing, constructing, and licensing the pre-irradiation facility.

The descriptions of two of the NASAP fuel cycles, both the heterogeneous and the homogeneous LMFBR's with U/Pu cores, U blankets, and spiked plutonium, call for the pre-irradiation of bulk excess plutonium oxide (or mixed U/Pu oxides) before storage. In view of the difficulties anticipated in licensing a reactor for the pre-irradiation of fabricated assemblies, the licensing problems for one designed for the irradiation of ton or multi-ton quantities of bulk oxide would appear to be formidable. This approach will not be considered further here, since it is not one of the ones listed in Table 3.2.-3 for bulk materials.

3.2.2.4. Attached Sources. A fourth method proposed by NASAP to provide a radiation barrier would be to attach radioactive sources mechanically to containers of SNM or to fuel assemblies, for protection during transit. These sources might consist, for example, of sleeves containing Co^{60} and locked in place by means of a hardened steel collar and several locks (as suggested in Table 3.2.-2).

This is the simplest method of all for providing the desired radiation barrier. It involves the least interference with the fabrication, accounting, quality control, and use of the fuel in reactors, and has no affect on either the fuel properties or the operation of the reactor, since the sources would be detached from the assemblies before use. Radiation levels requiring prohibitively large concentrations of spikant intimately mixed with the fuel would be easily attainable by the use of attached sources. The sources would also be available for reuse after a shipment, reducing the demand. If Co^{60} were used, it could be in metallic form and therefore less vulnerable to dispersal, compared with the compounds required for intimate mixing with the fuel.

On the other hand, the fuel would be protected only against attacks by terrorists or by third nations while it is in transit. The importing nation, after removing the sources, would have easy access to the material. The method would therefore provide minimal proliferation resistance. Since it is proposed to protect material in transit only, by this means, conventional safeguards would be required during fabrication or storage.

The use of detachable sources was considered in some detail in Vol. 2 of reference 3. Schemes were proposed that would provide radiation fields on the order of 50,000-100,000 r/hr at 1 meter from a fuel assembly or a shipping package containing up to 32 kg of PuO_2 (the standard shipping container design for the Barnwell plant). These fields are one to two orders of magnitude higher than those proposed in Table 3.2.-2 (it is assumed that the 10,000 r/hr dose rates specified in the third column of the table are total dose rates for any shipment of 1 kg or more of heavy metal), and therefore require correspondingly more Co^{60}, the radionuclide assumed in both Table 3.2.-2 and in reference 3.

The attached source method shares with the other methods the advantage of requiring heavy shielded casks for shipment of fuel assemblies or SNM. This in itself would be a substantial impediment to theft, but could be provided without resorting to radioactive sources simply by imposing a minimum weight requirement on all shipping containers of SSNM.

Of the four methods proposed for protecting SSNM with radiation the attached source method would require the least development. The main effort would be in designing secure methods for attachment, specialized casks, and handling tools and techniques, both at the processing plants and at the power reactor. Present spent fuel shipping casks could provide more than enough shielding, as pointed out in reference 3, but might not be optimal for the purpose proposed here. Co^{60} requirements could probably be met by present production capacity or by a modest expansion thereof, if the minimum dose rate criteria of Table 3.2.-2 (as interpreted parenthetically above) were adopted.

As with the other methods, NRC would have to set minimum dose rate requirements and standards for acceptable attachment and cask design.

Costs of mechanical attachment of sources were estimated in reference 3. These are discussed below.

3.2.3. Maintenance of Radiation Levels. Because of the decay of the radioactive sources, the protection afforded by the radiation barrier will continually decline with time. In setting its requirements, NRC will have to take into account a number of situations in which radiation levels may fall below the minimum standards. One of these is an unanticipated delay in the use or shipment of the fuel as a result of reactor construction or operating delays, reneging on contractual terms, political constraints, or some other cause. A second is the inevitable and unpredictable lags that will occur between production schedules and use. Because of the large capital cost of reprocessing plants and the need to process spent fuel to reduce storage requirements, there will be a strong incentive to operate them continuously at or near full capacity, regardless of the immediate demand for the plutonium; that is, the supply and demand for plutonium are likely to be only loosely coupled, because each is driven by its own imperatives, which only partially overlap. This will be less of a consideration in fabrication plants, but here the problems of left-over stocks and of scrap recovery will arise. If scrap is chemically treated to recover the plutonium, either the recovery process must be designed not to separate the radioactive source or else some method of replacing it must be provided. This would be an argument for spiking in place of or, at least, in addition to, partial processing, since a supply of makeup spikant could readily be provided at the fabrication plant (or scrap recovery plant, if it is a separate facility). Left-over stocks could also be accommodated by blending in additional spikant.

Upset conditions in the fabrication process could also lead to a loss of spikant and a consequent reduction in the radiation barrier. Under these conditions the affected material would probably have to be recycled through the scrap recovery plant, where makeup spikant could be added. This would be an argument in favor of locating fabrication and scrap treatment facilities together.

3.2.4. Effect of Radiation Barrier on Material Accountability. Both partial processing and spiking would adversely affect material accountability. The effects would be felt in sample taking, chemical analysis, non-destructive assay, and material-balance verification by both NRC and the IAEA. Both the accuracy and the timeliness of material accountability and verification, but particularly the latter, would suffer.

The high radiation fields would inhibit sample-taking for chemical assay, making the procedure both more time-consuming and laborious. Samples would have to be shielded for shipment to NRC or IAEA analytical laboratories. There would be a strong incentive on the part of the operator and that of NRC and IAEA inspectors to reduce sample-taking to the minimum. At the same time, the inability to use Non-Destructive Assay (NDA) would greatly increase the need for sampling, and the possible reduction in the accuracy of individual analytical results might have a similar effect.

Material accountancy at reprocessing plants would be least affected, since radiation levels in much of the process in such plants are already high and non-destructive assay is not so heavily relied on, either for operator analysis or for verification. The main effect would be felt at the product stage. One study[14] concluded that the 6-month LEMUF in a reprocessing plant like the one at Barnwell would be increased by 16%.

To our knowledge, the overall effect of high radioactivity levels on the accountability of conversion and fabrication plants has not been studied quantitatively. Such plants would have to be both operated and maintained remotely. This would simplify containment and surveillance and greatly limit direct access to sensitive materials, thus enhancing physical protection. However, most present non-destructive techniques for assaying feed, product, intermediate stocks, and waste and scrap would be made unuseable by the extremely high radiation from the spikant, which would completely overwhelm the gamma rays characteristic of plutonium or uranium and incapacitate fast neutron detectors.[3] Non-destructive techniques are essential for the assay of fabricated fuel rods and particularly useful in the assay of scrap and waste. Although substitute methods for doing these might be developed, a great deal of research and development would be required, and in the meantime the slower and much more expensive techniques of sampling and chemical analysis would have to be resorted to; the destruction of a finished fuel rod for chemical analysis would be a particularly expensive measure. Calorimetry of feed materials would also be adversely affected, unless the contribution of the spikant to the heat from the sample were accurately known. Gamma-ray methods for measuring the isotopic composition of plutonium, important for both neutron-coincidence and calorimetric assay of plutonium, would be unuseable. Neutron coincidence methods employing BF_3 detecitors or other types of detectors relatively insensitive to gamma-rays might still be operable, although it might be necessary to shield the samples heavily to avoid excessive gamma-ray pile-up. Plastic or liquid scintillation detectors, used in certain types of neutron coincidence counters, would be inoperable because of their high sensitivity to gamma-rays.

Since real-time or near real-time accountability systems depend strongly on the application of non-destructive assay, the hoped-for improvement in timeliness of detection of diversion would be sacrificed by the use of intimately mixed radioactive sources. The large increase in sample load at the operator's, NRC's, and the IAEA's analytical laboratories would also tend to degrade timeliness of detection. It should be noted, in this connection, that the IAEA in particular is heavily dependent on gamma-ray and neutron detectors for the verification of certain portions of the flows and inventories of processing plants, and this dependence is expected to grow.

It is difficult to estimate quantitatively the effect of radiation barriers on the accuracy of material accountability at conversion and fabrication plants, without a detailed study. A rough guess, however, can be made on the basis of the difference in NRC requirements on the maximum LEMUF in reprocessing and fabrication plants.[15] These allow the relative LEMUF in the plutonium material balance to be twice as large in the shielded portion of reprocessing plants as in fabrication plants (for different material balance intervals, however; six months for reprocessing plants and two months for fabrication plants). This suggests that for the same effort the accuracy of material balance in plutonium fabrication plants would be degraded by roughly a factor of two by the introduction of intense radioactivity into the fuel.

The use of the gamma-rays from the spikant to perform non-destructive assay on the fissile materials is a possibility. For this it would be necessary to know the ratio of spikant to fissile species to a high degree of accuracy (probably better than 1%). Whether a fixed ratio can be achieved and maintained throughout the fabrication process is unknown at present. In addition, allowance would have to be made for batches of material with different ages.

Another consideration that must be taken into account is that the presence of intense radiation would make it more difficult for both the NRC and the IAEA (and the operator) to investigate and resolve any anomalies that arise. This, also, would adversely affect the timeliness of detection of diversion.

Against all these adverse effects have to be balanced the increased physical protection and facilitation of containment and surveillance resulting from the high radiation levels. Diverted material would be much easier to detect during removal from the plant, either through the use of portal radiation monitors or of metal detectors capable of detecting the necessary shielding. However, no method of performing this "trade-off" quantitatively has yet been developed, and the weighing of these different factors by NRC would have to be performed on the basis of subjective, though informed, judgment.

It should be noted that many of the problems discussed above will also occur with U^{233} fuels, because of the radiation from the daughter products of U^{232}. The problems will not be quite as serious, however, because the radiation levels are expected to be somewhat lower and can be reduced even more by chemical clean-up before fabrication.

Finally, it should also be pointed out that it might be possible to achieve comparable accuracies in spiked and unspiked systems but with increased time, effort, and expense, and possibly only after a considerable period of research, development, and demonstration.

3.2.5. Effect of Radiation Barriers on Fuel Manufacture and Quality Control. Fabrication plants for fuels containing intimately mixed, intense radioactive sources will have to be operated and maintained remotely. The design of such plants, using the conventional mixed-oxide pellet-sintering process, has been described in reference 3, where the increased costs of fabrication have also been estimated.

It has also been suggested that alternative fabrication processes may be more readily adaptable to remote operation.[16, 17] The chief alternatives are those based on the use of gel microspheres in place of oxide powders and on the high-energy vibratory compaction of oxide powders. In the former, several sizes of spherical gel fuel particles are prepared and sintered, and then, by means of low-energy vibration, are compacted into a fairly dense mass in a fuel rod.[18] A variation is to form pellets out of the microspheres and sinter them, resulting in a more standard pelletized fuel but with improved properties. The two gel-sphere processes are called Sphere-Pac and Sphere-Cal, respectively. They have the advantage that the feed material is much more free-flowing than oxide powders, and the amount of dust produced is much reduced, compared with the standard process. These characteristics make it easier to operate the process remotely. The reduction in dust and fines may also have some accountability advantages.

The high-energy vibratory process, called Vi-Pac, is less promising because of the difficulty in achieving sufficiently high densities.

The development of these processes is far behind that of the conventional process. In most cases only cold laboratory or engineering-scale work has been done. In addition, although there have been some irradiation tests of fuel, both here and abroad, a great deal more work would be required to establish licensability. It is doubtful that any of these processes could be brought to the licensing stage in less than ten years, and a commercial fabrication plant probably could not be operating before the turn of the century. It is relevant to note also that, in the opinion of some, a reprocessing plant capable of producing partially processed or spiked fuel probably couldn't be operating before then, either.[19]

Regardless of the fabrication process chosen, quality control of the final product will be made much more difficult by the necessity to perform it remotely, thus causing a potential conflict between reactor safety and nuclear safeguards. At present, numerous quality control checks are made at every stage of the process. These include sampling and chemical analysis for heavy metals, impurities, moisture, oxygen, isotopic analysis, checking of ceramic and mechanical properties, inspection of welds, leak-testing, nondestructive monitoring of fuel rods for "rogue" pellets, mechanical gauging, visual inspection for defects, and so on. Both the safety and economics of the reactor are heavily dependent on these operations, most of which are now carried out manually. The adoption of remote processing would therefore require a considerable development program for remote performance of quality control.

Of course, there has been some experience with partially processed fuels with the experimental fast breeder reactor, EBR-II. However, the fuel is a metallic type, lending itself to relatively simple casting techniques, and the reactor was never licensed by NRC.

3.2.6. Physical Protection for Materials with High Radiation Levels. The basic assumption of the proposal to protect nuclear materials with radiation barriers is that they would then not need other, more conventional forms of protection. As support for this view Appendix A of the PSEIDs cites the exemption from the physical protection requirements of 10 CFR 73 of material not readily separable from other radioactive material and having a radiation dose rate in excess of 100 r/hr at 3 feet from any accessible surface (10 CFR 73.6(b)). Recent rulemaking by the NRC[20] establishing physical protection requirements for shipments of spent fuel makes the situation less clear, however. The new rule, to take effect July 16, 1979, would remove spent fuel in transit from the exemption of 10 CFR 73.6(b), and imposes some additional physical protection requirements specifically for this type of shipment. The Commission's action was prompted by a consideration of the potential consequences of sabotage of spent fuel shipments in urban areas. The new requirements are described as "interim" in nature, pending review by NRC of such public comments as are received, following which the regulations may be reconsidered or modified.

The new rulemaking applies only to irradiated fuel; whether it should be extended to all fuel and fuel materials accompanied by intense radiation, as in the various spiking schemes, is something NRC would have to decide if it considers the adoption of spiking. If SSNM is to be protected by conventional means as well as with a radiation barrier, the implication is not only that the latter is insufficient protection but that it constitutes an additional hazard. (This was also discussed in Section 3.2.1.) It would also mean that the costs of radiation barriers would not replace those of conventional physical protection but would add to them. Both these implications would weaken the case for spiking and similar schemes as safeguards measures.

3.2.7. Reconciliation with "ALARA" Philosophy. According to NRC regulations, licensees should make "every reasonable effort to maintain radiation exposures...as low as is reasonably achievable"[21] (the so-called ALARA philosophy). The history of regulation of exposure to radiation has been one of ever-increasing strictness. Inasmuch as both routine and accidental exposures would probably be increased by spiking or its variations, endorsement of it by NRC would appear to conflict directly with the ALARA philosophy and to run counter to the historical trend in nuclear regulation.

Such an apparent reversal could, perhaps, be justified on the grounds that it was necessary for safeguards. However, it would then first be necessary to show (a) that no better or equally good alternatives, not involving potential additional exposure to radiation, were available, and (b) that the risk to the public from such schemes is less than the risk of a safeguards incident (risk being defined here in its technical sense as the product of a probability of occurrence times the consequences). In the absence of either an actuarial history of safeguards incidents or evidence for the existence of a threat too great for conventional safeguards systems to cope with, it would be difficult to sustain either position. In particular, the historical record is against position (b), since there have been accidental exposures to radiation, but no one has been injured by a safeguards incident. Moreover, there is a possibility that routine exposures to workers would increase as a result of spiking.[3] Failing a convincing argument along these lines, by adopting spiking or its variations, NRC would be in the anomalous position of making radioactive material even more radioactive (i.e., more dangerous) in order to protect the public from it.

3.2.8. The Need for An Environmental Impact Statement. Spiking or its variations may have adverse effects on the environment through the production of increased amounts of radioactivity (e.g., Co^{60}) beyond those necessary for the generation of electric power and a significant increase in the potential for accidental release or exposure. An environmental impact statement may therefore be required.[22] It would have to include a cost benefit analysis and a consideration of alternatives.[23]

Implicit in such an analysis (or else a result of it) is the contention that the risk to the public of spiking is less than the risk of not spiking. Since, as noted in the previous section, there is no historical evidence of injury as a result of a safeguards incident but, on the other hand, injuries have resulted or may reasonably be expected to result from accidental exposure to radiation, this point would be difficult to sustain. The increased number of potential targets for saboteurs that spiking might make available would also argue against this view.

In order to demonstrate that spiking (or its variations) is the best alternative, it would have to be shown that the widespread use of plutonium or highly enriched uranium would pose a threat to public safety that conventional safeguards, even if concurrently expanded or improved, would not cope with — that is, that such conventional systems have serious weaknesses for which spiking would be the best cure. However, a recent NRC analysis of the safeguards problems of a mixed-oxide fuel cycle[1] did not identify any such weaknesses but, in fact, proposed a reference safeguards system based on existing, or extrapolations of, conventional elements.

So far the discussion has been based on domestic safeguards considerations. However, NASAP arose primarily out of foreign policy considerations (i.e., nonproliferation). In the absence of a strong argument for spiking based on the needs of domestic safeguards, NRC would have to justify imposing the measure on the domestic industry primarily to achieve foreign policy goals. NRC would then have to resolve the issue of whether it has the authority to act primarily out of these foreign policy considerations.

In any event, an environmental impact proceeding would involve appreciable delays.

3.2.9. Costs of Radiation Barriers. As noted in the previous section, an environmental impact statement would require a cost-benefit analysis of the various schemes for providing a protective radiation barrier. Costs estimates have been made in some of the references cited [2, 3, 7, 19,] but it must be recognized that these are subject to large uncertainties, since there is no experience in this area. Also, they may not include all costs, but only those felt to be the major ones. Research and development costs, for example, are usually excluded. Basic economic assumptions may also differ from one study to another. It must also be recognized that there are large uncertainties in the "base case" costs — that is, the costs of unspiked plutonium recycle. There has been little, if any, experience with the fabrication of multiply recycled plutonium, which, even without the additional of spikants, will be highly radioactive, due to the presence of Am^{241} and the neutron-emitting isotopes of plutonium.

In reference 2, it was estimated that partial processing, in which much of the Ru^{106} and Zr^{95} were retained, would increase fuel cycle costs by 10 to 50% (total electric power costs would increase by much less, relatively, since fuel cycle costs are a small percentage of total costs). This included the increase in costs in reprocessing, LWR-MOX fuel fabrication, and fresh fuel transport, and assumed decreases in safeguards costs (e.g., the elimination of armed guards in the transport of fresh fuel). By far, the major increase was in fabrication costs. The cost of non-spiked recycle was itself considered to have an uncertainty of roughly ± 40%. Since this uncertainty is not distributed uniformly across all components of the fuel cycle, it may strongly affect the relative incremental costs of spiking. For example, if the costs of fabricating unspiked MOX fuel are actually much higher than assumed, doubling those costs as a result of spiking will have a much greater overall impact on fuel cycle costs. Conversely, a large increase in the price of uranium would reduce the relative cost increment due to spiking.

The incremental cost of fabricating spiked LWR MOX fuel was also estimated in reference 3. There it was found that at spikant concentrations of 0.1-1 Ci Co^{60}/kg Pu, the fabrication cost increased very rapidly with increases in spiking level, then levelled out and increased much more slowly with further increases in concentration. The point at which the cost curve went up rapidly corresponded to radiation levels requiring remote maintenance as well as remote operation of the facility. Beyond this point the costs increased slowly because increasing radiation levels required only an increase in the amount of shielding.

The incremental cost of fabricating MOX fuel spiked at the levels considered in this report was $350-500 per kg of heavy metal (in 1975 dollars) depending on the number of parallel fabrication lines required to maintain the same throughput as in the unspiked case. These corresponded to increases of 0.175 to 0.25 mills/KW-hr in the cost of nuclear electric power, or 1.3-1.9% of the busbar cost of 13.2 mills/KW-hr then projected for 1982 (but expressed in 1975 dollars). In the same study the cost of fabricating unspiked MOX fuel was estimated to be $250-300/kg HM (in 1975 dollars).

The incremental costs as a function of spikant concentration are shown in Table 3.2.-4, from reference 3. These do not include the increased cost of reprocessing, waste management, transportation, fuel handling at the reac-

Table 3.2.-4.

Total Increase in Cost of Fabricating Mixed-Oxide LWR Fuel Spiked with High-Energy Gamma-Ray Emitter (1975 Dollars)[3]

Spikant Level (Ci/kg Pu)	Incremental Fabrication Cost ($/kg HM[a])	Incremental Nuclear Electric Power Cost (mills/kw-hr.)	Percentage Increase in Power Cost[c] %
10^{-5}-10^{-4}	3	0.0015	0.011
10^{-3}	30	.015	.11
10^{-2}	35	.018	.13
10^{-1}	40	.02	.15
1	350-500[b]	.175-.25[b]	1.3-1.9[b]
10	350-500	.175-.25	1.3-1.9
100	350-500	.175-.25	1.3-1.9
1000	350-500	.175-.25	1.3-1.9

[a] HM = Heavy Metal = U + Pu

[b] Lower figure refers to two fabrication lines, higher one to three

[c] Based on projected busbar cost in 1982 of 13.2 mills/kw-hr. (expressed in 1975 dollars)

tor, the cost of the spikant itself or of the slightly increased enrichment required to compensate for the Co^{59}, or research and development costs.

Estimates of the costs of attached sources were presented in Vol. 2 of reference 3. Attaching such sources only to the shipping casks for shipment of bulk fuel and assemblies increased busbar nuclear electric power costs by 0.13%; attaching the sources both to the SNM container itself and to the shipping cask increased the cost by 0.6%; attaching the sources to SNM containers and shipping casks in transit and to SNM containers in storage increased the cost by ~ 1%. These increments did not include any credit for possible reductions in other safeguards measures.

The incremental costs of fabricating spiked MOX fuel projected by the International Fuel Cycle Evaluation (INFCE) are about \$300/kg HM,[19] compared with an estimated \$420-720/kg HM for unspiked fuel. It is also estimated that reprocessing costs will increase by \$250/kg HM, based on a reference plant using semi-direct maintenance in the unspiked case and entirely remote maintenance in the spiked or partial processing case. The corresponding increase in total nuclear power costs is estimated to be 2 mills/KW-hr, or ~ 6% of an assumed nuclear power cost of 35 mills/KW-hr (this is almost a factor of 3 higher than assumed in references 2 and 3, but presumably includes distribution costs and may be referred to a different year; the various estimates discussed here have not been put on a common base).

The cost of pre-irradiation of fuel assemblies was estimated in reference 7 for the LMFBR fuel cycle. It depends on the dose-rate criterion for the irradiated assembly. For a 250 r/hr dose rate 3 feet from the assembly up to 180 days after irradiation the increase in LMFBR energy costs is estimated to be 4-6.5 mills/KW-hr, and, for a dose rate of 1000 r/Hr, 5.5-16.5 mills/KW hr. The two extremes in the latter case correspond to two different assumptions as to the number and power of the pre-irradiation reactors — that is, to one reactor of large size or three reactors each of one-third the size. The cost of the pre-irradiation reactor is by far the dominant cost in this scheme.

It is obvious that the uncertainties in all these cost projections are large. Probably not much can be done in the way of refining them further without some actual operating data based on laboratory or engineering-scale experience. Some such experience would therefore probably be necessary to arrive at a credible set of estimates for the purpose of making cost-benefit calculations for the spiking of special nuclear material.

It would also be necessary to determine whether and by how much the costs of conventional safeguards would be reduced by the use of radiation barriers. In this connection is should be noted that the need for protection against sabotage, particularly at reactors, would not be reduced but possibly even increased by radiation barriers, and these constitute a large fraction of total safeguards costs.

REFERENCES

1. "Safeguarding a Domestic Mixed-Oxide Industry Against a Hypothetical Subnational Threat," Nuclear Regulatory Commission, NUREG-0414, May, 1978.
2. "Denatured Plutonium: A Study of Deterrent Action," Principal Investigator Bruce A. Hutchins, Electric Power Research Institute, EPRI 310, July 1975.
3. E.V. Weinstock, Study Coordinator, "The Spiking of Special Nuclear Materials as a Safeguards Measure," Vols. 1 and 2, Brookhaven National Laboratory, Sept. 19, 1975. Vol. 2 of this study was written by T.B. Taylor and W.J. Reinhardt, of the International Research and Technology Corp., under subcontract to BNL, and was entitled "Modification of Strategic Special Nuclear Materials to Deter Their Theft or Unauthorized Use," IRT 378-R, Nov. 6, 1975.
4. "Barnwell Nuclear Fuels Plant Applicability Study," Vol. III, U.S. Department of Energy, DOE/ET-0040/3, Mar.1978.
5. "Chemical and Physical Considerations of the Use of Nuclear Fuel Spikants for Deterrence," J.E. Selle, Oak Ridge National Laboratory, ORNL/TM-6412, Oct. 1978.
6. "Practical Consideration of Nuclear Fuel Spiking for Proliferation Deterrence," J.E. Selle, et al., Oak Ridge National Laboratory, ORNL/TM-6483, Oct. 1978.
7. "Pre-Irradiation Concept Description and Cost Assessment," G.R. Pflasterer and N.A. Dearie, General Electric Co., GEFR-00402, Sept. 1978 (in three volumes).
8. 10 CFR 73.
9. "The Physical Protection of Nuclear Material," International Atomic Energy Agency, INFCIRC/225/Rev.1, June 1977.
10. R.G. Page, Nuclear Regulatory Commission, private communication, June, 1979.
11. "Chronology of U.S. and WOCA Nuclear Power Forecasts," Summary Analysis prepared by the Division of Nuclear Energy Analysis of the Office of Applied Analysis of the Energy Information Administration, June 15, 1979.
12. "Radioactive Cobalt for Heat Sources," by J. Walter Joseph, Jr., et al., Savannah River Laboratory, DP-1012, October 1965; T.C. Gorrell, Savannah River Laboratory, private communication, June 1979.
13. M. Levenson and E. Zebroski, "A Fast Breeder System Concept: A Diversion Resistant Fuel Cycle," Fifth Energy Technology Conference, Washington, D.C., Feb. 27, 1978.
14. J.C. Hall, "Evaluation of Alternatives for Processing Uranium-Based LWR Fuels," Allied-General Nuclear Services, AGNS-1040-3.1-15, May 1978.
15. 10 CFR 70.51(e)(5).
16. "Mixed Uranium-Plutonium Oxide Fabrication Facility for Gel-Sphere-Pac Fuel," draft U.S. paper submitted to Working Group 4 of the International Nuclear Fuel Cycle Evaluation (INFCE), ETN/W.G.4/Task4B/11.1-1, Aug. 1978.
17. "Fast Breeder Fuel Cycle," draft U.S. contribution to INFCE W.G. 5B, Aug. 4, 1978.

18. A.L. Lotts, "Fast Breeder Reactor Oxide Fuels Development-Final Report," Compiler, Oak Ridge National Laboratory, ORNL-4901, Nov. 1973.
19. "Reprocessing, Plutonium Handling, Recycle," draft final report of INFCE W.G. 4, Co-chairmen/WG4/73(A,B), Revision 4, May 15, 1979.
20. 44 Fed. Reg. 34467, June 15, 1979.
21. 10 CFR 20.1(c).
22. 42 USCA 4332.
23. 10 CFR 51.22, 51.23.
24. C.V. Chester and R.O. Chester, "Preliminary Evaluation of the Needs for Protection Against Dispersal of Byproduct Materials and Small Quantities of SNM," U.S. Nuclear Regulatory Commission, NUREG/CR-0059, Mar. 1978.

3.3. Coprocessing. Coprocessing means the processing of mixtures of uranium and plutonium or their compounds in such a way that the plutonium is always diluted by uranium. Most often the term is used for a possible mode of operation of spent fuel reprocessing plants in which the product consists of a mixture of uranium and plutonium oxides, coprecipitated from a mixture of nitrates in solution. A related term, co-conversion, is usually used to indicate the conversion of a mixed nitrate solution stream to solid material. The stream may be the end-product of a true coprocessing operation or merely of the mixing of two separate streams of Pu and U nitrates. In any case, co-conversion processes, as required in the NASAP cycles, have not been defined. Several are under investigation but, even for the best of these, further R&D will be required, especially on an industrial scale. New methods are required because the methods fully developed for conversion of individual solutions are not suitable for mixtures.

The alternative cycles considered herein, that involve the coprocessing and/or co-conversion of uranium and plutonium are:

a. the light water U/Pu recycle, in which the recycle fuel is also spiked,

b. the GCFR, in which the core is coprocessed,

c. all of the LMFBRs, except one in which the core is ~ 10% U^{233} in Th and the resulting small quantity of plutonium is diluted with depleted uranium (after processing) and stored, and another in which the core is 14% Pu in Th. In the latter case, the PSEID flow sheet implies that Pu and Th from the core are coprocessed. However, Thorex 3 is the cited process (which yields three separate streams, U, Pu, and Th) and there is at present no postulated process that separates U from Th and Pu leaving the latter two together. We assume therefore, that the Th and Pu product stream would be recombined prior to fuel fabrication. This, of course, is "co-conversion" without "coprocessing" and thus would require further R&D.

While some of the above flow sheets assume that no U and Pu separation occurs during reprocessing, others postulate partial separation so that a pure U product and a mixed Pu/U product result. For some of the

LMFBRs, where pure uranium is partially separated from the blanket for use as a fertile material, the postulated Pu/U streams from reprocessing sometimes contain 20-25% Pu, while those from core reprocessing, in which partial separation does not occur, may be 12-15% Pu.

Thermal recycle fuels typically consist of mixed uranium and plutonium oxides with a plutonium concentration of 2-5%. Feed to a mixed-oxide fabrication plant would have to be somewhat higher than this to allow for blending; a mixture with 10% plutonium oxide has been suggested. Fast breeder reactors require higher plutonium concentrations; mixed-oxide feed to an FBR fuel fabrication plant would probably have a plutonium oxide concentration of about 25%.

The major safeguards advantages of coprocessing are the increased quantity of material that a diverter would have to take for the same amount of plutonium and the increase in the time and resources required to convert the mixed oxide to a form suitable for use in an explosive weapon. The concentration of plutonium in mixed-oxides for thermal recycle fuels would probably be too low for direct use in an explosive. This may not be true for FBR mixed-oxide feed, with its much higher concentration of plutonium. Higher concentrations also tend to vitiate somewhat the advantages of coprocessing. In any case, the maximum allowable percentage of plutonium would have to be set by NRC regulation, and the values selected would have to be based on a consideration of the practical needs of the fabrication plants, the explosive utility of mixed-oxides as a function of plutonium concentration, and the attractiveness of the material to terrorists or other sub-national groups.

The needs of the fabrication plants for large batches (master blends) of mixed-oxides with specific plutonium concentrations and fissile composition would probably require prior blending at the reprocessing plant, either in the liquid nitrate or in the converted powder stage. If the former, then large nitrate storage and mixing tanks with associated pumps and piping would have to be provided and safeguarded, possibly as a separate material balance area. Identification of the accountability problems in this area would require detailed analysis. There has been some recent development work for co-precipitation processes but none on an industrial scale.

Apart from the problem just mentioned, coprocessing would be expected to have a minimum effect on material accountability. Because an additional measurement is required for the feed to a fabrication plant (the Pu/U ratio), the uncertainty in the Pu content of the feed will be slightly larger than for pure plutonium oxide. There may be some minor problems of inhomogeneity, but these could be solved by blending and improved sampling. The same remarks apply to the product of the reprocessing plant. After the blending stage, fabrication plants using mixed-oxide feed are essentially identical to those using mechanical blending of uranium and plutonium oxides, so from this point on the accountability should be unaffected by the nature of the feed.

Scrap recovery facilities processing dirty mixed-oxide scrap will have to be operated in a coprocessing mode also. Accountability should be essentially the same as for facilities producing separated oxides.

Recent and continuing improvements in analytical technology indicate that wet chemical analysis of coprocessed materials could be expected to overcome the sampling difficulties mentioned above and to return results equal in quality to those obtained on separately processed materials.[1] It also appears that the applicability (to coprocessed materials) of current NDA methods is straightforward and no difficulties are foreseen.[2] Within a timeframe consistent with the development of the processes, such new applications can easily be explored and necessary modifications provided if necessary.

REFERENCES

1. C.E. Pietri, J.S. Paller, C.D. Bingham, "The Chemical and Isotopic Analysis of Uranium, Plutonium, and Thorium in Nuclear Fuel Materials," in *Analytical Methods for Safeguards and Accountability Measurements of Spiked Nuclear Materials*, H.T. Yolken and J.E. Bullard, eds., National Bureau of Standards Spec. Pub. No. 528, Nov. 1978, pp. 1-18.
2. J.P. Shipley, D.D. Cobb, R.J. Dietz, M.L. Evans, E.P. Schelonka, D.B. Smith, R.B. Walton, "Coordinated Safeguards for Material Management in a Mixed-Oxide Fuel Facility," Los Alamos Scientific Laboratory, LA-6536, Feb. 1977, Appendix C.

3.4. The Use of U^{233}/Th Fuels. A number of the fuel cycles proposed by NASAP involve the use of U^{233}/ Thorium fuels. These include a majority of the proposed cycles such as:

- a light water reactor using U^{233}/Th fuel
- all of the light water breeders and prebreeders
- the recycle medium-enriched HTGR
- the GCFR
- four of the LMFBR cycles which variously involve the use of U/Pu, U^{233}/Th, or Pu/Th cores but all of which breed U^{233} in a Th blanket.

Compared with plutonium, U^{233} has the advantage that it can be denatured (i.e., rendered unsuitable for direct use in an explosive) with U^{238}; this advantage is shared by U^{235}, of course. The use of denatured fuels is discussed in a separate section. This section will concentrate on the general safeguards problems of U^{233}/Thorium fuels.

Present NRC regulations treat U^{233} as similar to plutonium rather than to U^{235}. Thus, U^{233} occuring is any enrichment is treated as strategic special nuclear material (SSNM), whereas uranium must be enriched to 20% or more in U^{235} to be so treated. For physical protection, threshold quantities of U^{233} are the same as those of plutonium and two-fifths those of U^{235}.

There is little experience with the commercial reprocessing of highly irradiated thorium fuels. Some fabrication has been performed for the light water breeder reactor program. It is therefore difficult to say at this stage whether present NRC material accountability regulations can be met in commercial size reprocessing and fabrication plants for U^{233}/Th fuels. Most likely it will be necessary to operate pilot plants owned by or under contract to the Federal government for a period of time in order to gain experience with these materials. One study estimates that the elapsed time requirements from initial development through demonstration for new reprocessing technology ranges from 12 to 20 years.[1] Since the Thorex systems are furthest from current large-scale practice, we assume that the latter figure is most applicable here.

There are two examples of Th/U^{233} fuel reprocessing that can be cited here. The first of these took place in 1966 when Nuclear Fuel Services (West Valley, New York) reprocessed a thorium-uranium oxide fuel from Consolidated Edison's Indian Point Reactor No. 1. This fuel had a total burnup of approximately 17000 megawatt days per metric tonne. Approximately 1700 kgs of fuel containing about 1000 kgs of uranium was processed. Of this, approximately 145 kg was U^{233} and the MUF was 0.7 kg or ~ 0.5%.[2]

The second example consists of the recently completed, 6-year effort at Oak Ridge National Laboratory, in which LWBR fuel was reprocessed. Over the six-year period 1.6 Te of U^{233} was processed (partly by solvent extraction and partly by ion exchange) with a MUF of approximately 0.23%.[3] While the performance and procedures that resulted in such a low value was not typical of that expected in industrial operations, these results indicate what can be accomplished. One important difference is that the U^{232} content of the Oak Ridge processed material was <8 ppm (with respect to the U^{233}), whereas the NASAP cycles are expected to contain hundreds of ppm with attendant analytical difficulties as discussed below.

The unique characteristic of U^{233} fuels is the high radiation levels associated with the presence of even trace quantities of U^{232} and its daughters. The levels are high enough to require remote fabrication. This has the advantage of limiting physical access to the material. However, it also greatly complicates the assay of U^{233} by nondestructive techniques because of the high gamma activity from U^{232} and its daughters. The magnitude of this gamma background depends strongly on the age and processing histories of both the U^{233} and the thorium in the fuel mixture. For a given amount of U^{232}, the older the U^{233} (i.e., the longer the elapsed time since its last purification) and the thorium, the larger is the background. For some U^{232} concentrations and ages likely to be encountered in any U^{233} recycle program, this background will completely swamp the gamma rays from U^{233}.[4] Large backgrounds will be produced in any gamma-sensitive detector, whether or not used for gamma detection (e.g., organic scintillators used for neutron detection). Nondestructive assay techniques will therefore have to be developed for any fuel cycle using U^{233}. Some effort along these lines has already been made in the HTGR recycle program but it was primarily of an exploratory nature.[5] The feasibility of performing real-time accountability in U^{233} fabrication plants will depend on the successful outcome of such efforts.

Accountability in reprocessing plants for U^{233}/Thorium fuels would be less affected by the radiation from the U^{232} decay chain because most assay in plants of this type is by standard chemical analysis, and radiation levels in much of the process, due to fission-product activity, are already very high.

There is reason to believe, however, that ultimately the accuracies of chemical analyses of these materials will be poorer than those of the more usual plutonium-uranium materials, for the same effort. Also, the high radiation levels, due to the presence of the U^{232} chain, will require that greater care be taken and will require that most of the analyses be done remotely in shielded locations[6] (this is now done only for samples of the dissolver solution and other highly contaminated samples). These effects, taken together may degrade typical analytical measurement uncertainties from ~ 0.1% in the case of U/Pu materials to ~ 0.3-0.4% for U/Th materials.[7] One of the mainstays of present analytical methodology is the use of isotope dilution mass spectrometry. When U^{235} is the important analyte, U^{233} is used as a spike and vice versa. However, if both U^{233} and U^{235} are present in significant amounts, the performance of the method is considerably degraded. For example, if only 0.1-0.2% U^{233} is present, the use of U^{233} as a spike will yield uncertainties (in the U^{235} analysis) of the order of a few tenths of a percent. But if 1-2% U^{233} is present, this uncertainty worsens to 1% or more. Another problem that may be anticipated is the relatively greater difficulty of getting thorium oxide into solution.

The verification activities of NRC inspectors will also be hampered by the high radiation levels in U^{233} fuels. As with spiked fuels (but to a lesser degree), the taking of samples will be laborious and time-consuming, and the samples will have to be sent off-site for analysis, with an attendant loss of timeliness.

Physical security for U^{233} fuels should be better than for plutonium fuels because of the remote nature of the fabrication process, limiting direct access, and because of the abundant and penetrating gamma rays from the U^{232} daughters (principally, those from T1^{208}), which should result in a greatly increased sensitivity of detection by portal radiation monitors.

There will also be a significant deterrent, analogous to that of spiking, from the activity of the U^{232} daughters. Thus, U^{233} bearing fuel will always be "spiked" to a degree. Since the U^{232} has a half life of over 70 years, the effect will be long-lasting. For example, denatured fuel generated via the fast Pu/Th transmuter is expected to contain approximately 150-750 ppm U^{232} in uranium.[8] For 500 g of 12-year old U^{233} containing 250 ppm of U^{232} this would result in a radiation level of 2 r/hr at ~ 1 meter.[9] Thus, for a 10 kg quantity, approximately 1 year old, radiation levels (at 1 meter) would be in the range

8 to 42 r/hr (neglecting self-shielding; the actual values would be somewhat lower). The $T1^{208}$ activity is the important contributor to the radiation. The pattern of growth of its activity following uranium purification results in a short period of time following purification during which the material may be safely handled (before significant $T1^{208}$ growth occurs). This may amount to several days and is useful for operations such as fuel fabrication.

If international safeguards were of concern, and the potential diverter was a national group, the timing of the fuel processing system would have to be controlled because there is an opportunity for such a diverter to circumvent denaturing by extracting Pa^{233} ($t_{1/2} = 27$ days) when the fuel is fresh. After separation, the Pa^{233} is then allowed to decay, and undenatured U^{233} is obtained. This would have to be accomplished within 1 or 2 months of removal from a reactor and is thus of no concern for domestic safeguards purposes.

In summary, a great deal of development and demonstration of accountability techniques will have to be done for U^{233}/Thorium fuels before it can be shown that NRC regulatory requirements for material accountability can be met. Achievement of a real-time accountability capability, if that should ever be required, would require considerably more development.

REFERENCES

1. "Barnwell Nuclear Fuels Plant Applicability Study," 2, U.S. Department of Energy, DOE/ET-0040/2, Vol. 2, April 1978, pp. 3-32 to 3-34.
2. S. Suda, Brookhaven National Laboratory, private communication.
3. R. Brooksbank, Oak Ridge National Laboratory, private communication.
4. E.A. Hakkila, J.W. Barnes, H.A. Dayem, R.J. Dietz, J.P. Shipley, "Preliminary Concepts: Coordinated Safeguards for Materials Management in a Thorium/Uraniu Fuel Reprocessing Plant," Los Alamos Scientific Laboratory, LA-7411-MS, Oct. 1978.
5. A. Carpenter, Jr., S.R. McNeany, P. Argentini, N.D. Holden, L. Abraham, "Material Control and Accountability Aspects of Safeguards for the USA ^{233}U/Th Fuel Recmycle Plant," Oak Ridge National Laboratory, ORNL/TM-6645, Jan. 1979; J.D. Jenkins, S.R. McNeany, J.E. Rushton, "Conceptual Design of the Special Nuclear Material Nondestructive Assay and Accountability System for the HTGR Fuel Refabrication Pilot Plant," Oak Ridge National Laboratory, ORNL/TM-4917, July 1975.
6. E.A. Hakkila, "A Critical Review of Analytical Techniques for Safeguarding the Thorium/Uranium Fuel Cycle," Los Alamos Scientific Laboratory, LA-7372, Oct. 1978.
7. C. Pietri, New Brunswick Laboratory, private communication.
8. D.T. Ingersoll, "Estimated ^{232}U Concentrations in Denatured Fuel," in "Interim Assessment of the Denatured ^{233}U Fuel Cycle: Feasibility and Non-Proliferation Characteristics," Oak Ridge National Laboratory, ORNL-5388, Dec. 1978, pp. 3-6 to 3-9.
9. J.D. Jenkins, "Fabrication and Handling of Denatured Fuel," in "Interim

Assessment of the Denatured ^{233}U Fuel Cycle: Feasibility and Non-Proliferation Characteristics," Oak Ridge National Laboratory, ORNL-5388, Dec. 1978, pp. 3-20 to 3-21.

3.5. Denaturing Denaturing may be defined as the addition of a non-fissile isotope to a fissile isotope of an element in such proportions as to make the fast critical mass of the mixture impracticably large for a nuclear explosive weapon.

Since all the isotopes of plutonium have appreciable fast-fission cross sections, plutonium cannot be denatured. The fast-fission cross section of U^{238} is low enough, however, to allow the fissile isotopes U^{233} and U^{235} to be denatured by its addition.

The choice of a threshold enrichment for denaturing is important. It will be noted that the definition given above does not imply a sharp enrichment cut-off. Such a cut-off could be defined as the enrichment at which the fast critical mass becomes infinite, but this choice would limit the use of U^{233} to enrichments in the neighborhood of 3% and U^{235} to those in the neighborhood of 5%. NRC regulations define a threshold such that material enriched to 20% or more in U^{235} is considered strategic special nuclear material, subject to the full requirements for physical security. This corresponds to a bare spherical critical mass of 850 kg of U metal. The enrichment in U^{233} at the same critical mass is about 12%, which is usually assumed to be the threshold enrichment for denaturing of U^{233} fuels in NASAP studies. The use of appropriate reflectors may substantially reduce the total mass of a nuclear explosive, however, and NRC may want to review the data for U^{233} before selecting an enrichment limit for uranium containing this isotope. Enrichment limits for uranium containing both U^{233} and U^{235} may also have to be set. Another consideration that may enter into setting threshold enrichmemts for uranium containing U^{233} is the greater ease[1] of separating this isotope from U^{238}, compared with that of separating U^{235}. Also, materials that are more highly enriched, although still below the above thresholds, are more easily further enriched to a weapons useable level. Although it is considered that isotopic enrichment is beyond the capabilities of domestic safeguards adversaries, uranium enriched in U^{233} would be a more attractive target for diversion and subsequent shipment for further enrichment to a foreign country whose government was interested in a clandestine weapons program.

The effect of the decay of U^{232} and its daughters on the nondestructive assay of U^{233} fuels has been noted in the previous section. This effect will occur in denatured U^{233} fuels as well, of course, and will subject material accountability for these fuels to all the disadvantages already noted. However, since by definition denatured fuels are not useful for nuclear explosives, the consequences of the somewhat lower accuracy of material balance and the impairment of the prospects for real-time accountability are not as serious. Of course the presence of U^{232} as a "spikant" also offers additional protection against the diversion of such fuels.

In some of the proposed fuel cycles involving denatured U^{233} fuels, such as the LWR, substantial quantities of plutonium appear in the spent fuel. The fuel will therefore have to be reprocessed by a combination of the Purex and Thorex processes. Very little, if any, experience in reprocessing such fuels exists, and therefore it is very difficult to say how well NRC's accountability requirements can be met in such a reprocessing plant, at least without detailed study. Certainly the chemical analysis of such mixtures will be more difficult than that of ordinary spent LWR fuels (see discussion in previous section).

The disposition of the plutonium separated from spent denatured fuels of this type is also important. It may be either stored, for eventual use in the fast breeder reactor cycle, or recycled in "secure" energy centers. In the former case, neither the form of nor the responsibility for storage has been worked out. If the Federal Government accepts responsibility for storage, NRC may not have a safeguards role. If storage is in licensed facilities, the safeguards problems will be essentially the same as those already considered in the GESMO proceeding (note that although the NASAP reports speak of "secure" storage, it is not clear how this differs from any safeguarded facility). Accountability for plutonium in storage is particularly simple if it is stored in discrete containers, each containing a few kg of Pu. Surveillance devices could be incorporated to give an instantaneous alarm in case of tampering. In a number of proposed cycles, it is suggested that Pu bulk material be spiked by preirradiation prior to storage. It is not likely that this will be accomplished or that if it were, that it will be effective for a significantly long storage period.

If the plutonium recovered from spent denatured fuel is recycled in energy centers, the safeguards technical problems are essentially the same as for the U/Pu cycle, with the modifications associated with the physical and administrative nature of energy centers. The safeguards regulatory issues involved in the operation of a multinational center are discussed in a separate report. Except for the reduction in the transport of SSNM, technical safeguards in energy centers are essentially the same as in dispersed sites. An additional complication would arise from the occurrence of non-denatured U^{233} in the blanket of a Pu/U/Th breeder, but the U^{233} could be denatured during the recovery process or shortly thereafter.

In some of the proposed cycles, when provision is made to denature the U^{233} that is bred, prior either to fuel fabrication or storage, highly enriched material is required as a makeup fuel. Otherwise, such denatured fuel cycles, in which spent fuel is recycled, tend to evolve toward increased plutonium and decreased U^{233} as more denatured fuel is added. In the case of the LWBRs, up to 93% enriched U^{235} is proposed as a makeup to prevent this "drift" from occurring.

Since all the proposed U^{233}-based cycles involve plutonium or highly enriched uranium, either to breed the initial U^{233} or as a product, the only safeguards advantage of denatured U^{233}-thorium cycles over U/Pu cycles is that, at least in principle, they permit the confinement of strategic special nuclear material to co-located centers, while permitting the denatured product of these centers, unattractive to subnational diverters, to be used in dispersed reactors. To gain even this advantage the centers would have to be of the power generating type; non-power-generating centers do not provide it. Furthermore, since reactors have to be strongly protected against sabotage anyway, regardless of the type of fuel they use, the adoption of denatured cycles would eliminate only the need for physical protection of the fresh fuel assemblies in transit. The domestic safeguards value of denatured fuel cycles as compared with U/Pu cycles therefore depends almost entirely on how attractive fresh MOX fuel assemblies in transit would be to subnational groups; at present, NRC can arrive only at a subjective but informed judgment concerning this matter.

While the statement is made above that plutonium cannot be denatured in the true sense, it has been pointed out that a Pu^{238} content in the range of 5-10% would make it extremely difficult to produce a weapon due to the heating effect in such material.[2] In at least one cycle, HTGR using 20% U^{235}/Th fuel, the plutonium in the spent fuel will have a composition in this range. While the cycle calls for storage of spent fuel, in this case, the plutonium would not be attractive to *subnational* groups for diversion even if it were reprocessed.

To conclude, the major safeguards technical problems associated with denatured U^{233} fuels are those common to any fuel using U^{233}, discussed in a previous section, the lack of experience with the reprocessing of mixed U/Pu/U^{233} fuels, and the refabrication of the denatured fuel. Important regulatory issues are the threshold enrichment at which U^{233} is considered to be denatured, the use of highly enriched makeup materials, and the use of moderately enriched (but below threshold) materials.

REFERENCES

1. Technical Support Organization, "Preliminary Safeguards Analysis of Denatured Thorium Fuel Cycles," BNL, File No . 5.8.13, Nov. 1976 (Rev. July 1977).
2. Allied-General Nuclear Services, "A Fuel Cycle Concept Utilizing Pu^{238} as a Heat Spike to Enhance Proliferation Resistance," Aug. 1978 (unpublished).

3.6 The Use of Heavy Water as a Moderator.

3.6.1. Introduction. One of the alternative fuel cycles under consideration in the NASAP program is based upon the use of heavy-water reactors (HWRs). There is also a possibility, proposed through INFCE, that an enhanced burn-up LWR system might be operated via spectral shift using heavy water upgrading. Comments made below regarding upgraders associated with HWRs are applicable for this case as well. There are two important safeguards problems associated with the use of this type of reactor: the availability of heavy water in large quantities, and on-line refueling. This section will consider only the first; the latter is discussed in part 4.

The significance of heavy water for safeguards is that it can be used to moderate reactors fuelled with natural uranium, and these can be used to produce plutonium. A substantial conmmitment to the heavy-water reactor fuel cycle in the U.S. would probably, therefore, require the imposition of safeguards on heavy water, not now required by NRC regulations. Safeguards would be required on the heavy water in reactors, in the concentrators for contaminated (i.e., light-water diluted) heavy water, in production facilities, and in storage. Safeguards would consist of material accounting and surveillance and containment. Since heavy water cannot be used directly in an explosive and is not highly toxic, physical protection would probably not be required for safeguards purposes. However, the tritium content of irradiated heavy water presents a radiological safety hazard.

In the U.S., production of heavy water is under Federal control and is not licensed or regulated by NRC. Conceivably, this situation could change if the heavy water reactor cycle were adopted.

If NRC is to require safeguards on heavy water it must decide on (a) the minimum amount of heavy water of safeguards significance, and (b) the threshold concentration of D_2O in water for safeguards to apply. Since heavy water would be safeguarded solely in the interests of non-proliferation, the values of these parameters should be at least consistent with international commitments. Safeguards on heavy water are not required under the NPT INFCIRC/153 system of the IAEA, but may be under bilateral or trilateral agreements or voluntary submissions. Consequently, the IAEA has not defined quantities of heavy water of safeguards significance. The trigger list of the London Suppliers Group required the imposition of safeguards when a country imports 200 kg of deuterium or more in any compound in which the ratio of deuterium to hydrogen exceeds 1:5000 (0.02 mole %), in one year. To set this number in perspective, a heavy-water moderated reactor with a plutonium production capacity of 8 kg per year would require an initial inventory of 10-20 tonnes of heavy water with a D_2O concentration of ~ 99.7% (concentration in normal water is 0.014 mole %). The contained deuterium would amount to 2000-4000 kg.

It should be noted that safeguards, including accountability, are required by the Department of Energy for heavy water under its control.[1]

Much of the following discussion is based on a recent report on heavy water safeguards.[2]

3.6.2. International Safeguards for Heavy-Water Production Facilities. Commercial heavy-water production facilities usually consist of two processes: the extraction process, in which heavy water is extracted from ordinary water and concentrated to a few percent D_2O, and the finishing process in which the product frocm the extraction stage is further enriched to a D_2O concentration of 99.75 mole percent. Most large production plants use the H_2O-H_2S dual-temperature exchange process (called the "GS" process) for the extraction stage, and a water distillation ("DW") process for the finishing stage.

For plants of commercial size (at least 200 Te of D_2O per year), present accountability techniques appear to be too inaccurate to detect the diversion from the extraction process of the minimum quantity ($\sim$ 10 Te) of D_2O required to supply the initial inventory of a small plutonium production reactor (annual production rate 8 kg Pu). Safeguarding such a plant would therefore require improved accountability techniques or increased reliance on surveillance and containment. This conclusion is tentative, since a careful analysis of the material balance problems in such a plant has not been done.

The finishing process, because of its much smaller flows, is more amenable to material balance techniques, and it appears that present methods have sufficient sensitivity to detect the diversion of significant quantities of D_2O. Improved design of this part of the process could reduce the present uncertainties even further. Surveillance and containment techniques would have to be developed to detect undeclared feed or product.

Because of the extremely large flows through such plants, NRC inspection would be facilitated by on-line flow and assay devices for feed, product, and waste. Currently, the chief weakness of the accounting system in large plants is the flow measurement. At best the uncertainties are approximately 1% corresponding to $\sim$ 18 Te/yr in at 200 Te/yr plant. Portable nondestructive assay instrumentation for the measurement of concentration would also be useful for inspection purposes.

It is clear that applying safeguards to such a plant would involve problems different from those NRC has encountered in other types of safeguarded plants so far. Considerable development of criteria and methods for safeguarding large plants of this type would have to be undertaken if they were to become a reality in the U.S. licensed industry. Such development could profit from the experience of DOE and the Canadians in this area.

3.6.3. Safeguarding of Heavy Water in Reactors. Typically the inventory of heavy water in HWRs is on the order of 1-2 Te/MWe, with newer plants being near the low end of the range. Normal operating losses in CANDUs amount to 1% or less per year. Accidental spills may be larger than this. Approximately 60% of the water is used for the moderator and the remainder is in the cooling circuit.

AECL is preparing a report for the IAEA on D_2O safeguards in CANDUs. It is expected that, with improved techniques, on a monthly basis the LEMUF in the reactor inventory of heavy water will be about 2% and on a yearly basis less than 1% — i.e., for a large power reactor roughly equal to the quantity of safeguards significance discussed above (~ 10 Te). Detailed data on current accountability capabilities need to be gathered before an assessment can be made.

Power reactors also often include an upgrader for light-water contaminated heavy water. These are usually of the distillation or electrolytic type. Because of the lower throughput, these would be easier to safeguard than the finishing units in production plants. "Waste" from a power reactor upgrader (~ 90% D_2O) is sent to a central reconcentrating facility, which is usually a DW and/or electrolytic facility similar, except in capacity, to the finishing processor for virgin D_2O. Irradiated D_2O is not processed in the finishing facilities for virgin D_2O because of the tritium contamination.

Research reactors require much smaller amounts of heavy water (usually substantially less than 100 Te). Loss of safeguards significant quantities can probably be detected by checking reactor operating characteristics. To keep tritium levels down, a substantial part of the inventory (e.g., one-third for the HFBR reactor at BNL) may be replaced each year. It will be necessary for NRC to keep track of such replacements and verify them as the occasion demands.

To summarize, inadequate data is available on the safeguarding of heavy water in power reactors and related facilities. Accountability for large reactors appears to be marginal at present, but it is felt that improvements can be made. Techniques for verification by inspectors will need to be worked out. Portable instrumentation for measurement of D_2O concentration will probably have to be developed.

3.6.4. Safeguarding of Heavy Water in Storage Facilities. D_2O is usually stored in 55-gallon drums. A storage facility may contain hundreds or thousands of these. NRC would have to develop sampling plans and methods for verifying the content of the drums. Portable instruments for verification would greatly improve the timeliness of detection.

Substantial amounts of D_2O may also be stored at or near reactors. The problems of accountability and verification will be similar.

In general, the technical problems of safeguarding storage facilities for D_2O would appear to be small compared with those for production facilities and large power reactors; however, the economic and operational impact would probably be significant.

REFERENCES

1. DOE Internal Management Directive 6104-A, p. 8.
2. "Heavy Water Accountability," Brookhaven National Laboratory, BNL-24941, September 20, 1978.

3.7. Storage of Spent Fuel and Waste. All fuel cycles involve at least the temporary storage of spent fuel at reactors and, possibly, at away from reactor storage (AFRs). Once-through fuel cycles require the indefinite or permanent storage of spent fuel, while those dependent on reprocessing of spent fuel produce large amounts of high-level waste which must be stored permanently and which will contain relatively small quantities of SSNM.

Domestic safeguards for spent fuel stored at reactors are specified by NRC in 10CFR70 (material control and accountability) and 10CFR73 (physical protection). Material accountability is based on item counting. Physical protection requirements are those which apply to the reactor as a whole (10CFR73.55) and are aimed at preventing sabotage. Similar accountability requirements apply to AFRs, but the physical protection requirements are those which apply to fixed sites (10CFR73.50) rather than to reactors.

NRC therefore has had considerable experience with the safeguarding of temporarily-stored spent fuel from light-water reactors, at least. Additional problems will arise in certain of the fuel cycles, particularly in the HWR, because of the continuous refuelling feature and large number of fuel bundles in this reactor. Problems specific to certain reactor types will be discussed in the next part of this report.

The indefinite or permanent storage of spent fuel is generic to all once-through fuel cycles. In the U.S. such storage would probably be in facilities owned and operated by the Federal Government or, conceivably, by a multinational agency. The Energy Reorganization Act of 1974 (Public Law 93-438) gives NRC regulatory authority over all high-level waste storage, whether retrievable or long-term; presumably this includes both surface and geologic storage of spent fuel.

Since diversion or seizure of spent fuel by a terrorist group for purposes of recovery of the contained SSNM is regarded as barely credible, the major safeguards concern is with national diversion; in addition, there is some concern over sabotage.

Under present IAEA regulations, safeguards over a material may be terminated if the Agency determines "that the material is consumed, diluted in such a way that it is no longer usable for any nuclear activity relevant for safeguards, or has become practicably irrecoverable."[1] Spent fuel is only partially consumed, and is clearly not dilute enough to become irrelevant to safeguards. However, the Agency might decide that, following decommissioning of a sealed, back-filled geologic repository, the spent fuel is practicably irrecoverable, and therefore that safeguards should be terminated. However, at the very least, international safeguards will be required during the active life of the repository (at least 20 years). NRC would therefore have to ensure that safeguards on such repositories were carried out in a manner consistent with IAEA

The main objectives of a safeguards system for a spent-fuel repository would be to ensure that the spent fuel has been tracked from the reactor or AFR to its final emplacement, and to detect any diversion from the repository. How these objectives can be achieved cannot be specified in the absence of a specific repository design and some information about institutional or policy limitations. Two recent studies[2,3] have therefore hypothesized the former on the basis of INFCE and US conceptual designs, and examined the possible kinds of instrumentation and procedures that would be required. It must be emphasized that the studies are highly speculative. However, they identify certain problems and issues that are likely to arise in any spent-fuel repository.

The repository was assumed to be excavated in a deep geologic formation (e.g., embedded salt or granite). It receives spent fuel and various forms of waste (not, however, mining or milling wastes or enrichment plant tails). Alternatively, if spent fuel is reprocessed, it may receive only processing wastes, including high-level wastes. It would serve a 100-GWe reactor industry, either in a once-through or a recycle mode. In the former case, approximately 20 spent fuel assemblies would be received per day; in the latter, 4-6 canisters of high-level waste. In addition, intermediate and low level wastes may be received at the rate of 250-2500 drums/day. The active lifetime of the facility would be at least 20 years.

It is planned to place spent fuel in cannisters before burying them. This could be done either at the shipping facility or at the repository. For safeguards purposes there are good reasons for recommending the latter. Drummed wastes will be placed in overpacks before burial.

Material control and accountability would be based primarily on item accounting, heavily supported by surveillance and containment. It will be necessary to verify, in the case of spent fuel, that shipments contain actual spent fuel assemblies, not dummies or high-level waste substitutes. This can be done by verifying the integrity of seals applied by an IAEA inspector at the shipping point. It will then be necessary to monitor the progress of the assemblies from the opening of the cask to cannistering (if done at the repository) to the descent to the burial level to emplacement in holes in the floor of one of the many burial rooms. The identity of the assembly will be verified and recorded and the location of its final disposition also logged.

Instruments required will be equipment for remote read-out of shipping cask seals, TV or film cameras for monitoring the opening of and inspecting the interior of the cask before it is closed up again and returned, counters that will not only count the number of fuel assemblies passing by but also their direction of passage, possibly radiation-signature detectors, etc.

Similar equipment will be required for the various forms of waste, although probably less elaborate and detailed monitoring will be required. More for criticality safety than for safeguards, it will be necessary to ensure that the incoming packages do not inadvertently contain large quantities of SSNM. A good remote-reading identification system for drums will be required.

The kinds of instruments described above exist mostly in prototypical form or only on paper, although recording automatic TV and film cameras are a part of present surveillance systems. Considerable work has been done on remote readable ultrasonic seals and on directional bundle counters (for spent CANDU elements). The use of radiation signatures as a means of identification, although easy to conceptualize, has not been explored systematically. Various candidates for remote-reading identification (e.g., bar codes, magnetic strips, etc.) have been suggested, but none have been developed specifically for this purpose. Obviously, a great deal of additional development of these various elements will have to be undertaken and then the elements will have to be assembled into a coherent system and demonstrated.

The degree of complexity of the instruments is determined to a great extent by whether inspectors are continually present or visit only periodically. It should be remembered that on the order of twenty spent fuel elements and hundreds of waste drums arrive each day, so activity at the repository is considerable and continuous. If inspectors visit only periodically, the instruments — including those for verifying seal integrity — must be capable of untended, remote operation, recording, and storage for future perusal; they must also be tamper- resistant or tamper-indicating. These features will be unnecessary if inspectors are always present. So a key question is that of resident versus periodic inspection. The latter would involve intervals of several months, at least, between inspections.

A second key question is whether fissile assay of receipts will be required at the repository. If so, a great deal of research and development will have to be done. Although methods for fissile assay of spent fuel and for the less demanding but more indirect determination of burnup have been proposed,[4] none has been demonstrated, yet, to have the desired accuracy. The problems, particularly for fissile assay, are formidable: complete masking of the characteristic gamma rays from the fissile species by those from the fission products, self-shielding of gamma rays, migration of fission products, self shielding of interrogating neutrons, non-uniform burn-up in assemblies, extended geometry, etc. The present status of burn-up and fissile-assay measurements is reviewed in references 3 and 4, which conclude that, although there are some promising techniques (more so for burn-up than for fissile assay), a great deal of additional research is required. It may be that direct fissile assay will never be developed to the required accuracy or will be impracticable, but that the indirect burn-up technique will be an acceptable substitute.

The assay of the various forms of waste at the repository is also difficult, though not quite as formidable as that of spent fuel. Here the problems are inhomogeneity, fission-product gammas (for the high-level and intermediate wastes), possibly unknown chemical or isotopic composition, dense or inadequately characterized matrices, inability to sample, unfavorable geometry, etc. These are strong arguments for requiring the originator of the wastes to assay them before shipping them out.

Concerning the measurement of radiation signatures for purposes of identification, reference 3 points out that even this technique is not simple or straightforward in any practical case in which a large variety of wastes is received from many different sources.

As noted above, whether or not fissile assay of wastes is required at the repository, it will probably be necessary to make some sort of "go, no-go" measurement, for criticality purposes, to provide assurance against the inadvertent inclusion of large quantities of SSNM in the waste drums. For plutonium wastes, some sort of neutron-coincidence device might be useful. U^{233} or U^{235} wastes might require an active neutron interrogation method. The prime requirements here will be sensitivity, not accuracy.

A third key question affecting the nature of the procedures at the repository is whether spent fuel is to be canned at the shipment point or at the repository. A strong argument is presented in references 2 and 3 for the former procedure. Once the assemblies are canned it is difficult to verify the contents. If canning is done before shipment, under certain conditions it might be possible for the nation to divert assemblies and replace them with substitutes, with little chance of discovery. On the other hand, canning at the repository would allow direct visual examination of the fuel assemblies.

The three key issues discussed above would have to be settled in advance of the design of the repositories, since they strongly affect it as well as the design of the instruments. The issues of fissile assay and canning of the fuel could be settled solely by NRC; the issue of resident inspection would be a matter of negotiation with the IAEA whose resolution would also depend on the kinds of instrumentation that will be available. Since the establishment of a geologic spent-fuel, high-level waste repository is not likely to occur till the 1990's, there is adequate time to develop the needed instruments.

It is important to note that the key issues identified above arise independently of whether the repository is deep geological or on the surface, as has also been proposed (e.g., for CANDU elements). The kinds of instruments needed might depend on this choice, however.

Decommissioning a geologic repository would involve backfilling and sealing it. Any attempt to retrieve the spent fuel would be an elaborate, time-consuming operation, easily detected.[3] Safeguards might therefore consist of visits by IAEA inspectors at intervals of a few months or, more likely, at longer (e.g., annual) intervals, to verify the absence of suspicious activities.

REFERENCES

1. "The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," International Atomic Energy Agency, INFCIRC/153, May 1971.

2. "Safeguards for Geologic Repositories," draft appendix to the report of INFCE Working Group 7, "Proliferation and Safeguards Concerns for Waste Management in the Nuclear Fuel Cycle," Mar. 14, 1979.
3. C.A. Ostenak, W.J. Whitty, and R.J. Dietz, "Preliminary Concepts: Safeguards for A Nuclear-Waste Geologic Repository," Los Alamos Scientific Laboratory (undated draft).
4. S.T. Hsue, "Nondestructive Assay Methods for Irradiated Nuclear Fuels," *et al.*, Los Alamos Scientific Laboratory, LA-6923, Jan. 1978.

3.8. Storage of U^{233} and Plutonium in Bulk. Several of the proposed alternative cycles involve the secure storage of bulk fissile materials for an indefinite period. These may be denatured (in the case of U^{233}), diluted with non-fissile material (e.g., plutonium mixed with depleted uranium), or protected by "spiking." Also some of the cycles call for the addition of fissile materials as a make-up for the fuel input. These materials come from some assumed stored supply which, by implication, also involves "secure" long-term storage. The cycles involving bulk SSNM storage, the materials and quantities involved, and any protection afforded are summarized in Table 3.8.-1. Cycles not shown in the table do not involve bulk SSNM storage.

Bulk storage facilities for SSNM are likely to have a capacity for storing very large stocks of inactive materials. The reason for this is that supply and demand of these materials tend to be only loosely coupled.[1] The supply of plutonium or U^{233} is dictated largely by the desire to dispose of spent fuel and to operate the extremely costly reprocessing plants at as near full capacity as possible. The demand, on the other hand, is affected by such factors as the cost of recycle fuels versus that of new fuels, availability of fabrication capacity, the demand for fast breeder fuels, etc.

As an example of the quantities that may be stored, Sandia Laboratories has prepared a conceptual design for a plutonium storage facility with a capacity of 40 tonnes of oxide.[1] Although designed for normal plutonium recovered from LWR spent fuel, it could also, with some modification (mainly with respect to shielding thickness and handling methods) be adapted to the storage of U^{233} or spiked plutonium. Suitability for U^{235} would depend on its chemical form — e.g., whether hexafluoride, oxide, or metal.

All operations except analytical ones are performed remotely. Plutonium is stored in canisters (up to 10 kg each) which in turn are placed in pressure vessels designed to vent the gases built up from the radiolysis of moisture and alpha decay. Up to four canisters may be stored in a pressure vessel. Pressure vessels are placed inside shipping containers for shipment off-site, and are received in these containers.

The storage vault is below ground. Pressure vessels are transferred into and out of it by means of a rotating remotely operated turntable. All other movement of materials is also controlled remotely, either by computer command or manually. The presence of individual containers is monitored

Table 3.8.-1.

Alternative Cycles Requiring Storage of Bulk SSNM

	STORED PRODUCTS			MAKE-UP MATERIALS		
		Quantities (kg/.75 GWe/yr)				
Cycle Description	Material	SSNM	Total HM	Material	SSNM	Total HM
LWR- Denatured U^{233}/Th	Pu (with ^{60}Co spike)	93	93	U^{233}	317	636
LWBR- Type I Prebreeder[c]	(a) Pu	95	95			
	(b) 93% U^{233}[a]	449	464			
Backfit Prebreeder[c]	(a) Pu	91	91			
	(b) 91% U^{233}[a]	250	278			
High Enriched, Backfit Prebreeder	74% U^{235}	586	792	93% U^{235}	230	248
High Enriched, Seed/ Blanket Breeder				67% U^{233}	97	145
HTGR- Denatured U^{233}/Th	(a) Pu	74	74	12% Denat. U^{233}	390	3300
	(b) 3% Denat. U^{233}	125	4250			
GCFR-	U^{233}[a] (Denat.)	421	3500	Pu in U (20% fiss.)	178	890
LMFBR- U/Pu Core/U Blanket	17% Pu/U	240	1190			
U/Pu Core/U Blanket (spiked)	(hetero-) 20% Pu/U	250	1250			
	(homo-) 20% Pu/U	238	1188			
U/Pu Core/U/Th Blankets	(hetero-) Denatured U^{233} (12%)	424	3570	20% fiss. Pu in U	208	1041
	(homo-[b]) Denatured U^{233} (12%)	324	2700	20% fiss. Pu in U	100	500
10% U^{233} Core/Th Blanket	18% Pu in U[a]	493	2760	25% U^{233}	319	1290

[a] Contains U^{232} as a "spike"

[b] No U in Blanket

[c] Owing to U^{232} contamination in material to be re-enriched, additional storage and makeup material requirements are likely. See Chapter 4.

continuously by special sensors. The safeguards virtue of this design is that it strictly limits direct access by personnel to the sensitive material.

For the storage of inactive stocks, material accountability would be based almost exclusively on item identification and accounting. Seals and identification of receipts would be verified upon removal from the transport vehicle. Containers would be checked for contamination before transferring them to storage. The use of the same containers for both storage and shipment would greatly reduce the need for handling of loose powders. Broken seals or damaged containers would require a capability for verifying the contents through sampling and analysis or by NDA, so an analytical laboratory and hot cells for opening the containers and sampling the contents would have to be provided.

The underground location of the vault and other sensitive parts of the facility greatly enhances both safety and security against overt attack. The only sensitive facilities located above ground are the loading and unloading bay for the transport vehicle.

The advent of the policy of deferring reprocessing caused further design work on this concept to cease (although the safeguards system design was not completed, an analysis of target attractiveness and vulnerabilities had been). However, the basic concept seems sound and would represent a considerable advance over present methods of storing SSNM.

Since up to 1000 pressure vessels, each containing up to 40 kg of Pu, might be stored at the facility, inventory verification by NRC and the IAEA would require considerable effort. Extensive reliance would have to be placed on remotely readable seals, which are still under development in a number of places. Spiked materials would be more difficult to verify in case of a damaged or broken seal, but no more so than the SNM content of the dissolver solution in a reprocessing plant. As noted earlier, since the facility is shielded and designed for remote operation anyway, it could probably be readily adapted for the storage of spiked SSNM also.

It therefore appears that the technology for improved safeguarded storage of inactive stocks of SSNM, whether or not spiked, is well in hand, with only straightforward extrapolation and application of existing techniques being required.

REFERENCE

1. Cecil S. Sonnier, "Baseline Description and Safeguards Concerns for a Fuel-Cycle Plutonium Storage Facility," Sandia Laboratories, SAND77-1494 (Revised), Feb. 1978.

3.9. International Fuel Service Centers. Most of the safeguards issues raised by international fuel service centers[1,2] (IFSCs) are institutional rather than technical in nature. That is, the same technical measures can be applied regardless of the nature of the management or whether the facilities are dispersed or co-located.

The co-location feature would provide certain safeguards advantages. For the most part it would eliminate shipments of bulk SSNM, with the attendant vulnerabilities to attack. The concentration of sensitive facilities should make possible some reduction in safeguards costs, through the sharing of personnel and some equipment. In power-generating IFSCs, in particular, because of their large size, a dedicated, centralized response force could reduce the number of guards at individual facilities. The layout of the IFSC could be designed at the outset to provide high mobility to the response force (this has the disadvantage, however, that it would also increase the mobility of attackers). It is important to realize, however, that the international or multinational character of fuel service centers, although possibly a nonproliferation advantage, does not necessarily make them any less vulnerable than private or national centers to diversion or attack by subnational groups. Nor are these threats necessarily reduced by the co-location feature. In other words, regardless of the co-location or the multinational feature, fixed-site safeguards at least equivalent to those described by present NRC regulations would continue to be required.

Transportation of SSNM in fuel assemblies would be eliminated only if the IFSCs were of the power generating type, with the reactors (e.g., Pu breeders or Pu/U^{233}/Th transmuters) being co-located with the processing plants. In this case only fuel assemblies containing spiked U/Pu oxides or denatured U^{233} would be shipped out of the centers. The latter would not need physical protection, if it were regarded as the equivalent, from a safeguards point of view, of uranium enriched to less than 20% in U^{235} (which, under present NRC regulations, it is not, of course). The question of physical protection of shipments of spiked SSNM has been discussed in Section 3.2.

More efficient use could also be made of both NRC and IAEA inspectors, since inter-facility travel times would be much reduced. Inspection equipment could be stored at central depots, making possible the use of more elaborate and diversified instruments. It would probably be economic, with the large power generating IFSCs, to station a permanent NRC or IAEA inspection force at the site. The IAEA could carry out simultaneous inspections at a number of linked or similar facilities, a nonproliferation advantage.

Probably not all shipments of SSNM would be eliminated. Some of the fuel cycles require highly enriched uranium make-up; this would have to come from an enrichment plant located outside the IFSC, since it is not proposed to include them in the centers. A breakdown, strike, or other work stoppage at either the reprocessing plant or the fabrication plant could require shipments of SSNM either to or from similar facilities located elsewhere, in order to avoid disruption of production schedules or exceeding local storage capacities.

The presence of thousands of construction workers for many years would be a safeguards disadvantage, since they could provide cover for potential diverters or terrorists.

The interaction between the domestic and the international safeguards systems at multinational IFSC's could affect some technical safeguards measures since, to avoid duplication, it might be desirable to use common instruments, procedures, and data for both purposes. For example, instruments for international use would have to have tamper-resistant features not required for domestic safeguards.

None of the few technical safeguards problems associated with centers, as compared with dispersed sites, appear to be significant enough to count against them. Much more significant are the institutional questions, which are treated in another report in this series.

REFERENCES

1. Preliminary Safety and Environmental Information Document, Vol. VII, Rev. 1, "Fuel Cycle Facilities," Department of Energy, NASAP 78-12, Jan. 1979.
2. "International Fuel Service Center Study," Burns and Roe Industrial Services Corp., (draft) Aug. 1978.

3.1[illegible]. Transportation There are no special issues associated with the transportation of spent fuel or SSNM in fuel assemblies in the alternative fuel cycles since such materials are already being transported (although only in limited amounts for the latter). However a number of the proposed alternative cycles involve the transport of bulk SSNM, spiked fuel, and the spikants themselves. The quantities involved are indicated in Section 2.2.4. and the properties of these materials are further described in appropriate sections of this part.

The quantities and types of materials to be shipped are quite sensitive to the co-location of facilities. As planned, reprocessing plants and fabrication facilities are to be co-located, thus minimizing the shipment of bulk materials. However, one can conceive of emergency situations in which, for example, a fabrication plant is shutdown and bulk material from the co-located reprocessing plant must go to a distant fabrication plant. Also, a number of the proposed cycles include the addition of make-up materials in bulk form to the fabrication process, which are to be taken from storage (which may not be co-located*) or which are to be transported from a remote enrichment plant in a highly desirable form. In addition, some cycles call for the storage of spiked SSNM in bulk and of waste containing SSNM. Under certain circumstances some of these materials might also be transported; for example, if adequate storage facilities are not co-located with the reprocessing-fabrication complex. Also, for several of the proposals involving recycling, until equilibrium is reached, there are additional requirements to be met by other sources which will undoubtedly add to transportation requirements.

Thus, a number of issues may arise vis-a-vis the physical protection, during transportation, of such materials. The quantities involved vary considerably as a function of the cycle. Thus, as indicated in Section 2.2.4., the mass of heavy metal shipped (as assemblies only) varies by a factor of 30, the number of truckloads by a factor of 10, and the quantity of SSNM by a factor of 150 over the range of the fuel cycles as planned, not including some of the peripheral and contingency factors mentioned above.

Additional regulations might be required concerning: (a) additional protection for highly desirable bulk SSNM, (b) consideration of spiked materials as spent fuel and at what level of spikant, (c) protection of large shipment of spikant (e.g., Co^{60}) and, (d) possible beneficial impact of SSNM dilution (as mixed oxides) in bulk and in fuel. None of these issues should pose any difficulty but will eventually need to be considered.

IV. ANALYSIS OF INDIVIDUAL FUEL CYCLES

In this chapter the individual fuel cycles are reviewed and both the generic and specific safeguards issues associated with them are identified. For a discussion of the generic issues the reader is referred to the appropriate section number in part 3. The additional issues specific to a particular fuel cycle are discussed under the heading for that fuel cycle, below.

4.1. Light-Water Reactors

4.1.1. "Standard" Once-Through PWR Using LEU (U^{235}) Fuel. This is the present reference cycle, for which the safeguards issues, except for one, are in place and well understood. The exception is the safeguarding of permanently stored spent fuel (see Section 3.7.).

4.1.2. Once-Through PWR Using LEU (U^{235}) Fuel with Extended Burnup. This cycle is essentially the same as the previous one, except for the slightly higher enrichment of the fuel and the reduced annual discharge of spent fuel (~3/5 that of the reference once-through cycle). The latter would reduce both the number of shipments of spent fuel and the number of spent fuel elements to be safeguarded in storage. As in the previous cycle, the

---

*For example, for the proposed LWR system using U^{233} in Th and U^{233} recycle, 50% fissile U^{233} is required as makeup from storage of unspecified origin. Similarly, an LWBR (seed-blanket concept) requires 67% fissile U^{233}, the GCFR and two of the LMFBR's require 20% fissile U/Pu material, one LMFBR requires 20% fissile Pu in Th, and another LMFBR requires 24.7% U^{233}, all from unspecified sources since these materials are not produced in the cycle itself. This situation could be alleviated if centers are established in which, rather than being wholly dedicated to a particular reprocessing-fabrication system, there is an additional capability for reprocessing fuel from other systems. This could presumably provide the required material for various reactors in a symbiotic relationship.

outstanding new issue would be the safeguarding of permanently stored spent fuel (see Section 3.7.).

4.1.3. PWR Using LEU (U^{235}) Fuel and Spiked, Self-Generated U/Pu Recycle Fuel. This involves all the issues raised in GESMO[1] but would force a detailed consideration of coprocessing (see Section 3.3.) and of the efficacy, practicality, legal status, and additional potential for sabotage or radioactive dispersal of spiking (see Section 3.2.). If a convincing case could not be made for the latter measure, the fuel cycle would be essentially the same one considered in GESMO. On the other hand, if spiking were regarded as both effective and permissible, it would relieve many of the anxieties concerning subnational threats against plutonium.

4.1.4. PWR Using Denatured U^{233}/Th Fuel, with Recycle of U^{233}. This cycle involves a number of safeguards issues. It requires an external source of highly-enriched uranium (50% U^{233}) and separates and stores ~90 kg of Pu per year, recovered from spent fuel and spiked with Co^{60}. The existence of a store of U^{233} implies the existence of other SSNM (e.g., Pu or HEU) elsewhere in the cycle for breeding purposes, but this source is not specified in the PSEID. The issue of storage of SSNM was discussed in Section 3.8. The advantages and disadvantages of spiking have been discussed in Section 3.2.

The PSEID refers to obtaining highly enriched U^{233} from a "secure" center. Likewise, after spiking the recovered plutonium is sent to a "secure" storage center. It is not specified how these centers are made "secure" or whether their presumed security stems from anything but the application of safeguards; the language in the PSEID implies that the security is distinct from that provided by the spiking. Since, apart from the reduction in transportation, there is nothing inherently more secure about a center than about dispersed facilities, it must be assumed that all the questions raised in GESMO concerning safeguards for SSNM at fixed sites would also be raised here.

The safeguards issues raised by the use of denatured U^{233}/Th fuels have been discussed in Section 3.5.

REFERENCE

1. "Safeguarding a Domestic Mixed-Oxide Industry Against A Hypothetical Subnational Threat," U.S. Nuclear Regulatory Commission, NUREG-0414, May, 1978.

4.2. Light Water Breeder Reactors

4.2.1. Prebreeder and Breeder Reactors Based on Shippingport LWBR Type I Modules. The prebreeder in this concept uses 20% enriched U^{235} as the driver fuel in a seed-blanket module, with thorium as the fertile element, some physically separable and some intimately mixed with UO_2. In reprocessing, essentially pure U^{233} (~440 kg/year) would be recovered and stored for use in the breeder. Accumulation of enough U^{233} for this purpose would take about 10 years. Pure plutonium (~96 kg/yr) would also be separated and stored (presumably for eventual use in some other reactor).

Since the partially burned driver fuel still has a U^{235} enrichment of 14%, it is planned to recover and recycle it to an enrichment plant for re-enrichment to 20% for make-up fuel. Recovery of the burned U^{235} for this purpose depends on the ability to selectively dissolve the annulus of the duplex pellet used in this concept from the thorium-oxide core containing the bred U^{233}. The expected isotopic composition of the uranium separated from the pellet annulus and core is shown in the second and third columns of Table 4.2.-1, which also shows analogous data for the backfit prebreeder (see below).

At the present time the maximum permissible concentration of U^{232} in the feed to diffusion plants is 0.11 ppm (relative to U^{235}) and it has been proposed to raise this limit to 0.3 ppm.[1] A simple calculation based on the data of Table 4.2.-1 shows that, with these current limits, the proposed selective dissolution procedure would have to yield a maximum cross-contamination of ~0.1% for the Shippingport. At the proposed new limits this value becomes ~0.3%.

Thus, the dissolution procedure would have to be extremely selective for the concept of re-enrichment to be viable for this type of fuel. The alternative would be a greatly increased requirement for enriched feed, for which there are two possibilities: recycling the partially burned U^{235} to some other reactor (e.g., a conventional LWR) and providing fresh 20% enriched make up for the prebreeder, or upgrading the 14% enriched U^{235} by adding to it uranium enriched to more than 20% in U^{235}. This, of course, is strategic special nuclear material that would have to be transported to the fabrication plant from the

Table 4.2.-1

Uranium Isotopic Composition for the Prebreeder LWBRs at Discharge

	Material (kg/0.75 G/GWe-yr)			
	Shippingport		Backfit	
Isotope	Core	Annulus	Core	Annulus
U^{232}	—	1.2	—	0.8
U^{233}	—	436	—	252
U^{234}	—	31.7	—	24.9
U^{235}	1327	8	438	3
U^{236}	296	0.9	344	0.2
U^{238}	7889	—	5656	—

enrichment facility, since it is not proposed to co-locate the two. Approximately 700 kg of highly enriched uranium (~90% U^{235}) would be required.

The breeder would be sustained by its own bred U^{233}. It would require the recycling of approximately 2000 kg/yr of uranium highly (84%) enriched in U^{233}, classified as SSNM. The safeguards issues associated with this are discussed in Sections 3.1. and 3.8. At equilibrium, the U^{232} concentration is expected to be 2500-3000 ppm with respect to the bred uranium. On the basis of the data presented in Section 3.4., this would imply a radiation dose rate of ~13 r/hr at 1 meter from a 1 kg sample of U^{233}, at one year after separation (for the lower U^{232} concentration). This is two orders of magnitude less than the minimum spiking dose-rate criterion of 1000 r/hr at 1 meter from 1 kg of Pu or HEU as the oxide in powder or pellet form, proposed in Appendix A of the PSEIDs. At shorter times after separation the dose rates would be even lower. In addition, the 2500-3000 ppm range is probably for the equilibrium case, the U^{232} concentration being appreciably less initially and increasing towards these values with repeated recycle. The actual dose rates can therefore be expected to be even lower during the approach to equilibrium.

It therefore appears that the proposed cycle would involve the production and use or storage of at least two forms of SSNM (Pu and U^{233}) and possibly a third (highly enriched U^{235}) in substantial quantities, raising essentially the same safeguards issues as those raised in GESMO with respect to plutonium recycle. The additional safeguards issues associated with the use of U^{233}/Th fuels have been discussed in Section 3.4.

4.2.2. Light Water Backfit Prebreeder Supplying Advanced Breeder. In this concept the initial driver fuel for the pre-breeder would have a U^{235} enrichment of 16%. The fuel would consist of duplex pellets with a pure UO_2 annulus and a ThO_2 core, and of pure ThO_2 pellets. Since the discharge enrichment of the uranium in the annulus would be ~7%, it is planned to recycle this to an enrichment plant for re-enrichment to 16% U^{235} for make-up fuel, as in the previous case. Also, as in that case a highly selective dissolution process would be required to prevent cross contamination by the U^{233} in the Th/U^{233} core (see Table 4.2.-1 for isotopic composition of pellet core and annulus). The present U^{232} contamination limit of 0.11 ppm (relative to U^{235}) corresponds to a maximum permissible cross contamination of 0.006% for the backfit pre-breeder; the proposed limit of 0.3 ppm would increase this to 0.016%. These are exceedingly strict limits and it is barely conceivable they could be met. If they cannot be, the discharged U^{235} could be upgraded to the required 16% enrichment by the addition of fresh feed material enriched to less than 20% in U^{235}, in contrast to the previous case. An alternative, as before, would be to recycle the recovered U^{235} to another type of reactor and provide entirely fresh 16% enriched feed to the pre-breeder.

Both plutonium (~90 kg/yr) and uranium highly enriched in U^{233} (~275 kg/yr) are recovered from the spent fuel from the prebreeder. The plutonium is stored indefinitely and the U^{233} and associated isotopes are stored until enough is accumulated to start up a breeder. This will take ~10 years. The breeder is operated on the highly enriched — i.e., non-denatured — uranium and is approximately self-sustaining; the annual recycle rate is ~2000 kg yr. At equilibrium the U^{232} concentration is expected to be in the range of 2500-4500 ppm.

This fuel cycle therefore involves the production, recovery, use, and/or storage of two forms of SSNM, plutonium and uranium highly enriched in [illegible] discussion of these safeguards issues see Sections 3.1., 3.4., and 3.8. It does not require uranium highly enriched in U^{235}, whereas the previous case may. The U^{232} concentration is high but not high enough to meet the spiking criteria of Appendix A of the PSEIDs, and, as noted in the previous section, the concentration will be below the cited equilibrium values during the lengthy approach to equilibrium and, regardless of the concentration, for a signifiicant period after chemical purification the radiation dose rates will be well below the Appendix A criteria.

With the possible exception of the transport of bulk forms of SSNM (e.g., powder or pellets) the backfit pre-breeder advanced breeder fuel cycle would raise safeguards issues similar to those in GESMO for plutonium recycle.

4.2.3. Light Water Backfit Prebreeder & Seed-Blanket Breeder System. In this version of the LWBR fuel cycle the prebreeder is fueled with highly enriched (93%) U^{235} and thorium. The annual flow rate of the former is ~1000 kg/yr. At discharge the spent fuel contains roughly equal quantities of U^{233} and U^{235} (320 and 270 kg/yr, respectively) which are recovered by Thorex processing and stored until enough has accumulated to fuel the breeder. The latter is not quite self-sustaining but requires make-up from highly enriched U^{233} in storage, the source of which is not specified. The flow of highly enriched uranium for this breeder is ~5000 kg/yr.

This cycle therefore involves the production, recovery, and use and/or storage of substantial quantities of two kinds of SSNM, uranium highly enriched in U^{233} and uranium highly enriched in U^{235}. The associated safeguards issues have been discussed in Sections 3.1., 3.4., and 3.8. In addition, since enrichment plants are not expected to be co-located with fabrication plants, the transport of large quantities (~1000 kg/yr) of highly enriched uranium will be required. Therefore, most of the safeguards issues addressed in GESMO will also be relevant here.

REFERENCE

1. "Uranium Hexafluoride, Table of Enrichment Services, Charges, Specifications, and Packaging," Summary of currently pertinent information from the following Federal Register notices, 32 Fed. Reg. 16289, Nov. 29, 1967; 34 Fed. Reg. 14039, Sept. 4, 1969; 36 Fed. Reg. 11877, June 22, 1971; 38 Fed. Reg. 13593, May 23, 1978; 38 Fed. Reg. 21518, Aug. 9, 1973.

4.3. Heavy Water Reactors

The NASAP version of the CANDU heavy water reactor uses slightly enriched uranium (1.2% U^{235}) and operates at a higher power and burnup. The safeguards issues associated with the use of heavy water have been discussed in Section 3.6. The safeguards implications of the permanent storage of spent fuel have been discussed in Section 3.7. The use of slightly enriched fuel does not involve any new safeguards considerations, relative to the LWR once-through cycle.

The on-line refuelling feature and large number and small size of the HWR fuel elements do introduce additional problems for the accountability of spent fuel, however. Thus, the NASAP HWR (1260 MWe) has 8880 fuel bundles containing 19 kg of uranium each (see Table 2.1.-5), compared with 241 assemblies containing 426 kg of uranium, each (see Table 2.1.-1), for the standard PWR (1344 MWe). One-third of the core is replaced per year in each case, but in the HWR this is accomplished by discharging 7-10 bundles per day and in the PWR by discharging approximately 80 elements at 12-month intervals. The latter are placed in racks in the storage pool, where they can be individually identified and counted. The discharged HWR bundles, on the other hand, are normally placed on trays containing 24 bundles each and the trays are placed in baskets containing 19 trays each,[1] or a total of 456 bundles per basket. The baskets are then sealed. After the initial contents of a basket have been determined, inspection of the seals may be used to verify the integrity of the basket periodically. Obviously, an identification and count of the individual bundles, which would be necessary initially and, in the event of a seal being broken, at later times, would be difficult, since many of them are obscured from view in the spent fuel pool. Special bundle monitors that sense the direction of motion of and count the fuel bundles as they are discharged have been developed but are not in general use.[1,2] The IAEA has also considered the possiblity of stationing inspectors at on-line refuelled HWR's to facilitate the application of safeguards.

The difficulties of safeguarding on-line refuelled HWRs are more significant from the international than from the domestic point of view. However, NRC would have the responsibility of imposing IAEA requirements on the operator of the reactor, and therefore would have to take these difficulties into account.

REFERENCES

1. M. Honami, D. Tolchenkov, D. Jung, "A Safeguards Approach for a CANDU-600 Reactor," International Atomic Energy Agency, STR-72, Aug. 1978.
2. V.H. Allen and A.J. Stirling, "Performance of a Prototype Spent Fuel Bundle Counter for 600-MW CANDU Reactors," presented to the Institute for Nuclear Materials Management, Albuquerque, New Mexico, July 16-18, 1979.

4.4. High Temperature Gas-Cooled Reactors

4.4.1. Once-Through Medium Enriched HTGR. The once-through medium enriched HTGR does not use SSNM for fuel. Since it is a once-through cycle, it raises the issue of the safeguarding of permanently stored spent fuel. Detailed descriptions of the methods of permanently storing HTGR spent fuel have not been provided by NASAP. What information has been supplied is somewhat inconsistent. In one source[1], it is stated that spent HTGR fuel arrives at the geologic repository as bare assemblies in shipping casks, is removed from the casks in a hot cell and placed in a canister, which is sealed by welding, and then handled in the same way as high-level waste. However, in the PSEID for fuel cycle facilities, it is stated that "it is not clear whether terminal repositories can, or will, accept HTGR fuel....It may be necessary to burn off the graphite and recan the fuel particles in an inert matrix because of combustion or canister configuration requirements at repositories."[2]

In the former case, the safeguards issues are essentially the same as those discussed in Section 3.7. In the latter case, the fuel is transformed, presenting an entirely different set of safeguards problems, more characteristic of a reprocessing plant — that is, problems of material accountability — since the spent fuel loses its unique identity in the process. Obviously, a host of new issues would arise in this latter case but, without a more detailed description, they cannot be pursued further here. However, it should be noted that the total amount of SSNM in the spent fuel is rather small — only 29 kg of fissile Pu per 0.75 GWe-yr — compared with that in the spent fuel from other reactors (see Figure 2.1.-18).

4.4.2. Recycle Medium Enriched HTGR. The recycle medium enriched HTGR operates on denatured U^{233}/thorium fuel. Since it is not a breeder, it requires a source of U^{233} for make-up, and in addition produces both plutonium and highly enriched U^{233}, the latter of which, after reprocessing, is denatured by the addition of depleted or natural uranium, while the former is stored. The unspecified external source of U^{233} implies the possible existence of other SSNM, either HEU or plutonium, elsewhere in the fuel cycle, used to breed the U^{233}. Thus, this fuel cycle involves the safeguards issues of the use and storage of SSNM (Sections 3.1. and 3.8.), the use of U^{233}/Th fuels (Section 3.4.), and denaturing (Section 3.5.). If uranium highly enriched in U^{235} is required for the breeding of the supplementary U^{233}, the issues involved in the transportation of bulk SSNM will also be raised (see Section 3.10.), since it is not proposed to co-locate enrichment plants with fabrication plants. In short, many GESMO-type issues would be suggested by such a fuel cycle.

Certain accountability problems specific to HTGR fuel manufacture have occurred in the past (i.e., during the fabrication of fuel for the Fort St. Vrain HTGR). These have resulted from the large amount of scrap generated during the manufacture process, the inhomogeneity of the reject microspheres, and interferences from the thorium. At present the overall LEMUF in the material balance is estimated to be 0.7%,[3] instead of the statutory 0.5%[4] for HEU^{235}; however, with the adoption of improved analytical methods and increased use of NDA, the LEMUF has gradually been reduced over the past few years, and may be expected to continue to do so until the regulatory goals are achieved, at least for the U^{235}-based fuels. The U^{233} fuels may be more recalcitrant, due to the necessity for remote fabrication, the decreased accessibility of the fuel for sampling, and the larger interferences from the gamma activity of the U^{232} daughters. The reduced accessibility is also a safeguards advantage, since it limits personnel access to the fuel.

Another domestic safeguards advantage of this fuel cycle is that the SSNM in the fresh fuel is in a form not readily separable from its matrix. The fuel elements are composed mainly of graphite, in which the microspheres are embedded. The latter have refractory coatings of silicon carbide and pyrolytic graphite, requiring special methods for the extraction of the U^{233}. On the order of seven fuel elements would be required to provide a threshold quantity (2 kg) of U^{233}, assuming 100% recovery. These factors would make the recovery of significant quantities of highly enriched uranium from fresh fuel elements seized during transport probably a more time-consuming and difficult task than for fresh LWR plutonium recycle fuel elements.

There has been no experience in the reprocessing of HTGR fuels, although pilot studies of various steps in the process have been undertaken. A major unknown factor is the amount of holdup to be expected in the mechanical head-end of the reprocessing plant, where the graphite elements are crushed and burned; other important uncertainties are in the degree of separation of fissile and fertile particles (which affects the economics) and in the recovery percentage of residual and bred fissile material, which directly affects the amount of fissile material discarded with the silicon carbide hulls. As a result of these uncertainties in the process, it is impossible to say at this stage how well the material accountability for HTGR reprocessing plants will be able to meet present regulatory requirements.[4]

REFERENCES

1. J.P. Keenan, ed., "Alternative Fuel Cycle Evaluation Program Data Base," Hanford Engineering Development Laboratory, 1979, Chapter 6, pp. 1.1.-22.
2. Preliminary Safety and Environmental Information Document, Vol. VII, Rev. 1, "Fuel Cycle Facilities," Department of Energy, NASAP-78 12, Jan. 1979, pp. 6-20.
3. Byron Disselhorst, General Atomic Company, private communication, July 16, 1979.
4. 10 CFR 70.51(e)(5).

4.5. Gas-Cooled Fast Breeder Reactor

The gas-cooled fast breeder reactor (GCFR) is designed to produce U^{233} for use in other reactors in denatured form. It is driven by a plutonium-uranium core, which, upon discharge, is reprocessed for recovery and recycle of the unburned plutonium, in the form of pre-irradiated fresh fuel assemblies. The U^{233} is recovered from the thorium blankets and denatured at some point in the reprocessing. Since the U^{233} is not fed back into it, in this mode of operation the reactor is not self-sustaining but requires an external source of plutonium stored as a co-processed mixture with uranium. The origin of this external source is not described in the NASAP reports.

The GCFR therefore involves the use and storage of two types of SSNM, plutonium and HEU^{233} (see Sections 3.1. and 3.8.), co-processing (see Section 3.3.), the use of U^{233}/Th fuels (see Section 3.4.), denaturing (see Section 3.5.), and the use of radiation barriers (see Section 3.2.). Assuming the co-location of reprocessing and fabrication (see Section 3.9.), only the fixed-site safeguards considerations of GESMO would be involved in this fuel cycle.

The GCFR fuel cycle also involves the reprocessing of fast-reactor plutonium fuels. Most likely a reprocessing plant for this type of fuel will closely resemble that for LMFBR fuels and, in fact, both types of fuel could probably be reprocessed in the same plant. For a brief discussion of LMFBR reprocessing see Section 4.6.1.

4.6. Liquid-Metal Fast Breeder Reactors

4.6.1. "Standard" LMFBR with Homogeneous U/Pu Core and U Blanket. Except for the elimination, through co-location, of the shipment of bulk SSNM, and the co-processing of the plutonium and uranium, the "standard" LMFBR fuel cycle involves all the safeguards questions raised in GESMO in connection with thermal recycle of plutonium. Co-location has been discussed in Section 3.3. and co-processing in Section 3.9. The use and storage of SSNM, in this case plutonium, have been discussed in Sections 3.1. and 3.8.

A feature specific to sodium-cooled reactors such as LMFBRs is the storage of spent fuel under sodium at the reactor. Thus, inspection by ordinary visual means is impossible. However, an ultrasonic technique for viewing assemblies in a sodium environment has been developed for the Fast Flux Test Facility and presumably would be available for both NRC and IAEA use.

The high fissile content (~95% Pu^{239}) of the plutonium recovered from the uranium blanket of LMFBR's makes it prime weapons-grade material. If the blanket fuel is reprocessed separately, the plutonium product will be more attractive to terrorists than core plutonium or that from LWR's. In that case, NRC may want to require enhanced safeguards for such material.

There has been some experience with the reprocessing of fast reactor plutonium fuels, but none in a commercial facility. Major differences in

LMFBR spent fuel reprocessing plants, compared with LWR plants, will occur in the head-end, where (for sodium-cooled LMFBRs) residual sodium will have to be removed before dissolution, and in the heavy metal throughput, which will probably be limited by criticality considerations to on the order of 200 tonnes yr. The head-end design should not affect material accountability, nor should the reduced heavy-metal throughput, since the plutonium throughput will be about the same (due to the higher concentration of plutonium in spent LMFBR fuel) as in LWR plants. Actually, the operation of a commercial LMFBR reprocessing plant is at least twenty to thirty years off, since initially, for a variety of reasons, LMFBRs will be fed with plutonium recovered from spent LWR fuel, so there is adequate time to work out modified or improved accountability techniques.

4.6.2. LMFBR with Heterogeneous U/Pu Core and U Blanket, Pu Fuel Spiked. This cycle is essentially similar to the previous one except for the internal uranium blanket and the pre-irradiation of excess bred as well as recycled plutonium (see Figure 2.1-22). It therefore involves all the safeguards issues mentioned before in Section 4.6.1.

As has been pointed out in the previous chapter (Section 3.2.), the proposed pre-irradiation of bulk plutonium oxide in multi-ton qualities in a reactor seems so fraught with licensing difficulties as to be hard to take seriously. More likely the excess plutonium would be spiked with Co^{60}. The ramifications of spiking have been covered in Section 3.2.

4.6.3. "Standard" LMFBR with Homogeneous Core and Spiking. Again, both recycled and excess (i.e., bulk) plutonium are pre-irradiated in this version of the standard U/Pu LMFBR, and the comments made above apply. Otherwise, this version of the LMFBR fuel cycle raises no safeguards questions not already identified in Sections 4.6.2. and 4.6.3.

4.6.4. LMFBR with Spiked U/Pu Core, U Axial Blanket, and Th Internal and Radial Blanket. Since all the U^{233} bred in the thorium blankets of this reactor is stored (after denaturing) for eventual use in another reactor, the reactor is not self-sustaining and requires an external source of makeup Pu. The nature of this source is not described. The reactor therefore involves all the issues identified for the previous three LMFBR designs except for the pre-irradiation of bulk plutonium oxide, and in addition involves the recovery of U^{233} and its storage as a denatured fuel material (see Sections 3.4. and 3.5.). No other issues specific to this LMFBR design have been identified.

4.6.5. LMFBR with Spiked Homogeneous U/Pu Core and Thorium Blankets. This is identical with the design of 4.6.3. except for the substitution of thorium for the uranium in the axial and radial blankets. Since all the plutonium is recycled (in a co-processing mode), only the refabricated plutonium assemblies are pre-irradiated. Make-up plutonium from an unspecified external source is required. The U^{233} recovered from the blanket is denatured and stored for eventual use in some other reactor.

This reactor concept therefore involves the generic safeguards issues of the use and storage of plutonium (Sections 3.1. and 3.8.), radiation barriers (Section 3.2.), co-processing (Section 3.3.), and the denaturing of U^{233} (Section 3.5.). Except for the transportation of SSNM, all the safeguards issues considered in GESMO appear here also. No additional safeguards issues not already considered in previous sections have been identified for this reactor.

4.6.6. LMFBR with Homogeneous Spiked Pu/Th Core and Th Blanket. This reactor would contain only plutonium, thorium, and bred uranium (mostly U^{233}). It requires makeup plutonium from an unspecified external source. The makeup and recycled plutonium are mixed with some of the recovered thorium, which contains a relatively high concentration of Th^{228} (from U^{232} decay), whose daughters (the same as those of U^{232}) are intensely radioactive. Supposedly this would provide a protective radiation barrier for the plutonium, but no evidence is given that it would meet the spiking criteria of Appendix A of the PSEIDs. A safeguards evaluation of this variation of spiking therefore cannot be made. However, if the method were as effective as those considered in Section 3.2., many of the issues discussed there would also arise here. Of course, Co^{60} spiking or pre-irradiation might also be used here, in place of the proposed method.

The U^{233} recovered from the core and blankets would be denatured and stored for eventual use elsewhere.

Obviously, several of the issues considered in connection with the previous LMFBR designs also occur here: the use and storage of SSNM (Sections 3.1. and 3.8.), denaturing (Section 3.5.), and radiation barriers (Section 3.2.), with the additional questions raised by the choice of spikant, discussed above. Except for the transportation of SSNM, all the safeguards issues raised in GESMO would also appear here.

4.6.7. LMFBR with Denatured U^{233} Core and Th Blanket. Although this reactor uses denatured U^{233} as fuel, residual U^{233} recovered from the core is supplemented by highly enriched U^{233} from the blanket and from an unspecified external source (see below, however), to bring the enrichment of the recycled U^{233} back up to the maximum of 12% allowed by the denaturing criterion. It also produces plutonium, which, after recovery from the core, is mixed with depleted uranium at a concentration of 20% and stored for eventual use elsewhere. Thus, the reactor involves the use and storage of SSNM in the form of plutonium and U^{233} and, therefore, except for the transportation of SSNM, the issues treated in GESMO. Concerning the generic issues, see Sections 3.1. and 3.8. for a discussion of the use and storage of SSNM, Section 3.3. for co-processing, Section 3.4. for the use of U^{233}/Th fuels, and 3.5. for denaturing. No other issues specific to this reactor have been identified.

4.6.8. LMFBR Symbiotic Systems. Two symbiotic systems linking LMFBR designs have been suggested, among the many that are possible. In one, called System A, the U^{233} for the LMFBR discussed in Section

4.6.7. comes from that produced by the LMFBR described in Section 4.6.5. The nature of the safeguards issues identified in connection with the individual reactor cycles is unchanged by this link. The same condition applies to symbiotic System B, in which the U^{233} for the LMFBR discussed in Section 4.6.7. is supplied by the LMFBR described in Section 4.6.6.

REFERENCE

1. N.C. Hoitinle and C.K. Day, "Under-Sodium Viewing System Development for FFTF," Hanford Engineering Development Laboratory, HEDL-TME 75-103, Dec. 1975.

V. SUMMARY AND CONCLUSIONS

Twenty-one alternative fuel cycles proposed under the Non-Proliferation Alternative Systems Assessment Program (NASAP) of the Department of Energy have been reviewed, on behalf of the Nuclear Regulatory Commission, for technical safeguards issues and problems that might affect regulation or licensing. The approach adopted was to identify generic features, common to two or more fuel cycles, and assess these independently of the fuel cycle in which they are involved. Then the individual fuel cycles were reviewed in order to identify additional unique features (i.e., those associated with a single fuel cycle, only.)

The issues or problems, except for international fuel service centers, associated with each fuel cycle are summarized in Table 5.1.-1. The fuel cycle is shown in the first column, the generic issues in the next eight columns, and special problems in the last column. The fuel cycles employing international fuel service centers are shown in Table 5.1.-2.

5.1. Generic Issues

The generic issues identified were the use, storage, and transportation of strategic special nuclear material (SSNM), the use of radiation barriers as a protective measure for SSNM, coprocessing, the use of U^{233}/Th fuels, denaturing, the use of heavy water as a moderator, the storage of spent fuel and waste, and international fuel service centers.

5.1.1. Radiation Barriers (Spiking). The issue of spiking (and its variations), central to many of the fuel cycles involving the use of SSNM, was assessed in varying detail with respect to its effect on accountability and verification by NRC and the IAEA, availability of suitable spikants, effect on health, safety, and economics, appropriateness of proposed radiation dose rate criteria, effectiveness as a safeguards measure, and so on. Four variations on spiking were proposed by NASAP and reviewed here: spiking (intimately mixing a radioactive additive with the SSNM), partial

Table 5.1.-1.

Summary of Issues

	SSNM[b]								
Fuel Cycles	**Use**	**Transportation**	**Bulk Storage**	**Radiation Barriers**	**Co-Processing**	**U^{233}/Th Fuels**	**Denaturing**	**Heavy Water**	**Others (Part 4)**
LWR-									
Once Thru									
Hi Burnup Once Thru									
U^{235}/Pu Spiked Recycle	**Pu**	**Makeup[c]**	**Co^{60}**	**U/Pu**					
U^{233}/Th Recycle	**50% U^{233}**	**Makeup[c]**	**Pu & Makeup**	**Co^{60} & U^{232}**		**Fuel & Product**	**3**		
LWBR-Shippingport									
Pre-breeder	**HEU?[d]**	**Makeup?[d]**	**U^{233}, Pu & Makeup**	**U^{232}**		**Product**			**Enrichment of Contaminated Material**
Breeder	**85% HEU[e]**			**U^{232}**		**Fuel & Product**			
LWBR-Backfit									
Pre-breeder	**HEU?[d]**	**Makeup?[c,d]**	**90% U^{233}**	**U^{232}**		**Product**			**Enrichment of Contaminated Material**
Breeder	**80% HEU[e]**			**U^{232}**		**Fuel & Product**			

Table 5.1.-1. (Cont'd)

Summary of Issues

Fuel Cycles	SSNM[b] Use	SSNM[b] Transportation	SSNM[b] Bulk Storage	Radiation Barriers	Co-Processing	U^{233}/Th Fuels	Denaturing	Heavy Water	Others (Part 4)
LMFBR-									
U/Pu/U Recycle									
Homogeneous -		[c]	Pu		U/Pu				Under-Sodium Viewing, High Fissile Pu
U/Pu/U Spiked									
Heterogeneous -		[c]	Pu	Preirrad.	U/Pu				"
Homogeneous -		[c]	Pu	Preirrad.	U/Pu				"
U/Pu/Th Spiked									
Heterogeneous -	Pu	[c]		U^{232} & Preirrad.	U/Pu	Product	12% U^{233} Product		"
Homogeneous -	Pu	[c]		U^{232} & Preirrad.	U/Pu	Product	12% U^{233} Product		"
Th/Pu/Th Spiked	Pu	Makeup [c]		U^{233} & Th daughters	Th/Pu	Fuel & Product	12% U^{233} Product		"
Denatured U^{233}/Th	% U^{233}	[c]	Pu	U^{232}		Fuel & Product	Bred U^{233}		"

[a] All cycles involve the issues of spent fuel and/or waste storage.

[b] SSNM in this table excludes that in spent fuel and includes Pu, > 12% U^{233}, and > 20% U^{235}. "Use" means as a source material. "Transportation" means movement outside International Fuel Cycle Centers. "Bulk Storage" includes either as product or as a source of supply.

[c] Depends upon inclusion in and type of International Fuel Cycle Center. See Table 5.1.-2.

[d] Depends on need for make-up owing to excess U^{232} contamination of spent fuel intended for re-enrichment. See Part 4.

[e] Mixed U^{235} and U^{233}.

LWBR-High Enriched Pre-breeder	93% HEU	Makeup[c]	47% Fissile U	U^{232}		Product			
Seed Blanket Breeder	67% HEU	Makeup		U^{232}		Fuel & Product			
HWR-Once Thru								800 MT Total ~3 MT/yr Makeup	Large Numbers of Fuel Elements
HTGR-Once Thru									Possible Loss of Identity of Spent Fuel During Storage Preparation
Denatured U^{233}/Th			Pu	U-232		Fuel & Product	12% U^{233} Fuel 3% U^{233} Product		Material Accountability During Reproc.
GCFR-U/Pu/Th Spiked Recycle	Pu	Makeup[c]		U^{232} & Preirrad.	U/Pu	Product	12% U^{233} Product		

Table 5.1.-2.

Effect of International Fuel Cycle Centers on SSNM Flows

Fuel Cycle[a]	Type of SSNM[b]	Total Flow (kg/.75 GWe-yr)	Flow Outside Center[c] (kg/.75 GWe/yr)
LWR-			
U^{235}/Pu	Pu	290 Pu	0
Spiked Recycle			
U^{233}/Th	50% U^{233} & Pu	[illegible] Pu (to storage)	0
Recycle		77[illegible] U^{233} (3[illegible]7 makeup)	0
LWBR-Shippingport			
Pre-Breeder	HEU?[d,e] Pu,	4[illegible]0 U^{233} (to storage)	0
	& 90% U^{233}	700 HEU[e] (makeup)?	700 HEU[e]?
		96 Pu (to storage)	0
Breeder	85%[f] HEU	1800 HEU[f]	0
LWBR-Backfit			
Pre-Breeder	HEU?[d,e], Pu,	250 U^{233} (to storage)	
	& 90% U^{233}	91 Pu (to storage)	0
		700 HEU[e] (makeup)?	700 HEU[e]?
Breeder	80% HEU[f]	1700 HEU[f]	0
LWBR-High-Enriched			
Pre-breeder	93% HEU[e] &	980 U^{235} (makeup)	980 U^{235}
	47% HEU[f]	600 HEU[f] (storage)	0
Seed-Blanket	67% U^{233} &	97 U^{233} (makeup)	0
Breeder	62% HEU[f]	5000 U^{233} + U^{235} (recycle)	0
HTGR-			
Denatured	Pu & U^{233}	50 fissile Pu (to storage)	0
U^{233}/Th		200 U^{233} (bred, recycle)	0

processing (leaving selected fission products with the SSNM during reprocessing of spent fuel), pre-irradiation of fabricated assemblies, and the mechanical attachment of radioactive sources to the material to be protected.

Spiking and partial processing have the advantage of protecting the SSNM during all or most of its history from production to use in a reactor, but greatly complicate and increase the cost of processing (principally, fabrication), handling, quality control, accountability, safeguards inspection, and use of the fuel. Pre-irradiation has no effect on processing or accountability but complicates handling, quality control for fuel assemblies, and use. It also protects the least vulnerable form of fresh fuel, the assembled element. Mechanically attached sources provide protection only during storage and transportation but interfere least with processing, quality control, accountability, and use of the fuel.

Table 5.1.-2. (Cont'd)

Effect of International Fuel Cycle Centers on SSNM Flows

Fuel Cycle[a]	Type of SSNM[b]	Total Flow (kg/.75 GWe-yr)	Flow Outside Center[c] (kg/.75 GWe/yr)
GCFR-			
U/Pu/Th	Pu	1100 fissile Pu (recycle)	0
Spiked		178 fissile Pu (makeup)	0
LMFBR-			
U/Pu/U	Pu	1350 fissile Pu (recycle)	0
Recycle		238 fissile Pu (to storage)	0
U/Pu/U Spiked			
Heterogeneous -	Pu	1700 fissile Pu (recycle)	0
		250 fissile Pu (to storage)	0
Homogeneous -	Pu	1350 fissile Pu (recycle)	0
		240 fissile Pu (to storage)	0
U/Pu/Th Spiked			
Heterogeneous -	Pu	1821 fissile Pu (recycle)	0
		208 fissile Pu (makeup)	0
Homogeneous -	Pu	1360 fissile Pu (recycle)	0
		100 fissile Pu (makeup)	0
Th/Pu/U Spiked	Pu	1700 fissile Pu (recycle)	0
		666 fissile Pu (makeup)	0
Denatured	25% U^{233}	1200 U^{233} (recycle)	0
U^{233}/Th	& Pu	319 U^{233} (makeup)	0
		490 fissile Pu (to storage)	0

[a] Includes fuel cycles involving SSNM except in reprocessed spent fuel.

[b] SSNM includes Pu, > 12% U^{233}, > 20% U^{235}.

[c] Assumes "Center" includes all facilities including: Storage of products from other cycles, reprocessing, fuel fabrication, storage of products from present cycle, reactor, pre-irradiation and other spiking facilities, and no enrichment facilities.

[d] Depends on need for make-up owing to excess U^{232} contamination of spent fuel intended for re-enrichment.

[e] U^{235}.

[f] U^{235} + U^{233}.

As far as the effects of spiking on the accuracy of accountability are concerned, it is likely that these could be overcome by more intensive use of traditional sampling and chemical analysis; that is, for the same effort the accuracy would be less (the difference in regulatory requirements on LEMUF for reprocessing plants and fabrication plants, a factor of two, gives some indication of the expected magnitude of this effect), but an increased analytical effort would probably make the accuracy similar to that for unspiked material. Timeliness of material accountability would be adversely affected, however. Inspection and verification efforts by NRC and the IAEA and the resolution of anomalies would be considerably hampered.

Suitable candidates for spikants are available; the most promising one is Co^{60}. Experimental work would be required to establish its compatibility with the fabrication process and the fuel. A very considerable development of remote fabrication and of accountability techniques (mainly for nondestructive assay) would have to be undertaken. Potential supplies appear adequate, a three-fold expansion of present production capacity being required by the year 2000.

Partial processing would also require a substantial development period, and, because of the relatively short half-life of the most suitable fission products (the most promising candidate, Ru^{106} has a half life of 368 days), might have to be supplemented by spiking.

Pre-irradiation involves serious problems in the licensing of the pre-irradiation reactor; a commercial pre-irradiation facility probably would not be operating for at least ten to fifteen years.

Requiring radiation barriers to protect SSNM would conflict with the "ALARA" philosophy, since it would probably increase the routine exposure of workers and certainly increase the potential for accidental exposure of workers and the public. Most likely an environmental impact statement would be required, in which case a cost-benefit comparison with alternative safeguards measures would have to be performed. It is not obvious that the comparison would favor radiation barriers over more conventional measures.

Costs of spiking, partial processing, and pre-irradiation tend to be rather high, as much as several percent of the total cost of nuclear electric power, according to some estimates. To this would have to be added the cost of much of conventional safeguards: material accountability (at least for international safeguards) and physical protection against sabotage; the latter might actually increase compared with the no-spiking case, since the spikant or radioactive source is an additional potential target, while the need to protect fuel cycle facilities, including the reactors themselves, against sabotage would not be eliminated. Physical protection for shipments of SSNM could probably be reduced, resulting in some saving; however, some doubt is cast upon this by the recent NRC ruling requiring physical protection for shipments of spent fuel.

The cost of mechanically attaching radioactive sources to materials in storage or in shipment would be much less than that of the other methods —1% or less of the total cost of nuclear power. It would provide essentially an equal amount of protection during transit and also require the least in the way of development.

The radiation dose rate criteria proposed by NASAP seem sufficient for achieving the desired objectives of deterrence and delay. However, there does not seem to be any objective way to demonstrate this, and in the end NRC would have to rely on subjective but informed judgment in choosing appropriate criteria.

Against the disadvantages of spiking and its variations has to be balanced the chief advantage of a considerable increase in the protection of strategic special nuclear material, through both deterrence and delay, albeit at a cost considerably in excess of that of current safeguards. Since, for the reasons given above, spiking would not eliminate the need for much of present safeguards (material accountability and protection from sabotage), it should probably be regarded not as a sufficient measure by itself but as an additional overlay of protection.

5.1.2. Coprocessing. Coprocessing of plutonium-uranium streams appears feasible and would require the diverter to steal more material and chemically separate the plutonium from the uranium in order to produce an explosive device, thus providing a delay and making detection more probable. It could probably not be adopted in existing reprocessing plants but would have to be introduced in the next generation, meaning a delay of at least ten to fifteen years before it could be introduced commercially; new methods for coprocessing of uranium-plutonium-thorium fuels and for coconversion would have to be developed for fuel cycles using denatured U^{233}/thorium fuels. Coprocessing would have minor effects on accountability, which could easily be overcome. NRC would have to set appropriate limits on concentration of plutonium in the mixture; 10% would probably be adequate for thermal recycle fuels and 25% for fast reactor fuels. Scrap recovery plants would have to be designed to make it difficult to produce a separated product.

5.1.3. U^{233}/Thorium Fuels. The use of U^{233}/thorium fuels would have a strong effect on accountability methods. Limited experience in the reprocessing of low burnup, low U^{232} fuels has given good accuracy in accountability, but there is little, if any, experience with high burnup, high U^{232} fuels, nor with mixtures of uranium, plutonium, and thorium. The performance of isotope-dilution mass spectrometry as an accountability tool in plants reprocessing spent fuels containing both U^{233} and U^{235} would be degraded. Analytical uncertainties of 0.3 - 0.4% are expected for uranium-thorium fuels, compared with ~0.1% for uranium-plutonium fuels. The intense radiation from the daughters of U^{232} imposes a requirement for remote fabrication of fuels and would incapacitate most present nondestructive assay methods. The development of appropriate nondestructive assay methods would be essential to the realization of a real-time accountability capability and to the reduction of uncertainties in the measurement of scrap. The situation would be similar to but less serious than that of spiked fuels since the radiation levels would be at least an order of magnitude lower.

The limitations on personnel access to U^{233} materials would be a safeguards advantage (except that inspector access would also be hampered), but the degree of protection would be less than in the spiked case, due to the less intense radiation. Also, "windows" exist after purification, during which radiation levels are much lower, as the U^{232} daughters grow in.

Detection sensitivity for U^{233} of radiation monitoring would be much better than for plutonium or U^{235} fuels, particularly the latter. Dispersal hazards for U^{233} are less than for plutonium.

The adoption of U^{233} fuels would therefore require additional development of accountability techniques, especially of nondestructive ones. Without some actual experience with high burnup, high U^{232} fuels, it is impossible to predict the performance of accountability systems. However, since the development and demonstration on a commercial scale of uranium-thorium systems is probably at least twenty years off, there is sufficient time to develop the required new or improved techniques.

5.1.4. Denaturing. Denaturing is a special case of the use of U^{233}/thorium fuels, so the conclusions above apply to denaturing as well. The breeding of plutonium in denatured fuels poses additional safeguards problems and, as noted earlier, complicates the reprocessing. To counteract the tendency of reactors using repeated recycle of denatured fuels to "drift" towards increased plutonium and decreased U^{233} production, it may be necessary to provide some highly enriched U^{233} or U^{235} makeup fuel, thus cancelling some of the advantage of using denatured fuels. On the other hand, restrictions on the use of denatured U^{233} fuels in dispersed reactors should be essentially no greater than for LEU^{235} fuels since it is not credible that a domestic diverter or terrorist would have an enrichment capability. Compared with U/Pu cycles, the main safeguards advantage would be elimination of the need for physical protection of fresh fuel in transit.

Regulatory issues for NRC would be the setting of an enrichment threshold for fuels containing U^{233} or mixtures of U^{233} and U^{235} (12% is the threshold usually accepted for uranium containing only U^{233} as the fissile isotope) and whether, because the greater ease of further enriching U^{233} compared with U^{235} fuels makes it a more attractive target for diversion and subsequent transmission to a foreign country, more stringent material accountability and control than for LEU^{235} should be required.

5.1.5. Heavy Water. The use of heavy water as a moderator in HWRs or spectral shift reactors (which have been studied under NASAP and INFCE but which have not been included in the list of reactors for review by NRC) raises the question of accountability for heavy water, which, if diverted, could be used for clandestine plutonium production reactors fueled with natural uranium. If accountability, including physical inventories, were to be required, NRC would have to define the minimum quantity of heavy water of safeguards significance and the threshold concentration of D_2O in water for safeguards to apply.

Facilities requiring accountability might include production plants (which, traditionally, have been Federally owned), reactors, upgraders for degraded heavy water, and storage facilities. Present accountability techniques for large commercial production plants appear to be inadequate for detecting the diversion of significant quantities (10-20 tonnes) of heavy water from the primary extraction process, which produces concentrations of a few percent D_2O. Accountability for the finishing stages, which produce the final highly enriched product, does appear to be sufficiently sensitive. Providing adequate safeguards for the entire plant would therefore require considerable development of improved accountability techniques for the extraction stages (e.g., better on-line flow and assay devices) and, perhaps, a greater reliance on containment and surveillance.

Very little has been done on accountability for the heavy water in large power reactors. Preliminary estimates indicate that the sensitivity is marginal but that improvements can be made. Sensitivity for research reactors is probably adequate, because of the much smaller inventory. Methods for sampling and analyzing D_2O in drums in storage facilities would be needed. The development of portable instrumentation for measurement of D_2O concentration would be desirable for a variety of situations.

5.1.6. Long-Term Storage of Spent Fuel and Waste. Long-term storage of spent fuel and waste, although Federally operated, is under NRC regulatory authority. The most significant safeguards problem would arise with the long-term storage of spent fuel, required for all once-through cycles. The significance would derive primarily from international rather than domestic safeguards considerations, since neither spent fuel nor high level waste is attractive to terrorists but the former, at least, is subject to IAEA safeguards.

Safeguards for geologic repositories would depend heavily on item identification and accountability and on containment and surveillance. Key issues to be decided would be whether spent fuel would be canned by the shipper or at the repository, whether fissile assay, in addition to identification and counting, would be required, whether IAEA inspection is to be continuous or periodic, and what the conditions would be, if any, under which safeguards would be terminated. These determined the design of the safeguards system and the necessary instrument development.

Some of the instruments needed for safeguards at geologic repositories exist in prototypical form (e.g., directional spent fuel counters and field-readable seals). Additional development and demonstration of these and of remote identification systems will be required. TV and film cameras for surveillance are in use at reactor spent-fuel pools. Assay techniques for highly radioactive spent fuel and waste have not been demonstrated and would require a great deal of research and development. The point of origin of waste would be the most logical place to assay it. Even the less demanding problems of burnup measurement for spent fuel and verification of radiation signatures for waste would require considerable development. Because of the long lead time for the establishment of geologic repositories, sufficient time for development is available.

International safeguards requirements for sealed, back-filled repositories could probably be met purely by containment and surveillance, with periodic but infrequent visits by IAEA inspectors. NRC would be responsible for assuring compliance with these requirements.

5.1.7. International Fuel Service Centers. International fuel service centers raise institutional issues, primarily. Although, through the pooling of personnel and equipment, they could increase the efficiency of inspection and reduce the cost of safeguards somewhat, they are not necessarily any more secure from diversion or attack by subnational groups than are dispersed sites. They do greatly reduce but do not entirely eliminate the need for shipments of bulk SSNM. The elimination of shipments of SSNM in fuel assemblies depends on whether the reactors using them are confined to the centers. Some fuel cycles require the use of HEU^{235} for initial or make-up feed which would have to be supplied from off-site enrichment plants. The effect of international fuel service centers on the transport of SSNM is shown in Table 5.1.-2. The fuel cycles are shown in the first column, the type of SSNM (defined here as plutonium or uranium enriched to more than 20% in U^{235} or 12% in U^{233}, the last being a NASAP, not an NRC, definition) in the second column, the total mass flows of SSNM per effective reactor-year in the third column, and the flow of SSNM outside the center in the last column. In the absence of centers, all the SSNM in the third column would be transported each year for each reactor. With centers, whether or not power generating, substantial shipments of highly enriched U^{235} would occur for one of the LWBR cycles and, if the recovered residual U^{235} is too contaminated with U^{232} for re-enrichment, might occur for the remaining two LWBR cycles. If the centers contain all "sensitive" power reactors (i.e., all those burning SSNM contained in fresh fuel) then the transport of all other SSNM would be confined to within their boundaries (assuming that processing facilities for linked fuel cycles were co-located at the center). If the centers contain only processing facilities — i.e., no reactors — then, except for the cases involving HEU^{235} noted above, no bulk SSNM would be transported outside the centers, but fuel assemblies containing SSNM (entries in Table 5.1.-2 not labelled "to storage") would be.

The presence of large numbers of construction workers could make access control more difficult.

Otherwise, the technical issues involved in international fuel service centers are few and minor in nature.

5.1.8. Use, Storage, and Transport of SSNM. Of the twenty-one fuel cycles, four were of the once-through type: the standard LWR, the high-burnup LWR, the high-burnup HWR, and the medium-U^{235}-enriched HTGR. None of these involve the use of SSNM anywhere in the cycle, except in the spent fuel.

Strategic special nuclear material appears somewhere in all the other fuel cycles either as makeup (plutonium, HEU^{235} or HEU^{233}) or as a product to be stored for eventual use in another, symbiotically linked, fuel cycle or reactor (see Table 5.1.-2). In some of the fuel cycles (e.g., some versions of the LWBR cycle) two or even three forms of SSNM (HEU, Pu, and U^{233}) appear.

From the data in Table 5.1.-2, it can be seen that all the cycles dependent on breeders, either directly or indirectly, involve annual flows of ton quantities of SSNM per reactor year. Non-breeders usually produce SSNM (in spent fuel) in quantities an order of magnitude lower, roughly.

The appearance of such large quantities of weapons-usable material in all the fuel cycles except the once-through LWR, HWR, and HTGR using low enriched uranium would necessarily raise all the safeguards issues identified in the safeguards supplement to GESMO,[1] and would probably require a similar under-taking, in which the vulnerabilities and proposed safeguards and alternatives would have to be assessed for the proposed cycle. Locating all sensitive facilities, including SSNM-burning reactors, in centers would eliminate most (but, in a few cycles, not all) routine shipments of SSNM but would not significantly reduce on-site vulnerabilities to diversion or sabotage. Spiking would eliminate or greatly reduce the vulnerabilities to diversion but not to sabotage and, in fact, might increase the latter. Accountability and physical protection would still be necessary. The use of spiking or some variation or combination of variations to protect all SSNM (attached sources would have to be used for shipments of highly enriched UF_6 unless some compatible gaseous spikant could be identified) would make all fuel cycles using SSNM essentially equivalent with respect to safeguards vulnerabilities. That is, all would thereby be well protected against theft but not against sabotage.

5.2. Issues Unique to Specific Fuel Cycles

A few of the fuel cycles involve problems not arising in the others (see Table 5.1.-2).

Two of the three prebreeders for the LWBR fuel cycle use selective dissolution to separate residual U^{235} from bred U^{233}, the former being reenriched after recovery, and recycled. Contamination of the U^{235} by U^{232} may prevent this (enrichment plants have strict limits on U^{232}) and result in a requirement for highly enriched uranium makeup.

The large number and small size of the fuel elements for HWRs, together with the on-line refuelling procedure, make accountability for spent fuel difficult. This is more of a problem for international than for domestic safeguards, however, although NRC would have to ensure compliance by the operator with the IAEA's requirements for verification.

Spent fuel from once-through HTGRs may require some processing to separate the fuel particles from the graphite matrix in order to comply with the requirements for long term storage. If so, the identity and discrete nature of the fuel element would be lost and item counting for accountability would nor longer suffice. Also, there is essentially no experience with the reprocessing of spent HTGR fuel. The amount of holdup in the mechanical head end, the degree of cross contamination of fissile and fertile streams, and the magnitude of the residual hold-up in silicon carbide hulls are all highly uncertain and could affect material accountability.

In LMFBRs, spent fuel is stored under sodium, making it difficult to verify inventories. However, special ultrasonic imaging devices being developed for FFTF may solve this problem.

5.3. General Conclusions

From the foregoing the following general conclusions concerning the twenty-one alternative fuel cycles considered here may be drawn:

(1) only the standard and high-burnup once-through LWRs, the once through medium-enriched HTGR, and the once-through high-burnup HWR are free of the safeguards problems associated with strategic special nuclear material;

(2) all other fuel cycles, including denatured cycles, involve the use of SSNM somewhere in the fuel cycle or in a symbiotically related fuel cycle; denatured cycles do, however, greatly reduce diversion concerns for the dispersed reactors;

(3) international fuel service centers not containing reactors eliminate routine shipments of bulk SSNM for all fuel cycles except for a few that may require highly enriched U^{235} initial or make-up fuel, but do not eliminate shipments of SSNM in fresh fuel assemblies;

(4) power-generating international fuel service centers in which all reactors burning SSNM are co-located eliminate all routine shipments of SSNM in any form except for spent fuel and those fuel cycles that require initial or make-up highly enriched U^{235};

(5) international fuel service centers are not necessarily more secure than dispersed facilities against on-site subnational diversion or sabotage;

(6) spiking or its variations, alone or in combination, could substantially decrease the vulnerability of all fuel cycles to diversion but would not eliminate the need for material accountability or for physical protection against sabotage;

(7) with or without spiking and/or international fuel service centers, the residual vulnerabilities of all fuel cycles, except denatured ones, involving the breeding and recycling of SSNM are similar and would require similar protective measures, so that domestic safeguards should not be a major factor in the choice of fuel cycle from this class; whether the main advantage of a denatured fuel cycle with respect to a U/Pu cycle, namely the unattractiveness to subnational groups of fresh fuel assemblies in transit to dispersed reactors, is a decisive factor for its adoption, is primarily a matter of judgment, depending on how attractive a target fresh U/Pu assemblies in transit are considered to be;

(8) because of the long lead time (~10-20 years) for the introduction of any of the proposed fuel cycles involving SSNM or for the establishment of long-term storage facilities for spent fuel and waste, there is adequate time to resolve the safeguards technical problems, e.g., accountability for U^{233}/Th or spiked fuels, surveillance and accountability of spent fuel in geologic storage, etc., identified for any particular fuel cycle.

REFERENCES

1. "Safeguarding a Domestic Mixed Oxide Industry Against a Hypothetical Subnational Threat," Nuclear Regulatory Commission, NUREG-0414, May 1978.

INDEX

Appropriate Compensation, 42-43
Congressional Intent, 12-15, 213-222
Constitutional Rights 252-253
Co-processing, 95, 103, 165, 203, 402-404
Deadly Force, 287-288
Denaturing, 97, 104, 167, 408-410
Department of Energy, 29, 246-247
Emergency Legislation, 251-252, 264-267
Enrichment, 71-77
Environmental Issues, 30, 155-156, 198-199, 397-398
Export Control, 8, 125, 190-209
    Subsequent Arrangements, 200-201, 222-226
Federal Bureau of Investigation, 246-247
General Accounting Office Reports, 118-126
Global Nuclear Power Programs, 131-142
    Generating Capacity, 132
Heavy Water, 99, 104, 204, 410-413
International Atomic Energy Agency, 22, 28, 50, 73-75, 81-92
    Heavy Water, 411-413
    Material Categories, 102
    Material Control and Accounting, 84-93, 393-395
    Material Conversion Times, 87
    Physical Protection, 127-128
    Reporting, 81-83
    Safeguards Agreement, 81-83
    Threshold Quantities, 85, 102
International Auspices, 41-42
    Courts, 51-52
International Organizations, 46-57, 75-77
    Dispute Resolution, 55-57
International Plutonium Storage, 115-118
Liabilities, 18-19, 32-35, 272-273
Licensing, 20, 144-168
    Chronology, 178-183
    Construction Permit and Operating License, 148-151
    Exports, 190-199
    Hearings, 152-154
Multinational, 7, 376-378
    Agreements, 10
    Away From Reactor Storage, 40-60
    International Nuclear Fuel Authority, 5-22, 420-422
    Legislation, 7-10, 44-46
    Undertakings, 7, 420-422
National Security, 248, 278-280
Nuclear Alternative Systems Assessment Program Fuel Cycles, 105-107, 346-347, 355-378
Nuclear Emergency Search Teams, 246-247
Nuclear Materials Management and Safeguards System, 83
Nuclear Non-Proliferation Act, 5, 7, 120-126, 187-209
    Developing Countries, 126
    Timely Warning, 211-228
Nuclear Regulatory Commission, 20-22, 29, 35-37, 116-118, 236-237
Physical Security, 396
    Doorway Monitors, 237-238
    Locating Material, 243-257
    Regulations, 236-241, 246-252
    Search and Seizure, 248-257, 260-263
Ranking Fuel Cycles, 291-340
    Criteria, 294-296, 315-320
    Method, 293-294, 308-309, 324-325
    Software, 334-339
Reprocessing Methods, 369-370
Sovereign Immunity, 16-18, 43-46
Spiking, 94, 101, 163, 202, 235-237, 243-246, 269-288, 308-400
State/Federal Interface, 31
Thorium Fuels, 96-97, 103-104, 166-167, 203-204, 404-407
Transportation, 30, 37, 373-376, 422
Treaty on the Non-Proliferation of Nuclear Weapons, 118, 132-134, 197-198
United States Policy, 6-7, 25-26, 187-189, 233-234, 235
Waste Handling, 99-100, 372-373, 413-417
    Away From Reactor Storage, 26-40, 371
    Legislation, 38-39
    Regulation, 35-38
    Repositories, 168, 371-372