NUREG-0414

SAFEGUARDING A DOMESTIC MIXED OXIDE INDUSTRY AGAINST A HYPOTHETICAL SUBNATIONAL THREAT

Manuscript Completed: May 1978
Date Published: May 1978

Division of Safeguards
Office of Nuclear Material Safety and Safeguards
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

7811100009

ABSTRACT

This report treats the feasibility of safeguarding a wide-scale domestic mixed oxide industry. It presents the results of an effort originally undertaken as part of the GESMO environmental impact statement and is being published as a technical report in order to provide information which would otherwise be unavailable due to the termination of the GESMO activity.

The characteristics of a projected wide-scale MOX industry, the perceived threat to that industry, and the possible consequences of sabotage or theft of nuclear material are discussed. Safeguards strategies, technical approaches, and currently existing safeguards requirements and their applicability to a MOX industry are examined. Several alternative approaches to safeguarding a MOX industry are discussed and their economic costs and societal impacts assessed.

TABLE OF CONTENTS

---

*Executive Summary is separately bound. Its table of contents are included so reader can obtain some understanding of its contents.

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF TABLES

Tables Page

APPENDICES

FOREWORD

This document is a staff technical report. The Commission has not specifically addressed many of the policy issues in the specific context of this report, and has, therefore, not approved its conclusions. The Commission has authorized publication because it believes that the information should be available to the public.

The content of this report is current as of mid-1977 and 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). Its content focused on the feasibility of safeguarding a domestic U.S. mixed-oxide industry. The issues of international safeguards, the possible effect of a domestic mixed-oxide industry on international considerations, and any influence on international nuclear proliferation were beyond the scope of this report.

Prior to completion and publication of this document as an environmental impact statement, President Carter, on April 7, 1977, announced some of the conclusions he had reached following a thorough review of nuclear power issues. The issues raised by the President's statement were sufficiently fundamental to cause Commission reassessment of the course being followed with respect to GESMO. As a result of the reassessment, which included consideration of public comments and the views of the Executive Branch, the Commission announced termination of the GESMO proceedings in 42 FR 65334.

While directing the termination of the GESMO proceedings, the Commission recognized the value of making the results of the effort devoted to the study of safeguards issues available to the public. Accordingly, the NRC staff is providing such information with its publication of this document as a technical report. Thus, the information contained herein becomes publicly available for use in addressing nuclear power issues. Any questions or comments on this document should be referred to the Director, Division of Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

GLOSSARY

AC	Access Control Station
ACLU	American Civil Liberties Union
AEC	Atomic Energy Commission
BEIR	Biological Effects of Ionizing Radiations
BWR	Boiling Water Reactor
CAS	Central Alarm System
CCTV	Closed Circuit TV
^{252}Cf	Californium
CFR	Code of Federal Regulations
CIA	Central Intelligence Agency
^{244}Cm	Curium
^{60}Co	Cobalt
DOE	Department of Energy
DOD	Department of Defense
ERDA	Energy Research and Development Administration
FBI	Federal Bureau of Investigation
FES	Final Environmental Statement
FFBI's	Full-field Background Investigations
FFTF	Fast Flux Test Facility
FGF	Federal Guard Force
FR	Federal Register
GESMO	Generic Environmental Impact Statement on the use of recycle plutonium in mixed-oxide fuel for light water reactors
gm	gram
HEPA	High-efficiency Particulate Air
HEU	High Enriched Uranium
IAEA	International Atomic Energy Agency
ICA	Item Control Area
ICV	Integrated Container - Vehicle
IFCF	Integrated Fuel Cycle Facility

kWh	Kilowatt-hours
Kg	Kilograms
LEMUF	Limit of Error for MUF
LLEA	Local Low Enforcement Agencies
LWR	Light Water Reactors
MAA	Material Access Areas
MBA	Material Balance Areas
MFMD	Magnetic Field Metal Detector
MOX	Mixed Oxide
MT	Metric Tons
MTM	Metric Tons Metal
MTU	Metric Tons Uranium
MUF	Material Unaccounted for
MWe	Megawatts Electric
NEC's	Nuclear Energy Centers
NEPA	National Environmental Policy Act of 1969
NEST's	Nuclear Emergency Search Teams
NRC	Nuclear Regulatory Commission
NSA	National Security Agency
Pu	Plutonium
Pu_f	Fissile Plutonium
$Pu(NO_3)_4$	Plutonium Nitrate
PuO_2	Plutonium Dioxide
PWR	Pressurized Water Reactor
R&D	Research and Development
RETIMAC	Real-time Material Accounting and Control
SECOM	Secure Communications
SEV	Special Escort Vehicle
SNM	Special Nuclear Material
SSNM	Strategic Special Nuclear Material
ST	Short Tons
STOL	Short Take Off and Landing
SWU	Separate Work Units

UF_6	Uranium Flouride
USAEC	United States Atomic Energy Commission
VA	Vital Areas
VHF	Very High Frequency

CHAPTER 1

INTRODUCTION

In considering the proposed wide-scale use of mixed-oxide (MOX) fuel in light water nuclear reactors, the Nuclear Regulatory Commission (NRC) prepared an environmental impact statement in accordance with the National Environmental Policy Act of 1969 (NEPA). In its notice of November 1975 (40 FR 53056), the Commission described the scope, procedures, and schedule for completing that statement and indicated that before it reached a decision on the wide-scale use of mixed-oxide fuel, there must be a full assessment of safeguards issues. Toward that end, the Commission directed its staff to prepare, and to circulate for written comment, a Draft Safeguards Supplement to GESMO, the Atomic Energy Commission's "Generic Environmental Statement on the Use of Recycle Plutonium in Mixed-Oxide Fuel in Light Water Cooled Reactors." The draft GESMO (WASH-1327) was issued in August 1974, and the Health, Safety, and Environment portion of the final GESMO (NUREG-0002) was issued in August 1976. In its notice of December 30, 1977 (42 FR 65334), the Commission stated its decision to publish the Draft Safeguards Supplement to GESMO as a staff technical report. This report is that document.

The draft GESMO (WASH-1327) reviewed the then current safeguards program, presented some cost estimates for safeguards, and noted numerous measures that could contribute to upgrading the program. In the draft, the AEC staff concluded that the safeguards problems would be manageable and that there did not appear to be any safeguards-related rationale sufficient to delay a decision on the wide-scale use of mixed-oxide fuel for light water reactors.

In commenting on the draft GESMO, the President's Council on Environmental Quality, in a January 20, 1975, letter to the NRC, expressed the view that, although the statement was well done and reflected a high quality effort, it was incomplete because it failed to present 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. The Council believed that such a presentation should be made by the Nuclear Regulatory Commission before it made its final decision on the wide-scale use of mixed-oxide fuel. This report is intended to be fully responsive to the views offered by the President's Council on Environmental Quality, other expressions of views, and to a directive from the Commission to its staff.

This report addresses only the safeguards that would be associated with LWR mixed-oxide fuel.* Other aspects of environmental impacts associated with LWR mixed-oxide fuel were treated in the draft GESMO, and subsequently in the Health, Safety, and Environment portion of the final GESMO (NUREG-0002).

---

*Safeguards are defined as those measures employed to prevent the theft or diversion of special nuclear materials (plutonium, ^{233}U, or uranium enriched in the ^{235}U isotope) and the sabotage of nuclear facilities.

The basic issue addressed in this Supplement is the safeguarding of the additional plutonium or plutonium-containing materials that would be introduced into commercial operations by the wide-scale use of mixed-oxide fuel in light water reactors. The safeguards concerns about plutonium arise from its potential use in nuclear explosives and its radiological toxicity. The quantities of these materials now in the licensed industry are limited to those present in the spent fuel of light water nuclear reactors, and to those used for R&D purposes. Approval of the LWR mixed-oxide fuel cycle would result in the introduction of much larger quantities, in more accessible form, in commercial operations.

The question of whether safeguards are adequate can be discussed only on a dynamic basis. There are no static answers because both the problems and the solutions change as the nuclear industry, the perceived threats to society, and the security technologies that can be brought to bear continue to change.

Chapter 2, BACKGROUND, treats in greater detail the history which led to the preparation of this document. The remaining chapters are based, as indicated below, on providing answers to three basic questions:

1. What would be the potential incremental risks to society from malevolent acts directed at large quantities of plutonium in the commercial sector? The answers to this question are to be found in the characteristics of the projected mixed-oxide fuel cycle industry, the potential threats to that industry or its commerce, and the consequences those threats would bring if they were carried out successfully (i.e., if safeguards failed). These matters are dealt with in Chapter 3, SAFEGUARDS CONSIDERATIONS FOR THE MOX FUEL INDUSTRY.

Section 3.2, "Description of a Mature MOX Fuel Industry," uses an industry model to describe the characteristics such an industry would have--including the numbers and nature of facilities which would exist and the operations which would be conducted in them--and describes the requirements for safeguarding the resulting commercial transport of plutonium-containing materials. This industry description is based on the same growth projections as are used in the Health, Safety, and Environment portion of the final GESMO (NUREG-0002), projections which reflect significant changes which have occurred in estimates of nuclear industry growth rates since publication of the draft GESMO (WASH-1327).

Section 3.3, "Threats to a MOX Industry," and Section 3.4, "Possible Consequences of Theft or Sabotage," describe the threats of theft and sabotage that might be brought to bear against the MOX industry and the consequences that might result. The discussion of potential threats characterizes classes of groups and individuals who might be considered as potential adversaries It describes their motivations, their aims and objectives, and their potentials for undertaking activities threatening to a mature MOX industry. The discussion of potential consequences treats the difficulties which adversaries might encounter in manufacturing and employing crude nuclear explosive or dispersal devices and in carrying out sabotage for the release of radiation, as well as the extent of public injuries and damage which might result therefrom.

2. Could MOX in wide-scale commercial use be sufficiently well-protected, under the concept of continued civil order, to assure that the risks to society from malevolent acts would be acceptably low? Chapter 4, APPROACHES TO SAFEGUARDS, describes the strategies, technical means, and existing regulations through which safeguards can be implemented, now and in the future.

Chapter 5, THE REFERENCE SAFEGUARDS SYSTEM, describes a set of integrated measures which could be employed to achieve an adequate safeguards system (referred to as a reference system) for protection of a mature MOX industry, explains why the system is considered adequate and estimates its cost.

Chapter 6, ALTERNATIVE SAFEGUARDS OPTIONS, considers potential alternatives to the reference system which might enhance safeguards effectiveness or mitigate the reference system's economic or societal impacts. It discusses the effectiveness and costs of these alternatives and the extent to which they might involve new legislation, additional societal burdens, or possible perturbations to the model industry.

3. If adequate safeguards could be provided, would their economic and other societal impacts (i.e., on civil liberties, laws, institutions, physical environment, etc.) be acceptable? Some answers to this question are provided in Chapter 7, SOCIETAL IMPACTS, which describes the societal impacts of the reference safeguards system and compares them with the impacts of programs which would be needed to protect a mature nuclear industry without mixed-oxide fuel. The impact of the reference system on civil liberties receives special attention followed by a discussion of the societal impacts of the alternative safeguards approaches, and a comparison between these impacts and those of the reference system.

Due to geographic and social characteristics, the analysis and conclusions expressed in this report pertain only to the United States. Also, this report does not address the possible impact of domestic recycle on international questions, including any potential effect on the proliferation of nuclear weapons. Other Government agencies such as DOE, the Arms Control and Disarmament Agency, and the Department of State, with lead responsibility in this area, are currently studying such questions.

This report does not address an overall GESMO final cost-benefit analysis the emphasis is on setting forth a factual and conceptual basis for assessing the adequacy and the costs of safeguards for wide-scale use of mixed-oxide fuel. A substantial body of technical information upon which the document relies can be found in the references cited at the end of each chapter.

CHAPTER 2
BACKGROUND

2.1 GENERAL

Unlike fossil fuel plants, which discharge ash with no fuel content, nuclear reactors produce fuel residues containing appreciable quantities of fissile uranium and plutonium. From the early days of the nuclear power industry, electric utilities have anticipated that this spent fuel would be chemically reprocessed to recover the plutonium and uranium and that these recovered elements would be recycled into fresh reactor fuel. Projections of nuclear power industry growth indicate that by the time the industry matures, each year's production of such residues could have a fuel value in excess of $1 billion.*

Anticipating such economic incentives, the Atomic Energy Commission (AEC), from 1956 to 1972, conducted a Plutonium Utilization Program which demonstrated the technical feasibility of plutonium recycle. In 1967, major industry programs were initiated by Westinghouse Electric Corporation and the General Electric Company, supported by the Edison Electric Institute, on mixed oxide fuel development and testing. These were followed by a performance demonstration program in commercial reactors. Large MOX fuel research programs have also been conducted in Belgium and Italy and smaller ones in Sweden, Norway, Germany, England, and France. These programs have confirmed that recycle is technically feasible. Three light water nuclear power reactors (Big Rock Point in Michigan, and Quad-Cities 1 and Dresden 1 in Illinois) are now licensed to operate on an experimental basis with a limited amount of MOX fuel.

It is expected that future reprocessing plants would each be able to process 1,500 to 2,000 metric tons of spent fuel annually, while MOX fabrication plants would have annual capacities of approximately 300 tons. Currently, no plants with such capacities are in operation. The Nuclear Fuel Services, Inc. reprocessing plant at West Valley, New York, which has been shut down, operated between 1956 and 1971, during which period it processed 640 metric tons of spent fuel. A number of small fabrication plants capable of producing modest quantities of MOX fuel (approximately 50 tons per year) have been licensed, and the Nuclear Regulatory Commission has pending several related licensing actions, the most advanced of which are:**

> Allied-General Nuclear Services' separations and uranium conversion facility and spent fuel storage facility in Barnwell, South Carolina, the construction of which is nearing completion.
>
> Westinghouse Electric Corporation's application for approval to construct a MOX fuel fabrication plant near Anderson, South Carolina.

---

*NUREG-0002, Volume 4, Page XI-1, shows a net cumulative fuel value, 1976-2000, of $18 billion, with most of this value accruing after the industry matures.

**The Commission announced its decision to terminate the proceedings on these licensing actions in 42 FR 65334 on December 30, 1977.

Exxon Nuclear Company's application for approval to construct separation and conversion facilities near Oak Ridge, Tennessee.

2.2 DRAFT GESMO, WASH-1327

On February 12, 1974, in accordance with the National Environmental Policy Act of 1969 (NEPA), the AEC directed its regulatory staff to prepare an environmental impact statement on the use of MOX fuel in light water reactors (LWR's). At first, health and safety considerations dominated the AEC analysis. During the course of document preparation, however, Government and public perception of the issues changed as increased incidence of worldwide terrorism led to greater concern that nuclear materials might be diverted from the fuel cycle in order to fabricate explosives or dispersal devices. The draft statement was therefore modified to give greater emphasis to security considerations.

On August 5, 1974, the AEC's regulatory staff issued for public comment its draft Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in LWR's (WASH-1327, referred to as GESMO). The 1,000-page document concluded that the wide-scale use of MOX fuel should be approved. This conclusion was based in part on findings that plutonium recycle would actually reduce slightly the adverse environmental impacts of the nuclear fuel cycle while causing no change in the safety of reactor operations; that it would extend the life of uranium reserves; and that it would reduce requirements for uranium enrichment. After noting that a decision on specific safeguards measures for a mature MOX fuel industry should be made within a year after issuance of the final impact statement, the draft GESMO concluded further that safeguards problems were manageable, and that there were no safeguards issues which should delay a decision on whether to allow use of MOX fuel.

2.3 THE ENERGY REORGANIZATION ACT OF 1974*

On January 19, 1975, the Energy Reorganization Act of 1974 became effective. It abolished the U.S. Atomic Energy Commission and assigned its responsibilities for the regulation of the nuclear power industry to a newly created agency, the Nuclear Regulatory Commission (NRC). The statute reflected, in several ways, congressional concern about the need to protect the public against the consequences of nuclear theft or sabotage. For example, the legislation provided for an Office of Nuclear Material Safety and Safeguards within NRC and provided both broad and specific guidance concerning the safeguards functions of that Office.

2.4 COMMENTS ON DRAFT GESMO

In a January 20, 1975, letter to the newly formed NRC, the President's Council on Environmental Quality (CEQ) expressed the view that, although the draft environmental statement (GESMO) was in general a high quality effort, it was incomplete because it failed to present a detailed and comprehensive analysis of the environmental impacts of the potential diversion of special nuclear materials and of alternative safeguards programs to protect the public from such a threat. The Council contended that the NRC should make such a presentation before reaching its final decisions on plutonium recycle. The Council also expressed the view that care should be taken to avoid actions which would foreclose safeguards alternatives or which would result in unnecessary "grandfathering" during the period in which the safeguards issue was being resolved.

---

*42 U.S.C. §§ _et seq._

Approximately 100 letters were received from the public relating to the draft GESMO, and approximately 40 percent of these raised issues related to safeguards. The analysis contained in this report responds to this public expression of concern as well as the points raised in the CEQ letter.

2.5 SAFEGUARDS STUDIES

In addition to providing for an Office of Nuclear Material Safety and Safeguards within NRC, Section 204 of the Energy Reorganization Act directs the Office to conduct an overall review of safeguards needs. The Act specifies that the Office should review the "need for, and feasibility of, establishing a security agency within the Office for the purpose of performing safeguards functions." The Act also requires that NRC make a review of the advantages of locating on the same site facilities performing sucessive steps in the nuclear fuel cycle. In compliance with these requirements of the Act, the NRC prepared reports known as the Security Agency Study and the Nuclear Energy Center Site Survey, respectively (Refs. 1 and 2). In addition, the NRC initiated a program of special safeguards studies designed to address safeguards questions raised after publication of the draft GESMO. The results of NRC's study efforts in these three fields are summarized below.

2.5.1 Security Agency Study

The Security Agency Study concentrated on the merits of using Federal guards, organized in a Federal security agency, to protect nuclear facilities and materials, in place of the present system of utilizing guards hired by private industry. Much of the study group's effort was devoted to onsite visits, to meetings with Government and industry groups familiar with nuclear plant and materials security, and to meetings with legal, academic, and public interest groups. The study found that creation of a special security force within NRC would not result in a higher degree of guard force effectiveness than could be achieved by use of private guards. It concluded that no need exists for the Federal Government to assume operational responsibility for security forces to protect the licensed commercial industry and, accordingly, that there is no need to create a security agency within the Nuclear Regulatory Commission. The study's analysis of the existing regulatory structure indicated that NRC can fulfill its responsibilities to ensure adequate physical protection of licensed facilities and materials through appropriate regulations, stringently enforced, and through an increased role for NRC in functions related to the qualification, training, and certification of private guard forces.

2.5.2 The Nuclear Energy Center Site Survey

The Nuclear Energy Center Site Survey analyzed the practicability and feasibility of three different types of nuclear energy centers: power-plant centers, in which 10 to 40 nuclear power plants would be grouped together; fuel cycle centers, which would group together spent fuel reprocessing plants, mixed oxide fuel fabrication facilities, and waste management facilities; and combined centers, which would collocate both power plants and fuel cycle facilities.

The study concluded that power plant centers and fuel cycle centers are feasible and practical, but that no compelling need for such centers is evident. The study also noted that fuel cycle centers might offer safeguards advantages by reducing the routine shipment of plutonium compounds between fuel reprocessing and fuel fabrication plants.*

2.5.3 The Special Safeguards Study

In February 1975, as an outgrowth of previous USAEC consideration on the widescale recycling of plutonium in light water reactors, the NRC directed that an effort to determine a safeguards program for plutonium recycle be established. These efforts were known as the "Special Safeguards Study" (Ref. 3) and included support by various contractors. The results of the Special Safeguards Study were extensively utilized in preparing this document, and references to the contractor reports are included as appropriate.

2.6 NRC PROVISIONAL VIEWS OF MAY 8, 1975

In the May 8, 1975, Federal Register (40 FR 20142), the Nuclear Regulatory Commission stated its provisional views on the process to be used in reaching decisions on the possible wide-scale use of MOX fuels, and requested public comment thereon. Subject to consideration of comments to be received and the results of then ongoing studies, the Commission view was that before it reached a decision on wide-scale use of mixed-oxide fuels in light water reactors, a cost-benefit analysis of alternative safeguards programs should be published in both draft and final environmental impact statements.

In response to the May 8 notice, more than 200 comments were received by the NRC.** These focused on the following issues:

- Whether the Commission's decision on wide-scale use of MOX fuel in LWR's should be delayed, pending the completion of a cost-benefit analysis of alternative safeguards programs.

- Whether current NRC regulations for related licensing actions are adequate to protect against theft or diversion of plutonium.

- What procedures should be utilized by the Commission in reaching its decision on wide-scale use of MOX fuel, and what should be the procedures for public hearings related to that decision.

2.7 NRC ANNOUNCEMENT OF CONCLUSIONS**

On November 11, 1975, the Commission announced the conclusions it had reached after review of the extensive public comments on its published provisional views and further deliberations. The following were highlights of the announcement:

- A cost-benefit analysis of alternative safeguards programs for the wide-scale use of MOX fuel would be prepared as a supplement to the draft GESMO published by the AEC in

---

*A discussion of the possible safeguards advantages and disadvantages of collocation of fuel cycle facilities appears in Chapter 6 of this report.

**These comments have been placed in the Commission's Public Document Room, 1717 H St., N.W., Washington, D.C., and are available for review by the public.

August 1974 (thereby establishing this report supplement to the GESMO as a separate document moving forward on a separate but compatible time schedule). In the meantime, the final statement on health, safety and environmental matters would be prepared, based on portions of the draft GESMO (WASH-1327) and on analysis of public comments. An overall cost-benefit analysis would be published at the time that this report was issued.

- Proposed rules to be applied in the event of wide-scale use of MOX fuel would be published for comment concurrently with publication of final portions of the GESMO.
- In the event of a favorable decison on wide-scale use, final rules would be issued at the time of the decision.
- The public would have an opportunity to participate in the ultimate decison by commenting on the draft of this report and the proposed rules and by participating in hearings.
- The NRC staff would continue reviewing applications already submitted for MOX-fuel-related activities and would commence review of any new application received.

2.8 JOINT NRC/ERDA TASK FORCE STUDY

The report of a Joint NRC/ERDA (now DOE) Task Force on Safeguards was presented to the Commission in July 1976 and published in February 1977 (Ref. 4). The Task Force addressed the current status and future direction of physical security safeguards at 15 NRC-licensed fuel cycle facilities, the majority of which process nuclear materials under DOE contracts.

The Task Force found no evidence of any imminent threat of theft or diversion of SSNM. In the absence of evidence of threats, the Task Force report indicated that safeguards planning must necessarily be based on assumptions of motivations and estimates of capabilities of hypothetical threats. However, the Task Force concluded that prudence requires providing higher levels of security to increase assurance to cope with threats that might develop in the future. Accordingly the Task Force proposed that future safeguards be designed to provide more effective protection against internal conspiracies and determined violent assaults.

The report recommended that: (a) the NRC/ERDA/DOE approach to raising the levels of future safeguards for weapons-grade nuclear materials be a continuation of current upgrading programs; (b) NRC and ERDA/DOE maintain comparable safeguards: and (c) the safeguards design level for all significant quantities* of strategic special nuclear material be raised for both existing and future facilities.**

---

*Significant quantities are defined as two kilograms or more of plutonium or five kilograms or more of ^{235}U (contained in uranium enriched to 20% or more in the ^{235}U isotope). The significant quantities for special nuclear materials are established at a level judged to be substantially less than that required for the illicit manufacture of a nuclear explosive. In general usage, the term "strategic" quantity is synonymous with the term "significant" quantity.

**A further discussion of enhanced safeguards is given in Chapter 5 of this Supplement.

In a January 21, 1977, press release, the NRC announced plans, consistent with the foregoing, for an orderly upgrading of existing safeguards. On July 5, 1977, in keeping with this plan, the NRC published for comment proposed changes to 10 CFR Parts 70 and 73, changes which, if adopted, would implement the upgrading.*

2.9 FINAL GESMO: HEALTH, SAFETY, AND ENVIRONMENT

The Health, Safety, and Environment portion of the Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors (NUREG-0002) was published in August 1976.

In this document the NRC staff considered five fuel cycle alternatives and evaluated them on the basis of health, safety, and environmental--but not safeguards--effects. Principal staff findings were as follows:

- The safety of reactors and fuel cycle facilities would not be affected significantly by recycle of fissile materials.
- Nonradiological environmental impacts resulting from a fuel cycle involving recycle of fissile materials from spent fuel would be slightly smaller than those from a fuel cycle without recycle.
- Plutonium recycle would extend uranium resources and reduce enrichment requirements, while requiring reprocessing and fabrication of plutonium-containing fuels.
- While there are uncertainties, wide-scale recycle would probably have an economic advantage over a fuel cycle without recycle.
- Differences in health effects attributable to recycle are too small to provide a significant basis for choosing among fuel cycle options.
- No waste management considerations were identified that would bar recycle of uranium and plutonium.

The statement reiterated the Commission's position that a final decision on wide-scale use of MOX fuel would be based on analysis of both the Health, Safety, and Environment statement and the final report supplement to GESMO, as well as on the results of the public hearings to be held on the two statements. Publication of an overall cost-benefit analysis was deferred pending completion of this report.

2.10 PRESIDENTIAL STATEMENT OF APRIL 7, 1977

On April 7, 1977, President Carter announced some of the conclusions he had reached following a thorough review of nuclear power issues. Among other things, he concluded that the

---

*Federal Register, Vol. 42, No. 128, July 5, 1977, pp. 34310-34326.

risks of proliferation of nuclear weapons required a major change in U.S. domestic nuclear programs and a concerted effort among all nations to prevent proliferation.

As to specific programs, the President announced his intent to:

- Defer indefinitely U.S. commercial reprocessing and recycling of plutonium.
- Restructure the U.S. breeder program to give greater priority to alternates to the plutonium breeder and to defer the introduction date of a commercial breeder.
- Redirect the U.S. nuclear R&D program to accelerate research into alternate fuel cycles not involving direct access to materials useful for weapons production.
- Increase U.S. enrichment capacity so that the United States can be a reliable supplier for both domestic and foreign needs.
- Propose necessary legislative steps to permit the United States to sign firm supply contracts with other nations.
- Continue to embargo the export of equipment or technologies needed for enrichment or chemical reprocessing.
- Continue discussions with supplier and recipient countries on a wide range of international approaches and frameworks which permit all countries to achieve their own energy needs while at the same time reducing the spread of nuclear weapons capability.

2.11 COMMISSION DECISION ON DRAFT SAFEGUARDS SUPPLEMENT TO GESMO

The issues raised by the President's statement were sufficiently fundamental to cause Commission reassessment of the course being followed with respect to GESMO. As a result of the reassessment, which included consideration of public comments and the views of the Executive Branch, the Commission announced termination of the GESMO proceedings in 42 FR 65334.

While directing the termination of the GESMO proceedings, the Commission recognized the value of making the results of the effort devoted to the study of safeguards issues available to the public. The President's statement, by its very emphasis on the dangers of proliferation of nuclear weapons, highlights the need for a comprehensive source of information on the types of nuclear safeguards available, their probable cost, and their possible societal impacts. Accordingly, the document, originally conceived as the Draft Environmental Impact Statement Safeguards Supplement to NUREG-0002, is published herewith as a Technical Report.

CHAPTER 2

REFERENCES

1. U.S. Nuclear Regulatory Commission, "Security Agency Study: Report to the Congress on the Need for, and the Feasibility of, Establishing a Security Agency within the Office of Nuclear Material Safety and Safeguards" (NUREG-0015), August 1975.*

2. U.S. Nuclear Regulatory Commission, "Nuclear Energy Center Site Survey - 1975" (NECSS-75) (NUREG-0001), 5 vols. Vol. V, Pt. 1, "Summary and Conclusions," January 1976.*

3. U.S. Nuclear Regulatory Commission, "Special Safeguards Study, Scopes of Work," (NUREG-75/060), June 1975.*

4. U.S. Energy Research and Development Administration, U.S. Nuclear Regulatory Commission, "Joint ERDA-NRC Task Force on Safeguards (U)" (NUREG-0095) (ERDA 76-163), July 1976 (U).**

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

**Available in NRC PDR for inspection, and copying, for a fee.

BIBLIOGRAPHY

1. Aerojet Nuclear Company, Idaho National Engineering Laboratory, Allied Chemical Corp., Final Report, "Evaluation of the Real-Time Material Control Concept for Safeguards in Highly Enriched Uranium Fuel Cycles," September 1975.

2. Aerojet Nuclear Company, Idaho National Engineering Laboratory, Draft Summary, INEL Summary for Ch. 8, "Material Control and Accounting Systems," Part E, "Extension of Real-Time Material Control Safeguards Concepts to Highly-Enriched Uranium Fuel Cycles," September 1975.

3. Battelle Columbus Laboratories, "The Development of a Statement of Objectives for the Safeguards Program," June 1975.

4. The BDM Corp., "Analysis of the Terrorist Threat to the Commercial Nuclear Industry," Draft Working Paper C, "Supporting Appendices," BDM/W-75-176-TR, September 1975.

5. Brookhaven National Laboratory, "Draft Final Report on Evaluation of the Impact of Safeguards Measures," File No. 5.9.2, August 1975.

6. Brookhaven National Laboratory, "Limitations on Personnel Access to Special Nuclear Material Records," November 1975.

7. Cusack, J. H., E. V. Weinstock, H. P. Indusi, W. A. Higginbotham, Brookhaven National Laboratory, "Draft Final Report on Confirming the NRC Safeguards Objective," File No. 5.9.3, August 1975.

8. Lawrence Livermore Laboratory, Final Report, "Technical Appendix for the Special Safeguards Study on Material Control and Accounting Systems," September 1975.

9. Lawrence Livermore Laboratory, Science Applications Inc., Final Report, "Executive Summary of the Special Safeguards Study on Material Control and Accounting Systems," September 1975.

10. McSweeney, T. I., J. W. Johnston, R. A. Schneider, D. P. Granquist, Battelle Pacific Northwest Laboratory, "Improved Material Accounting for Plutonium Processing Facilities and a ^{235}U - HTGR Fuel Fabrication Facility," BNWL-2098, UC-16, October 1975.

11. The MITRE Corp., 'The Threat to Licensed Nuclear Facilities," MTR-7022, September 1975.

12. Rodenburg, W. W., Mound Laboratory, Monsanto Research Corp., "Plutonium Isotopic Control: A Special Safeguards Study Performed for the United States Nuclear Regulatory Commission," September 1975, and "Addendum to Special Safeguards on Pu Isotopic Control," October 1975, pp. 64-72.

13. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle"

    Vol. I--"Executive Summary" (Unclassified)
    Vol. II--"Fixed-Site Physical Protection System(U)" (Confidential)
    Vol. III--"Elements of Physical Protection for Fixed Sites(U)" (Secret)
    Vol. IV--"Transportation Mode Analysis(U)" (Confidential)
    Vol. V--"Elements of Physical Protection for Transportation" (Secret)
    Vol. VI--"Relocation and Recovery(U)" (Secret)

    SAND-75-0457, March 1976.

14. Science Applications, Inc., "An Evaluation of Real-Time Material Control and Accountability in a Model MO_2 Fuel Plant," SAI-75-648-LJ, September 1975. (Section 4, pp. 127-147, "Evaluation of Prompt Theft Indicators," Confidential, has been deleted.)

CHAPTER 3

SAFEGUARDS CONSIDERATIONS FOR THE MOX FUEL INDUSTRY*

3.1 INTRODUCTION

Plutonium is the natural byproduct of the operation of today's uranium-fueled light water power reactors. Its fuel value is roughly equivalent to that of ^{235}U. Some of the plutonium produced in a reactor is fissioned in place, but about half of the bred-in plutonium, about [illegible] kilograms per metric ton of uranium fuel, remains in the spent fuel. Spent fuel can be stored so that its highly radioactive properties do not present health hazards, or it can be reprocessed so that uranium or plutonium or both can be recovered and used in new fuel. If plutonium is recovered and reused, the recycle fuel is a mixture of plutonium oxide and uranium oxide, referred to as "mixed oxide" (MOX).

If plutonium recycling is encouraged and a MOX industry is initiated, public risks which are not now present might result. These risks would arise from the increased radioactivity of the spent fuel and the possible malevolent use of plutonium compounds in nuclear explosives or radiotoxic dispersal devices. It is of concern that the use of MOX as a standard fuel would greatly expand the presence of plutonium in the commercial nuclear power industry and that there may exist individuals and groups who would wish to threaten or inflict destruction upon society by means of plutonium-containing devices. Those factors involved in examining the safeguards considerations of a commercial power industry based on the wide-scale use of MOX fuel are treated in this chapter.

- Section 3.2 presents a description of a future MOX fuel industry. The description assumes a technologically well-developed industry, still growing, that includes 507 light water reactors and supporting facilities to process spent fuel and fabricate fresh fuel.

---

*The safeguards considerations presented in this chapter are based upon the estimated size of the MOX fuel industry for the United States if plutonium recycle should be approved. The analysis and conclusions regarding safeguards assume current and expected geographic and social characteristics specific to the United States. Geographic factors include a land area sufficient to allow extensive acreage as part of the physical safeguards of a facility, but also requiring lengthy transportation of SNM; lengthy unguarded borders allowing fairly free movement of would-be malefactors; and many areas of geographic remoteness available as a base for malevolent acts. Social and political factors include: a democratic/Federal form of government; extensive protection of civil liberties by Constitution and law; unrestricted internal mobility of citizens; an interconnected network of State, Federal, and local law enforcement officials possessing highly sophisticated surveillance and communication equipment; a historically conditioned reluctance of citizenry to commit malevolent acts against society at large; extensive public participation in political and regulatory decision-making processes; an extensive and excellent internal highway network; virtually unlimited individual access to vehicles and small aircraft; an absence of any national requirement for individual identity papers; and very limited firearms controls. Thus, the observations and conclusions made here--particularly those regarding threat assessment--may be of limited applicability to other countries, where geosocial conditions vary significantly from those in the U.S.

Section 3.3 discusses, in generic terms, the nature of the potential threat from malevolent activity to a mature MOX industry. Adversary groups which are considered able to develop and implement such threats are discussed in terms of their aims and objectives. Currently, there appears to be little basis for believing that such groups would be motivated to engage in illicit nuclear activities; nevertheless, prudent planning demands that MOX industry safeguards be identified for dealing effectively with the threats considered to be within their capabilities.

Section 3.4 discusses in some detail the potential consequences of theft of nuclear materials or sabotage of a nuclear facility or transport vehicle. It emphasizes the wide range of expert opinion on how difficult it is to use plutonium illicitly and concludes that specific answers are less important than the fact that even the lower range of effects caused by the malevolent use of plutonium is sufficient to require a safeguards system that minimizes the risk of loss of plutonium-containing material.

3.2 DESCRIPTION OF A MATURE MOX FUEL INDUSTRY

This section presents a snapshot of a MOX fuel industry, growing at a rate of about 5 percent per year, as it might exist when fuel processing techniques have matured and there are 507 nuclear power reactors of 1,000-MWe generating capacity each.* The description of this "mature" MOX industry is consistent with projections for the year 2000 used in the final GESMO (NUREG-0002). The facilities of such a MOX fuel industry are, with a few exceptions, not even designed or under construction. To aid in establishing the safeguards needs of this "mature" MOX industry, generic descriptions of plutonium-handling facilities are also presented in this section, as well as a discussion of the accessibility of plutonium in these facilities. Finally, types of plutonium-bearing materials are defined.

For comparative purposes, the safeguards needs of this projected MOX industry are measured against the safeguards needs of an LWR industry providing the same level of power generation but permanently storing its spent fuel rather than reprocessing it. This reference industry is referred to as the "throwaway" industry. Such an industry would have no spent fuel reprocessing so that plutonium would be found only in its reactors and in spent fuel, which would be stored in cooling pools on reactor sites, in permanent storage, or in transit to permanent storage.

3.2.1 Overview

The magnitude of the nuclear safeguards problem and its societal implications depends in part on the characteristics of the various nuclear materials involved and on the forms, containment, and locations of these materials throughout the industry.

Figure 3.1 depicts the facilities and material flow paths of a mature MOX industry. A comparison of the projected number of facilities in the MOX and throwaway industries and of their annual production rates is given in Table 3.1.

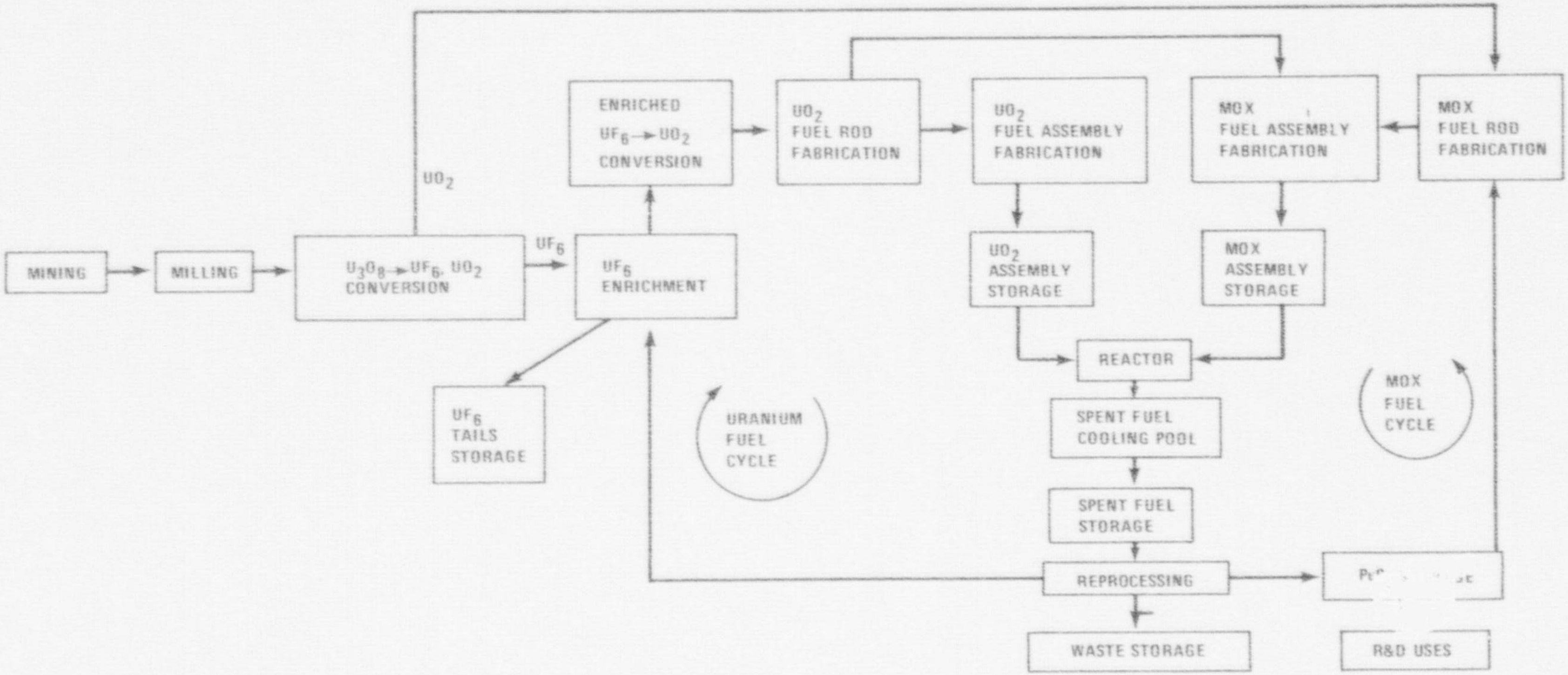


Figure 3.1 Material Flow Diagram of the Mature MOX Industry

TABLE 3.1

COMPARISON OF PROJECTED "THROWAWAY" AND MOX LIGHT WATER REACTOR INDUSTRIES IN THE YEAR 2000

Industry Component	Annual Capacity[a,b]	Number of Facilities		Annual Industry Production[b]	
		Throwaway (GESMO Alt. 6)	MOX (GESMO Alt. 3)	Throwaway	MOX
LWR's	1,000 MWe	507	507	2.9×10^{12} kWh	2.9×10^{12} kWh
Mines					
Underground	20,000 ST ore	5,600	4,000	-	-
Open Pit	200,000 ST ore	240	170	-	-
Mills (model)	1,050 ST U_3O_8	110	80	110,000 ST	81,000 ST
UF_6 Conversion Plants	15,000 MTU (Natural Uranium)	7	5	87,000 MTU	59,000 MTU
Enrichment Plants	8,800 MT-SWU	6	5	45,000 MT-SWU	36,000 MT-SWU
Fuel Assembly Fabrication Plants[c]	2,000 MTM	9	7	13,500 MTU	9,400 MTU 4,100 MTM (in MOX)
Reprocessing Plants	2,000 MTM	0	5	0	10,000 MTM
MOX Rod Fabrication Plants	360 MTM	0	8	0	2,600 MTM
Federal Repository for Spent Fuel, High Level Waste and Transuranic Waste		2	2	8,400 MTM	720 M^3 H-Level Waste[d]
Commercial Burial Grounds	1×10^6 cu. ft.	11	11	-	12,000 M^3 Transuranic waste

---

[a] Annual capacity means the amount of output that can be reasonably expected under normal operating conditions. It is lower than a maximum practically achievable capacity by 10 to 20 percent. In general, most plants in these LWR industries would operate at somewhat less than the rated annual capacity because of variable rates of production and the small number of plants. For this reason, the rated annual capacity multiplied by the number of facilities will not exactly equal the respective annual production rates in the above table.

[b] Units for capacity and production rate are the same, except where noted. MT = metric tons, ST = short tons, SWU = separative work units, MTM = metric tons metal, and MTU = metric tons uranium.

[c] These plants include facilities for UF_6 to UO_2 conversion and UO_2 fuel rod fabrication, and facilities for UO_2 and MOX assembly fabrication. In the throwaway case, the annual capacity is 1,500 MT of UO_2 per plant.

[d] To be solidified by the year 2005 and shipped to repository by the year 2010.

The models presented herein for the mature MOX industry and for the throwaway industry are based on descriptions presented and discussed in NUREG-0002. The mature MOX industry is represented by GESMO Alternative 3, and the throwaway industry by GESMO Alternative 6. For purposes of this assessment, it is assumed that in both cases there would be 507 LWR's of 1,000-MWe generating capacity each.

The safeguards needed for the MOX industry would clearly exceed those needed for the throwaway industry due to the great amount of plutonium (a flow of about 82 metric tons of fissile plutonium each year) that would be processed and transported by licensees. Special facilities would be needed for spent fuel reprocessing, MOX fuel production, and MOX fuel rod fabrication and MOX fuel element assembly. There would also be a requirement for the transportation of plutonium-bearing materials and other radioactive products between these facilities. An industry based on GESMO Alternative 5 (uranium recycle only) would also require incremental safeguards, as compared to the throwaway industry, if the plutonium were separated at the reprocessing plant, but not if it were left in the spent fuel wastes.

3.2.2 MOX Fuel Cycles

As shown in Figure 3.1, a mature MOX industry would involve two segments, or cycles, one for low-enriched uranium fuel and the other for MOX fuel. It is useful at this point to include a brief description of each of these fuel cycles.

3.2.2.1 Uranium Cycle

The front end of the uranium fuel cycle in a MOX industry would parallel the cycle now employed for LWR's. This begins with the mining of uranium ore, transportation to and processing at mills, where the uranium is extracted from the ore as yellowcake (U_3O_8), and shipment to and processing at conversion plants where the yellowcake is converted to uranium hexafluoride (UF_6). This conversion to UF_6 produces a very pure compound which is solid at room temperature and pressure, but which is a gas at either a slightly elevated temperature or at reduced pressure.

The next step is enrichment of the UF_6 in the isotope ^{235}U from the natural form (0.7% ^{235}U) to a low enrichment (3%-5% ^{235}U). The low-enriched UF_6 is then shipped to a conversion plant where it is converted into a UO_2 powder. The UO_2 fuel rod fabrication plant forms the UO_2 powder into pellets and seals the pellets in Zircaloy tubes approximately 12 feet long and up to 1/2 inch in diameter. These fuel rods are then collected into fuel assemblies, each of which contains approximately 300 rods.

Fresh fuel assemblies are shipped to reactor sites where they are stored until used. About once a year, a reactor is shut down for refueling, spent fuel is removed and new fuel assemblies are inserted. From one-fourth to one-third of the fuel in light water reactors is replaced in this manner each year. Since the spent fuel is highly radioactive, it is stored for at least four months in cooling pools at the reactor site to permit the level of radioactivity to decrease.

If reprocessing plants were in operation, the spent fuel would then be shipped to them in heavily shielded casks. At the reprocessing plants the assemblies would first be stored until suitable further decay of radioactivity takes place. Then they would be chopped into pieces, and the fuel dissolved in nitric acid and separated into uranium, plutonium, high-level radioactive wastes, and Zircaloy hulls. The radioactive wastes would be solidified and sent to a Federal repository for disposal. The recovered uranium would be converted to UF_6 and shipped to an enrichment plant, as previously described, thus closing the uranium fuel cycle. The separated plutonium would be recycled in LWR's as described below.

3.2.2.2 Plutonium Cycle

Plutonium would be recovered from spent fuel at reprocessing plants as a plutonium nitrate solution $Pu(NO_3)_4$. It would then be converted to plutonium dioxide (PuO_2) powder. The oxide powder would next be blended with natural UO_2 to make a mixed oxide (MOX), a blend of about 5% PuO_2 and 95% UO_2. In a manner similar to that employed for enriched UO_2, MOX fuel rods would be made by pressing MOX powder into pellets which would be inserted and sealed into tubes. The MOX rods would be fabricated into fuel rod assemblies containing both MOX rods and low-enriched UO_2 rods or assemblies containing only MOX rods. These MOX fuel assemblies would then follow the same steps through the reactor to the reprocessing plant as do the uranium assemblies.

3.2.3 Facilities in the Industry

The following paragraphs present a summary description and discussion of the facilities which would comprise the fuel cycle portion of a mature MOX industry. The facilities involved would include spent fuel reprocessing plants, MOX fuel rod fabrication plants, low-enriched UO_2-MOX fuel assembly fabrication plants, and waste storage facilities. Each type of facility is described in terms of its processes, capacity, and flow of materials. Greater descriptive detail can be found in NUREG-0002, Chapter IV. The estimates used herein on the future growth of nuclear power as well as those on raw material and fuel cycle production levels needed to meet anticipated demands are also based on data presented in NUREG-0002.

3.2.3.1 Nuclear Power Plants

The net generating capacity of each individual power reactor is taken as 1,000 MWe. Each nuclear power facility would contain one or more reactors and the storage areas for new and spent fuel. All the reactors would be light water reactors (LWR's) of either the pressurized water reactor (PWR) or the boiling water reactor (BWR) type. It is assumed, for both the throwaway and the mature MOX industries, that there would be 507 LWR's, of which two-thirds would be PWR's and one-third BWR's. In the mature MOX industry, 250 reactors would use some MOX fuel, and 257 would use only low-enriched UO_2 fuel (see Table 3.2).

In the BWR's using MOX, 40% of the rods in each assembly would be MOX; whereas in the PWR's using MOX, 40% of the assemblies would consist of MOX rods only and 60% of low-enriched UO_2 rods only.

TABLE 3.2

LWR's IN MATURE MOX INDUSTRY

Type	Fuel UO_2 Only	 MOX	 Total
PWR	171	167	338
BWR	86	83	169
Total	257	250	507

In order to maintain reactivity and to remove poisons, approximately one-third of the fuel assemblies in each PWR and one-fourth of the assemblies in each BWR would be replaced each year. The irradiated fuel would be stored in cooling pools at individual reactor sites for 4 to 6 months to allow short-lived isotopes to decay. Spent low-enriched uranium fuel contains up to 9 kg plutonium per MT of fuel, while spent MOX fuel contains up to 20 kg of plutonium per MT. Additional safeguards would be required at those LWR's using MOX fuel in order to protect the new MOX fuel assemblies until they are loaded into the reactor core. Although the intense radiation field of the spent fuel generally provides theft protection, it must also be protected from sabotage. The heavy shipping cask, required for health and safety reasons, could provide this protection during shipment, but would not be used during storage.

3.2.3.2 Reprocessing Facilities

It is projected that a mature MOX industry would include five reprocessing plants, each with a capacity to process 2,000 metric tons of heavy metal (MTM) per year. These five plants would process a total of 10,000 MTM/year of spent fuel, yielding 123 MT/year of plutonium. Each metric ton of plutonium would contain 0.67 MT of fissile plutonium (Pu_f),* which would be equivalent to 1.13 MT of PuO_2.

Spent fuel assemblies arriving at a reprocessing facility from pool storage at the reactor site would be stored an additional 3 to 6 months to permit further decay of radionuclides into more stable products. After a suitable storage period, the assemblies would be subjected to a series of physical and chemical processes yielding plutonium in the form of oxide, recycle uranium in the form of uranium hexafluoride, and high- and low-level wastes. The discrete steps involved would be:

1. Storage of spent fuel

2. Shearing of spent fuel assemblies and rods

3. Dissolution of fuel pellets

4. Separation of uranium and plutonium from fission products

5. Separation of uranium from plutonium and purification of each separated product

6. Conversion of recovered uranium to UF_6

---

*Fissile plutonium refers to those plutonium isotopes which will fission on interaction with with thermal neutrons, namely, ^{239}Pu and ^{241}Pu.

7. Conversion of recovered plutonium to PuO_2

8. Storage of recovered UF_6 and PuO_2

9. Conversion of some liquid wastes to solids and storage of both liquid and solid radioactive wastes.

During these steps, plutonium would require protection from theft and sabotage.

3.2.3.3 Fuel Rod Fabrication Plants

PuO_2 would be shipped from the reprocessing facility to be blended with natural UO_2 at a MOX fuel rod fabrication plant. It is projected that in the mature MOX industry, there would be eight such plants, with an annual production of 360 MTM each. These would convert a total of 82 MT Pu_f per year into 2,600 MTM of MOX fuel rods. The fabrication processes would consist of the following operations:

1. Receiving, unloading, and storage of PuO_2 and natural UO_2
2. MOX powder blending and storage
3. MOX pelletizing and green pellet storage
4. Pellet sintering and storage
5. Pellet grinding, inspection, and storage
6. Fuel rod loading, inspection, and storage
7. Loading of fuel rod shipping containers and shipment to a MOX fuel assembly fabrication facility
8. Pu scrap recovery operations.

Each of these operations would have safeguards significance, especially numbers 1 and 8.

3.2.3.4 Fuel Assembly Plants

MOX fuel rods would be shipped from a MOX fuel rod fabrication plant to a UO_2-MOX fuel assembly plant to be incorporated into MOX fuel assemblies. It is assumed that these plants would have two process lines, one for low-enriched UO_2 assemblies, and a specially safeguarded one for MOX assemblies. It is assumed further that these plants would include facilities for converting UF_6 to UO_2, and for UO_2 fuel rod fabrication. The individual assemblies for a MOX-fueled PWR would contain either slightly enriched UO_2 or MOX rods, but not both, whereas each assembly for MOX-fueled BWR reactors would have a mixture of low-enriched UO_2 rods (60%) and MOX rods (40%). In the mature LWR industry, seven 2,000-MTM/year* fuel assembly plants would produce

---

*The capacity refers to the rated individual plant production rates of UO_2 and MOX fuel rod assemblies. Individual plants would probably operate at slightly under this rated annual capacity. (See Table 3.1, footnote a).

approximately 13,500 MTM of assemblies annually, of which 6,600 MTM would be for the 240 MOX-fueled reactors. Since 60% of the assemblies for a PWR using MOX would not contain plutonium, only about 4,100 MTM of the assemblies for PWR's and BWR's combined would contain plutonium and require plutonium-related safeguards.

The steps of safeguards significance in the manufacture of MOX fuel assemblies would include:

1. Receiving and unloading MOX fuel rods
2. Storage of MOX Fuel rods
3. Fabrication of MOX fuel assemblies
4. Storage of MOX fuel assemblies
5. Shipment of MOX fuel assemblies to the reactor.

3.2.3.5 Waste Storage Facilities

With either uranium or plutonium recycle, the high-level radioactive wastes produced at fuel reprocessing facilities would contain more than 99 percent of the total radioactivity of all the wastes produced in the fuel cycle, including mill tailings. The reprocessing wastes would contain virtually all of the fission products, about 0.5 percent of the uranium and plutonium originally present in the spent fuel, and all the other actinides which were present. These high-level wastes could be stored temporarily as liquids at reprocessing facilities until processed into solid form and transferred to a Federal repository.*

In the uranium only recycle case, Alternative 5 of GESMO, facilities and safeguards for waste disposal would generally be the same as for Alternative 3 (prompt recycle of uranium and plutonium). The basic difference between the two would be that some care would have to be taken in Alternative 5 to avoid criticality problems with plutonium-bearing wastes.** This can be accomplished using existing materials-handling techniques.

Wastes other than high-level wastes are also generated during reactor operations, during MOX and UO_2 fuel fabrication, and during fuel reprocessing. Such wastes would be stored at Federal repositories or commercially operated burial sites.

Radioactive wastes require protection from sabotage or theft, but much of this protection would be provided by the nuclear shielding and container integrity already required for health and safety reasons.

---

*The technology for long-term management of high level nuclear waste and eventual disposal is being developed and actual demonstration by DOE and licensing by NRC have not yet occurred. Existing safeguards technology appears more than adequate to accommodate future waste management practice. A more pertinent consideration, however, is the fact that proper waste management procedures will be required with or without plutonium recycle.

**If plutonium should be separated from the waste for storage, this would simplify the waste storage problem, but it would generate a requirement for secure storage of the separated plutonium.

3.2.4 Transportation Requirements

The characteristics of fuel transportation in the mature MOX industry are summarized in Table 3.3. Because of safeguards concerns, the use of special transport vehicles, described in Section 3.4.3.3 and in Chapter 5, is assumed. Estimated costs for transportation are included in Appendix A.

TABLE 3.3

FUEL SHIPMENTS IN MATURE MOX INDUSTRY

Facility	Form of Plutonium	Quantity Shipped Per Year (MTM)[a]	Average Shipping Distance (Miles)	Number of One-Way Trips per Year
Reactor to Reprocessing	Irradiated Fuel Assemblies	10,000	1,000	2,700
Reprocessing to MOX Fuel Rod Fabrication	PuO_2	123	300	280
MOX Fuel Rod Fabrication to MOX Fuel Assembly Fabrication	MOX Fuel Rods	2,600	200	810
MOX Fuel Assembly Fabrication to Reactor	Unirradiated MOX Fuel Assemblies	4,100	1,000	1,310

Note: Numbers have been rounded.

---

[a] 1 MTM (metric ton of metal) = 1.13 MT of oxide (UO_2, PuO_2, or MOX); thus, 123 MTM of Pu becomes 139 MT of PuO_2.

In determining the number of trips in each transportation leg, it was assumed that the vehicle could carry up to:

- 10 irradiated (spent) PWR assemblies (4.3 MTM), or 24 irradiated BWR assemblies (4.5 MTM) from a reactor to a reprocessing plant;
- 500 Kg of PuO_2 from a reprocessing plant to a MOX fuel rod fabrication plant;
- 3.4 MT of PWR MOX fuel rods or 3.0 MT of BWR MOX fuel rods from a MOX fuel rod fabrication plant to a fuel assembly plant; and
- 8 PWR assemblies (3.4 MT) or 16 BWR assemblies (3.0 MT) from a fuel assembly plant to a reactor.

It was also assumed that solidified high-level waste would be shipped from a reprocessing plant to a Federal repository by rail in casks estimated to weigh between 70 MT and 100 MT.

Each cask could contain 12 canisters of waste. Each canister, about 1 foot inside diameter by 10 feet long, would hold the waste from about 3.2 MT of spent fuel.

3.2.5 Facility Safeguards Features

Two former reprocessing plants, one at West Valley, N.Y. owned by Nuclear Fuel Services, Inc., and one at Morris, Ill., owned by General Electric, are being used to store spent fuel. At Barnwell, S.C., Allied-General Nuclear Services is building a reprocessing plant which is in the final stage of construction. This plant must incorporate features to meet the NRC safeguards requirements specified in 10 CFR Parts 50, 70, and 73.*

3.2.5.1 Plant Areas For Safeguards Purposes

A general layout for a typical reprocessing or MOX fuel rod fabrication plant is illustrated in Figure 3.2. In this layout, plutonium is confined to certain areas known as material access areas (MAA's)--whether it is being stored, processed, or analyzed--whenever it is not in transit between facilities.

Areas which do not contain plutonium but do contain equipment or material whose failure, destruction, or release could directly or indirectly endanger public health and safety are called vital areas (VA's). Examples of VA's are those containing emergency utilities, filter banks, and radioactive waste and scrap. Access to MAA's and VA's would be limited to persons who require such access to perform their duties.

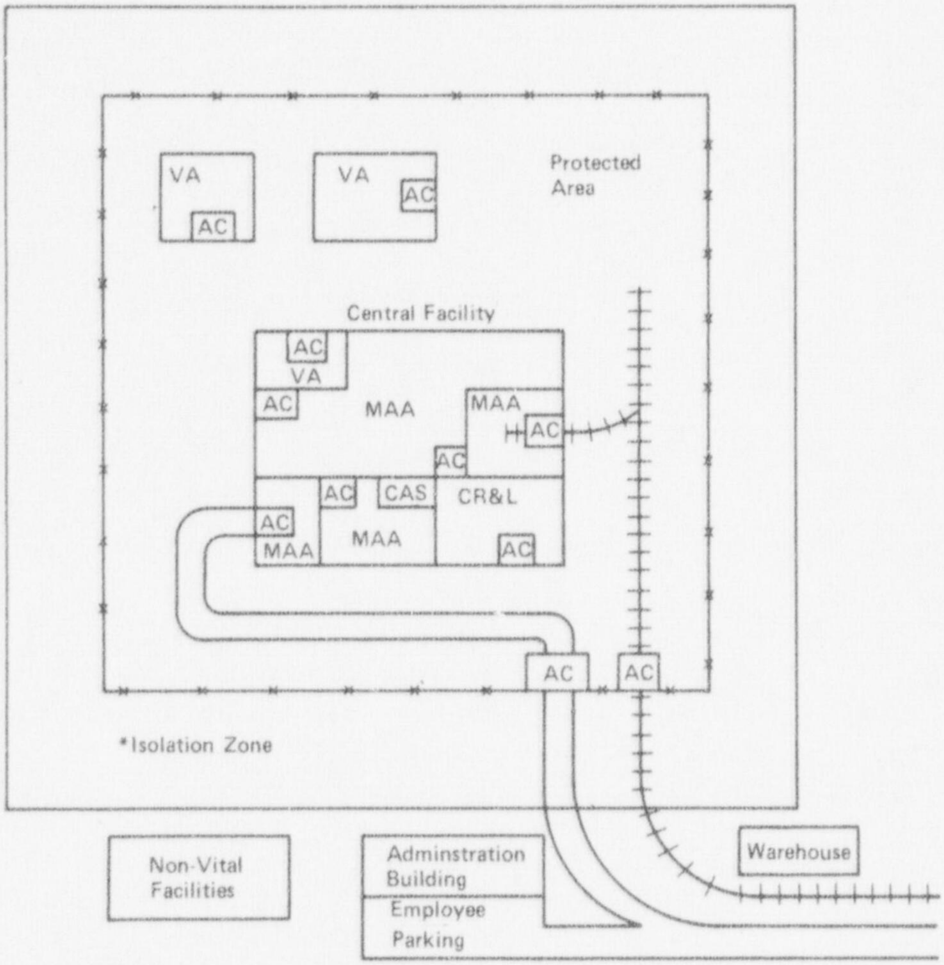
Because of the radiotoxicity of plutonium, a slight negative pressure with respect to the atmosphere would be maintained in MAA's for health and safety reasons; also, personnel would be required to wear work clothes inside the MAA's, and to shower before leaving. A system of pressure control and work clothing changes is already standard procedure for all existing facilities handling plutonium.

In order to achieve adequate process and quality controls, detailed material controls would be required throughout the MAA's. To perform these functions, an analytical laboratory is needed, and each MAA would be particioned into material balance areas (MBA's) and item control areas (ICA's). Examples of MBA's would include well-defined operations areas such as pellet sintering or grinding areas, and analytical laboratories. Storage areas and vaults would be examples of ICA's. In order to control and account for the movement of plutonium through a facility, sensitive instruments would be used to identify materials, count or weigh them, measure heat generation or various types of nuclear radiation, and perform chemical or nuclear assays.

Each facility would have an area protected from unauthorized intrusion, called the protected area. It would contain the MAA's and VA's. The perimeter of the protected area would consist of various physical barriers, such as walls or fences, and intrusion detection devices. An open isolation zone would be located along the perimeter, and plant functions not requiring safeguards

---

*The Commission announced its decision to terminate the proceedings on this licensing action in 42 FR 65334 on December 30, 1977.



AC - Access Control Station
CAS - Central Alarm System
CR&L - Change Room and Lunch Room
MAA - Material Access Area (plutonium present)
VA - Vital Area (no plutonium present)

*Includes a clear zone within the protected area boundary

Figure 3.2 Layout of Safeguards Features in a Typical Fuel Cycle Facility would be located outside the isolation zone. Thus, administration buildings, employee parking lots, warehouses, cooling towers, pumphouses, stacks, and auxiliary chemical processing plants might be so located.

All of the detectors at the perimeter and within the protected area would be connected with both the central alarm station and a secondary alarm station. These alarm stations would monitor plant activity and respond to alarms by dispatching physical protection forces (guards) and by notifying local law enforcement or other backup response forces.

3.2.5.2 Reprocessing Facilities

Facilities at a reprocessing plant not requiring safeguards might include: a utility area, a fluorine plant, and warehouses to receive process chemicals (e.g., nitric acid), replacement parts, and other non-nuclear materials. All these could be located outside the isolation zone. The warehouses also could provide temporary storage for products, scrap, and waste not requiring safeguards.

Trucks and railroad cars carrying the cooled and shielded casks or containers used for delivery of spent fuel assemblies and for removal of high- and low-level radioactive waste would be admitted into the protected area. Trucks would also be admitted to transfer the PuO_2.

The central facility might include a lunch room, clean storage areas, and the following ICA's: a spent fuel receiving and storage area (where casks would be lifted from trucks or rail cars, the spent fuel assemblies unloaded into a storage pool, and the cask returned to the vehicle); a Pu product storage vault; and a PuO_2 shipping area. MBA's might include a separations area where the assemblies would be chopped and the contents dissolved and separated; an analytical laboratory; a plutonium nitrate-to-oxide conversion area; and waste storage areas. VA's might include an emergency utility building; an enclosed waste tank equipment gallery; waste tanks; and a process area ventilation blower station, including high-efficiency particulate air (HEPA) filters.

Most of the steps in the processing of spent fuel are either highly automated or require remote handling in order to protect the personnel from radiation and chemical hazards. The plant areas of special safeguards concern would be those containing plutonium after it is separated from the high-level radioactive fission products, especially those areas where the plutonium is in concentrated form.

3.2.5.3 Fuel Rod Fabrication Plants

Facilities not requiring safeguards which could be located outside the isolation zone of a MOX fuel rod fabrication plant could include a utility area, and warehouses which would receive natural UO_2, Zircaloy tubes, and other materials not requiring safeguards.

Protected area access control systems would control delivery of PuO_2 and shipment of MOX fuel rods and low-level waste. VA's might include an emergency utility area, waste and scrap storage buildings, ventilation equipment, and HEPA filter banks. The central facility could include a lunchroom, a UO_2 receiving and storage area, other storage areas not requiring safeguards, and the following MAA's: PuO_2 receiving and storage areas; the fabrication area; fuel rod inspection, storage, packaging, and shipping areas; and the analytical laboratory.

These MAA's could be further subdivided into MBA's. For example, the fabrication area could be compartmentalized into MBA's where the following processes were performed: blending PuO_2 with UO_2, pressing the MOX into pellets, sintering the pellets, grinding the pellets, loading the pellets into the Zircaloy tubing and sealing the fuel rods, plus all the storage and inspection steps in between.

3.2.5.4 Access to Plutonium

Because of the radiotoxicity of plutonium compounds, they must be contained in gloveboxes or in sealed containers in order to avoid health hazards to employees. In addition, most operations involving large quantities of these materials are carried out behind thick shielded walls either by automated machinery or with remote handling equipment. Small quantities can be handled in gloveboxes, as in the analytical laboratories. At the reprocessing plants, PuO_2 containers could be loaded and sealed either in gloveboxes or by remote handling. At the MOX fuel rod fabrication plants, these seals would be broken and the PuO_2 powder unloaded, also in gloveboxes or by remote handling.

At the end of the MOX fuel rod fabrication line, sealed fuel rods, each about 6 to 12 feet long, weighing about 2 kilograms, and holding about 80 grams of PuO_2 in MOX pellets, could be handled in the open. The fabrication of MOX fuel assemblies could also be done in the open.

During planned maintenance, or after abnormal occurrences such as a machine failure or a leak, some maintenance personnel might be given direct access to plutonium compounds. Under such circumstances, however, the safeguards system would be alerted and special controls instituted.

3.2.6 Forms and Quantities of SNM

Special nuclear material (SNM) is defined as plutonium, ^{233}U, or uranium enriched in the 235 isotope. Strategic SNM (SSNM) is a subset of SNM that includes only those materials which could be used in the fabrication of a nuclear explosive. This subset includes plutonium, ^{233}U, and uranium enriched to 20% or more in the 235 isotope.

In a mature MOX industry, plutonium would be present in fixed facilities as well as in the transportation links between them. It would be present not as a metal but as a chemical compound, such as the oxide or nitrate, and in mixtures such as MOX. Table 3.4 summarizes the forms of plutonium in the MOX fuel cycle, the amount of each form necessary in order to have 2 kg of contained plutonium, and the processes necessary to convert the material to pure PuO_2.

The difficulty a malefactor faces in attempting to fabricate a nuclear explosive or dispersal device depends greatly on the nature of the materials available to him. For purposes of

TABLE 3.4

FORMS OF PLUTONIUM IN THE MOX FUEL CYCLE

Material	Type	Where Found in Fuel Cycle	Approximate Amount for 2 kg of Contained Pu[a]	Chemical Processing Necessary to Convert to PuO_2
PuO_2	I	Reprocessing, MOX fuel rod fabrication, transport	2.3 kg	None
$Pu(NO_3)_4$	II	Reprocessing	36 liters of 10% solution (40 kg)	Oxalate conversion[b]
MOX (4% PuO_2)	II	MOX fuel rod fabrication	60 kg powder, or 6,000 pellets	Chemical separation
MOX fuel rods[c]	II	MOX fuel rod fabrication, MOX fuel assembly fabrication, transport	30 rods (60 kg)	Open tubing, then same as MOX
Unirradiated MOX fuel assembly	II	MOX fuel assembly fabrication, reactor, transport	1 BWR or PWR assembly[d]	Cut out MOX fuel rods, then process as above
Irradiated fuel assembly	III	Reactor, reprocessing, transport	2 UO_2 - BWR assemblies,[e] or 1 UO_2 - PWR assembly, or 1 MOX - BWR assembly, or 1 MOX - PWR assembly	[f]

---

[a] Special safeguards are required by 10 CFR Part 73 for quantities of plutonium exceeding 2 kg. Several times this amount may be needed in order to fabricate a nuclear explosive.

[b] For oxalate conversion process, see NUREG-0002, Figure IV D-1. PuO_2 can also be produced by direct denitration.

[c] Each MOX fuel rod contains approximately 2 kg of MOX.

[d] Assumes: 0.188 MTM per BWR assembly
0.428 MTM per PWR assembly

[e] Assumes a spent UO_2 rod has 0.8% plutonium; a spent MOX rod has 2% plutonium.

[f] Process would entail: remote handling, cutting out MOX fuel rods, cutting them up and dissolving MOX, chemically separating plutonium from uranium and fission products, and either oxalate conversion to PuO_2 or direct denitration.

safeguards discussion, plutonium-bearing materials can be divided into three types,* ranked in increasing order of difficulty for illicit use, and thus in decreasing order of attractiveness to a malefactor:

- Type I. Those materials whose physical, molecular, and isotopic form makes them suitable either directly or with relatively minor processing for use in the manufacture of nuclear explosives. These include plutonium oxide, plutonium spiked for detection or aggressor disablement, and mixed oxide compounds having a high content of plutonium.

- Type II. Those materials which require relatively modest facilities and effort for conversion into Type I materials (Ref. 1). Although it may be theoretically possible to use materials in this category directly in nuclear explosives, very large quantities would be required. Within the MOX fuel cycle, Type II materials include MOX powder, including concentrations as low as those of the Puechl concept (0.12 to 1.0% PuO_2);** MOX fuel pellets, both sintered and unsintered; MOX fuel rods; unirradiated MOX fuel assemblies; and plutonium spiked to degrade weapon performance. As discussed in Chapter 6, means are available to convert material from Type I to Type II early in the fuel cycle.

- Type III. Those materials, such as spent fuel assemblies, which require major facilities and processing efforts for conversion into Type I materials. Because they require such facilities and efforts, these materials are considered to be essentially self-protecting from theft. They must, however, be protected from such sabotage as could lead to the release of radioactivity into the environment.

Reactor-grade (recycled) plutonium is somewhat less desirable for use in an explosive device than weapons-grade plutonium, which has a substantially higher fraction of ^{239}Pu. The isotopic composition of recycled plutonium is shown in Table 3.5. The isotopes ^{239}Pu and ^{241}Pu have similar fission cross sections. The isotopes ^{240}Pu and ^{242}Pu are similar in that both have poorer fission cross sections for fission spectrum neutrons and are thus less reactive than ^{239}Pu and ^{241}Pu. Therefore, the amount of material required for an explosive device will increase as the ^{240}Pu and ^{242}Pu concentration increases. Nevertheless, the critical mass of even fourth generation recycled plutonium is smaller than the critical mass of high-enriched uranium.

Weapons fabrication using reactor-grade plutonium is further complicated by the increased neutron background due primarily to the spontaneous fission of isotopes ^{238}Pu, ^{240}Pu, and ^{242}Pu and to alpha-neutron reactions when an oxide form is present. This increased neutron background

---

*This categorization, employed for the purposes of this document, should not be confused with categories employed by other agencies, such as the IAEA, for other purposes.

**For a discussion of the Puechl concept, see Section 6.4.2.3.

TABLE 3.5

APPROXIMATE ISOTOPIC CONTENT OF PLUTONIUM
(AGED 1 YEAR AFTER REPROCESSING)

Isotope	Percent of Total Weight 1st Recycle	2nd Recycle	3rd Recycle	4th Recycle
^{238}Pu	3	3	4	5
^{239}Pu	57	40	34	31
^{240}Pu	23	30	30	27
^{241}Pu	11	15	16	16
^{242}Pu	5	10	15	20
^{241}Am*	1	1	1	1

Source: Adapted from NUREG-0002, Table IV D-5. Totals do not necessarily add to 100, due to rounding.

*Results from decay of ^{241}Pu during the first year after reprocessing.

causes handling problems, and it could cause premature detonation of weapons, resulting in substantially reduced yield. Nevertheless, since nuclear explosives can be constructed using reactor-grade plutonium, appropriate safeguards measures would be necessary.

A mature MOX industry would include a significant quantity of Type I and Type II materials in the form of PuO_2 pellets, fuel rods, or unirradiated fuel assemblies.* The amount of plutonium likely to require safeguards protection at any given time was calculated as follows: reprocessing the spent fuel and shipping the PuO_2 for fabrication would require about 3 months (Ref. 2). For approximately half this time, the plutonium would be in the form of PuO_2. It would take approximately 6 months from the time plutonium enters the fuel rod fabrication plant until the finished fuel assemblies are put into the reactor (Ref. 2). This would include the time spent in fuel rod and fuel assembly fabrication, shipping, and preloading inventories. Based on such process times, the projected quantity of unirradiated plutonium (the plutonium requiring safeguards protection) at any particular time would amount to the reprocessing plant output for about 7-1/2 months.

Table 3.6 shows the projected annual reprocessing plant output of plutonium for selected years, based on the "low growth" MOX industry, Alternative 3 in NUREG-0002, Chapter 3. The plutonium inventory that would need safeguards protection, as estimated by the method discussed above, is also shown. While the plutonium would occur only in oxide form, it is convenient for purposes of comparison with high-enriched uranium (HEU) and other forms of SSNM to refer to the amount of metal in the oxides.

---

*Once fuel assemblies are used in a reactor, they become so radioactive as to be virtually self-protecting from theft or diversion. Accordingly, the plutonium inventories of primary safeguards concern are those not yet irradiated.

TABLE 3.6

PROJECTED ANNUAL PLUTONIUM PRODUCTION AND SSNM INVENTORY[a]

	Metric Tons of Metal[b]					
	1976	1980	1985	1990	1995	2000
Annual Reprocessing Pu Output		5	21	47	87	123
Plutonium (PuO_2 + MOX) Inventory[c]	1	10	13	29	54	77
High-Enriched Uranium Inventory[d]	>20	>20	>20	>20	>20	>20

[a] Material handled by licensees under NRC regulation. Excludes material in weapons programs. The plutonium inventory is approximately 5/8 of the annual production. (See text.)

[b] The plutonium and uranium used in MOX fuels occur only in oxide form. The weights shown here refer only to the metal contained in the oxides.

[c] Approximately 20 percent of this quantity would be in the form of PuO_2; the remainder would be in plutonium concentrations of less than 10 percent, primarily as MOX fuel.

[d] Assuming no major changes in the programs, taken as a whole, which use HEU.

To complete the projection of SSNM under licensee control, Table 3.6 also includes the projected quantities of high-enriched uranium. Not shown in Table 3.6 are the larger quantities of SSNM processed by AEC/ERDA (now DOE) during the past 30 years in support of the nation's weapons programs. Safeguards programs for a MOX fuel industry would build on the safeguards experience gained to date in handling both the HEU shown in Table 3.6 and the additional SSNM involved in weapons programs. For example, in the year 1972 alone, there were between 1,200 and 1,300 shipments of plutonium and high-enriched uranium over substantial distances in the U.S. in support of DOD-oriented programs (Ref. 3, p. 63).

3.2.7 Effect of Fuel Cycle Alternatives on Industry Characteristics

The Health, Safety, and Environment portion of the final GESMO, NUREG-0002, discusses five of the alternatives treated in the draft GESMO (WASH 1327). The sixth alternative discussed in WASH 1327 (Alternative 4) is essentially the same as Alternative 3. The five alternatives treated in NUREG-0002 are:

- Alternative 1: prompt fuel reprocessing, prompt uranium recycle, delayed plutonium recycle
- Alternative 2: delayed fuel reprocessing followed by uranium and plutonium recycle
- Alternative 3: prompt uranium and plutonium recycle
- Alternative 5: uranium recycle, no plutonium recycle
- Alternative 6: no uranium or plutonium recycle

The description of a future industry given thus far in this section has focused on Alternative 3. Figure 3.3 displays all the alternatives. The following discussion shows the effects which adoption of other alternatives would have on industry characteristics.

3.2.7.1 Alternative 1

This alternative involves prompt fuel reprocessing (1978), prompt uranium recycle (1978), and delayed plutonium recycle (1983), with temporary plutonium storage before plutonium recycle begins. The resulting mature industry would be essentially the same as that for Alternative 3, although its size in a given year could differ slightly, depending on how rapidly the stored plutonium is assumed to have been recycled. Before 1983, however, there would be no plutonium recycle, and a flow diagram such as Figure 3.1 for this alternative would show no MOX fuel rod fabrication or fuel assembly plants and no MOX assembly storage. There would still, however, be incremental safeguards (as compared to Alternative 6) associated with plutonium storage and transportation of the plutonium from the reprocessing plants to the temporary storage facility. By 1983, the temporary storage facility would hold 34 MT of PuO_2.

3.2.7.2 Alternative 2

This alternative involves delayed spent fuel reprocessing (1986) with temporary storage of spent fuel elements until reprocessing begins. Again, the mature industry would have essentially the same characteristics (including size) as that for Alternative 3. Before 1986, the industry description would be essentially the same as that of the present industry. There would be no incremental safeguards before 1986, as the plutonium is considered to be self-protected in the spent fuel assemblies.

In the years immediately following 1986, the Alternative 2 industry would resemble a delayed Alternative 3 industry. While Alternatives 1 and 2 result in less SSNM to be safeguarded in earlier years than Alternative 3, this situation is reversed during intermediate years, causing the cumulative totals of SSNM transported to reach about the same level for all three by the year 2000. Thus, the overall safeguards requirements would not be significantly affected by the delays involved. Technical advances in reprocessing and safeguards that could occur during the years of delay might confer an advantage on Alternatives 1 and 2 relative to Alternative 3.

3.2.7.3 Alternative 5

This alternative involves delaying spent fuel reprocessing and uranium recycle until 1986 (a time when it is forecast that the price of uranium would warrant utilization of recovered uranium) and permanent storage and disposal of the plutonium either as separated PuO_2 or as part of the spent fuel wastes. The mature industry would have no MOX fuel rod or fuel assembly fabrication facilities or MOX assembly storage at reactor sites. The MOX fuel cycle shown in Figure 3.1 would thus be absent. If the plutonium were separated from the wastes, one or more plutonium storage facilities would be needed. Then, by the year 2000, a cumulative total of approximately 1,200 MT of PuO_2 would be in permanent storage and would require special safeguarding. Incremental safeguards would be needed to protect PuO_2 during transportation from reprocessing plants to permanent storage and disposal facilities. This plutonium would have to be guarded in perpetuity, or until it is reused for some future purpose. If plutonium were left in the wastes, on the other hand, no special plutonium storage facilities would be required

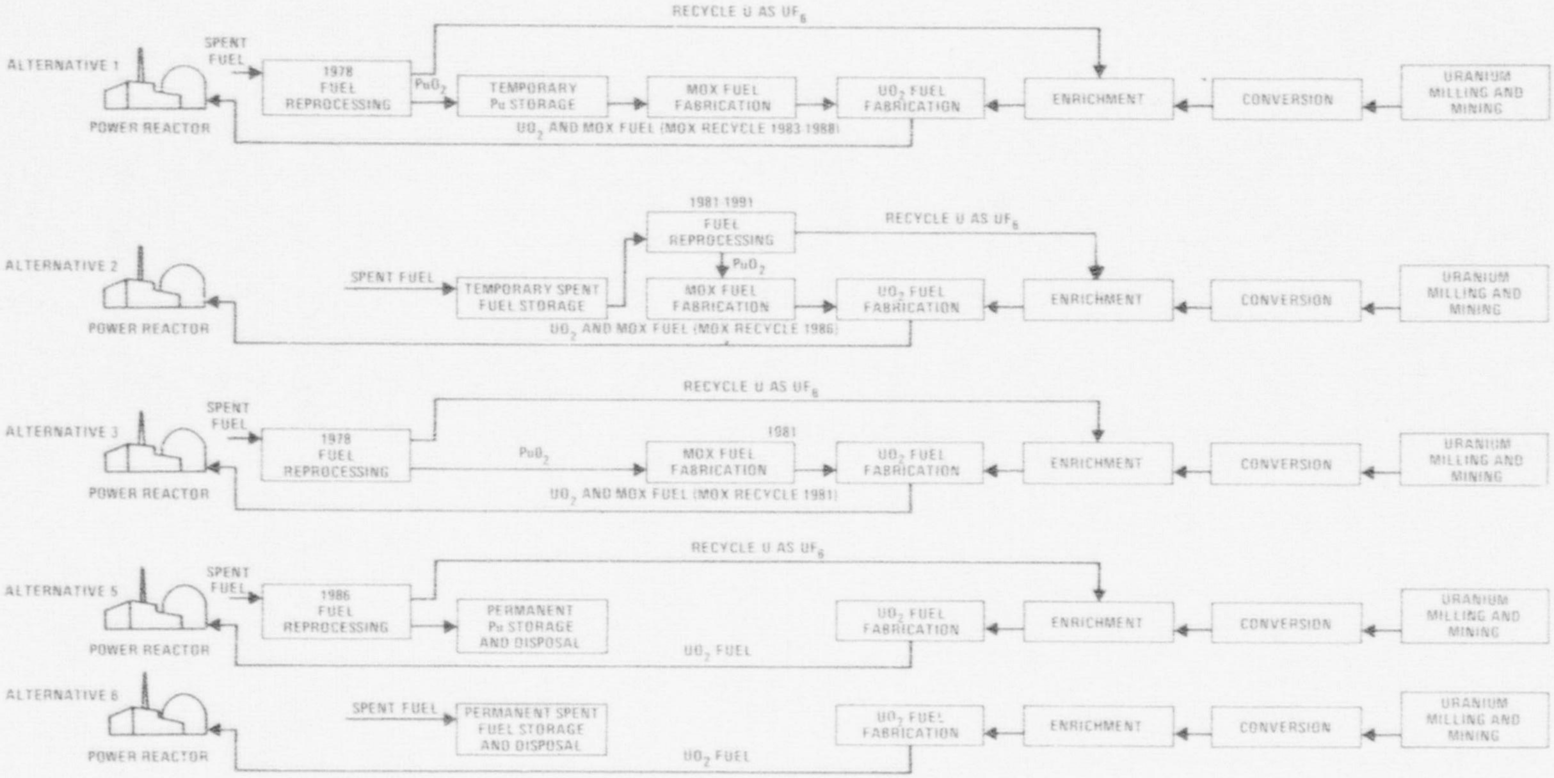


Figure 3.3 Alternatives for the Disposition of Plutonium

because, as part of the spent fuel wastes, it would be so radioactive as to be "self-protecting." In this event, no incremental safeguards would be required.

3.2.7.4 Alternative 6

This would be basically the same as the present industry except for size. There would be no recycle of spent fuel. By definition, no incremental safeguards costs would be associated with this alternative, as it constitutes the base against which the safeguards of all the other alternatives are measured.

3.3 THREATS TO A MOX INDUSTRY

3.3.1 Background

A common public perception is that public health and safety are presently in jeopardy because of threats to the nuclear power industry, and that the jeopardy would increase if that industry undertook to recycle plutonium. An example of this perception is the following quotation:

> Nuclear power represents an added dimension to the issue of public health and safety, one that arises from the fact that the same nuclear material that is capable of providing light for a city's thoroughfares, buildings, and residences is, when fabricated correctly and employed as a weapon, also capable of obliterating that city and its inhabitants. (Ref. 4, p. 120)

The evidence upon which such perceptions are based consists of violent incidents in the past involving targets other than nuclear industry; speculations based on this history concerning potential threat actions and potential adversary attributes; and current intelligence. The evidence is interpreted against a background which involves increased evidence of terrorism throughout the world and a willingness to tolerate terrorism on the part of some governments, which appear to accept it as falling within the bounds of acceptable human behavior. Such tolerance has been manifested by the willingness of some governments to supply terrorists with modern weaponry and training, and the readiness of terrorists to avail themselves of such weaponry and training.

In studies done barely 10 years ago, safeguards concerns relating to plutonium and nuclear power generation were primarily directed at the danger of nuclear weapons proliferation (Refs. 5 and 6) among additional national states. While such concerns persist, current concerns relate also to the ability of subnational "adversary groups" (including terrorists) to endanger the public health and safety through nuclear means (Refs. 1, 7, 8, 9). These means are generally recognized as falling into three categories of maximum potential effectiveness, which, in descending order are: the detonation of a clandestine nuclear device, the dispersal of radioactive substances (in particular, plutonium), and the sabotage of nuclear facilities. It is difficult to estimate the probability that threats, in any of these categories, actually exist now, or will exist in the future. It is in fact quite uncertain that threats against the nuclear industry can be predicted with any confidence, from the fund of knowledge now in hand about conventional forms of violent activity.

There is a considerable, and growing, amount of literature about potential threats from societal segments thought to have the capability to inflict serious harm on the public health and safety by subverting elements of nuclear fuel cycles--in particular, cycles in which plutonium is recovered and used in mixed oxide fuels. These societal segments, or adversary groups, have been characterized in varying degrees of detail on the basis of recent historical events. Their perceived capabilities are often described in terms of their various accomplishments, as well as in terms of what is known concerning their manpower resources, geopolitical affiliations, funding, armaments, motives, dedication, and other attributes.

Studies thus far undertaken of threats to the nuclear industry have generally been based on extrapolations of historical data dealing with conventional forms of violence. Such extrapolations are tenuous, because violence directed against nuclear targets would be likely to involve quite different motivations, skills, resources, and commitments, both qualitatively and quantitatively, than attacks against other targets. Based upon compiled chronologies of terrorist events (Refs. 10, 11), one BDM Corporation study (Ref. 12) examined adversary group sizes in detail. After noting that there was wide use of a rather arbitrary figure of a twelve men attack force in safeguards debates, the study stated that "...when considering the variables of motivations and resources needed for an attack on a nuclear facility coupled with past experience with respect to group size, it seems that this figure (12) is high." The BDM study further concluded that, "...the probability of more than twelve attackers attempting such an attack in today's environment is less than one percent, while the probability of seven to twelve is somewhere around four percent." These conclusions were based entirely upon extrapolations from historical data involving non-nuclear targets and consequently, for reasons noted above, their relevance to the nuclear industry may be questionable.

An accurate prediction of the anticipated threat to a mature MOX industry is not in fact possible at this time. Even the existence of any actual threat cannot be definitely proven. Consequently, the performance criteria for the design of a safeguards system for a projected MOX industry must be based in large part on the judgment of experts in the field (see Chapter 5).

The discussion which follows addresses some of the more salient aspects of potential threats to a MOX nuclear industry and the resulting safeguards concerns for that industry, under prevailing civil order.

3.3.2 Threat Categories

Threats can be categorized as being of high or low consequence, based on their potential effects on the public. Estimates of these potential effects depend on such factors as the nature of the threatened event, its likelihood of success, and the number of people who might be affected. The latter, in turn, would depend on such factors as population density, proximity to the event, and prevailing meteorological conditions.

Such threat categorization is somewhat arbitrary; the placement of threats into a high or low consequence category was primarily based on the maximum public risk each threat represents.

3.3.2.1 High-Consequence Threats

There are several classes of social groups and individuals which have, in the past, been suggested as posing a potential threat to the nuclear industry. The mere fact that such groups could exist contemporaneously with a mature MOX industry leads some to perceive them as threatening to that industry. The potential threats they might represent are describable in terms of a range of threat alternatives. These alternatives, unsupported by specific evidence, are based on inferences from historical data and cover a wide spectrum in which putative perpetrators of threats are deemed to include disaffected employees in the nuclear industry, representatives of organized crime, and terrorists. Speculations concerning the motivations of such groups to commit hostile acts against a mature MOX industry include desire for revenge, financial gain or publicity, and intent to create mass destruction. The scenarios developed to satisfy these motives include sabotage of nuclear facilities such as to cause substantial offsite release of radioactivity, theft of SSNM, establishment of a black market in SSNM, construction of a clandestine nuclear device with stolen SSNM, and detonation of a clandestine nuclear device. For MOX safeguards planning purposes, threats should be considered to involve individuals outside the nuclear industry, individuals within the industry (including management and security forces), and individuals inside and outside the industry acting in collusion.

Insiders. There are numerous credible, though not necessarily probable, threat scenarios involving employees within a MOX nuclear industry. Those scenarios with the greatest potential significance, insofar as public health and safety are concerned, include sabotage of a MOX facility and collusion for purposes of diverting SSNM.

With respect to sabotage of a MOX industry facility, those acts which could have greatest potential for harming the public would be sabotage of a nuclear power reactor--this could be equally harmful whether or not plutonium is recycled--or sabotage of the high-level liquid waste storage facility of a nuclear fuel reprocessing plant.* Sabotage of either of these types of facilities could conceivably lead to a significant offsite release of radioactivity.

A Sandia Laboratories report, (Ref. 13, p.8), discusses sabotage of reactors. This study indicates that such an act would be within the capabilities of a group of several dedicated and highly talented individuals with an intimate knowledge of the operation of the reactor and its engineered safety systems. It would be only marginally within the capabilities of a single technically qualified insider, however, because the operating status of a reactor is continuously monitored by control room operators and other individuals throughout the facility who should be able to override actions of a single would-be saboteur.

Assessing the threat of sabotage to high-level liquid waste storage facilities at nuclear fuel reprocessing plants is more difficult, since such facilities are not yet operational. However, there is some analogy between them and the spent fuel storage pools at nuclear power reactors which may currently contain approximately one-half the radioactive inventory of the reactor core itself. Some reactor storage pools are above grade (above the level of the surrounding ground surface), while others are below grade. Using the only available test data,

---

*For more discussion of facility sabotage, see Section 3.4.3.

which are for above-grade pools, the Sandia Laboratories study (Ref. 13) indicates that an act of sabotage on spent fuel storage pools which would be sufficient to cause an offsite release of radiation would require sophisticated knowledge of explosives. (Stand-off weapons, such as rocket or missile launchers with armor-piercing munitions, would be inadequate.) It would also require quantities of explosives that, on the one hand, would be difficult at best for even two disaffected employees to manage physically, and, on the other hand, would be subject to virtually certain detection by site security measures.

Existing high-level liquid waste storage facilities, used for defense-related nuclear programs, are all constructed below grade. To produce an offsite release of radioactivity by sabotage of such vault-like structures would be extremely difficult. A saboteur would first need to attain access to the containment structure, which in some instances is accessible only after several feet of covering soil are removed. A large quantity of explosives, configured for breaching purposes, would be required to penetrate the containment. Then additional large quantities of explosives would have to be placed within the structure, under very high radiation fields, to explosively discharge some quantity of the high-level wastes from the containment. In addition to this, the roof over the storage facility would have to be breached in order to disseminate some fraction of the explosively discharged liquid wastes into the atmosphere outside the building.

It is quite possible that high-level liquid waste facilities may not exist in a future MOX industry. A trend is beginning, even now, to solidify high-level wastes in the process stream through a process of calcination and/or vitrification. Explosive dispersal of these wastes would be not only difficult to achieve but highly inefficient, since the material is not of a particle size which could easily be dispersed offsite, even under favorable meteorological conditions.

It is conceivable that one or more disaffected employees might engage in collusion with outside groups for the purpose of diverting SSNM or of sabotaging a nuclear facility. The likelihood that outside groups would be interested in such collusion is considered in the following paragraphs.

Organized Crime. Organized crime is of interest as a potential adversary group because much of its experience seems adaptable to actions against a MOX industry. For example, it is well known that members of these groups: (1) regularly engage in cargo hijacking and burglary; (2) use violence as a standard method of enforcement; (3) are involved in extortion on virtually a daily basis; and (4) utilize black market activities to obtain both illegal goods and services (Ref. 14).

Some question has been raised as to whether organized crime would be inclined to become involved in hostile acts against the nuclear power industry. It has been stated, for example, that patriotism would prevent such activities, at least those which could lead to mass destruction. That conclusion is doubtful. First and foremost, organized crime is in the business of making money. Nothing in its past history (Ref. 15) indicates that it would be dissuaded from this objective by sentiments of patriotism. During World War II organized crime was involved in black market activities as well as in racketeering involving defense industries. There were also indications of collaboration between organized crime and Mussolini after he was considered an enemy of the United States. Organized crime has also served foreign governments through assassination, gunrunning, and political influence-peddling.

A number of arguments may be made that in spite of its talents, organized crime, which can be characterized as a relatively stable, profit-making enterprise (Ref. 16), would not be likely to become involved in illicit nuclear activities, even the indirect one of black market operations in SSNM, which could adversely affect the public because of fear of public and government reprisals. They are acutely aware that

> [C]rimes of violence, particularly against innocent victims [are] sure to arouse even the most complacent (Ref. 17, p. 37).

One observer of organized crime maintains that it is interested in public relations to the extent that

> . . .all strong actions which might influence the public must be cleared with the Cosa Nostra leaders. . . (Ref. 18, p. 14).

Other authors cite a tendency towards specialization as characteristic of organized crime (Refs. 18 and 19). This is consistent with organized crime's goal of maximizing profits while limiting effort and risk. The risk of activities threatening to a mature MOX industry would be high and the potential payoff relatively small compared to other activities of organized crime. Under many circumstances, moreover, this type of activity would be limited to a one-shot affair. As has been noted, organized crime

> . . .is not the type of criminal activity in which the criminal can make a few secretive hit-and-run sorties and hope to retire. It is essentially a continuous, fairly open life of criminal activity (Ref. 20, p. 22).

Neither would an SSNM black market, characterized by a necessarily limited number of customers, small likelihood of repeat business, and much secrecy, seem a pursuit likely to attract the efforts and resources of organized crime.

Terrorists. Of all the adversary groups which are thought to pose a threat to the nuclear industry, terrorists have received the most attention. They and the threat they represent have been the subject of numerous books, reports and monographs, a few of which are cited in the references at the end of this chapter (Refs. 9, 10, 21-27).

Terrorism has been defined as

> . . .symbolic [action] designed to influence political behavior by extranormal means, entailing the use or threat of violence (Ref. 28, p.73).

The analyses of terrorism found in the popular press often state the concern that terrorists will ultimately acquire a nuclear capability (obtaining material from either civilian or military sources), and then be in a position to wield extraordinary powers of extortion or political blackmail (Refs. 29-33). Similar sentiments have been expressed in various monographs and studies about terrorists (Refs. 25, 34, 35). Recently, however, the raison d'etre of terrorist movements has been reassessed. The once prevalent assumptions that terrorists would eventually acquire means for inflicting mass destruction as a natural evolutionary sequence are no longer so strongly supported (Ref. 36-39).

There is no question that, under appropriate circumstances, terror is an effective and efficient psychological weapon. No other technique is as immediately available or offers as much return for relatively small investments. Conditions are important, however, and

> . . .the competent practitioners of terrorism usually know how their actions will affect their enemies and what reactions they can expect from those not directly involved (Ref. 40, p. 66).

Implied in the above quotation is the requirement that there be limitations to any terror campaign. Most authorities agree that non-institutionalized terrorism is generally a tactic of the weak. This being the case, in order for terror to be an effective tactic for coercion, terrorists must be able to make the public understand what is being attempted, that there are limited penalties involved and that innocents will be spared to the degree possible (Ref. 41). Indiscriminate use of weapons of mass destruction, such as clandestine nuclear devices, violate these criteria. Such use could kill or injure innocent people in very large numbers, a penalty far in excess of presently accepted norms; and the terrorist message would likely be lost in the ensuing revulsion.

The recent shift in perspective--from perceiving the terrorist (in particular, the transnational terrorist) as naturally progressing to a nuclear capability to the current, more realistic appraisal of terrorism, its uses and objectives--has revealed some analytical shortcomings in the earlier literature. Only recently have there been attempts to reexamine the terrorist movement in terms of ultimate capabilities and objectives, especially insofar as its potential employment of weapons of mass destruction is concerned. For example, a recent exhaustive search of the literature dealing with the Arab terrorist <u>fedayeen</u>, which is replete with references to non-nuclear military and guerrilla strategies, has revealed only one reference to the possible <u>fedayeen</u> use of nuclear explosives. This reference arose in an interview with a Western scientist who discussed the potential ease of manufacture of a clandestine nuclear device (Ref. 37).

Historians and social scientists are beginning to point out that many of those terrorist organizations with the capability to engage in transnational terrorism are heavily subsidized by some governments and in a few instances may even be connected to governmental branches (Refs. 35 and 36). This in itself is conducive to caution in the employment of weapons of mass destruction, since such employment could lead to countermeasures against any government involved.

Since terrorist organizations not aligned with a government would also be constrained from deploying mass destruction weapons (by factors considered earlier: aversion to risking the lives of very large numbers of people, excessive penalties, and loss of sympathy for the movement), it is difficult to discern any set of conditions short of sheer desperation which would systematically and logically lead terrorist groups to the conclusion that it was in their interest to employ a weapon of mass destruction.

With respect to the possibility that a clandestine nuclear device might be used in desperation, several observations may be made. Obtaining material for such a device, manufacturing the device, and taking steps to use it would require very thorough and detailed advance planning. This seems the obverse of desperate action. Even if it were conceded, against apparent logic, that a plan to use weapons of mass destruction could be included in the strategy of a terrorist movement, there are much easier and more certain ways of going about it than stealing SSNM and attempting to fabricate a nuclear device which may or may not function. It is universally concluded that chemical and biological weapons require less technological skill than nuclear weapons; that they expose the perpetrators to less risk of detection or personal harm; that they require orders of magnitude less in terms of resources; and that they require raw materials which are much more easily obtained than SSNM. Moreover, the processes required to cause mass destruction with a chemical or biological weapon, including the necessary chemical, biological, and delivery methods, are available in the open literature.

There is also the frequently cited scenario of terrorists holding a city or government hostage for purposes of extortion by threatening the use of a weapon of mass destruction. However, there are still, as must be apparent, effective non-nuclear means of hostage-taking for ransom; and there is as yet no indication that terrorists have reached the upper bounds of what governments or corporations will pay for the return of kidnapped representatives. This is not to say, of course, that there is no upper bound. Hostage-takers cannot, for example, demand more than can be paid. They cannot demand of a government more than the government's constituency is prepared to give. Nor can they demand the dissolution of a government, or even a major policy change, since such demands would be unenforceable unless the terrorists could maintain a long-term enforcement capability.

Terrorists are generally aware of these considerations; the most capable terrorist organizations are politically astute. Thus, the more the city- or government-hostage scenario is examined, the more unlikely it seems to become.

What seems a most credible scenario, however, is that in which a city or government might be held hostage for the release of prisoners with whom the terrorists are in sympathy. In this case, there might be no money demand; the time for compliance could be relatively short; and once the demand was met, there would be no continuing requirement for the terrorists to maintain the threat. This is not to say that many other difficulties, both practical and political, do not stand in the way of perpetrating such a threat. The practical difficulties are discussed in Section 3.4 of this document; some of the political difficulties are discussed in the following paragraphs.

Many of the organizations with the resources needed to mount a nuclear threat, or ones which may have ties to a parent organization which can provide those resources, also have ties to one or more legal governments. Moreover, these governments are often the ultimate source of the support for the terrorist organizations. Thus, there might well be acute political problems if such a threat were mounted.*

The question that must be asked, then, is what can transnational terrorists accomplish through the use of nuclear terror that they could not accomplish with conventional military and guerrilla methods at less risk and cost, and without the almost certain increase in public abhorrence and potential retaliation for their methods.

Indigenous terrorists (those who operate almost entirely within their own countries) would be under additional constraints against the use of weapons of mass destruction. They must retain a reservoir of favorable public opinion in order to satisfy at least some of their objectives. Recent history shows several instances where indigenous terrorist violence was curbed. Wohlstetter (Ref. 37) points out that during the Cuban revolution, indiscriminate use of violence by the 26 of July Movement had to be curbed because of unfavorable public reaction. In Uruguay, violence perpetrated by the Tupamaros reached such proportions that the Uruguayan government finally acceded to its army's request for special powers to destroy the movement, which was done, although at a considerable cost to civil liberties (Refs. 24 and 42).

It should be further noted that as yet there has been no identifiable threat, of the type under discussion, to the nuclear power industry. Nor has any group with the motivation to establish such a threat been identified, and no such domestic threat has occurred in the past. It is, however, a matter of record that one poorly conceived attempt was made to precipitate a mass destruction event through the use of biologicals (Ref. 43). Although mustard gas is not a particularly lethal form of poison gas, it is severely incapacitating and capable of inflicting mass casualties. It is a matter of record that 53 canisters of mustard gas were stolen from a storage depot in West Germany in 1975 (Ref. 44).

Weapons of great mass destruction have been available for the last two or three generations. Mass destruction itself has been practiced since the beginning of recorded history, although it was, until recently, technology-limited. Methods for manufacture of such weapons have been available in the open literature for at least a generation. The single recorded attempt mentioned above to employ biologicals was by a group with ill-defined objectives, and since it was poorly conceived and clumsily executed, it was not carried out to completion. It appears that, while terrorists may indulge in other acts which can only be viewed with revulsion, they have not yet chosen to cross the threshold and use weapons of mass destruction.**

3.3.2.2 Low-Consequence Threats

Up to this point, the discussion of threat considerations has focused on what are termed high-consequence threats, those involving diversion of SSNM for purposes of constructing a clandestine nuclear device, or sabotage of a nuclear facility in order to endanger local populations. However, low-consequence threats are probably more credible than are high-consequence threats. A useful listing of low-consequence threats may be derived from Jenkins (Ref. 36).

---

*This assumes, of course, that the governments involved behave rationally according to Western standards, which may not always be the case.

**See Section 3.4.4 for additional discussion of this subject.

For purposes of this discussion they include: nuclear hoaxes, low-level sabotage of a nuclear facility, seizure of a nuclear facility, radioactive contamination of a symbolic target, and dispersal of plutonium.

The nuclear hoax may take and has in fact taken several forms. Perhaps the most publicized was the Orlando, Florida event which involved an extortion demand by a teenager who claimed to have constructed a nuclear device, and who provided some substantiation to back up that claim. ERDA (now DOE) received several threats (as did its predecessor, the AEC) in which the perpetrator claimed to possess a nuclear device or a plutonium dispersal weapon. All appear to have been hoaxes.

Between May 1969 and the end of December 1975, 99 threats of violence against licensed nuclear facilities were recorded (Ref. 44). Of these, 75 were bomb threats to reactors which were never carried out. A small number of the remaining threats actually involved small pipe bombs or incendiary devices which were found at research facilities, or at the offices of corporations in the nuclear industry. A smaller number yet of these 99 incidents involved break-ins, or apparent attempts to break in (Ref. 45).

The well-publicized intentionally set blaze at the Indian Point #2 reactor site, the bombing of the Fessenheim reactor construction site in France, and the bombing at the Mt. D'Arèe reactor site (also in France), are the best known incidents involving low-level sabotage of a nuclear facility. The Indian Point incident was caused by a maintenance worker before the reactor became operational. Damage was extensive, but confined to a reactor auxiliary building.

There have been no instances in the U.S. of seizure of a nuclear facility. The single publicized incident of this nature was at the Atucha reactor construction site in Argentina. This incident involved the occupation for a short time of some reactor buildings by urban guerrillas, who painted slogans, stole some weapons, and then left.

Radioactive contamination of a symbolic target has never occurred in the U.S. A mentally deranged individual did, however, contaminate two or more railroad coaches in Austria with radiopharmaceuticals stolen from a hospital (Ref. 10).

Plutonium dispersal is placed in the category of potential low-consequence threats for several reasons, all of which relate to questions about its toxicity (see Section 3.4 for additional discussion). For plutonium to be a significant toxic hazard, it must be converted into an aerosol (Refs. 46 and 47). The problems involved in creating and effectively dispersing an aerosol of plutonium serve to limit the actual threat represented by plutonium toxicity (Ref. 46). Furthermore, effects from plutonium dispersal are very difficult to predict. Such effects on individuals as may result are not likely to occur until a mean time of about 15 years subsequent to exposure; it is almost certain that there would be no immediate measurable radiobiological effects. This delay in results limits the utility of plutonium dispersal to a terrorist.

Purposeful dispersal of plutonium is not known to have occurred anywhere in the world (with the possible exception of an incident which may have involved surreptitious removal of trace amounts of plutonium from a plant by an employee).

Although plutonium dispersal seems to lack the essential threat ingredients of immediate effects and an obvious cause-effect relationship, its potential long term biological effects and the potential economic penalties associated with the area exclusion and decontamination which would follow such an action require that MOX industry safeguards be designed to protect against it. In general, the industry can be protected against low-consequence threats through prudent planning of safeguards against high-consequence threats. The requirements for such safeguards are discussed in Chapter 5.

It should be noted that the most severe low-consequence threats represent levels of adversary actions comparable in many ways to acts of industrial sabotage or vandalism. With the exception of plutonium dispersal, there is nothing about such threats which is unique to the MOX industry. That is to say, the likely results of those low-consequence threats which might actually be implemented differ very little, if at all, from the same level of violence expressed against other parts of the industrial sector. Furthermore, with the exception again of plutonium dispersal, there would be little difference in this regard between a MOX nuclear industry and a non-MOX one.

3.3.3 The Regulatory Approach

The present regulatory approach to safeguards permits some latitude in the nature of threats against which safeguards are expected to be effective. Even without a specific definition of the potential adversary, regulations can be drafted to prescribe the measures a licensee should follow. Currently, licensees possessing SSNM must implement a level of safeguards which will be effective against what may be termed a limited terrorist threat aided by an employee.

For contingency planning purposes, several formal and informal information exchanges with other Federal agencies concerned with security and safeguarding domestic interests have been undertaken by NRC. These exchanges have strengthened NRC's posture in meeting perceivable threats, and have contributed to safeguards planning.

After several years of operating experience at NRC safeguards levels, there is no indication that during this period, serious attempts have been made by malevolent interests to exploit them. Nevertheless, it was considered prudent in today's climate to upgrade safeguards for all facilities handling SSNM, including any future mature MOX industry, to deal with acts of collusion and violent armed assault. (The requirements of a system which meets these objectives are discussed in Chapters 4 and 5.)

3.4 POSSIBLE CONSEQUENCES OF THEFT OR SABOTAGE

If an adversary should acquire significant quantities of SSNM, or attain a position where he could commit an act of sabotage to a facility containing such materials, there would be a broad spectrum of possible consequences. Most important of these would be:

- The detonation of a nuclear explosive.

- The dispersal of plutonium-derived radiological agents.

Sabotage of nuclear facilities in such a way as to cause the release of radioactive materials outside the boundaries of the facility.

- Threats to use the nuclear materials for malevolent purposes unless certain demands were met (blackmail or extortion).

In defining the possible consequences of such adversary actions, it is useful first to look at the steps which an aggressor would have to undertake and the ease or difficulty of accomplishing them. A collateral benefit of the study of the ease or difficulty of constructing and exploiting a nuclear explosive or dispersal device is the light which it sheds on the attractiveness, or lack thereof, of nuclear materials and facilities to terrorists.

3.4.1 Nuclear Explosions

3.4.1.1 Fabrication of Explosives

As indicated in Section 3.2, some of the processed plutonium-containing materials that would occur at various points in the MOX fuel cycle would be suitable for use in nuclear explosives with little or no processing, while the fuel involved in the current low-enriched fuel cycle could not be so used without major facilities and processing efforts. Accordingly, intense public concern and speculation have centered around the ease or difficulty of making a crude nuclear explosive from illicitly obtained MOX fuel cycle nuclear materials. The following discussion strives to illuminate the issue, without offering a handy "how to do it" guide for a potential aggressor. Complicating this discussion is the fact that nuclear weapons design depends on many factors such as the type, form and quantity of nuclear material; the availability of essential accessory equipment; capability for handling hazardous components, including radioactive materials and explosives; and knowledge of the technical features of a nuclear device. There is essentially no likelihood that a terrorist group could fabricate an efficient bomb such as those in military inventories. There is, however, a low but credible probability that such a group could assemble a crude device which would produce a fission yield. It is this possibility that must be minimized by industry safeguards.

The capabilities required to design and construct an illicit nuclear device are dependent largely on the materials available and the transportation or exploitation constraints which impact on the design approach chosen. While a small group of competent people might be able to carry out such a project, the successful design and construction of nuclear explosives are not easy, and the chances of success are highly dependent on the time, effort, and abilities applied to the project.

A theoretical knowledge of nuclear physics and the unclassified literature on nuclear weapons, while helpful, is not a sufficient basis for the design of a practical nuclear explosive. Many more theoretical designs will fail than will work. The critical knowledge needed comes not only from theory but also from practical experience in design, fabrication, and testing of actual nuclear devices, the experience of having tried and experimentally determined what will and will not work and why. This latter kind of knowledge is not widespread.

While knowledge of the design details of military nuclear weapons would be useful, this also is not a sufficient basis for the confident design of a simple nuclear explosive. The sophisticated designs for military nuclear weapons emphasize efficiency, low weight, small size, and reliability more than simplicity or ease of fabrication. Such designs are not readily adaptable to the means available to those who might wish to fabricate an illicit nuclear explosive.

Depending on the design approach and materials to be used, sophisticated knowledge and skills may be required. They could include knowledge of and skills in precision machining, chemical processing, foundry processes, use of electromechanical devices, electronics, and high-explosives handling. Such knowledge and skills are not rare, but gathering together those who possess them in a clandestine project, with the common motivation to build and detonate a nuclear weapon for unlawful purposes, would be difficult.

The equipment required for such a project would be strongly related to the importance attached to the lives of the participants, to the requirements for reliability of the device, to the explosive power sought, and to the kind and form of nuclear materials available. Equipment needs could approach those of a large nuclear laboratory.

The designer of a nuclear explosive faces several dilemmas. The simpler and less sophisticated the design, the larger the size and weight of the device and the greater the requirements for nuclear materials and high explosives. If large quantities of material are available, the design can be unsophisticated, but the resulting device is also more likely to be heavy and to require a team of people or special equipment to assemble and transport it. Conversely, if the available amount of nuclear material is small, the design must be sophisticated, requiring additional skills and more time for fabrication.

The risks in fabricating a crude nuclear explosive device are both numerous and significant. The very nature of the activities in such a project, the kinds and numbers of people required, and the materials involved all combine to enlarge the total size of the aggressor group, stretch the time and activity required for completion, and thereby facilitate detection of the enterprise.

Further, the manufacture of nuclear weapons involves use of extremely hazardous materials and introduces a substantial chance that amateurs would suffer accidents involving criticality, plutonium poisoning, conventional chemical hazards, or the mishandling of high explosives. In the history of making nuclear weapons such accidents have occurred under highly controlled conditions, and their probability would be enhanced by the conditions to be expected in a clandestine project. While the accidents that have occurred have had no adverse impact on society, they have had serious effects upon some of the individuals involved.

Assembly and delivery of nuclear weapons pose opportunities for lethal radiation exposures, premature nuclear detonation or accidental explosion of conventional high explosives. The problem is that any general design which does not violate the basic concepts required for a nuclear explosive can be constructed successfully by knowledgeable experts, but correct recognition of basic concepts does not guarantee a successful device. Even if a crude explosive is successfully assembled, it will remain an uncertain tool in the hands of its creators. It may fail to explode; it may simply disperse radioactive material; or it may give a wide range of possible nuclear yields.

Experts are divided as to how formidable these problems might be and as to how great might be the minimum qualifications, equipment and time which a determined group would need in order to undertake the simplest possible means of creating a crude but effective nuclear explosive. Three opinions are quoted below in an attempt to present a range of views:

1. Willrich and Taylor (Ref. 9, pp. 20-21):

   > As a result of extensive reviews of publications that are available to the general public and that relate to the technology of nuclear explosives, unclassified conversations with many experts in nuclear physics and engineering, and a considerable amount of thought on the subject, we conclude:
   >
   > Under conceivable circumstances, a few persons, possibly even one person working alone, who possessed about ten kilograms of plutonium oxide and a substantial amount of chemical high explosive could, within several weeks, design and build a crude fission bomb. By a "crude fission bomb" we mean one that would have an excellent chance of exploding, and would probably explode with the power of at least 100 tons of chemical high explosive. This could be done using materials and equipment that could be purchased at a hardware store and from commercial suppliers of scientific equipment for student laboratories.
   >
   > The key persons or person would have to be reasonably inventive and adept at using laboratory equipment and tools of about the same complexity as those used by students in chemistry and physics laboratories and machine shops. They or he would have to be able to understand some of the essential concepts and procedures that are described in widely distributed technical publications concerning nuclear explosives, nuclear reactor technology and chemical explosives, and would have to know where to find these publications. Whoever was principally involved would also have to be willing to take moderate risks of serious injury or death.

2. J. Carson Mark* (as quoted in Ref. 48, pp. 59-60):

   > If one thinks of a small group wanting to build a bomb, and if one supposes that their primary requirement is that it give a "nuclear yield" (as to say, for example, "the yield must be at least so much; but it is all right if it should turn out to be a few times larger") then I think that such a device could be designed and built by a group of something like six well-educated people, having competence in as many different fields. As a possible listing of these, one could consider: a chemist or chemical engineer; a nuclear or theoretical physicist; someone able to formulate and carry out complicated calculations, probably requiring the use of a digital computer, on neutronic and hydrodynamic problems; a person familiar with explosives; similarly for electronics; and a mechanically-skilled individual. Among the above (possibly the chemist or the physicist) should be one able to attend to the practical problems of health physics which would arise. Clearly, depending on the breadth of experience and competence of the particular individuals involved, the fields of specialization and even the number of persons could be varied, so long as areas such as those indicated were covered.

3. E. Zebroski and M. Levenson (Ref. 49, p. 125):

   > Perhaps a more skeptical view of this possibility [of producing a crude nuclear weapon] would be by analogy to the ability of a reasonably well-informed technical person to sketch up a workable concept for a small jet propelled airplane, or a medium sized computer. Given access to manufactured modules for most of the critical parts, construction of such a project by a small dedicated group of artisans is conceivable.

---

*Former head of the Theoretical Division, Los Alamos Scientific Laboratory, which includes many of the nation's leading designers of nuclear weapons.

> However, if the project must literally start from the raw materials in inconvenient chemical and physical form, and with very substantial hazards associated with handling and processing the materials, one obtains a rather different view of the probability of the "garage operation weapon."

Analysis indicates less difference among the foregoing views than initially appears. Willrich and Taylor, starting with the assumption that the aggressor had acquired approximately 10 kilograms of plutonium oxide, state that he could fabricate a crude nuclear device within several weeks. Levenson and Zebroski, assuming that the aggressor must chemically process and refine his plutonium from some much less readily usable substance, highlight the difficulties inherent in obtaining such readily usable materials as 10 kilograms of plutonium oxide. J. Carson Mark, in listing six different skills required, does not deny that those skills could be gathered together in a group of less than six persons.*

Conclusions which may be drawn from the foregoing include the following:

- To fabricate an illicit nuclear explosive requires a group of individuals with special knowledge, skills and experience covering several technical fields.
- To bring together in a coordinated effort persons who combine the requisite qualifications with the motivation to use a nuclear weapon would be most difficult but not impossible.
- Should such a group exist, it might well be deterred by the difficulties involved in the job; for example, the need to acquire significant quantities of a heavily guarded material and the significant hazards of working with the material.
- The true challenge of safeguards is to make such difficulties even greater, thereby reducing the likelihood that any attempt will be made.

3.4.1.2 Possible Effects Of Nuclear Explosions

The destruction resulting from a nuclear explosion depends primarily upon the energy yield of the explosion and the circumstances at the time and place of its detonation. A nuclear explosion has several immediate effects: blast, the release of heat and light energy (thermal radiation), and the release of nuclear particles and gamma rays (nuclear radiation). In addition, a nuclear explosion occurring at or near the earth's surface (as would probably be the case with an illicit weapon) would cause heavy localized contamination by prompt radioactive fallout, in addition to global scale contamination by delayed fallout, the extent of which would be determined largely by the yield and existing meteorological conditions.

The yield of a nuclear explosion is expressed in terms of the quantity of TNT required to release equivalent energy. Yield of a particular weapon depends upon such factors as the amount of fissionable material, the weapon design, and the quality of fabrication. Design and fabrication determine the efficiency of a weapon, or the percentage of its nuclear material which

---

*After the above was written, Secretary of Defense Harold Brown was quoted to the effect that "an atomic bomb could be fabricated within a year by perhaps 100 skilled workers with access to a machine shop and fissionable material" (Ref. 50). Before becoming Secretary of Defense, Dr. Brown had wide experience in matters involving nuclear weapons design and fabrication.

actually fissions. Accordingly, it is difficult to predict the yield of an illicit fission bomb. Such a device could be considered a success if it produced a yield in tens of tons; it could conceivably have a yield in the kiloton range.

The only historical information concerning human casualties from a nuclear explosion, that obtained from study of the explosions over Hiroshima and Nagasaki, is in many details irrelevant to the problem at hand. Those explosions were air bursts delivered diractly to the desired detonation point by a team supported by the resources of the U.S. government. The yields, roughly 20 kilotons each, while not impossible, are improbably large for an illicit weapon. The population in Japan had had no warning and no experience or background information on how to minimize fallout hazards. In this worst-case situation, about one-fourth of the people in each city were killed, and a similar number injured.

The information provided by this experience and a thorough study of potential weapons effects is not sufficient to predict with certainty the casualties that might result from a specific explosion in a U.S. metropolitan area. There is no doubt that the consequences would be severe, including blast, fire, and radiation hazard over a considerable area. The magnitude of the effect would depend, however, on such factors as weapon yield, height of burst, types of structures present, meteorological conditions, time of day, and the presence or absence of warning.* Willrich and Taylor discuss these variables as follows:

> We can illustrate such differences by a few examples. A nuclear explosion with a one-ton yield in the open in a sparsely populated area might produce slight damage. But the same explosion on a busy street might deliver a lethal dose of radiation to most of the occupants of buildings, as well as to people along the streets, within about 100 meters of the detonation. A nuclear explosion with a yield of ten tons in the central courtyard of a large office building might expose to lethal radiation as many as 1,000 people in the building. A comparable explosion in the center of a football stadium during a major game could lethally irradiate as many as 100,000 spectators. A nuclear explosion with a 100-ton yield in a typical suburban residential area might kill perhaps as many as 2,000 people, primarily by exposure to fallout. The same explosion in a parking lot beneath a very large skyscraper might kill as many as 50,000 people and destroy the entire building (Ref. 9, pp. 22-23).

Using methods explained in his article, "Review of Nuclear Weapons Effects" (Ref. 51), Dr. Harold L. Brode has calculated for the NRC the effects of nuclear explosives with yields of 1 ton, 10 tons, 100 tons, 1 kiloton, 10 kilotons, and 20 kilotons. Table 3.7 shows these effects.

> People in the open within a radius of 160 meters would receive a lethal dose of radiation.**

---

*A rational aggressor's ability to cause heavy casualties is limited by the fact that demands for compliance with his wishes would give a measure of warning, permitting the evacuation of the most highly concentrated targets. Another point not generally noted is that crude nuclear devices, destructive as they might be, would be more "block-busters" than "city-busters." (For more details and differing views, see Ref. 38.)

**The percentage of a city's population "in the open" is normally quite low. Even during the rush hour, most people are either in cars, buses or trains, all of which provide some degree of shielding from blast, thermal radiation, nuclear radiation and fallout.

TABLE 3.7

DAMAGE RADII FOR VARIOUS EFFECTS OF NUCLEAR EXPLOSIONS

(Range in Meters)

	Explosive Yield					
Effects	1 Ton	10 Tons	100 Tons	1 Kiloton	10 Kilotons	20 Kilotons
			Range, Meters			
Lethal fallout	76	240	760	2,400	7,600	11,000
Onset of radiation sickness	230	430	710	1,050	1,400	1,500
Lethal radiation dose[a]	160	325	570	880	1,200	1,300
Severe damage to apartment-type building	29	76	185	410	930	1,200
Severe damage to multistory wall-bearing building	21	56	140	320	700	870
50% second-degree burns	21	73	260	800	2,200	3,200
50% third-degree burns	18	61	210	660	1,900	2,600
Spontaneous ignition of dry wood[b]	14	46	160	500	1,400	2,000

Source: Developed for NRC using methodology contained in Ref. 51.

[a] Without medical attention, 50% of the people exposed will die in 60 days.

[b] Assumed to occur at about 75% of the range for 50% third-degree burns. At these distances, thin wood, such as shingles, will often continue to burn after the thermal pulse has passed. Thicker wood will usually self-extinguish.

- If people who escaped the initial effects subsequently exposed themselves for extended periods, those within 76 meters would receive lethal fallout radiaion.

It is should be noted, however, that Table 3.7 does not allow for the substantial effects of buildings in shielding people from radiation. To include this factor would require very detailed onsite calculations.

3.4.2 Radiological Dispersal Weapons

While there have been isolated, small-scale incidents,* neither the technical nor physchological effectiveness of large-scale malevolence utilizing radiological dispersal service has been demonstrated. In principle, there are many toxins available which would kill tens of thousands of people in the most vulnerable target areas in the U.S. Some, such as botulism toxin and anthrax spores, are much more lethal than plutonium (Refs. 46 and 54).

---

*For a summary of known radiological "incidents," all at a low hazard level, see Ref. 36. For a summary of known and alleged biological "incidents," see Ref. 55.

Except in large doses, inhaled plutonium produces no discernible effect until the possible development of cancer 15 or more years later (Refs. 52 and 53). (Even in the case of possible large doses, almost impossible to deliver to large numbers of people, death would be delayed for weeks or months.) Thus, instantaneous dramatic effects usually sought by terrorists would not be available.

Experts are at present unable to determine whether any individuals or groups might be motivated to use plutonium radiotoxicity for malevolent purposes, and especially whether such motivations are likely to be held by those capable of conducting such an operation. In order to achieve large-scale effects, there would be a need to prepare plutonium in a suitable form and to design, build, and test a dispersal device, hazardous tasks for which no precedents exist. These efforts would be complicated by the radiotoxicity of plutonium and, in some cases, by the bulk or radiotoxicity of the other materials used in the fuel cycle.

Widespread effective dispersal of plutonium is difficult to achieve. In fact, dispersal efficiency was a major problem in animal experiments on plutonium toxicity. Only a narrow range of plutonium particle sizes is suitable--particles that exceed about 7 microns in diameter will not penetrate deeply into the lungs. Of the small particles that do penetrate deeply, only about 30 percent will be deposited. The rest will be expelled by exhaling. (See Refs. 56 and 57.)

The consequences of radiological dispersal weapons are less understood than those of nuclear explosives. The critical path for exposure to a plutonium dispersal device is inhalation and dosage to the lungs (Ref. 58).* The amount of plutonium which, if inhaled and retained in the lungs of man, is likely to produce a death from cancer has been calculated, using the conservative linearity assumption, ** to be 1,400 micrograms of insoluble ^{239}Pu. Plutonium obtained from a reactor fuel cycle is considered more dangerous than pure ^{239}Pu because it contains isotopes with shorter half-lives; accordingly, the cancer-causing inhalation dose of this "reactor plutonium" has been computed to be only 260 micrograms (Ref. 58, Ref. 9, Ref. 59). Any deaths resulting from these cancers would occur 15 to 45 years after the exposure. To cause death within a period as short as 2 months might require doses 50 times greater (Ref. 58).

Studies by Bernard L. Cohen (Ref. 46) and by Schmidt and Bodansky (Ref. 48) suggest that dispersal of plutonium in the atmosphere would have relatively small consequences as compared to other disasters that can be more easily induced in our complex society. For example, Cohen calculates that dispersal of 1 gram of reactor plutonium without warning in a crowded football stadium could eventually cause two fatalities. If dispersal occurred on an average city street, the estimated fatality rate would drop to one per 15 grams of reactor plutonium if there were no warning and one per 150 grams with warning (Ref. 46, pp. 15-23).

It has been estimated that plutonium dispersed in the ventilation system of a large building could be very effective, causing perhaps 70 eventual deaths per gram of reactor plutonium

---

*See also Ref. 46, pp. 7-10, and Ref. 59. As explained in pages 5-23 of Ref. 46, a very small portion of the dispersed plutonium actually reaches potential victims.

**The linear response theory assumes equal effects per extra unit of dosage independent of dosage time rate, with no minimum threshold below which there would be a zero effect.

dispersed (Ref. 46, pp. 15-23).* It should be noted, however, that, while any of several toxins dispersed in this manner would be highly effective, use of such a threat for a rational objective, such as extortion, would tend to give warning, thereby permitting countermeasures that could significantly reduce the hazards. Among the simpler countermeasures would be the temporary shutdown of ventilation systems in the more likely target areas pending thorough search.

Some interested scientists believe that the health effects of dispersed plutonium would be far worse than those estimated by Cohen (Ref. 46). For example, Dr. John W. Gofman (Ref. 60), estimates the cancer-causing dose of inhaled plutonium to be 3,520 times smaller than that calculated by Cohen on the basis of the BEIR Report (Ref. 59).**

The subject of radiological effects is so complex that interested experts disagree by as much as orders of magnitude. It should be noted in passing, however, that the results of prolonged observation of 25 Los Alamos employees, who in 1944-45 inhaled plutonium aerosols to the extent that 10 microcuries of plutonium were deposited in their lungs, support the lower hazard estimates. Calculations such as Cohen's (Ref. 46) using the lower range of effects found in the BEIR report (Ref. 59) show a 50% probability that one case should have developed to date within this group, and that perhaps one to two cases would eventually develop. As a matter of fact, there have been no cancers in the group. Studies of British uranium workers, uranium miners, metal miners and fluorspar workers also support the lower estimates (Ref. 46).

A theory which has attracted considerable attention, but which has now been generally rejected, held that immobile plutonium particles above a certain level of radioactivity lodging in the lungs could cause fatalities several orders of magnitude in excess of those previously calculated. This "hot particle" theory has been extensively investigated by the British Medical Research Council, the AEC, the National Academy of Sciences, and the NRC with all studies concluding that there is no evidence to support it. Following a definitive review of all available evidence, the NRC, on April 12, 1976, denied a petition by the Natural Resources Defense Council, Inc. to establish specific health protection standards for "hot particle" materials.†

Despite debate as to precise hazards, the following general conclusions emerge:

- Plutonium is potentially a very toxic material which must be carefully safeguarded.

---

*Willrich and Taylor estimate that 100 grams of plutonium could be a deadly risk to everyone working in a large office building or factory (Ref. 9, p .25).

**Cohen calculated the cancer-causing dose for adults based on the absolute risk level given in the BEIR report. Gofman bases his estimates on a relative risk model, also treated in the BEIR report. Gofman derives a cancer-causing dose value for non-smokers and a value for smokers that are 30 times less and 3,520 times less, respectively, than Cohen's calculated value for adults.
(Gofman's estimates imply a cancer-causing dose for the average adult that is about 1,800 times smaller than Cohen's estimate.)

†For a detailed review of the issues involved and the basis for the NRC decision, see 41 FR15371, Monday, April 12, 1976, "Notice of Denial by NRC of NRDC Petition Based on Hot Particle Theory."

3.4.3 Sabotage

3.4.3.1 General

Considerable opposition to plutonium recycle stems from concern that the presence of increased quantities and different forms of plutonium in the nuclear power industry might increase the potential for wide-scale public harm through acts of sabotage leading to the off-site dispersal of radioactivity. Such concerns could apply to three areas: MOX-fueled nuclear power reactors, MOX fuel cycle facilities, and transportation links.

Careful study of the possible consequences of accidents (including sabotage-induced accidents) to light-water-cooled nuclear reactors (LWR's) indicates that there is no significant difference between the consequences for reactors which use MOX and those which do not.** Accordingly, this section will consider only the hazards which could stem from sabotage to MOX fuel-cycle facilities and transportation links. For three reasons, however, in studying these two elements liberal use will be made of studies of accident and sabotage-related consequences that were directed primarily at (LWR's):

1. Since mature industry-scale commercial MOX fuel-cycle facilities do not exist, no detailed experience has been gained in the construction and operation of such large through-put facilities or the transport of commercial quantities of plutonium oxides, and no detailed consequence studies, based on actual operating experience, have been possible.

2. Since LWR's are already a prominent feature of American life, and becoming more so, very detailed studies about them have been conducted, and the results have been subject to careful scrutiny.

3. The experience gained in the study of LWR's is generally applicable to MOX fuel-cycle facilities and transport because:

    a. The primary problem in all cases is the containment of radioactivity and the prevention of its offsite release.

    b. The experience gained in successfully containing radioactivity at LWR's, in accord with 10 CFR Part 50, is being applied to all facilities that contain significant quantities of plutonium.

    c. As indicated below, the characteristics which make LWRs difficult to sabotage--i.e., massive structures, multiple containment barriers, and high-efficiency filters--will be common to all facilities processing large quantities of plutonium (Ref. 61).

---

*NUREG-0002, Vol. 3, pp. IV C-133 to 135.

3.4.3.2 Sabotage of MOX Fuel Cycle Facilities

Nuclear facility features required for protection against natural phenomena also protect against sabotage. While specific designs for future reprocessing and fuel fabrication facilities are incomplete, strict health and safety standards will require that they conform, in general, with existing standards and be augmented with such changes as may be devised to increase existing safety levels. Portions of plants used for storing or processing plutonium must currently be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, and floods. Depending on the site, they must provide, for example:

- Penetration resistance to a tornado-driven large plank traveling 300 miles per hour

- Protection against tornado-generated differential pressures of 3 pounds per square inch

- Resistance to damage by earthquakes

- Reinforcement and waterproofing to protect against "worst possible floods."*

It would take large quantities of explosives strategically placed to rupture the reprocessing structures and cause an offsite release of radiation.

Additional protection against sabotage is provided by the massive biological shielding included in reprocessing facilities to protect plant personnel and the public from radiation hazards. This shielding may include underground construction and/or reinforced concrete walls up to 6 feet thick.**

Because reprocessing facilities, in order to safely contain plutonium, are similar to reactors in the ruggedness of their construction and in their philosophy of design, a recent study by Sandia Laboratories of the vulnerability of nuclear power reactors to acts of sabotage (Ref. 13) is generally applicable to reprocessing facilities. Under "Study Results," the report lists as "characteristics of commercial nuclear power plants which greatly increase the difficulty of releasing radioactivity by sabotage," the following:

1. The "defense-in-depth" concept of reactor plant design;
2. The massive structure of the plant, which protects critical components from external attack;
3. The safety design basis of the plant, which emphasizes system reliability, flexibility, redundancy, and protection against common mode failures; and
4. Engineered safety features, which are added to the basic system to cope with abnormal operations or accidents.

In examining the possibility of sabotage the report states:

---

*10 CFR Part 50 and 10 CFR Part 70 and Ref. 61, p. 2-17.

**This subject is covered in greater detail in Ch. IV of NUREG-0002.

> Sabotage which might endanger the public could only be carried out by knowledgeable, capable personnel having a high degree of technical competence. Such an attack would require thorough planning in order to mount an effort coordinated to bypass the plant security system and to disable or destroy elements of several plant systems in the multiple plant defenses against a radioactive release.

In considering the consequences of a successful act of sabotage, the report continues:

> The elapsed time between the initiation of a sabotage-induced failure sequence and the actual release of radioactive materials would vary considerably. For many credible sequences, such as long-term transient incidents, sufficient time is available after initiation for a plant damage control team to nullify or mitigate the consequences of the attack. . . .
>
> Many factors influence the consequences: the sabotage option chosen, the operating status of the engineered safety features, the containment failure mode, the time and space variation of the wind and meteorological conditions, the site population distribution, and the extent of emergency response by onsite and off-site personnel. Control of all these factors is well beyond the capabilities of a credible sabotage operation. Accordingly, evaluation of the consequences arising from the sequences developed by the adversary teams yielded values that are a small fraction of the maximum consequences considered by the Reactor Safety Study.

While the Reactor Safety Study (Ref. 62) was primarily concerned with the probability and consequences of accidents, it did address the question of the consequences of sabotage as follows (p. 71):

> The worst consequences associated with acts of sabotage at reactors are not expected to lead to consequences more severe than the maximum consequences predicted by the study. The expected consequences of successful sabotage are but a small fraction of these maximum consequences.
>
> Nuclear power plants appear far less susceptible to sabotage than most other civil or industrial targets.*

Of the various accidents that could occur, including sabotage-induced accidents, the ones with the greatest potential for releasing radioactivity into the environment are those which cause melting of fuel. The most serious of these would be a loss of coolant leading to melting of a reactor core or of spent fuel storage units (Ref. 62. p. 24).

The most likely consequences of a core melt accident were estimated in the Reactor Safety Study as follows (Ref. 62, Executive Summary, p. 9):

Type of Consequence:	Magnitude of Consequence:
Fatalities	Less than one
Injuries	Less than one
Latent fatalities per year	Less than one
Thyroid nodules per year	Less than one
Genetic defects per year	Less than one
Offsite property damage	Less than $1,000,000

---

*For a description of the construction features which make such plants poor targets for sabotage, see Ref. 62, pp. 34-39, and App. IX.

Chapter IV, Section C, of NUREG-0002 describes in considerable detail the specific systems that help to prevent accidents (or sabotage) in LWR's and which then serve to limit the consequences of either accidents or sabotage. Sections D and E cover in similar detail the protective systems that would surround fuel reprocessing and mixed oxide fuel fabrication plants. The following information is based on that description.

Fuel Reprocessing Plants. Operations at reprocessing plants having a potential for accidentally dispersing significant amounts of radioactive contaminants are performed within process cells or buildings. These cells or buildings are designed to confine contaminants in the event of accidents or natural phenomena much more severe than have been experienced historically at or near such facilities. It is expected that during the life of these facilities, some equipment failures will occur. Accordingly, monitors are provided to detect process or equipment failures, and to initiate or signal the need for corrective action. These facilities are also designed to cope with unplanned and sabotage-induced accidents; and their cells, buildings, and equipment are designed to be decontaminated and to facilitate repair or replacement of equipment. Their ventilation systems are designed so that the contaminated air from any inadvertent releases within the facility would be routed through high-efficiency filters to remove airborne radioactive particulates before the ventilation air is discharged.

These plants have been analyzed over a wide spectrum of credible accidents and resulting consequences. While major equipment failures, or spills of radioactive materials within the facility, might disrupt operations and cause the facility to shut down for cleanup and repair, such occurrences are not expected to result in the release of significant amounts of offsite radioactivity. Only a few accidents involving radioactive materials have occurred in existing fuel reprocessing facilities, and none has resulted in significant contamination beyond the immediate vicinity of the plant. The experience gained from these few accidents has resulted in adoption of improved safety procedures and features so that the probability of similar occurrences in the future has been significantly reduced.

In assessing possible consequences, NUREG-0002, Chapter IV, Section E, compares the effects of reprocessing plant accidents for two types of operations, one in which both plutonium and uranium are being reprocessed and one in which only uranium is being reprocessed. For the worst types of accident, calculations show that Pu recycle might slightly increase the accidental radiation dose. With Pu recycle, the maximum individual bone dose, that from the hypothetical concentrator explosion accident, would be 13 mrem. Without Pu recycle, the maximum individual bone dose would be 12 mrem. The population bone dose would be 141 person-rem with Pu recycle and 137 person-rem without Pu recycle. The maximum individual bone dose from the specified reprocessing plant accident would be about 13 percent of the annual dose from natural background radiation.

The amount of plutonium released would be equivalent to about 0.25 percent of the release limit, for an unrestricted area, as set forth in 10 CFR § 20.106(a). NUREG-0002 also covers in detail the design features that make serious accidents in fuel reprocessing plants highly improbable.

In accordance with 10 CFR § 73.50, the storage of liquid high-level wastes at fuel reprocessing plants would be within vital areas. As indicated in Section 3.2 and in Chapter 5, vital areas would be protected by two barriers and controlled access. Additional protection within the vital areas would be provided by the safety-related structural design of waste storage tanks. The cooling equipment for liquid high-level waste storage tanks is also considered "vital" and would be within the vital area. For additional details on liquid waste storage, see Section 3.2.3.5.

In summary, reprocessing facilities are designed to: (a) make accidents or sabotage highly unlikely; (b) cope with potential accidents or sabotage; and (c) minimize the offsite consequences of such events, should they occur.

MOX Fuel Fabrication Plants. A mixed oxide fuel fabrication plant would also be designed, fabricated, constructed, tested, and operated to avoid accidents, prevent sabotage, and mitigate the offsite consequences of such events, should they occur. Monitors would be provided to detect equipment failure or process-upset conditions that have a potential for causing damage. As appropriate, corrective action would be automatically initiated. The ventilation system would be designed to function during and after accidents and to pass all plant ventilation air through high-efficiency particulate air (HEPA) filters before release to the atmosphere.

Accidents in MOX fabrication plants with the worst consequences would be those arising from fires or explosions. Therefore, the possibility of fire or explosion must be considered in detail during the design, construction, and operation of these plants. Regulatory Guide 3.16 (Ref. 63) presents a fire protection program acceptable to NRC's regulatory staff. Licensees must either adopt such a program or devise equally effective alternatives.

In discussing "Contributions to the General Exposure," NUREG-0002 states that the total dose commitment to the U.S. population from MOX fuel fabrication plant operation for 1975-2000 (GESMO model industry) would be about 1×10^{-3} of the total dose commitment from the entire LWR industry during this period. NUREG-0002, Chapter 4, Section D, states that the calculated additional dose commitment from a major fire at a MOX fabrication plant would be approximately 10 percent of the annual dose commitment* estimated to accrue from normal operations at the plant. NUREG-0002 further states that the dose commitment resulting from an explosion would be roughly equal to that from a fire.

3.4.3.3 Sabotage of Transportation

Transport Vehicles for PuO_2 and MOX. Vehicles transporting plutonium might be more vulnerable to sabotage than fixed facilities. Accordingly, extensive design effort has been devoted to sabotage- and assault-resistant transport vehicle and container designs. This effort has led to the conclusion that an integrally designed combination vehicle/container would be a

---

*Annual dose commitment refers to the total radiation dose received by the body over a one-year period.

cost-effective means of moving plutonium-containing materials. One such combination, known as the Integrated Container-Vehicle (ICV), looks promising.

While details of ICV design are not yet final, and while specific features will be classified to prevent simplifying the task of an aggressor, an ICV which could handle the large quantities of plutonium involved in a MOX industry can be described conceptually.* It would consist of a cylindrical steel secondary pressure vessel containing a number of primary pressure vessels loaded with PuO_2. Surrounding the secondary pressure vessel would be a layer of lead for gamma shielding, a layer of plastic for neutron shielding, a layer of plastic-ceramic composite for resistance to projectiles and shaped charges, and a thick layer of interwoven materials for penetration and crash resistance. An outer shell of steel or aluminum would form the main structure of the vehicle. Conductors or cooling systems would carry heat from the secondary pressure vessel to the outer shell, where it would be dissipated into the atmosphere.

Preliminary effectiveness tests on such a design indicate that hand tools, portable power tools, cutting tools, and various high-technology explosive attacks, including shaped charges, could not readily penetrate the ICV.

While intended primarily for the transport of plutonium, the ICV is expected to be adaptable to the transport of fresh MOX fuel. As to possible hazards resulting from sabotage of an ICV, the following conclusions may be drawn:

- To penetrate this vehicle in such a manner as to cause a significant radioactive release to the atmosphere would require either an unusual explosive device or the time needed to work progressively through the various layers of protection.

- For such time to be available, an attack would have to occur in a remote area, far from alert response forces. In such remote areas the radiation hazard to the public from a successful sabotage attack appears negligible.

- If an attack utilizing sufficient explosive force to breach the many layers of protection were to occur in a populated area, the hazard to the populace from the conventional explosives could well exceed the radiation hazard from dispersion of the protected cargo.

- If an aggressor wished to mount as sophisticated an attack as would be required to create significant radioactive hazard to the populace, he would be more inclined to attempt to gain possession of the entire cargo.

Transport of Spent Fuel. With or without a MOX fuel industry, spent fuel must be removed from reactors and shipped either to reprocessing plants or to spent fuel storage sites. As discussed in NUREG-0002, Chapter 4, Section G, differences in the radiological characteristics of spent fuel as found in a MOX and non-MOX industry would be slight. In either case, as shown

---

*Based on unclassified extracts from Ref. 64. Additional transport options are discussed in Ch. 6.

both in NUREG-0002 and in Ref. 65, the radiological consequences from very severe transportation accidents or sabotage involving spent fuel would be small.

Transport of High-Level Waste. In a MOX fuel industry, the high-level waste product resulting from reprocessing of spent fuel would have to be removed from reprocessing plants and shipped to a waste repository facility within ten years of reprocessing. Although no firm plans have been submitted to NRC for approval, high-level waste is expected to be shipped as a vitreous solid in a cask built much like a spent fuel shipping cask. Ref. 66 contains a conceptual design of such a cask.

Calculations made by NRC staff (Ref. 67) support the conclusions that the radiological consequences of sabotage to a high-level waste cask would be low. It might cause release of about one percent of the glassy solid material as a respirable aerosol. Under the worst set of weather conditions, and with a population density of 100 persons per square mile, the number of early deaths from sabotage of a cask containing the high-level waste from about 40 spent fuel elements of a pressurized water reactor could be approximately as high as 13, and the number of latent cancer fatalities almost as high as 130, using a ratio of 4 in looking at Table II, p. 10 (Ref. 67). Average weather conditions would markedly reduce the effects.

3.4.4 Threats or Hoaxes

Threats to explode a nuclear device unless certain demands are met have been made* and doubtless will recur. While the increased presence of materials suitable for fabrication of nuclear weapons, no matter how carefully safeguarded, would enhance the credibility of such threats, no analytical techniques have been devised for measuring the extent of such increased credibility or the vulnerability of society to such threats. However, some general observations can be made, concerning high-consequence threats and the likelihood of their being implemented.**

- Threats and acts of terror involving large loss of life, such as the placement of bombs on aircraft, have usually been the work of individuals or very small groups.

- The more sophisticated organizations which might have the ability to execute so complex an event as fabricating an illicit nuclear bomb have limited themselves to the killing of relatively small numbers of people. While the destruction often seems wanton in the sense that innocent bystanders are victims, it usually seems to the perpetrators to further their cause. It is unlikely that well-organized groups would conceive that killing thousands of people and leaving many others with terminal illnesses would further their interests.

- If a group did have such an objective, there are alternative means available which are much easier to accomplish than explosion of a nuclear device and which have the advantage of causing quick, rather than lingering, death. Such alternatives include:

---

*All appear to have been hoaxes.

**These observations are based on studies of terrorism made in conjunction with the preparation of this document. These include the writings of Dr. Bernard L. Cohen (Ref. 38), and Brian Jenkins of the Rand Corp. (Ref. 36), and other documents referenced in Section 3.3.2.1, above.

a. Releasing poison gas into the ventilation system of a large building,

b. Poisoning a city water supply,

c. Blasting open a large dam; and

d. Explosion of a tanker carrying a cargo of liquefied natural gas into a congested metropolitan harbor.

The problem of nuclear terrorist extortion is discussed in Ref. 36, p. 24 as follows:

> Terrorists believed to possess a nuclear weapon could ask for the world. Or could they? The problem with asking for the world is that it is hard to deliver or collect. There are limits to the demands made by terrorists regardless of what they may possess or threaten. Let us deal with the most dangerous end of our spectrum for a moment--hijacking a city--and suppose that the action is accompanied by some set of demands. What might terrorists holding a city hostage ask for? Huge monetary ransoms would pose tremendous logistics difficulties. A billion dollars in small bills, tens and twenties, would weigh anywhere from 10 to 100 tons and require a fleet of armored trucks; a billion dollars in gold at current market value would weigh around 185 tons. ...Sixty million dollars is the largest known monetary ransom that has been collected to date. It was received by Montoneros in Argentina in return for the safe release of Juan and Jorge Born, members of the international trading conglomerate, Bunge and Born. It required months of negotiations in Argentina and Europe to arrange the transfer of money. It seems unlikely that a city could be held hostage for that length of time.

Having raised such issues, the next question should naturally be: Where would the conspirators go to enjoy their gains, after having committed an act of war against a nation such as the United States, with the entire resources of the victimized nation, and of most of an outraged world, arrayed against them?

The history of large robberies, such as the Brinks case, exposes some of the difficulty in exploiting large, illicit gains, even on a scale far smaller than here contemplated. These problems may help explain why none of the available techniques for mass hostage/extortion scenarios has been tried.

3.5 CONCLUSIONS

Based on the description of the mature MOX industry, the analysis of possible threats to that industry, and the potential consequences of successful theft or sabotage presented in this chapter, some general conclusions can be drawn:

1. A substantial quantity of SSNM is currently being safeguarded under the regulatory authority of the NRC, and greater quantities are being handled by facilities under ERDA (now DOE) supervision.

2. The mature MOX industry projected for the year 2000 would increase the quantity of SSNM regulated by the NRC from its current level of more than 20 tons to approximately 97 tons, and the number of fuel cycle facilities to be safeguarded from 13 to approximately 35.

3. From the standpoint of the greatest potential risk involved in theft or diversion of SSNM--the fabrication of a nuclear explosive--the SSNM currently being safeguarded under DOE and NRC regulation is at least as attractive to an adversary as would be the plutonium oxide introduced by wide-scale use of MOX fuel. The basic differences between them are the radioactive hazards involved in handling plutonium oxide and the fact that reactor-grade plutonium also has a high neutron background (due to spontaneous fissions), which would complicate the construction of a nuclear explosive.

4. An additional, though lesser, risk with PuO_2 is its potential use as a toxic agent intentionally dispersed or dispersed through acts of sabotage against facilities handling it.

5. It is not possible from the available evidence to conclusively demonstrate that any imminent threat to the nuclear fuel industry actually exists. It is apparent, however, that:

   a. There may be people who have the skills necessary to plan and execute an operation against the industry.

   b. Conceivably such people could be gathered together and motivated to conduct such an operation.

   c. Although the possibility appears extremely low, such a group could create a major civil disaster if it succeeded in obtaining significant quantities of SSNM. A crude nuclear explosive could destroy one or more city blocks. A plutonium dispersal device could be created with a potential, depending on many variables, of killing as many as several hundred people. Acts of sabotage could also create significant but less severe hazards.

Since such possibilities exist, the wide-scale use of MOX must include safeguards adequate to ensure that the incremental risk to society is minimal. Such safeguards would initially build on the systems now in existence, systems which, for NRC-licensed facilities, currently guard an inventory of SSNM approximately one-third the size of that which would be produced by wide-scale use of MOX fuel in the year 2000. Then, as appropriate, additional features considered necessary for a wide-scale MOX industry would be added. Chapter 4 describes the safeguards techniques and procedures currently available, and discusses how these ingredients have been combined to form the safeguards system now in effect.

CHAPTER 3

REFERENCES

1. John McPhee, The Curve of Binding Energy, Ballantine Books, New York, 1973.†

2. U.S. Atomic Energy Commission, "Nuclear Power Growth: 1974-2000," WASH-1139(74), UC-80, February 1974.*

3. William A. Higinbotham, "Meeting the Challenge," Proceedings, Institute of Nuclear Materials Management, Inc. IV, No. III, 57-63 (Fall 1975).***

4. Lawrence Scheinman, "The Nuclear Safeguards Problem," The Nuclear Fuel Cycle, Ch.5, pp. 120-39, MIT Press, Cambridge, 1975, Rev. Edition.***

5. Victor Gilinsky, The Rand Corp., "Where is Nuclear Reactor Technology Taking Us?" P-3589, April 1967.[b]

6. Victor Gilinsky, The Rand Corp., "Fast Breeder Reactors and the Spread of Plutonium," RM-5148-PR, March 1967.[b]

7. David Krieger, "Terrorists and nuclear technology," Bulletin of the Atomic Scientists 31, No. 6 (June 1975).***

8. David M. Rosenbaum, John N. Googin, Robert M. Jefferson, Daniel J. Kleitman, and William C. Sullivan, "Special Safeguards Study," mimeographed press release, April 1974.[b]

9. Mason Willrich and Theodore B. Taylor, Nuclear Theft: Risks and Safeguards, Ballinger Publishing Company, Cambridge, 1974.†

10. P. A. Karber, H. C. Greisman, R. W. Mengel, G. S. Newman, E. J. Novotny, and A. G. Whitley, the BDM Corp. "Analysis of the Terrorist Threat to the Commercial Nuclear Industry," Draft Working Paper C, "Supporting Appendices," BDM/W-75-176-TR, September 1975.[b]

11. Brian Jenkins and Janera Johnson, The Rand Corp., "International Terrorism: A Chronology, 1968-1973," WN(L)-8433-DOS/ARPA, December 1973.[b]

12. R. W. Mengel, The BDM Corp., "Analysis of Group Size," BDM/W-75-247-TR, December 1975.[b]

13. Sandia Laboratories, "Safety and Security of Nuclear Power Reactors to Acts of Sabotage," SAND 75-0504, January 1976. (For further information, see classified version.)[b]

14. The President's Commission on Law Enforcement and Administration of Justice, Task Force on Assessment, Task Force Report: Crime and Its Impact--An Assessment, U.S. Government Printing Office, Washington, D.C., 1967.[a]

15. Ralph Salerno and John S. Tompkins, The Crime Confederation: Cosa Nostra and Allied Operations in Organized Crime, Doubleday and Company, Inc., Garden City, 1969.†

16. George B. Vold, Theoretical Criminology, Oxford University Press, New York, 1958.†

17. Gerard L. Goettel, "Why the Crime Syndicate Can't be Touched," p. 37, Harper's Magazine, (November 1960).†

18. Ed Reid, The Grim Reapers: the anatomy of organized crime in America, Henry Regnery Company, Chicago, 1969.†

---

*Available for purchase from National Technical Information Service (NTIS), Springfield VA. 22161.

***Available in public technical libraries.

†Available in public libraries.

[a] Available from GPO.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

19. Marshall B. Clinard and Richard Quinney, *Criminal Behavior Systems: A Typology*, Holt, Rinehart and Winston, Inc., New York, 1967.†

20. Earl Johnson, Jr., "Organized Crime: Challenge to the American Legal System, Part II - The Legal Weapons: Their Actual and Potential Usefulness in Law Enforcement," *The Journal of Criminal Law, Criminology, and Police Science*, *54*, No. 1 (March 1963).***

21. C. D. Brennan, et. al., MITRE Corporation, "The Threat to Licensed Nuclear Facilities," MTR-7022, September 1975.[b]

22. Robert K. Mullen, "The International Clandestine Nuclear Threat," International Association of Chiefs of Police, 1975. Available from the International Association of Chiefs of Police, 11 Firstfield Rd., Gaithersburg, MD. 20760.

23. J. Bowyer Bell, "Transnational Terror," American Enterprise Institute for Public Policy Research, AEI-Hoover Policy Study 17, 1975.[b]

24. Brian Crozier, "Transnational Terrorism," International Association of Chiefs of Police, 1974. Available from International Association of Chiefs of Police, 11 Firstfield Rd., Gaithersburg, MD. 20760.

25. P. A. Karber, H. C. Greisman, R. W. Mengel, G. S. Newman, E. J. Novotny, and A. G. Whitley, The BDM Corp., "Analysis of the Terrorist Threat to the Commercial Nuclear Industry," Draft Working Paper B, "Summary of Findings," BDM/W-75-176-TR, September 1975.[b]

26. David L. Milbank, U.S. Central Intelligence Agency, "International and Transnational Terrorism: Diagnosis and Prognosis," RS PR 76 10030, April 1976.[b]

27. Mason Willrich, "Terrorists keep out!" *Bulletin of the Atomic Scientists* *31*, No. 5, 12 - 16 (May 1975).***

28. T. P. Thorton, "Terror as a Weapon of Political Agitation," *Internal War: Problems and Approaches*, Harry Eckstein (Ed.), MacMillan, New York, 1964.†

29. Thomas M. Conrad, "Do-It-Yourself A-Bombs," 455-57, *Commonweal* *90* (July 1969).†

30. Alan M. Adelson, "Please Don't Steal The Atomic Bomb," 130-33, 44, *Esquire* *71*, No. 5 (May 1969).†

31. Lowell Ponte, "Better Do As We Say: This Is An Atom Bomb and We're Not Fooling," 32-34, 103-4, *Penthouse* (February 1972).†

32. Lowell Ponte, "The Danger of Terrorists Getting Illicit A-Bombs," *Los Angeles Times* (January 15, 1973).†

33. Robert A. Jones, "Nuclear Terror Peril Likely to Increase," p. 18, pp. 4-F, 5-F, *Los Angeles Times*, April 1976.†

34. Mihajlo Mesarovic and Eduard Pestel, *Mankind at the Turning Point*, E. P. Dutton & Co., Inc., New York, 1974.†

35. Brian M. Jenkins, The Rand Corp., "International Terrorism: A New Kind of Warfare," P-5261, June 1974.[b]

36. Brian Jenkins, "Will Terrorists Go Nuclear?" paper, California Seminar on Arms Control and Foreign Policy, November 1975.[b]

37. Roberta Wohlstetter, "Terror on a Grand Scale," 98-104, *Survival* *18*, No. 3 (1976).***

38. Bernard L. Cohen, "The Potentialities of Terrorism," mimeographed, University of Pittsburgh, Pittsburg, 1976.[b]

39. Eric D. Shaw, Leo Hazlewood, Richard E. Hayes, and Don R. Harris, "Analyzing Threats from Terrorism," CACI-Inc.-Federal, mimeographed, Washington, D.C., April 1976.[b]

***Available in public technical libraries.

†Available in public libraries.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

40. Howard R. Simpson, "Terror," 65-69, U.S. Naval Institute Proceedings 96 (1970).***

41. Nathan Leites and Charles Wolf, Jr., Rebellion and Authority: An Analytic Essay on Insurgent Conflicts, Markham Publishing Co., Chicago, 1970.†

42. Richard Clutterbuck, Living with Terrorism, Faber & Faber Ltd., London, 1975.†

43. "Chicago Charges Pair with Plot to Poison Midwest Water Supply," p. 9, Los Angeles Times, January 19, 1972.†

44. "Terrorist Use of Gas Feared," p. 3, Washington Post, May 13, 1975.†

45. John G. Davis, Acting Director, Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, letter to James M. Cubie, Public Citizen, January 19, 1976, with enclosure and incoming letter dated December 31, 1975.[b]

46. Bernard L. Cohen, "The Hazards in Plutonium Dispersal," University of Pittsburgh, Pittsburgh, July 1975.[b]

47. D. S. Myers, "The Biological Hazard and Measurement of Plutonium," paper, Proceedings of Radiological Defense Officer Conference, Governor's Office of Emergency Services, Sacramento, California, 1974.[b]

48. Fred H. Schmidt and David Bodansky, The Energy Controversy: The Role of Nuclear Power, University of Washington, Seattle, Washington, February 1975. (Revised August 1975).†

49. E. Zebroski and M. Levenson, "The Nuclear Fuel Cycle," Annual Review of Energy 1, 101-130, (1976).***

50. "Brown Says 100 Civilians Could Build A-Bomb," p. 1, The Washington Star, April 1, 1977.†

51. Harold L. Brode, "Review of Nuclear Weapons Effects," Annual Review of Nuclear Science 18, 153-202, (1968).***

52. Charles W. Mays, Glenn N. Taylor, Webster S. S. Jee and Thomas F. Dougherty, "Speculated Risk to Bone and Liver From 239-Pu," Health Physics 19, 601-10 (1970).***

53. W. J. Bair and R. C. Thompson, "Plutonium: Biomedical Research," Science 183, 715-22 (1974).***

54. J. H. Rothchild, Tomorrow's Weapons, McGraw Hill, New York, 1964.†

55. J. P. Robinson, "The Rise of CB Weapons," Vol. I of The Problem of Chemical and Biological Warfare, Stockholm International Peace Research Institute, Humanities Press, New York, 1971.†

56. Task Group on Lung Dynamics, "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract," Health Physics 12, 173-207 (1966).***

57. R. F. Phalen and O. G. Raabe, "Aerosol Particle Size as a Factor in Pulmonary Toxicity," p. 353 in Proceedings of the Fifth Annual Conference on Environmental Toxicology, AMRL-TR-74-125, Paper No. 23, Lovelace Foundation for Medical Education and Research, 1974.[b]

58. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection," (adopted September 1965), ICRP Pub. No. 9, 1966; "Evaluation of Radiation Doses to Body Tissues from Internal Contamination Due to Occupational Exposure," (adopted April 1967), ICRP Pub. No. 10, 1968.***

59. National Academy of Sciences and National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, Washington, D.C., 1972.***

***Available in public technical libraries.
†Available in public libraries.
bAvailable in source file for USNRC Report NUREG-0414, May 1978.

60. John W. Gofman, "The Cancer Hazard From Inhaled Plutonium," Congressional Record-Senate, S-14610-S-14620 (July 31, 1975). †

61. U.S. Atomic Energy Commission, "The Safety of Nuclear Power Reactors (Light Water-Cooled) and Related Facilities," WASH-1250, July 1973.*

62. U.S. Nuclear Regulatory Commission, "Reactor Safety Study--An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400 (NUREG-75/014), October 1975.*

63. U.S. Atomic Energy Commission, Regulatory Guide 3.16, "General Fire Protection Guide for Plutonium Processing and Fuel Fabrication Plants," January 1974.**

64. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. V--"Elements of Physical Protection for Transportation," SAND-75-0457, March 1976. (Secret)**

65. U.S. Atomic Energy Commission/U.S. Nuclear Regulatory Commission, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants," WASH-1238, December 1972, Supplement 1 to WASH-1238 (NUREG-75/038) and Supplement II to WASH-1238 (NUREG-0069), July 1976.*

66. U.S. Energy Research and Development Administration, "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle," ERDA 76/43, Vol. 3, May 1976.*

67. C. Vernon Hodge and James E. Campbell, "Calculations of Radiological Consequences from Sabotage of Shipping Casks for Spent Fuel and High Level Waste," U.S. Nuclear Regulatory Commission, Division of Fuel Cycle and Material Safety, and Sandia Laboratories, (NUREG-0194) September 1976.*

---

*Available for purchase from National Technical Information Service (NTIS), Sprinfield VA. 22161.

**Unclassified version of classified reference and copies of unclassified references are available in NRC PDR for inspection and copying, for a fee.

†Available in public libraries.

CHAPTER 4

APPROACHES TO SAFEGUARDS

4.1 INTRODUCTION

Safeguards measures are designed to deter, prevent, or respond to:

1. the unauthorized possession or use of significant quantities of nuclear material through theft or diversion, and

2. sabotage of nuclear facilities.

Any safeguards program applied to the nuclear industry is intended to simultaneously insure that neither of these illicit activities will occur and that the measures adopted for their prevention, under the concept of prevailing civil order, will not introduce unacceptable risk of public injury or property damage.

This chapter discusses the general safeguarding approach adopted by the current nuclear industry and serves as a transition between Chapter 3, which describes the nature of a projected MOX industry, potential threats to that industry, and the potential consequences, and Chapters 5 and 6, which treat possible approaches for safeguarding that industry.

The safeguards responsibilities of the Nuclear Regulatory Commission extend to facilities and nuclear material under the control of private citizens, universities, public utilities (both investor and publicly owned), other commercial enterprises, and some government research facilities. It is within the context of this responsibility that the discussion on current approaches to safeguards is presented.

It is recognized that nuclear industry safeguards, as regulated by the NRC, are only one element of the various procedures that have been introduced to ensure adequate public protection. In addition to the NRC and operators of licensed facilities, other participants who contribute in the broad sense to a national capability for safeguarding the public include:

1. National Security Council

2. Department of State

3. Department of Defense

4. the intelligence community

5. Federal Bureau of Investigation

6. Department of Energy

7. U.S. Coast Guard

8. Civil defense and disaster agencies

9. State and local law enforcement agencies

Whereas the focus of the NRC effort is on maintaining fixed-site and transportation security, the focus of most of these other participants is on maintaining civil order, evaluating available intelligence, and effecting recovery should some nuclear material be obtained by unauthorized sources.

4.2 NRC REGULATORY PHILOSOPHY

The NRC regulatory philosophy is based on the premise that loss of significant quantities of SSNM could have grave consequences. Accordingly, great emphasis is placed on detecting and preventing the diversion or theft of SSNM. In pursuit of this philosophy, the prescribed level of protection has not remained static.

Early safeguards for SSNM were similar to those typically provided to valuable materials in other industries. With the increase in the level of violence and sophistication involved in terrorist acts throughout the world and concurrent changes in perceptions of the ease or difficulty of exploiting illicit possession of SSNM, safeguards requirements have been increased. Thus, a safeguards posture is evolving from one designed to protect against limited terrorism and against internal acts by a single insider, to one that provides high levels of protection against dedicated armed assaults and acts of conspiracy involving insiders.

This incremental development of U.S. safeguards has made available a wide range of specific measures for protecting nuclear materials and facilities. Frequent changes, stemming from a widening range of materials needing protection and from changing concepts of materials control, have been made either generically or on a site-specific basis, as the situation requires, but always with the general objective of providing a level of protection that would insure against significant risk of injury, death, or property damage to the public. This sequence has led to a great variety of safeguards procedures, programs, techniques, and alternatives.

4.2.1 Regulatory Procedures

The primary safeguards procedures utilized by the NRC are licensing, inspection, and enforcement. They emphasize physical protection and material control both at fixed sites and during transportation.

4.2.1.1 Licensing

The NRC initiates licensing aspects of the safeguards process by establishing the minimum requirements that licensees must meet for handling and physically protecting SSNM. Before approving construction of facilities which will handle and store significant quantities of SSNM, the NRC examines the basic design of the plant to ensure that it includes adequate safeguards. After plant construction and before granting an operating license, the NRC examines the actual construction and planned operating procedures to assure that operations can be conducted in compliance with safeguards regulations. (Section 4.4.2.1 discusses the provisions of the security plan in some detail.)

To ensure that licensees attain the desired level of safeguards, the NRC requires that they assemble a configuration of technical hardware, procedures, and personnel which clearly meet specified requirements. Title 10 of the U.S. Code of Federal Regulations, Parts 70 and 73, contains the specific requirements for physical protection and accountability of SSNM.

Implementation of these regulations by licensees is aided by a set of Regulatory Guides that identify specific technical approaches which the Commission finds acceptable. (These approaches serve as examples of acceptable methods of compliance; licensees may, of course, find other ways of complying with the requirements.) In addition, specific license conditions are imposed to ensure that site-specific aspects of safeguards are adequately addressed. As of early 1977, 13 NRC-regulated nuclear fuel cycle licensees possessed significant quantities of SSNM. The total amounted to more than 20 metric tons, mostly high-enriched uranium.

4.2.1.2 Inspection

During operation of a licensed facility, NRC conducts onsite inspections to ensure that the protection plan is being implemented effectively. Each licensee must provide the inspectors an opportunity to inspect the nuclear materials and the facilities where they are handled. The licensee is required to maintain and test all systems and equipment to ensure their effectiveness. The licensee's procedures implementing this requirement are subject to inspection along with all records pertaining to his possession, use, and transfer of materials. This inspection strategy is based on systematic coverage with the scope, frequency, and intensity of inspection being determined primarily by the strategic value and the accessibility of the SSNM in question.

4.2.1.3 Enforcement

If deficiencies are found in the licensee's implementation of safeguards requirements, the licensee is instructed to take prompt corrective action and to report the results. Violators of the Atomic Energy Act or of any regulation or order issued thereunder may be guilty of a crime, and, upon conviction, may be punished by fine or imprisonment or both.

4.2.2 Alerts

As the recipient of available intelligence information, the NRC is prepared to evaluate this information and to initiate appropriate action in a timely manner.

4.2.3 Response to Emergencies

Existing procedures provide for response to abnormal presence, activity, or intrusion into certain areas of a licensee's plant. In addition, contingency planning is undertaken to deal with threats, thefts, and sabotage at licensee facilities. Both site-specific and national-level contingency plans now under development, and those which would be developed in support of a MOX fuel industry, rely heavily on the experience gained by those agencies which have participated in successfully guarding SSNM processed by the AEC, DOE (formerly ERDA), and DOD during the past three decades.

4.3 SAFEGUARDS PROGRAM ELEMENTS

4.3.1 General

In response to comments received on the draft GESMO, the NRC initiated a number of safeguards study efforts (known as the Special Safeguards Study) which reviewed available safeguards measures in some detail. This section summarizes the results of these and other related studies and provides a comprehensive review of nuclear industry safeguards techniques, equipment, and procedures currently available or technologically feasible.

Safeguards measures can be placed into one of the following categories, each of which is discussed in turn:

- Measures to provide physical security for SSNM at fixed sites
- Measures to provide physical security for SSNM in transit
- Material control measures
- Measures to aid in locating and recovering stolen SSNM
- Other measures.

4.3.2 Physical Security Measures at Fixed Sites

Measures which aid in providing physical security at fixed sites include physical barriers, intrusion alarm systems, access controls, containment mechanisms, internal surveillance systems, active delay devices, security and response forces, and onsite and offsite communication systems.

4.3.2.1 Physical Barriers and Alarm Systems

The initial level of protection against overt sabotage and theft can be provided by multiple barriers around protected areas, devices at and between barriers to detect actual or attempted intrusion, and an alarm system to alert the guard force to the location and severity of an intrusion.

Automatic intrusion alarm systems combined with remote assessment capability can effectively monitor external areas under most environmental conditions. Redundant detection and alarm systems, functioning in conjunction with roving guards, provide improved effectiveness. A number of sophisticated intrusion alarm systems are available on an off-the-shelf basis.

Fixed barriers of steel and concrete can delay unauthorized intrusion into material access and vital areas through the exterior walls of buildings. Designs are also available for barriers at emergency portals. Various types of barrier systems are already widely used and have demonstrated a generally benign impact on the environment.*

---

*A more extensive discussion of barriers and intrusion alarms appears in a Sandia report (Ref. 1, Vol. 3, pp. 139-226).

4.3.2.2 Access Controls and Admittance Systems

Elimination of the need for access to any sensitive materials or records is the ideal access control. Where this is not feasible, a system of limited access based on need must be established.

Control of access to computer programs and computer files is not unique to the commercial nuclear industry, and systems have been developed to prevent the unauthorized use of data files and alteration of computer programs. Automatic admittance systems and card keys may be used in conjunction with a system of passwords to identify and control access to sensitive data stored in computer systems.

Another technique for access control is the commonly used "buddy" system of surveillance whereby two or more persons are present whenever access to SSNM or vital equipment is granted. Surveillance of employees working with SSNM can also be maintained by indirect means such as closed-circuit television.

Vehicle access can be limited to essential traffic. Time-limited access into a protected area can be granted to visitors and service personnel, if there is screening to detect obvious contraband, and continuous escort and surveillance are provided. Longer access to a specific area can be granted after a detailed search, but it should be rescinded if the vehicle leaves the area. Procedures for screening cargo entry and departure are especially significant and must be given particular attention, since attempts at material diversion may involve cargo-carrying vehicles. Special attention must also be given to vehicle access control under emergency conditions, since incidents can be created to exploit such conditions.

Admittance systems work in concert with barrier and surveillance systems to limit facility access to authorized personnel only. A variety of such systems is available, and all require that identity be sufficiently established for an admittance decision to be made by site security personnel. The simplest and most common method is to display a picture identification badge to a guard. Variations of this approach include the use of remote viewing equipment to protect the guard, the use of stored images for comparison, and an exchange badge system which requires use of a special badge issued and worn only in a secure area and never removed from that area. Since admittance decisions are made by guards, a hazard in the use of badge systems is the possibility of collusion between guards and potential adversaries.

There are a number of automatic systems through which admittance is granted, based upon some unique aspect of personal identity such as fingerprints, signature dynamics, hand measurements, or voice identification. With these systems, the basis for the admittance decision is automatic and the potential for guard force collusion is substantially reduced. Currently available automatic systems, however, are expensive, may be susceptible to mechanical failure, have a fairly high error rate, and require longer pass-through times.

Machine-readable cards, commonly called card keys, can be useful as an admittance system and can serve other purposes such as time and attendance logging. However, card keys do not positively identify the bearer and are susceptible to defeat by an adversary who can obtain or fabricate an acceptable card.

A system which utilizes both card keys and ID picture badges provides a high level of effectiveness. Entry to secure areas is gained by use of a card key, reducing the possibility of guard collusion. The picture badge is then observed by a guard who verifies the authenticity of the badge and identity of its bearer. Such combined ID photograph/card key admission systems are used extensively in industrial and commercial establishments.*

4.3.2.3 Containment Mechanisms

Implicitly included in the containment control category are all the attributes of the industrial process which make difficult the removal of material from normal process streams. Some of these may be motivated primarily by health and safety requirements and only perform safeguarding function as a byproduct. Other measures may be specifically designed for safeguards purposes. Such measures include vaults and vault-type rooms and methods for the surveillance of people working with the material. The removal of SSNM by routine disposal paths is a special concern. Explicit containment controls can be provided for area-level entry and departure points, emergency exits, and the site perimeter entry and exit paths.

Relatively unsophisticated containment techniques include visual inspection of persons' packages, combined with hands-on search, and the use of change rooms and clothing exhanges, possibly combined with surveillance augmented by SSNM detection procedures. More sophisticated detection techniques are based on the use of X-rays or, more sophisticated still, gamma or neutron detecton.

4.3.2.4 Detection Systems**

Sensors capable of detecting concealed contraband items protect both against the introduction of weapons, explosives, or counterfeit SSNM into a nuclear facility and against the removal of concealed SSNM from the facility.

Detection of important quantities of proscribed material can be aided by a physical (hands-on) search conducted by security personnel. However, to search personnel by this method is time-consuming and expensive, and tends to be socially objectionable. Consequently, a variety of equipment has been developed with which to conduct searches in a more expeditious, cost-effective, and socially acceptable manner.

Commercially available metal detectors are quite effective in detecting weapons. They also detect some forms of SNM shielding and, under certain circumstances, will detect the metallic components of explosive devices.

X-ray inspection systems can be highly effective in detecting contraband concealed in packages or SNM concealed on or in the body. However, many factors discourage their use for

---

*For a more extensive discussion of admittance systems, see Ref. 1, Vol. 3, pp. 7-32.

**Some functions of detection systems also serve the purpose of material control and are consequently mentioned briefly in that section (4.3.4) as well as here.

personnel searches: e.g., the increased level of radiation to which such systems would expose the work force (about 25% over natural background per year if used on a routine basis), their high initial cost ($150-$200 thousand), and high maintenance costs. X-ray package inspection equipment, which produces no personal radiation hazards and costs only about $35,000 per unit, appears attractive and acceptable.

Most devices for detecting explosives have significant limitations. Even the most promising, the trace vapor analysis system, cannot detect all types of explosives with good sensitivity. Dogs are very useful in detecting concealed explosives and can also perform other security functions; but dogs are expensive to maintain, may be objectionable to the work force and, because of limited attention span, do not perform well in portal screening.

Currently available gamma detectors can detect unshielded SNM, but their effectiveness can be reduced if the material is shielded. The use of neutron detectors in combination with gamma detectors avoids this problem since the amount of shielding needed to avoid both neutron and gamma detection would be noticeably bulky.

Detection system performance is highly procedure-dependent. For example, use of change rooms and clothing exchange allows detection equipment to operate in a controlled environment free of substances which could interfere with its sensitivity. Thus, if company-provided coveralls are devoid of metal, the sensitivity of metal detectors is sufficient to detect very small amounts of metal.

Another procedure to enhance detection system performance is the random selection of personnel for hands-on search. This adds an element of uncertainty which can deter attempts to defeat other detection methods. Also, procedures whereby detection equipment is used to its maximum sensitivity (with a resultant increase in false alarms which must be resolved by hands-on search) force an adversary attempting to steal SSNM to make more frequent sorties through the system with smaller amounts, thus increasing the likelihood of apprehension during a hands-on search.*

The most effective procedure for screening vehicles is to prohibit offsite vehicles from entering a protected area. If a vehicle must enter, the personnel associated with it can be required to pass through the site detection systems while their vehicle is being carefully screened for contraband. Search effectiveness can be enhanced by the use of hand-held detectors, effective in locating explosives and SSNM, and by use of dogs. Escorting the vehicle while it is within the protected area is a feasible added precaution.**

4.3.2.5 Active Delaying Systems

Nonlethal active delaying materials and devices can substantially extend the time needed by an adversary to reach material access or vital areas. An unprepared adversary can be impeded by a markedly unfavorable condition, such as dense smoke which reduces visibility; unbearably

---

*Some worker objection to random searches can be expected. This question is treated in more detail in Chapter 7.

**Ref. 1, Vol. 3, pp. 33-102, presents a more extensive discussion of detection procedures.

loud noises which reduce or eliminate communications between adversaries; disorienting lights which reduce efficiency; heat or skin irritants which create discomfort and reduce effectiveness; and foams, extremely sticky substances, or slippery substances which limit movement.

Additional active delaying materials are nonlethal gases or chemical agents which tend either to immobilize the adversary or to reduce his effectiveness for a period of time. The effect of such systems would be temporary, but, even so, they should be considered for use only in certain normally unoccupied places such as vault storage areas where SSNM may be stored.

The current use by industry of active delay systems is practically nonexistent, and very little information is available on their actual effectiveness, cost, or societal acceptability.*

4.3.2.6 Fixed-Site Guard Forces

The element of a fixed-site safeguards program that is most effective in dealing with a malevolent act, whether by outsiders or insiders, is the guard force. The functions of the guard force include:

- Detection of unauthorized attempts to penetrate protective barriers and portals.
- Detection of procedural violations which might be associated with the theft of SSNM or with sabotage.
- Assessment of detected events to determine the nature of the threat and the appropriate response.
- Call for assistance from offsite forces as needed.
- Immediate response to adversary actions in order to prevent theft or sabotage.
- Prevention of successful attempts at diversion.

In addition to performing these functions, fixed-site guards also perform a variety of routine duties including access control, escort, recordkeeping, plant activities surveillance, communications, incident investigation, and accident control.

In the event of an attack, the responsibility of on-duty guards is to alert offsite response forces and to deploy immediately in order to secure and defend SSNM and predesignated vital areas of the facility. Other emergency measures, such as cordoning off the incident area, crowd or riot control, first aid, and pursuit and apprehension of adversaries, would be undertaken by secondary (offsite) response forces.

---

*Additional discussion of such systems is presented in Ref. 1, Vol. 3, pp. 227-50.

The number of guards required per shift varies with the circumstances at a specific facility, the availability of effective secondary response forces, and the response times needed for such forces to react.

To obtain well-qualified and highly motivated guards, guard compensation levels must be set significantly higher than the local average. For the purpose of this study, the 40-hour week rate is being calculated, in 1975 dollars, at $15,000 per guard per year, plus $7,500 for fringe benefits.*

4.3.2.7 Fixed-Site Communications

A variety of systems is available to provide rapid and continuous communication among onsite security force personnel and between onsite and offsite response forces. Offsite communications needs, for example, can be met by using telephones for routine communications and a radio link for emergency communications. Similarly, a radio communication system consisting of base stations, mobile radios, and hand-carried portable transceivers of good quality can meet onsite communications needs under most conditions.

Communications systems can be supplemented by a variety of signaling devices for notifying both onsite and offsite security personnel. These devices range from radio paging systems and two-way public address systems to klaxons, sirens, whistles, or pyrotechnic devices designed to alert all personnel to an emergency condition. Extensive precedents already exist for the use of such communications systems.**

4.3.2.8 Offsite Response Forces

In the event of an attack on a nuclear facility, the response force must react in a timely and effective manner. The first response would be provided by the tactical deployment of onsite guards to fixed defensive positions in order to secure and defend SSNM and predesignated vital areas of the plant.

Contingency plans provide for any necessary emergency support to the onsite guards. Depending upon the site, off-duty guards may serve as reserves to reinforce the primary response, and local law enforcement agencies (LLEA) may undertake secondary response functions, such as cordoning off an incident area, blocking escape routes, crowd control, first aid, and pursuit and apprehension of adversaries. In some areas, the FBI, police, special weapons and tactics teams, military units, the National Guard, and State or local civil defense units can also play a role in providing added response capability.

Use of LLEA forces is attractive since they are likely to be familiar with the specific installation and the surrounding area, and their experience in responding to local law enforcement problems should reduce any adverse societal impact of their activity. Aside from a

---

*A more detailed discussion of fixed-site guard forces appears in Ref. 1, Vol. 3, pp. 251-55. See also Ref. 2.

**For detailed treatment of fixed-site communication, see Ref. 1, Vol. 3, pp. 137-38.

possible subsidy for the cost of training, the added expense introduced is minimal. Accordingly, the NRC and DOE are currently sponsoring programs to increase reliance on LLEA's as off-site response forces, while proceeding on the basis that the safeguards system must delay attackers long enough for offsite response forces to be effective.

Detailed contingency planning is necessary to establish the primary and secondary response capability for each site. Training and frequent exercises are also needed to coordinate the operational procedures to be used by the various forces in the event of an overt attack or during other emergencies.*

4.3.3 Physical Security Measures for SSNM In Transit**

4.3.3.1 General

Present regulations, (see Section 4.4), permit transportation of SSNM by rail, water, road, and air. For domestic movement of SSNM, however, use of rail and water is generally limited. Although these modes have great weight-carrying capability, they do not provide ready access to all current and projected nuclear facilities. Road and air transport present broader potential utility for a future nuclear industry, and the focus of in-transit safeguards for the wide-scale use of MOX is anticipated to be on these modes. A reference safeguards system, described in Chapter 5, is based on the use of road transport; and one of the alternatives, discussed in Chapter 6, is the use of air transport for portions of the route.

Various measures are available for providing in-transit physical security. They include the use of secure, penetration-resistant transport vehicles, special material containers, armed escorts and convoys, in-transit communications, and thorough planning and control. A brief discussion of each of these measures follows.

4.3.3.2 Secure Transport Vehicles

Specially constructed penetration-resistant vehicles can reduce susceptibility to theft or sabotage. The objective is to provide a sufficient delay against attack to allow for arrival of response forces. Depending upon its specific design and the form of the SSNM, the vehicle itself could provide a delay of minutes to hours against an adversary action.

Currently available commercial road-transport vehicles offer only limited resistance to penetration by explosives. A study of transport vehicles specifically designed to withstand attempts at theft or sabotage suggests that an effective approach for the shipment of plutonium would be to combine the material containers and the transport vehicles into an Integrated Container Vehicle (ICV). (Designs for such vehicles are discussed in Ref. 1, Vol. 5, pp. 7-32.) The ICV concept offers improved penetration and crash resistance and is applicable not only to road transport but also to air, rail, and water transport. Section 3.4 describes the ICV concept in more detail. The discussion of current requirements for safeguarding SSNM in transit is given in Section 4.4.2.2.

---

*For more details on offsite response procedures, see Ref. 1, Vol. 3, pp. 251-66.

**Chapter 7 treats the possible environmental impact of armed convoys on the highways. Chapter 6 reviews alternatives which might reduce transportation requirements.

4.3.3.3 Special Material Containers

Both safety and safeguards needs must be considered when transporting SSNM. This dual concern is especially important in the design of containers for transporting materials of the mixed oxide fuel cycle. From a safety point of view, protection must be provided against radiation, heat generation, accidental dispersion, and the accumulation of critical quantities. From a safeguards viewpoint, both the penetration and theft of the container are to be prevented.

Currently utilized container designs generally emphasize the safety issues, relying on other measures to achieve safeguards objectives. Although add-on safeguarding features can be provided for existing container designs, they would not be as effective as a container initially designed with integral safeguarding characteristics. A review of container technology suggests that a variety of safeguards features can be built into SSNM containers to enhance their security. These range from tamper-proof features to aids in locating a stolen container.*

4.3.3.4 Escorts and Convoys

Road shipments are currently protected by the use of armed escort and convoy procedures. The specific functions of escorts and convoys are similar to those of fixed-site security forces: to deter, detect, or delay adversary attacks or, if necessary, to defeat them.

The number of escort vehicles and armed personnel in convoys transporting SSNM can vary depending upon the specific form of material being transported, the terrain and distance of the shipment, and the security level or hardness of the transport vehicle.

If a transport convoy is attacked, the escorts must either defeat the attackers or delay them at the attack site until a secondary response force can arrive. This requires that the escorting personnel be adequately deployed, equipped, and protected. Both the drivers and escort personnel must, therefore, be trained in defense procedures, and the escort vehicles must be appropriately armored and equipped with intraconvoy and external communications to alert each convoy element and local law enforcement unit.

Truck transport will probably continue to be the primary mode of SSNM movement. However, there may also be limited movement by rail, ship, or air. Although each of these other modes imposes unique safeguards requirements, escorts would still be utilized. The specific procedures used and the number of people involved will depend upon the specific circumstances (Ref. 1, Vol. 5, pp. 138-65).

4.3.3.5 In-Transit Communications

Effective in-transit communications are needed between the vehicles in a transit convoy. Such communications must also be maintained between the convoy and shipment control center to track the convoy's progress, to report attempted attacks or thefts, and to provide a means for reporting other problems and for requesting and coordinating appropriate aid.

---

*For a description of a possible Integrated Container Vehicle, see Section 3.4, and Ref. 1, Vol. 5, pp. 39-104.

Intraconvoy communications needs can be met by the use of good quality VHF mobile and portable radio transceivers. These are readily available from commercial sources. Communications between the convoy and the shipment control center are more difficult to establish because this may require a system which can provide fast and reliable communications on a nationwide basis. One currently operating system meeting these criteria is DOE SECOM II high frequency system (Refs. 3 and 4). Shared use of this system by DOE and NRC could meet short-term to mid-term needs. An alternative solution could be the development of a dedicated communication system to communicate directly with the local police along various routes. The practicality of satellite communications should also be considered (Ref. 1, Vol. 5, pp. 105-37).

4.3.3.6 Shipment Planning and Control

Procedures employed in safeguarding shipments require as much attention as the actual equipment and hardware employed. Selection of the most advantageous transportation mode, route, and schedule; command procedures; coordination with local government and law enforcement authorities along the route; documentation, receipt and reporting controls; and loading and unloading procedures all contribute to reducing the risk of intransit material theft or diversion.

In-transit procedures currently used in the commercial nuclear industry can be adapted to the MOX fuel cycle but it is anticipated that, as the volume and frequency of SSNM transportation increase, new and improved planning and control methods will also be developed and adopted.

4.3.3.7 Response to Attacks

In the event of an attack on an SSNM shipment, a neutralizing force must be brought to bear in a timely and effective manner. Convoy escorts must be capable of rendering immediate assistance. Should an SSNM transporter be immobilized by adversary action, escorts would establish defensive positions to protect the shipment. The objective of the primary response force would be to thwart the attack so as to prevent loss of control over SSNM, or to restore control in the event of an unauthorized intrusion into the secure vehicle. (To reduce the likelihood of such encounters on the highways, deterrent and defense techniques, such as hardening transport vehicles, and reducing transportation needs, are under consideration.)

For each convoy operation, contingency plans can be made for providing emergency support to the escort forces. Local law enforcement agencies and, in some cases, off-duty guards can be enlisted for response functions, with duties and advantages similar to those discussed above in Section 4.3.2.7.

The availability of secondary response forces will vary considerably between shipment routes. Detailed contingency planning and coordination are required to establish and develop the capability of local law enforcement and other agencies to provide emergency support to convoy security forces. Frequent training exercises need also be employed to perfect the operational procedures which would be used during an actual incident (Ref. 1, Vol. 5, pp. 166-89).

4.3.4 Material Control and Accounting

Material control is that part of the safeguards program encompassing management and process controls to assign and exercise responsibility for nuclear material; maintain vigilance over the material; govern its internal movement, location, and utilization; monitor the inventory status of all material and assessment for all material. The material accounting part encompasses the procedures and systems to perform nuclear material measurements; maintain records; provide input; and perform data analysis to account for nuclear material.

Measures which aid in providing material control include management control, custodial control, inventory control, and accounting.

4.3.4.1 Management Control

A vital feature of any material control system is the organizational structure employed to manage it. Overall responsibility for material control functions of a licensee must be assigned to an individual at an organization level high enough to provide independence of action and objectivity of decisions. An organizational plan must specify the functional responsibilities of each individual or organizational unit of the material control system. A fundamental criterion is that the organizational structure provide a separation of the custodial, measurement, accounting and audit functions for SSNM such that the activities of an organizational unit or individual having responsibility for one of these functions will serve as a control and/or a check of the activities of those responsible for other functions. This clear division of functional components provides protection against loss of material through collusion or poor judgment and helps guarantee the integrity of both material control and material accounting records over the many steps involved in their preparation.

A key measure for providing assurance concerning the material control system is audits. The audit is an independent check of the entire material control system to provide information concerning the soundness, adequacy, and actual application of material controls. The extent of compliance with procedures should be evaluated and the quality of performance in carrying out the material control system procedures should be determined. The reliability of data and information within the control system should be evaluated. A record of the response of management to audit recommendations should also be kept.

4.3.4.2 Custodial Control

Custodial control measures are those designed to ensure that nuclear material is only stored in authorized locations and used in authorized processes. They are procedures to confine SNM to authorized locations and uses, assignment of responsibility, and vigilance over material. Each of these measures, which place great responsibilities on individual employees, must have strong built-in checks and balances, such as a reliable overlapping system of records of the transfer of material between controlled areas.

The custodial control measure of confinement to authorized locations and uses provides the procedures and checks to ensure that when material is moved, put into or taken out of process, it is under proper control in the appropriate place at the appropriate time. Assignment of responsibility is provided by a set of procedures designed to assure effective stewardship over material by assigning authority and responsibility for the custody of material to specific individuals.

Close vigilance over material is necessary to ensure that material is handled and moved in accordance with approved production and safeguards procedures on a continuing basis. Vigilance over material means those practices designed to detect variances from normal material handling operations and protective practices that may constitute early warning signals or alarms of surreptitious behavior. Close vigilance over operations also serves to identify conditions that may require changes in material control procedures. This feedback, if properly handled, enables the material control system to adjust efficiently to changing processing conditions.

4.3.4.3 Inventory Control

The inventory control measures of the material control system incorporate procedures to monitor the processing and transfer of material, to analyze process data, and to ensure that material (being used in an authorized process or stored in an authorized location) is handled in an authorized manner. These measures of control consist of process monitoring, which requires a material measurement and quality control program; the analysis of data obtained in process monitoring; and controls over the use of items and containers. Inventory control elements, like custodial control elements, require a built-in system of checks and balances to ensure that the work of one individual or organizational unit serves as a control over the activities of others. Inventory control elements can serve as sources of alarm arising from the material control system.

Process Monitoring can provide a key element of material control. In this context, process monitoring is the set of measurement and data analysis procedures designed to detect process abnormalities, to monitor production and control its quality, and to assess inventory status. Loss of process control, as indicated through process monitoring, may indicate a production problem, or a diminished level of, or a complete loss of, material control. Process monitoring can contribute significantly to the control of special nuclear material in addition to providing production control information.

In order for process monitoring to be effective, movement of material into, out of, or within the process must be conducted on the basis of measured transfers, i.e., measured quantities. The process monitoring aspect of the material control system can be structured to take advantage of the measurements already made for quality control and product control.

In order for process measurement results to be meaningful, it is necessary to have a quality control program specifically for process measurement systems. A process measurement quality control program encompasses those operations and procedures designed to ensure the calibration of process measurement systems and a continuous high quality of measurement performance. Such a program includes not only the initial calibration of the measurement system against appropriate standards and the establishment of measurement uncertainties, but also appropriate monitoring of the measurement system to ensure continued calibration accuracy and controlled measurement uncertainties. A process measurement quality control program can include those procedures and records useful in determing alarm criteria.

Another element of the inventory control aspect of material control is data analysis. Data analysis is that set of procedures by which the measurement and statistical data generated during process monitoring, production control, and quality control operations are examined to determine whether the process control system is operating properly. Use of such data analysis by the material control system can contribute substantially to safeguards. This material control element can form a basis for alarm assessment, issuance of reports on the status of material at a facility and for detection of irregularities which may indicate theft or diversion. The data analysis may also provide early warning alarms of the deterioration of the material control system.

The inventory control aspect of the material control system is relevant to items and containers as well as bulk materials. However, in the case of items and containers, material controls are simply controls over their location and use, and they comprise those procedures designed to keep track of the identity, quantity, and location of the units as well as checks to assure their integrity. Material control procedures may be implemented through methods for uniquely identifying such units; the use of perpetual inventory records to document the identity, quantity, and location of the units; and frequent checks to validate the information and to assure unit integrity.

4.3.4.4 Accounting Systems

Material accounting assists in deterring or detecting theft or diversion by providing information on the status and amount of SSNM. In the event of theft or diversion, it aids in assessing the extent of loss, the place where the loss occurred, and the form and composition of the missing material. This results in a capability to narrow the search.

Material accounting includes recording the receipt, internal transfer, discard, location, and shipment of SNM and conducting of periodic physical inventories. The key measure employed in accounting control at the present time is the difference between the book inventory (the amount of material that is supposed to be present according to the accounting records) and the physical inventory (the amount of material that is actually found to be present). Since all physical measurements are subject to some error, differences between the two occur. In assessing the significance of an inventory difference, it is necessary to consider the measurement uncertainties involved. These are estimated by statistical methods and, by regulation, may not exceed certain limits. Inventory discrepancies within these limited measurement uncertainties are accepted, but if a significant inventory discrepancy is observed, a reinventory is generally undertaken to confirm the apparent discrepancy.

Accounting source data are usually checked by accounting clerks or computer edits. In addition, independent audits of material accounting records and material control and accounting procedures are performed annually by individuals whose normal responsibilities are independent of the functions being audited.

Significant improvement in measurement capability has been achieved as a result of the extensive research conducted during the last twenty years. It is now possible to measure the major flows of SNM and most inventory items in the existing fuel cycle. Difficulty persists, however, in the accurate measurement of dissolver solution at reprocessing plants, and of scrap, waste, and material located in processing equipment at the time of physical inventory. Additional research is now being performed to develop improved measurement methods for such trapped material and to raise the accuracy of existing methods, especially nondestructive assay techniques.

Material balance closures are performed at intervals specified by regulations, presently two months or six months. To meet any need for more frequent accounting, the development of rapid systems of accounting and improved methods for monitoring inventory status are being pursued in research programs. Such systems are already operating in high throughput plants in non-nuclear industries.*

4.3.5 Recovery of Stolen SSNM

A prime objective of any safeguards program is, of course, to prevent the actual or apparent theft of SSNM. It is, nevertheless, appropriate to provide for the contingency that an attempt may be successful, and to have in readiness measures for locating and recovering stolen SSNM.

Should SSNM be stolen or diverted from either a fixed site or during shipment, a specially trained and equipped force will be called into action to locate and recover the material. The force would operate under a contingency plan into which appropriate roles for law enforcement and other investigatory agencies have been factored. The operation relies to a considerable extent on the expertise and organizational structure developed under the DOE/DOD weapons program. The FBI investigates all incidents, including nuclear threats, which involve actual or suspected violations of Federal law. It also has primary Federal jurisdiction and responsibility for coordinating and directing Federal operations, including operations for the recovery of SSNM, in the event of hostile actions against commercially produced nuclear material or commercial nuclear facilities. DOE supports the FBI by providing Nuclear Emergency Search Teams (NEST's) to locate and identify radiation-producing materials. DOE also provides teams to support work on ordnance disposal. As appropriate, DOD explosive ordnance dispersal teams will work with DOE experts in locating and disarming explosive ordnance, including nuclear devices.

DOE maintains an emergency plan for its NEST's which is regularly exercised. Numerous DOE laboratory personnel, industrial personnel, and technical specialists are available to support the NEST activity. A wide variety of ground and airborne detection equipment, logistic and communication support, and Federal and local law enforcement personnel also aid the effort. Moreover, since time is a vital factor (the search area increases with time) the recovery procedures are designed to begin as soon as possible after the initial alarm.

Technological developments are continuously improving this location and recovery capability. For example, electronic locators have a range and precision capability many orders of magnitude

---

*For a comprehensive review of advanced accounting systems and research in progress, see Refs. 5-13.

greater than radiation detectors, and introduction of electronic signal generators into shipping containers could significantly aid the location process.*

4.3.6 Other Measures

4.3.6.1 Personnel Screening

Some employees in the licensed sector of the nuclear industry might have the opportunity to attempt theft or sabotage or to assist others in such acts. Accordingly, an assessment of the character, reliability, and emotional stability of these industry employees could contribute to the safeguarding process.

The Congress has granted the NRC specific authority to establish a personnel clearance program for individuals in the commercial sector who work in activities involving significant quantities of SNM. The NRC is in the process of establishing clearance requirements for certain key individuals such as security and security management personnel in fuel cycle facilities, and some operating personnel with access to, or control over, SNM.**

A testing program to assure the continuing reliability and emotional stability of individuals in sensitive positions (similar, perhaps, to the Personnel Assurance Program used by DOE in its weapons-related "criteria duties assessment") may also be appropriate. Methods used for reliability testing vary widely. In determining which, if any, are to be used by the licensed sector of the nuclear industry, the anticipated benefits must be carefully weighed against the associated impact on the civil liberties of the affected individual employees.***

4.3.6.2 Collocation

Collocating (locating on the same site) plants performing successive steps in the nuclear fuel cycle is frequently suggested as a safeguards measure. Any step in the fuel cycle that can be eliminated is one less step to safeguard. Similarly, any step which can be simplified or reduced in magnitude is likely to be easier and less costly to safeguard. Collocation, by eliminating some transportation links, might thus be expected to produce some safeguards benefits.

Analysis in the Nuclear Energy Center Site Survey (Part IV, Chapter 7, Ref. 14) of possible plant groupings indicates that either the collocation of reprocessing and fabrication facilities or the use of "combined centers" (sites containing from 10 to 40 reactors plus the reprocessing and fabrication facilities to support them) might indeed offer safeguards advantages. As compared to a dispersed siting plan, either of these alternatives would significantly reduce shipments of plutonium oxide. In addition, the combined center would virtually eliminate the offsite transport of fresh mixed oxide fuel. (Section 6.5 of this report discusses collocation in greater detail.)

---

*For more details on recovery, see Section 4.2 and Ref. 1, Vol. 6, pp. 7-60. For specific information on active electronic locators, see Ref. 1, Vol. 6, pp. 39-40.

**Federal Register 42, No. 52, March 17, 1977, pp. 14880 to 83.

***For possible societal impacts of personnel screening, see Chapter 7.

4.3.6.3 Modification of SSNM (Spiking)

Modification of SSNM by addition of selected materials has been proposed as a means for improving safeguards. Such modification could make SSNM detection easier, both in the plant and during recovery efforts offsite following theft or diversion; make it more hazardous for a thief to handle SSNM; and make the SSNM less suitable for weapons use. It is technically feasible either to "spike" (modify) SSNM with lethal or disabling levels of radioactivity or to mechanically attach high-intensity radioactive sources to shielded fuel assemblies, shipping containers, or storage containers.* Either approach would assure that adversaries would be unable to utilize the material, even if they were successful in obtaining it, unless they had elaborate materials-handling and shielding facilities.

From the standpoints of radiation output, ease of manufacture, and ability to disable an aggressor before he could penetrate the containers and gain access to the material, only ^{60}Co appears suitable as a "spikant" (spiking agent) (Ref. 15). To enhance detection capability, such agents as ^{252}Cf and ^{244}Cm seem most effective.

While modification of SSNM has the potential advantages indicated above, it would add significant financial costs and personnel hazards in the commercial handling of the material. For example, the cost that would stem from adding ^{60}Co spikant in the PuO_2 at the reprocessing plant is estimated to be comparable to the total cost for the reference safeguards system described in Chapter 5. Workers in plants handling spiked fuel would receive significantly higher radiation exposures than those working with unspiked fuel, and the hazards from accidents or sabotage would also be significantly greater. It should be noted also that use of spikants in the disabling (and potentially lethal) quantities necessary to prevent theft could raise difficult legal problems since the potential exists to summarily execute a person before he has been tried and convicted of a crime.

Adding a spikant in less than disabling amounts would be less hazardous and less expensive, and would serve the purpose of making the SSNM easier to detect within a facility or in offsite recovery operations. This measure would not prevent a forceful theft of material, would be expensive, and would have the same type of hazards as disabling levels of spiking, though to a lesser degree.

On the basis of the considerations noted above, and supported by in-depth studies such as Ref. 15, the NRC staff has concluded that, while spiking is technically feasible, other measures, such as increased guard forces or redundant detection devices, could provide improved safeguards benefits with markedly less potential for societal impact.

4.3.6.4 Blending

Another material modification alternative which has received consideration is the blending of plutonium oxide with uranium oxide at the fuel reprocessing plant. With such blending, the necessity for transportation or storage of pure plutonium compounds anywhere in the mixed

---

*Attaching a radioactive source, such as ^{60}Co, to containers of PuO_2 or MOX, during shipping and storage, would be less costly than mixing the spikant into the material. Estimated costs for a mature MOX industry in the year 2000 are approximately $130 million per year to attach such a source to containers of all forms of plutonium, or $28 million per year to attach it only to containers of PuO_2.

oxide fuel cycle could be avoided, the amount of material to be acquired to fabricate an illicit explosive weapon increased, and a need for separation of the plutonium oxide from the uranium oxide introduced. Several variations of this dilution or blending approach have been studied and appear feasible. The economic impact, which could be significant for certain blending options, would result from the design changes required for the spent fuel reprocessing and fuel fabrication plants. A detailed discussion of blending is presented in Chapter 6.

4.3.7 General Observations

The preceding paragraphs all represent currently feasible approaches to nuclear safeguards. Some further extensions of safeguards technology are under study, and some of them will doubtless develop into cost-effective substitutes for the items discussed above long before wide-scale use of MOX fuel could become a reality. Accordingly, the deliberate selection of only proven technology is probably a conservative procedure which tends to overstate the cost of safeguarding a future MOX industry.

Past regulatory practice has been to specify the components and procedures which must be included in a specific safeguards system, and that approach was used in developing the "Current Safeguards" system described in Section 4.4. However, regulatory philosophy is under reexamination, and future safeguards requirements may stress performance capabilities rather than specific safeguards elements. In either case, future safeguards requirements must be carefully scrutinized to ensure that they are thoroughly compatible with existing safety requirements.

4.4 CURRENT SAFEGUARDS

Section 4.3 describes procedures and techniques currently available for SNM safeguards. This section examines how such concepts and program elements have been combined to produce the system currently in being. The discussion includes a brief review of the legal basis for current safeguards, and consideration of current requirements, implementation, and contingency planning.*

4.4.1 Legal Basis

NRC responsibility for safeguards derives from the Atomic Energy Act of 1954, as amended; and from the Energy Reorganization Act of 1974, which provides that "all licensing and related regulatory functions of the Atomic Energy Commission" be transferred to the NRC. The Atomic Energy Act explicitly authorized the AEC to set standards and impose regulatory controls over nuclear materials in order to "promote the common defense and security or to protect health or to minimize danger to life or property."**

The essentials of the safeguards system formulated by the AEC and now administered by the NRC are presented in regulatory requirements. Supplementary information appears in various Regulatory Guides issued to assist applicants in complying with these regulations.

---

*Ref. 16 discusses current safeguards at 15 licensed facilities and makes certain recommendations for improvement.

**42 U.S.C. § 2201(b).

4.4.2 Current Requirements For Safeguarding SSNM*

4.4.2.1 Physical Protection of Fuel Cycle Facilities

Each fuel cycle facility licensee authorized under NRC regulations to possess or use at any site, or contiguous site subject to control by the licensee, any of the following: ^{235}U contained in uranium enriched to 20 percent or more in the ^{235}U isotope, ^{233}U, or plutonium, or any combination of such materials in a quantity of 5,000 grams or more computed by the formula, grams = (grams contained ^{235}U) + 2.5 (grams ^{233}U + grams plutonium) must comply with established physical protection requirements. A physical protection plan must be submitted to the NRC for approval, and must demonstrate how the licensee will satisfy the regulatory requirements.

The licensee must maintain a physical security organization, including armed guards, to protect his facility against industrial sabotage and the special nuclear material in his possession against theft. All guards or watchmen must be properly trained, equipped, and qualified, and they must be requalified at least annually.

All "vital equipment" (which is defined as any equipment, system, device, or material whose failure, destruction, or release could directly or indirectly endanger public health and safety) must be located within a separate structure or barrier designated as a "vital area." All vital areas and material access areas must be located within a larger protected area which is surrounded by a physical barrier. An isolation zone is required around the outer physical barrier. It must be kept clear of obstructions, illuminated, and monitored to detect the presence of individuals or vehicles attempting to gain entry to the protected area, and it must allow response by armed members of the facility security organization to suspicious activity or to the breaching of any physical barrier. SNM not in process must be stored in a vault or in a vault-type room equipped with an intrusion alarm.

Personnel and vehicle access into a protected area,** material access area,** or vital area** must be controlled. A picture badge identification system must be used, and visitors must be registered and escorted. Individuals and packages entering the protected area must be searched. Admittance to a vital area or material access area must be controlled, and access must be limited to those persons who require such access to perform their duties. Methods to observe individuals within a material access area, in order to assure that special nuclear material is not being diverted, must be provided and used on a continuing basis. All individuals, packages, or vehicles must be searched for concealed nuclear material before exiting from a material access area. Keys, locks, combinations, and related equipment must be controlled so they will not be compromised.

Intrusion alarms must be in operation on all emergency exits in the protected area, vital areas, and material access areas. Each unoccupied material access area must be locked and alarmed. All alarms must annunciate in a continuously manned central alarm station located within the protected area and in at least one other manned station.

---

*As found in 10 CFR Parts 70 and 73, supplemented by specific license conditions.

**For definitions of protected area, material access area and vital area, see Section 3.2.5, above.

Each guard or watchman on duty must be capable of maintaining continuous communications with an individual in a continuously manned central alarm station within the protected area, who must be capable of calling for assistance from other guards and from local law enforcement agencies. To provide the capability of continuous communication with local law enforcement agencies, two-way radio voice communications must be available in addition to conventional telephone service.

Licensees must establish liaison with local law enforcement agencies, and must have a response capability to neutralize threats to the facility by appropriate direct action and by calling for assistance from local law enforcement agencies.

Security records must be maintained of all individuals authorized to have access to vital and material access areas, including visitors, vendors, and others not employed by the licensee. Routine security tours, and all of the tests, inspections, and maintenance on security-related equipment and structures must be documented. A record must be maintained on each alarm, false alarm, alarm check, intrusion indication, or other security incident, and the record must include details of the response by facility guards.

Immediate reports to NRC must be made regarding all suspected thefts, unlawful diversions, and/or industrial sabotage. A detailed written report must follow within 15 days.

4.4.2.2 Physical Protection of SSNM In Transit

Each licensee who transports SSNM or who delivers SSNM to a carrier for transport must submit a plan to NRC for review and approval, outlining the methods to be used for the protection of the material while in transit.*

General requirements are as follows: If a common or contract carrier is used, the SSNM must be transported under established procedures which provide a system for the physical protection of valuable material in transit and require a hand-to-hand receipt at origin and destination and at all points enroute where there is a transfer of custody. Transit times of all shipments must be minimized, and routes selected to avoid areas of natural disaster or civil disorder. SSNM must be shipped in containers with tamper-indicating seals. The outer container or vehicle must be locked and sealed. No container weighing 500 pounds or less may be shipped by open vehicles such as open trucks or railway flatcars.

All shipments by road must be made without any scheduled intermediate stops. All motor vehicles must be equipped with a radiotelephone. Calls to the licensee or his agent must be made at predetermined intervals, normally not to exceed two hours and, if calls are not received when planned, the licensee or his agent must immediately notify an appropriate law enforcement authority and the NRC. Shipments by road must be accompanied by at least two armed guards in a separate escort vehicle, positioned so that a single act cannot disable both vehicles. The shipment and escort vehicles must have intervehicle communication, as well as a continuous capability for sounding an alert by radiotransmission.

---

*10 CFR Part 73, supplemented by specific license conditions.

Air shipments of special nuclear material in quantities exceeding (a) 20 grams or 20 curies, whichever is less, of plutonium or ^{233}U, or (b) 350 grams of ^{235}U (contained in uranium enriched to 20 percent or more in the ^{235}U isotope) are prohibited on passenger aircraft. Shipments on cargo aircraft must be arranged so as to minimize the number of scheduled transfers. Such transfers, when necessary, must be monitored by armed guards. Export shipments must be accompanied by an unarmed designated individual, who may be a member of the crew (10 CFR 73.32).

Rail shipments must be escorted by two armed guards in the shipment car or in an escort car. Continuous on-board radiotelephone communications capability must be provided, with conventional telephone backup. Periodic calls to the licensee or his agent are required at the same time intervals as for road shipments.

Sea shipments must be made on vessels which make a minimum number of ports of call. Transfer at domestic ports from other modes of transportation must be monitored by a guard. Shipments must be placed in a secure compartment which is locked and sealed. Export shipments must be escorted by an authorized individual, who may be a crew member, from the last port in the U.S. until they are unloaded and delivered to the consignee in a foreign port. Ship-to-shore communications must be made every 24 hours to relay position information and the status of the shipment as determined by daily inspections.

A licensee who makes a shipment must notify the consignee of the shipment schedule and details, including its estimated time of arrival. In addition, the licensee must notify the NRC Regional Office of the shipment seven days in advance of shipment. A licensee who receives a shipment must immediately notify the shipper. Shipments which fail to arrive at the destination on time must be traced. Unaccounted for shipments must be reported immediately to NRC, followed by a detailed written report within 15 days. For any series of shipments of special nuclear material by a licensee to the same consignee in which individual shipments are less than the quantities requiring physical protection in transit under 10 CFR 73.30, but more than 200 grams computed by the formula, grams = (grams contained ^{235}U) + 2.5 (grams ^{233}U + grams plutonium), the licensee must confirm and log the arrival at the final destination of each shipment in the series before releasing the subsequent shipment from his control.

4.4.2.3 Material Control & Accounting

Each person who is licensed or applies for a license to possess at any one time and location more than 1 effective kilogram* of SNM in unsealed form must comply with detailed material control requirements, as stipulated in his fundamental nuclear material control plan, which he must submit to NRC for approval.** The plan must demonstrate compliance with requirements

---

*"Effective kilograms" of special nuclear material are:

- for plutonium and ^{233}U--their weight in kilograms:
- for uranium with an enrichment in the isotope ^{235}U of 0.01 (1 percent) and above--its element weight in kilograms, multiplied by the square of its enrichment expressed as a decimal-weight fraction, and
- for uranium with an enrichment in the isotope ^{233}U below 0.01--its element weight in kilograms multiplied by 0.0001.

**10 CFR Part 70.

relating to facility organization, facility operation, measurement and statistical controls, inventories, storage and internal control, shipping and receiving, and management of the material control and accounting system. These requirements are summarized below.

Facility Organization and Operation. Responsibility for material control functions must be assigned to a single individual at an organizational level sufficient to provide independence of action. The SSNM custodial, measurement, accounting, and audit functions must be separated in a manner which assures that the activities of an organizational unit or individual performing one function serve as control over, and a check on, the activities of organizational units or individuals performing a different function.

A manual of approved material control procedures must be maintained and reflected in the facility process specifications, manufacturing instructions, and standard operating procedures. A formal program for the training and periodic requalification of personnel assigned to material control and accounting functions must be developed and documented.

Material Balance Areas (MBA's) or Item Control Areas (ICA's) must be established for physical and administrative control of nuclear material. The custody of all nuclear material within any MBA or ICA must be the responsibility of a single individual. Each MBA must be an identifiable physical area such that material assigned to a given area is kept separate from material assigned to any other area, and such that the quantity of nuclear material moved into or out of an MBA is represented by a measured value.

ICA's may be established according to the same criteria as those used for MBA's, except that material must be inventoried and moved into or out of ICA's by item identity and count. The validity of previously measured quantities of SNM must be assured by the application of tamper-indicating seals or devices to each item or container. The number of ICA's and MBA's established at a plant must be sufficient to localize nuclear material inventory discrepancies.

Measurement and Statistical Controls. The licensee must determine by measurement the nuclear material content of all receipts, shipments, discards, and material in inventory. He must identify the various measurements that are used in nuclear material control, and must describe the measurement methods and procedures, stating the measurement uncertainties. Error models, including the basic statistical methodology and techniques, must be provided to demonstrate the licensee's capability to meet adequate measurement criteria.

A system of control must be established and maintained that will assure that measurement uncertainties during any material balance period do not exceed specified limits.

Inventories. Physical inventories of SSNM must be conducted every two months, except in the case of material that is in the inaccessible portion of a plant. Inaccessible SSNM and uranium enriched less than 20 percent in the isotope ^{235}U must be inventoried every six months. (Licensees authorized to possess less than one effective kilogram, but more than 350 grams of SNM, must conduct annual physical inventories.)

A principal measure of SSNM control is the magnitude of inventory differences. This measure is a calculated value which represents the difference between the amount of material that is supposed to be present according to the accounting records (taking into account measured receipts, transfers, and discards) and the amount of material actually found to be present during a physical inventory. The probability that no inventory difference will exist is very small, since the measurements required to establish the amount of material present are subject to error. A knowledge of the magnitude of these measurement errors is necessary for the proper interpretation of an inventory difference.

The NRC has proposed new guidelines to assure that corrective action will be taken when the amount of inventory difference reaches NRC's allowable limits. Under the regulation published for public comment on July 17, 1975, absolute limits are specified for inventory differences. More significantly, the new regulation would require that when such limits are exceeded the licensee would have to take specific action such as immediate reinventory, investigation of excessive differences or adoption of new procedures to prevent recurrence. In some cases of reinventory, it might be necessary to shut down the plant.*

Storage and Internal Control. A documented system of control over the SSNM within a facility must be maintained and all transfers of material between MBA's and ICA's must be documented and validated. Storage and internal handling controls must be established, maintained, and followed to provide timely information on the identity, quantity, and location of all SSNM within a plant in discrete items or containers. A unique item identification system must be established to ensure that no two items can have the same number. Records must be maintained which show the identity, source, and disposition of all items.

A program must be developed and implemented for the control, processing, and disposition of scrap since uncertainty of scrap measurements, if large, could be used to mask theft. No item of scrap with an SNM content that is measured with an uncertainty greater than ± 10 percent is permitted to remain in inventory longer than six months when such scrap contains SSNM.

Shipping and Receiving. As a rule, shipments and receipts must be independently measured by both the shipper and receiver. Shipper/receiver differences must be reviewed and evaluted, and appropriate investigation must be made of statistically significant differences to decide whether corrective action is necessary, or more important, whether diversion or theft has occurred. The detection of missing material and, in turn, the discovery of diversion or theft must be timely.

Audits. Annual audits are required under the material control program. The results of these audits must be documented, reported to appropriate plant management, and kept available at the facility for inspection. Losses of discrete items or containers must be investigated and the results of the investigation reported to licensee management and to the NRC.

---

*Federal Register, Vol. 40, July 17, 1975, p. 30133.

4.4.3 Implementation of Safeguards Requirements

4.4.3.1 Licensing Activities

Title 10 of the Code of Federal Regulations (10 CFR Part 70) provides that, with certain limited exceptions, no person may receive title to, own, acquire, deliver, receive, possess, use, transport, import, or export SNM without a license. On the basis of this provision, the NRC carries out the following activities: (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. In accordance with 10 CFR Part 2, the details of licensee safeguards plans are withheld from public disclosure.

4.4.3.2 Inspection and Enforcement

The licensee must afford the NRC the opportunity, at all reasonable times, to inspect SNM and the premises and facilities where SNM is used, produced, or stored; and to review the procedures for, and observe, the offsite movement of SNM. In addition, each licensee must make available for inspection any relevant records and must perform, or permit the NRC to perform, any tests deemed necessary for the administration of the NRC regulations.

Following each safeguards inspection, a letter setting forth the inspection findings is prepared and sent to the licensee. Where items of noncompliance or deficiencies are found, licensees are directed to take prompt corrective action and to inform the NRC of the results. In addition, the NRC can take one or more of the following steps: assess a civil penalty, suspend the license, revoke the license, or modify the license.

4.4.3.3 Physical Protection Contingencies

In the event of unusual activity which appears to threaten the security of the facility, a licensee must inform the NRC promptly and would normally also inform local law enforcement agencies. Onsite guard forces would respond immediately. The extent to which local law enforcement agencies would reinforce the onsite guards would depend on the perceived size and nature of any threat to the facility.

4.4.4 Experience in Safeguarding SSNM

During the past 30 years the AEC and ERDA (now DOE) have handled large quantities of plutonium and high-enriched uranium in forms considerably more suitable for construction of nuclear explosives than would be the reactor grade plutonium involved in a MOX fuel industry.* In the process they have developed and implemented a complex safeguards program. (For detailed description of DOE's current system, see Refs. 17 and 18.)

The reference safeguards system described in this report builds on the AEC/ERDA/DOE experience. Future safeguards for a mature MOX industry would continue to benefit from ERDA (DOE) experience in safeguarding SSNM and from planned safeguards research such as that described in the DOE "Master Plan" (Ref. 19).

---

*See Section 3-2 for a brief discussion of the different types of plutonium.

CHAPTER 4

REFERENCES

1. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle (U)"

   Vol. III--"Elements of Physical Protection for Fixed-Sites (U)" (Secret)**
   Vol. V --"Elements of Physical Protection for Transportation (U)" (Secret)**
   Vol. VI --"Relocation and Recovery(U)" (Secret)**

   SAND-75-0457, March 1976.

2. U.S. Nuclear Regulatory Commission, "Security Agency Study: Report to the Congress on the Need for, and the Feasibility of, Establishing a Security Agency within the Office of Nuclear Material Safety and Safeguards," (NUREG-0015), August 1976.*

3. Sandia Laboratories, "System Description for SECOM II - ERDA Digital Security Communications System," April 1975. (Confidential)†††

4. J. M. Montmollin, Sandia Laboratories, "Communications for Safeguarding Cargo," SLA-73-0822, September 1973.[b]

5. Science Applications, Incorporated, "An Evaluation of Real-Time Material Control and Accountability in a Model MO_2 Fuel Plant," SAI-75-648-LJ, September 1975.[b] (Section 4, pp. 127-147, "Evaluation of Prompt Theft Indicators," Confidential, has been deleted.)

6. Lawrence Livermore Laboratory and Science Applications, Inc., "Executive Summary of the Special Safeguards Study on Material Control and Accounting Systems," Final Report, September 1975.[b]

7. U.S. Nuclear Regulatory Commission, "RETIMAC--A Real-Time Material Control Concept for Strategic Special Nuclear Material," Working Paper B, January 1975.**

8. Thomas E. Shea, "Instrumentation for Real-Time Materials Control," IEEE Transactions on Nuclear Science NS-22, No. 1, 752-58 (February 1975).***

9. Thomas E. Shea, "RETIMAC - A Real Time Material Control Concept for Strategic Special Nuclear Material," Proceedings, Institute of Nuclear Materials Management, Inc. IV, No. III, 376-85 (Fall 1975).***

10. Thomas E. Shea, "A Real Time Material Control Concept for Safeguarding Special Nuclear Material in U.S. Licensed Processing Facilities," SM 201/7, paper, International Atomic Energy Agency Meeting, Vienna, Austria, October 1975. (Proceedings to be published.)[b]

11. G. R. Keepin (Ed.) "Los Alamos Scientific Laboratory, Development and Implementation of Dynamic Materials Control," LA-UR-75-1004, 1975.[b]

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA. 22161.

**Unclassified versions of the classified references and copies of the unclassified reference are available in NRC PDR for inspection and copying, for a fee.

***Available in public technical libraries.

†††This document is not publicly available because it contains national security information.

[b] Available in Source File for USNRC Report NUREG-0414, May 1978.

REFERENCES (Cond't.)

12. Los Alamos Scientific Laboratory, "Dynamic Materials Control--A Balanced Approach to Nuclear Safeguards," United States Atomic Energy Commission Contract W-7405-ENG-36, undated.[b]

13. E. F. Gambill, "New Emphasis on Material Accountability's Role in Special Nuclear Materials Security," Y-DJ-17186, Preprint for submission to Institute of Nuclear Materials Management, New Orleans, Louisiana, June 18-20, 1975; prepared for the U.S. Nuclear Regulatory Commission under Contract W-7405-ENG-26.[b]

14. U.S. Nuclear Regulatory Commission, "Nuclear Energy Center Site Survey - 1975" (NECSS-75) (NUREG-0001), 5 vols. Part I of Vol V, January 1976.*

15. Theodore B. Taylor and William J. Reinhardt, National Research and Technology Corporation, "Modification of Strategic Special Nuclear Materials to Deter Their Theft or Unauthorized Use," Vol. 2, "Spiking for Deterrence," IRT-378-R, September 1975. (Under classification review--Confidential)[†††]

16. U.S. Energy Research and Development Administration, U.S. Nuclear Regulatory Commission, "Joint ERDA-NRC Task Force on Safeguards (U)," Final Report, (NUREG-0095) (ERDA 76-163), July 1976.*

17. U.S. Atomic Energy Commission, AEC Manual, Chapter 2401, "Physical Protection of Classified Matter and Information," pp. 2401-01-2401-06, January 1975, and AEC Manual, "Physical Protection of Classified Matter and Information--Security Handbook," July 1976.**

18. U.S. Energy Research and Development Administration, ERDA Manual, Ch. 2405, "Physical Protection of Unclassified Special Nuclear Material," June 1975.[††]

19. U.S. Energy Research and Development Administration, "Master Plan - Division of Safeguards and Security," ERDA 76/122, September 1976.[††]

---

[b] Available in Source File for USNRC Report NUREG-0414, May 1978.

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

[†††] This document is not publicly available because it contains national security information.

**Unclassified versions of the classified references and copies of the unclassified reference are available in NRC PDR for inspection and copying, for a fee.

[††] Available in DOE (ERDA) PDR for inspection and copying, for a fee.

CHAPTER 5

REFERENCE SAFEGUARDS SYSTEM

5.1 INTRODUCTION

This chapter describes a reference safeguards system which can be used as a basis for evaluating the costs and risks to society of the safeguards necessary, in a state of civil order, to protect a nuclear industry in which there is wide-scale use of mixed oxide fuel (MOX).

The reference system is derived from extrapolation of safeguards policies and practices either currently in use or under consideration for implementation in the licensed nuclear industry. Accordingly, it is based on proven technology, complies with the existing statutory framework, and can be implemented within the existing regulatory base without restricting private industry's choices of technology or siting options.

It should be noted that for an industry as complex and diverse as a wide-scale MOX industry is expected to be, no single set of detailed safeguards measures can be selected at this time to meet all future needs. The reference system must be viewed, therefore, not as a recommended system, but as a representative system which provides a basis for assessing MOX safeguards costs and impacts as well as for comparing alternative MOX safeguards approaches. It should also be noted that a significant amount of time may elapse before wide-scale use of MOX occurs. During this period, technologies which are more cost-effective might evolve, the regulatory base might be broadened, and new techniques for processing, transporting, or safeguarding plutonium might be adopted.

The general design objectives utilized as the basis for a MOX safeguards system are described in Section 5.2. The philosophy and design approach utilized in converting these general design objectives into a reference system are treated in Section 5.3. The resulting configuration of safeguards hardware, procedures, and personnel needs is discussed in Section 5.4. (A more detailed description of the reference system elements and their component costs is presented in Appendix A.) The application of the reference system to the alternative recycle industries identified in NUREG-0002 (Ref. 1) is summarized in Section 5.5. Section 5.6 treats the economic feasibility of implementing such a system in a MOX industry. A summary of the chapter is presented in Section 5.7. A discussion of several possible means for contributing to more cost-effective safeguards procedures than are represented by the reference system is presented in Chapter 6.

5.2 GENERAL DESIGN OBJECTIVES

As an initial step toward establishing adequate safeguards at licensed nuclear facilities, NRC must define what is required and ensure that systems which are adopted by the licensee meet these requirements. This can, in theory, be accomplished by setting performance objectives through regulation, while leaving the choice of measures implemented entirely to the licensee. Alternatively, one could choose to limit the choice of measures to be implemented by establishing criteria which specify, to the detail appropriate in a complex industry, the technical approaches considered satisfactory for meeting the desired performance. In formulating the reference system, a mixed regulatory approach was used, namely, one which involves imposing overall design objectives and performance requirements combined with the more specific requirements contained in 10 CFR Parts 70 and 73 (see footnote in Section 5.3.4). The fundamental concepts behind the design objectives are to limit access to sensitive materials, to detect any unauthorized entry and access or any act of theft or attempted sabotage, and to provide appropriate and timely response to any such unauthorized action. For convenience, these design objectives have been grouped into fixed site protection objectives and transport protection objectives.

5.2.1 Fuel Cycle Fixed Site Design Objectives

Seven general design objectives were identified as aids in establishing the MOX safeguards system performance desired at fixed sites. These objectives, and their implications for safeguards design, are as follow:

(1) Ensure that only authorized personnel and materials are admitted into material access areas (MAA's) and vital areas (VA's). Achieving this objective involves designs which provide: (a) barriers around MAA's; (b) access authorization procedures and controls for each area; and (c) devices and procedures to detect, assess and communicate in a timely fashion any unauthorized access or penetration.

(2) Ensure that only authorized activities and conditions occur within protected areas, MAA's, and VA's. Achieving this objective involves safeguards designs which: (a) establish specified authorized activities and conditions appropriate for each area of a facility; and (b) implement detection and surveillance measures for discovering and assessing in a timely fashion unauthorized activities and conditions in each such area.

(3) Ensure that only authorized movement and placement of strategic special nuclear material (SSNM) occurs within MAA's. Achieving this objective involves designs which provide: (a) established locations for such nuclear materials and procedures for their movement; (b) measures which maintain current knowledge of material location and movement; and (c) measures that will provide timely detection of unauthorized material placement or movement.

(4) Ensure that only authorized and confirmed forms and amounts of SSNM are removed from MAA's. Achieving this objective involves designs which provide: (a) barriers that channel persons and materials leaving an MAA to exit control points; (b) controls and procedures that identify the properties and quantities of material being removed and the persons making the removal; and (c) detection and communication subsystems and procedures that will alert the security organization to any unauthorized attempt to remove material.

(5) Ensure timely detection of unauthorized entry into the protected area of facilities. Achieving this objective involves the same general design approach as that for controlling

access into MAA's and VA's, namely: (a) barriers around the area; (b) access controls; and (c) devices to detect, assess, and communicate, in a timely fashion, any unauthorized access.

(6) Ensure that the reponse to each unauthorized activity is timely and appropriate. Achieving this objective requires: (a) trained and qualified security personnel; (b) an established plan for responding to emergencies and safeguards contingencies at each facility*; (c) appropriate equipment for the security organization; (d) design features that facilitate rapid assessment of and reliable reponse to safeguards contingencies; and (e) communications networks for rapid and accurate transmission of security information between onsite security personnel as well as to offsite assistance forces.

(7) Ensure the presence of all SSNM in the plan by location and quantity. Achieving this objective involves: (a) monitoring processes and operations involving SSNM to detect missing quantities of material; (b) maintaining records of all SSNM within the plant by location and quantity; (c) measuring SSNM as it is received into, moved within, and removed from the plant; and (d) periodic inventories and audits to verify the location and quantities of SSNM and the accuracy of the records.

5.2.2 Transport Design Objectives

Three general design objectives were identified as aids for establishing desired safeguards performance during transportation phases.

(1) Restrict access to and activity in vicinity of transports. To implement this objective requires safeguards system designs that include: (a) temporary protected areas, access to which would be controlled in order to isolate shipments or transports before and after movement and at all scheduled and emergency stops; (b) authorization schedules and entry criteria for persons, materials, and vehicles entering these areas; (c) systems and procedures that detect, assess and communicate in a timely fashion any unauthorized penetration into these areas; and (d) planning and information systems to permit shipments in transit to avoid areas where they might be more vulnerable.

(2) Prevent unauthorized entry into transports or unauthorized removal of SSNM from transports. Achieving this objective would involve safeguards designs which utilize: (a) containers and vehicles which delay attempts to gain unauthorized access to the cargo; (b) systems and procedures which specify and verify persons authorized to remove and receive material and the authorized times for such removal and receipt; (c) removal procedures for emergency situations; and (d) systems and procedures that detect, assess and communicate any unauthorized attempt to penetrate the transport.

(3) Ensure that the response to unauthorized attempts to enter vehicles and remove materials is timely, effective and appropriate. Procedures for achieving this objective include use of: (a)

---

*A proposed change to 10 CFR Part 73.50 (g)(2) would require licensees to instruct guards to prevent or delay theft or sabotage by using a sufficient degree of force to counter the force directed at them, including the use of deadly force when there is a reasonable belief it is necessary in self-defense or in the defense of others. See Federal Register 8382, Doc 77-4165. Filed 2-9-77.

trained and qualified security personnel with appropriate equipment; (b) escort vehicles; (c) a predetermined plan for responding to emergencies; and (d) communication networks that enable escorts to communicate security information, among themselves, to a movement control center and to local law enforcement agencies or other assistance forces.

5.3 REFERENCE SYSTEM DESIGN APPROACH

5.3.1 Sources of Safeguards Design Information

Current safeguards systems reflect experience with previous systems, perceived needs to improve those systems, and the results of extensive research and development intended to produce the needed improvements. This combination has led to wide diversity in the number and types of subsystems available for use, a diversity reflected in the description of currently available safeguards measures presented in Chapter 4. As a design conservative approach, this diversity is used to create subsystem redundancy to insure adequate coverage.

Both NRC and DOE are currently sponsoring programs to improve analytic safeguards system design and evaluation methods. These programs include development of quantitative methods for assessing the safeguards effectiveness of physical protection systems, transportation systems, and material control and accounting procedures (Ref. 3).

At present, however, no single, rigorous analytical technique exists for synthesizing a safeguards system. This is borne out by a recent study (Ref. 2) which reviewed currently available quantitative design and evaluation techniques and concluded:

> ...useful evaluation models do exist in various stages of development. Extensive further development would be required before either NRC or licensees could claim the ability to fully test projected or existing safeguards approaches against postulated performance requirements without having to put significant reliance on expert judgment (Ref. 2, p. 1-7).

Accordingly, the reference system described herein is based on expert judgment, supplemented by detailed subsystem studies and analyses and by accumulated experience with existing safeguards systems. The following subsections briefly discuss these studies and analyses and the past experience.

5.3.1.1 Technical Studies

In a wide range of studies, the NRC staff has investigated the cost and effectiveness of various safeguards measures. In particular, the recent NRC Special Safeguards Studies, mentioned in Section 2.5.3, (Refs. 4-17) addressed a variety of subsystems that could be employed at MOX facilities under the current general scope of 10 CFR Part 73, e.g., barriers, alarms, admittance systems, detection systems, personnel access controls, transport escorts, and fixed site and transport communications. The studies also addressed systems and procedures currently under the general scope of 10 CFR Part 70 that could be applied at MOX facilities to achieve closed material balances, including automated integrated measurement systems and material inventories conducted at various intervals. In addition, the studies examined advanced techniques beyond the general scope of current regulations and not currently in use in commercial facilities, such as active delay devices and the use of isotopic control to simplify and enhance the effectiveness of material measurements. These technical assessments formed the principal basis for selection of MOX industry subsystems that provide a reasonable balance between cost, effectiveness, and impact on employees and the public.

5.3.1.2 Analytical Techniques

Several analytical techniques, including force interaction analysis and failure mode analysis, provided additional guidance in assessing the specific safeguards measures considered.

Failure mode analysis includes the fault-tree methodologies developed to evaluate nuclear safety risks (Ref. 18), the similar "societal risk" approach to safeguards design (Ref. 19), and diversion path analysis methodologies (Refs. 20, 21). Diversion path analysis can be used to examine the large range of action sequences leading to successful diversion of nuclear materials and to evaluate safeguards capabilities to detect and interrupt these action sequences at various points. Diversion path analyses have been conducted on a number of actual installations as well as on proposed MOX facility designs.

A general method of failure mode analysis was developed to assist in synthesizing and evaluating the generic safeguards measures of the reference system and to identify the minimum number of safeguards elements which must be overcome to divert plutonium from a MOX fuel cycle facility (Ref. 22). The layout of a prototype facility was analyzed by taking each area in the facility and identifying every possible path from one area to another which could constitute a diversion path segment. Various paths were analyzed to identify all safeguards elements needed and to identify possible deficiencies in the proposed reference systems. Using this method, the final design configuration selected provided at least two safeguards measures of protection for every diversion path identified.

Diversion path analysis tends to focus on adversary acts involving stealth or deceit rather than force. Other means are appropriate for analyzing and configuring safeguards capabilities against armed attacks. Available techniques for force interaction analysis were applied to both fixed site and transport convoy cases. Probabilistic or stochastic models were utilized to investigate outcomes of armed engagements between guards and armed attackers (Refs. 12, 23). The results of these analyses were compared with each other as well as with comparable safeguards practices utilized in other contexts (Ref. 23) to identify and assess the capability of the various designs considered. As a final design check, these quantitative and comparative analyses were complemented by a detailed technical analysis of the capabilities of the reference system to protect against armed attack. That analysis considered the relative effectiveness of specific measures incorporated into the design and the net effectiveness of these measures (Ref. 71).

5.3.1.3 Safeguards Experience of Other Agencies

For many years, both government agencies and commercial firms have dealt with the problems of safeguarding special nuclear material (SNM) and other sensitive items, both at fixed sites and while in transit. This safeguards experience represents a rich source of information and expertise. The stated safeguards objectives and requirements of the various agencies and firms provide independent sources of expert opinion as to what constitutes an appropriately balanced and comprehensive safeguards system. Those practices which were of potential relevance were reviewed and the findings were considered during the design of the reference system.

5.3.2 Design Constraints

A variety of alternative safeguards equipment, techniques, and operating procedures can be identified which, in proper combination, can meet the design objectives set forth in Section 5.2. The reference system described in Section 5.4 is one such system. It consists primarily of measures typical of existing safeguards practice and technology. Thus, technical uncertainties can be avoided in the system and its costs estimated with high confidence. Other measures can, of course, be utilized and their selection may ultimately be preferable. Should this eventually occur, such changes can be treated as individual technical or procedural changes to the reference system and evaluated accordingly.

Both fixed sites and road transport are currently protected by physical security measures identified in 10 CFR Part 73. The fixed site measures include armed guards; physical barriers around MAA's and VA's; control of access into protected areas, MAA's and VA's; detection aids such as intrusion alarms and emergency exit alarms; communication with local law enforcement agencies; surveillance of MAA's; and control of egress from MAA's. Road transport protection currently utilizes hardened vehicles, armed escorts, and communications with a central station. These same measures have been incorporated into the reference system design, but have been uniquely configured and augmented, where appropriate, to meet the design objectives listed in Section 5.2.

The measures outlined in 10 CFR Part 70 constitute the material control and accounting procedures currently required at licensed facilities for handling and transferring SNM. Included are measurement and reporting procedures to reconcile SNM book inventory quantities with physical inventory quantities and to reconcile shipper/receiver differences; computation of material balance by plant area or subcomponent to detect and localize SNM losses or theft; and materials management and control, including tamper-indicating devices for both containers and storage vaults. Similar measures are included in the reference system.

Measures requiring Federal or State legislation or additional agreements between government entities were avoided in the reference system design. Thus, the reference system discussed in Section 5.4 is typical of a safeguards system that could be implemented under current NRC authority. Options which would require special legislation, i.e., using Federal guards or employing special weapons, are treated in Chapter 6, along with measures which introduce specific limitations on industrial processes or site choices and measures which require modification of SSNM for specific safeguards purposes (such as blending plutonium with uranium early in the fuel cycle).

5.3.3 Effect of Material Type

As indicated in Chapter 3, a variety of material forms, ranging from pure compounds of plutonium to highly radioactive waste, would exist in a MOX industry. Consideration must be given to the emphasis desired in protecting the various material types and quantities against theft as compared to sabotage protection.

According to current regulatory requirements, any licensee who possesses more than five kilograms of high-enriched uranium or two kilograms of plutonium or ^{233}U must provide physical protection. The current regulations also require that a licensee possessing one kilogram or more of such SSNM also maintain appropriate accountability of the material. Since these amounts (known as threshold quantities) are significantly less than are required to fabricate a crude nuclear explosive weapon, the current regulations provide a conservative safeguards design basis for protection against the use of these materials for that purpose. It should also be noted that regulations are currently under consideration which would provide improved capabilities of physical security and material control systems to protect against attempts to accumulate threshold quantities of SSNM in a series of small thefts over a period of up to one year and that such capability is also appropriate for MOX safeguards.

A MOX safeguards system must protect against all adversary actions that could lead to a public disaster. Because both Type I and Type II materials* have the potential for being fabricated into nuclear weapons, safeguards systems should be designed to protect, with equal confidence, against theft of weapons quantities of material of either type.**

Two situations are of interest, one where the total quantity of plutonium is less than two kilograms, and the other where two or more kilograms are present. In the former case, the safeguards system would be determined primarily by concern about sabotage or theft of small quantities for use in a dispersal weapon. In the latter case, the safeguards system must also protect against theft of nuclear weapon quantities.

In a MOX industry, circumstances where small quantities of plutonium would not be protected by the safeguards provided for much larger quantities of materials would occur primarily during the shipment of low-level waste to storage. Typically, these shipments might contain up to 15 grams of plutonium per barrel, dispersed in small amounts throughout solid materials.*** NRC staff considers that the risk to public health and safety of such shipments is so low that additional physical security measures are not necessary.

Where larger quantities are involved, the effectiveness of certain elements of a safeguards system is a function of the amount of material over which control is desired. For example, the effectiveness of both neutron and gamma detectors, as well as of material balance accounting, diminishes as design threshold quantities of material become smaller. As previously indicated, NRC is considering a requirement that material containment systems for the current industry demonstrate the capability to detect attempts to accumulate two kilograms of plutonium through successive small thefts during a one-year period. This requires detection of unauthorized

---

*As defined in Section 3.2.6, Type I materials, such as plutonium oxide, are suitable immediately or with relatively minor processing for direct use in nuclear weapons. Type II materials, such as plutonium nitrate and mixed oxide fuels, require relatively modest facilities and effort for conversion into Type I materials. Type III materials, such as spent fuel assemblies, require major facilities and processing efforts for conversion into Type I materials. The definitions of "types" in Section 3.2.6 are for use in this report. They should not be confused with definitions of material categories utilized by the International Atomic Energy Agency and other organizations for their respective purposes.

**This policy does not diminish whatever advantage there might be in utilizing blending as an additional safeguards measure so as to change Type I materials to Type II materials early in the fuel cycle. (See Ch. 6 for a discussion of this option.)

***The maximum amount of plutonium in such containers would be limited, for both safeguards and economic reasons. (See Paragraph 5.4.1.3, Waste and Scrap Stream.)

movements of quantities as small as several grams, thus providing an effective capability against the theft of small amounts for dispersal purposes. When such material containment systems are used in combination with other safeguards systems and procedures such as access controls and direct surveillance, whose effectiveness is virtually independent of the quantities of material to be controlled, protection against theft of very small quantities becomes considerable. In fact, the level of such protection would exceed that currently applied in the United States to numerous non-nuclear materials whose malevolent use could also have severe consequences (see Section 3.3).

The MOX industry would probably involve shipments of highly radioactive materials between reactor and reprocessing plants and between reprocessing plants and waste storage sites. Shipments of spent fuel from reactors to various storage locations are currently protected against sabotage by massive shipping containers. Even if a deliberate breach resulting in a release of volatile radioactive materials were made in one of these containers, the consequences would be relatively minor, with very few fatalities (see Chapter 3). Such consequences would be similar to those resulting from the release of certain other toxic or dangerous substances currently not subject to any special protection (see Section 3.4). Accordingly, NRC currently requires no specific physical security measures during shipment of spent fuel, and there appears to be no present need to alter this policy for a wide-scale MOX industry.

The MOX industry sabotage hazards from shipments of high-level wastes are considered equivalent to those from spent fuels. Consequently, no in-transit safeguards measures would be added to the protection already provided high-level wastes by the packaging required for health and safety reasons.

5.3.4 Threat Considerations

Many aspects of a properly designed safeguards system, such as barriers, material detection and alarm systems, measurement systems, and guard training, can be designed to be relatively threat-independent. Moreover, current DOD, DOE and NRC safeguards systems emphasize design principles of redundancy and diversity to further reduce the sensitivity of safeguards designs to uncertainties about threat levels and capabilities. The reference safeguards system design has been based on this approach, and key aspects of this approach will be discussed in the succeeding subsections.

In relation to possible threats, the system is designed to attain performance levels consistent with present and proposed safeguards requirements. The NRC is currently upgrading performance levels of safeguards for both the existing licensed nuclear fuel industry (Ref. 24) and nuclear reactors (Ref. 25).* As a result, safeguards at these facilities (and MOX industry safeguards) will afford protection against (a) determined, violent assaults by a small group armed with automatic weapons and explosives, possibly with the assistance of an insider, as well as (b) internal conspiracies involving fuel industry employees.

---

*Revisions to 10 CFR 73 were published in the Federal Register on July 5, 1977, for public comment. These revisions upgraded the physical protection requirements for fuel cycle facilities and associated transportation activities.

Because it is not possible to state precisely what the nation will perceive as a threat against the MOX industry in the 1980's and beyond, the costs of varying the level of onsite security forces, a principal factor in both the cost and effectiveness of safeguards (particularly physical protection safeguards), were examined.

The specific design considerations for both internal threats and external threats are discussed in the succeeding subsections.

5.3.4.1 Internal Threats

For unauthorized actions involving stealth or deceit by employees, necessary protective capability depends on the number of employees involved and the positions they hold. The threat could conceivably range from a single employee to a conspiracy involving key plant personnel such as guards or management officials. A recent study (Ref. 26) indicates that, for threats involving stealth or deceit by insiders, the number of participants is not likely to be as critical as ability to fraudulently misrepresent authority.

Safeguards to deal with the internal threat posed by more than a single employee have been based on three major design strategies: (1) use of measures which monitor the movements of material; (2) limitations on personnel access to nuclear materials; and (3) use of security clearances.

Successful diversion of nuclear materials would require physical removal across numerous strategically placed boundaries. An appropriate safeguards system can detect any such attempted diversion by detecting the movement of the materials themselves, without being sensitive to the number of people involved in the attempt, as long as the integrity of the detection system itself is maintained.*

Vulnerability to internal threat can be further reduced by limiting material access to those employees specifically requiring such access. Implementation of such a design strategy significantly reduces both the number of people capable of effecting a theft and the number of opportunities for theft.

NRC regulations in 10 CFR Part 73 as well as the design objectives discussed in Section 5.2 emphasize the above measures to provide control of material access as well as detection of unauthorized material movements. Such measures are generally not affected by the number of employees who may be involved in an attempt at diversion, provided that the security system itself is not compromised, and they provide a basic framework for MOX safeguards to significantly limit the number of employees who could effectively conspire to commit theft.

Given such designs, there are a few employees in positions of responsibility with respect to the safeguards system itself who could be effective participants in a conspiracy. Such employees include personnel involved in management, security, security equipment maintenance, material control and accounting, and health and safety. The effectiveness of measures regarding

---

*For example, as discussed in Appendix B, the effectiveness of radiation monitors used to detect plutonium diversion is not strongly affected by the number of persons involved in an attempt to divert two kilograms of plutonium, provided proper procedures are utilized.

material access and movement against a conspiracy which includes personnel in such positions is influenced by the numbers involved and the precise positions they occupy. Security clearances are one of the most effective means for ensuring that only reliable individuals occupy positions of trust.

The use of security clearances and careful employee screening should markedly reduce the risk of collusion among employees. It is generally accepted that individuals who have been so screened are less likely to undertake unauthorized actions. In particular, it is a basic presumption of current Federal security systems that a conspiracy involving two or more cleared individuals is unlikely.

In Government agencies where highly sensitive materials or information are involved, some responsible individuals undergo pre-employment security clearances involving an extensive background investigation. This is augmented after they are hired by a reliability assessment program involving periodic monitoring and assessment of their physical and mental health, job competence, and overall reliability.

The NRC staff believes that an equivalent level of protection could be obtained in commercial MOX facilities by combining preeployment evaluations with conservative assumptions regarding their effectiveness. As a design requirement, clearances involving full background investigations should be required of all security personnel as well as all individuals with access to or control over nuclear materials. Since employees with direct access to materials could, in some cases, effectively collaborate with non-security employees who do not have such access, all personnel with access to the protected area should receive a clearance involving a national agency check prior to employment.*

Additional safeguards measures are, of course, desirable to augment the protection against conspiracies offered by a clearance program. In particular, a clearance program should not be considered sufficient in itself to prevent a cleared individual from acting alone or in collaboration with an uncleared employee. Technical measures and operational procedures such as those discussed in Section 5.4.1.4 must also be provided to protect against this possibility.

5.3.4.2 External Threats

As previously indicated, the NRC is currently upgrading safeguards protection against external attacks for fuel cycle facilities (Ref. 24, NUREG-0095 and 42 FR34310 July 5, 1977). The upgraded safeguards are designed to protect against violent, dedicated attacks by a small group of well trained individuals armed with light automatic weapons and having the assistance of an insider. This level of protection should also be achieved by the reference safeguards system.

It should be emphasized that the reference system approach is not based upon any estimate of a "maximum credible" threat. Rather the system is designed to protect with high assurance against the threats that seem possible under the concept of continued civil order while, concurrently, providing considerable protection against larger threats should they unexpectedly

---

*A similar policy is under consideration for currently licensed facilities (Federal Register, March 17, 1977, Ref. 37).

materialize. Important to this design approach is the fact that a system designed to protect with high assurance against attack by a small group of well-armed and dedicated attackers would retain considerable capability against larger groups. With the aid of an extensive detection and warning system, the well-trained guard force provided by the reference system could offer prompt organized resistance to any external attack. Combining delaying tactics with the communication system, barriers, vaults and other delaying devices provided by the reference system, such a guard force could delay a large attack force for a considerable period. The resulting combination of onsite safeguards and subsequent reinforcement by local law enforcement personnel should provide adequate protection against external attacks over the range of threats conceivable within the domain of civil order in the United States.

5.3.5 Site-Specific Considerations

The specific characteristics of a properly designed safeguards system are highly site-dependent. For example, the safeguards system design for protection of a MOX industry facility against armed attack would depend upon such factors as terrain, specific plant type, layout, detailed design, and the proximity of local law enforcement support. In an industry as complex and diverse as a wide-scale MOX industry is expected to be, no single set of detailed safeguards measures would meet all individual needs. As has been previously emphasized, the reference system must, therefore, be viewed only as a generic description of a representative safeguards system being utilized to assess MOX safeguards costs and impacts and alternative safeguards approaches.

The effectiveness of MOX safeguards is especially dependent upon the guard force size. The procedures utilized to establish the reference system guard force size are discussed in Section 5.4.1.5.

In fixed facilities, a number of guards are needed to perform the internal security functions of entrance and exit control, surveillance, equipment maintenance, and general security operations. Guard deployment for these functions in the generic MOX fuel facilities resulted in a substantial in-place security force. If provided with appropriate training, equipment, planning, and supporting facility design, these force levels were considered able to offer a self-contained protection needed against armed attacks by a small group, and to delay a larger force until reinforcements arrive. Thus, the reference system design was not dependent upon the site-specific consideration of the availability of a local law enforcement capability.

In the case of transport, it was conservatively assumed for the reference system design that all MOX shipment routes would be sufficiently isolated to preclude ready assistance from local law enforcement agencies. Although such a degree of isolation would not be typical of the majority of shipment routes, it provides an upper bound for estimating the economic and other costs and impacts of protecting MOX industry shipments.

5.4 DESCRIPTION OF THE REFERENCE SYSTEM

The safeguards measures adopted for the reference system can be divided into three general categories:

- Measures for protection of reprocessing, fuel fabrication and fuel assembly plants.
- Material transport physical security measures.
- Measures for protection of fresh MOX fuel at reactors.

The following discussion provides a general description of these measures. Additional details appear in Appendix A.

5.4.1 Measures for Protection of Fuel Reprocessing, Fabrication and Assembly Plants

The reference safeguard system is based on the concept of performance-oriented regulations. Measures to meet the performance requirements for safeguarding future MOx fuel cycle facilities would include perimeter security around protected areas, perimeter security around MAA's and VA's, material control in MAA's, and surveillance of MAA's and VA's. Redundancy was introduced in certain cases in order to provide an upper bound cost estimate, even though not all elements might be required under the performance regulations.

5.4.1.1 Perimeter Security at Protected Areas

Standard practice developed through extensive experience in sensitive facilities operated by other government agencies as well as by private industry is to utilize perimeter fences, guard patrols, intrusion detection sensors, and controlled access entry portals or gates for restricting access to an area. The reference system provides dual fences around the protected area perimeter. Outside the outer fence, between the fences, and inside the inner fence, clear zones free of any object which might provide cover for an intruder are maintained. At night and during periods of reduced visibility, the clear zones are illuminated. The independent and complementary sensors (seismic, microwave, and CCTV), each deployed in a clear zone between the fences, provide a high-confidence detection capability against intrusions under anticipated environmental conditions. This perimeter design, based on multiple and redundant sensor systems to detect intruders, was selected in order to minimize expensive manpower requirements for patrols (Refs. 13 and 28).

At the protected area portals, procedures are provided to limit entry to individuals with legitimate business within the facility, and to ensure that articles or materials which could be used in a diversion or sabotage attempt would not be introduced within the facility. Typical entry-control safeguards methods utilized by other government agencies and private industry involve documentation identifying the individual and authorizing his entry, as well as searches of individuals, packages, and vehicles for unauthorized items. Numerous technical options are available for verifying identity, including personal recognition, picture badge exchanges, code words, combination locks, and card-keys (Refs. 13 and 29). (Advanced technical systems, such as voice or handwriting recognition, may eventually be useful in such applications, see Ref. 13.)

In the reference system, employee access at the permanent portal is controlled by use of both a card-key and a picture badge. An authorized card-key activates a turnstile and allows the employee into a passage so configured as to channel the employee past a protected guard post where display of a picture badge permits access into the protected area (after the screening process described below). The use of this technique reduces the likelihood of an outside adversary surprising the portal guards. Two guards* and CCTV are used to protect against unauthorized acts by any single guard, and the guards are in hardened, protected positions.

In the reference system, entering personnel and hand-carried packages are screened for firearms and explosives via package searches, passage through a metal detector, and random searches with hand-held detectors sensitive to metal and explosives (Ref. 29). Vehicles are visually searched and inspected and screened with hand-held detectors. All portal activities are CCTV monitored at a central facility to ensure that proper procedures are being followed. The perimeter access portals are designed to be guard-activated and can be closed when necessary to delay exit.

A summary of the perimeter security features utilized in the reference system is given in Table 5.1. Additional details for each element listed in Figure 5.1 as well as for the other safeguarding elements discussed in Section 5.4 are presented in Appendix A.

Should a violation of perimeter security be detected, the initial response is the responsibility of the onsite security force. The level of offsite support eventually provided will depend upon the specific facility and its location. A more extensive discussion of guard force responsibilities is provided in Sections 5.4.1.5 and 5.4.1.6.

TABLE 5.1

PERIMETER SECURITY FEATURES

Protected Area Perimeter

Outer clear zone (15 m wide)
Outer fence
Microwave sensor

Seismic sensor
Alarm/assessment CCTV cameras
Inner fence
Lighting
Inner clear zone (15 m wide)

Protected Area Portal

Personnel gates/turnstiles
Vehicle gates/barriers
Enclosed, hardened guard station
Card-key reader
Fixed metal detector
Hand-held explosives detector
Hand-held metal detector
CCTV camera
SSNM detectors

5.4.1.2 Perimeter Security at MAA's and VA's

Reference system security measures at the perimeter of the MAA's and VA's are designed to:

- Detect unathorized entry or introduction of contraband into a VA or MAA
- Detect attempts by employees to remove SSNM from a MAA
- Provide sufficient delay time against an assault by outsiders so that a response force capable of neutralizing the attack force can be introduced before a theft is successfully completed.

---

*All guards in the reference system would have security clearances. Clearance policy is discussed in greater detail later in Section 5.4.1.8.

For MAA's and VA's, the reference system includes access controls for detecting unauthorized entry or introduction of contraband. MAA controls are similar to those at the protected area portal. However, since the need for access to VA's (which are normally closed and alarmed) would be rare, the reference system requires direct escort into VA's.

During periods when MAA's or VA's are not in use, the system provides for intrusion detection sensors to monitor the areas so that no surreptitious entry or unauthorized activity takes place. In addition to CCTV, volumetric sensors are used to indicate entry into an MAA or VA. In the reference system, doors to VA's and equipment storage garages are alarmed with balanced magnetic switches and seals to indicate any unauthorized door opening.

Screening of personnel for contraband is performed at a portal with fixed walk-through detector systems. A clothing change room, required for safety purposes as well, increases the difficulty of entering or leaving the MAA with contraband materials (Ref. 29).

To detect unauthorized removal of SSNM, the system provides for employees leaving a MAA to be scanned by equipment capable of detecting the gamma radiation and neutrons emitted by isotopes of plutonium. In this connection, studies sponsored by NRC (Refs. 30 and 31) indicate that random searches with highly sensitive devices at the rate of about 1 per 100 employee exits, combined with fixed sensors employing a combination of available neutron and gamma detection technologies, would detect with high confidence (>99 percent) attempts to accumulate significant quantities of material by any number of employees, each attempting to exit with very small concealed amounts, even assuming that they used sophisticated shielding techniques. These studies are summarized in Appendix B.

Based on these findings, screening of personnel at MAA exit portals with a fixed neutron-gamma sensor system (having characteristics typical of those discussed in Appendix B) plus a metal detector, combined with random searches using highly sensitive hand-held detection equipment, are adopted for the reference system.

To prevent introduction of contraband, not only would material and supplies entering a MAA be identified and screened in a manner similar to that used for personnel, but checks would also be maintained against the formal authorizations requesting such movement.

To detect unauthorized removal of plutonium, any material and supplies leaving the MAA would be examined by means of highly sensitive hand-held gamma-ray detectors, visual search of packages, and as appropriate, package or equipment dismantling. Trucks leaving the MAA would be exposed to a visual inspection and search utilizing a hand-held gamma-ray detector.

All material transfers from storage to shipment would be under direct surveillance by at least one guard. To protect against unauthorized action by a single member of the guard force in collusion with another non-security employee, all portal operations involving either material or personnel movement would be conducted by at least two guards and would, in addition, be monitored by CCTV. The purpose of the CCTV is to ensure that portal procedures are being followed by the security personnel.

A summary of the security features employed in the reference system to detect unauthorized entry into, and prevent unauthorized removal of material from, the MAA's and the VA's is given in Table 5.2.

TABLE 5.2

MAA and VA BUILDING SECURITY FEATURES

Building Perimeter

Exterior CCTV
Exterior lighting
Hardened emergency exits (one-way turnstiles)
Door-opening alarms
Vehicle barrier

MAA Portal (continuously manned by guards)

Portal doors/turnstile
Protected guard position
Change room
Fixed & hand-held metal detectors
SSNM detectors
Badge exchange system
Card-key readers
Fixed explosives detectors
CCTV cameras

MAA or VA Portal (intermittently manned)

Portal doors
Hand-held SNM detectors
CCTV cameras
Badge exchange system
Card-key readers
Vehicle barriers

MAA or VA Interior (when unoccupied)

CCTV cameras
Volumetric sensors

5.4.1.3 Material Control and Accounting in MAA's

General. For health and safety reasons, plutonium compounds are processed in confined areas having a limited number of access portals, all of which are alarmed. Such measures limit the accessibility to plutonium-containing compounds and also help in detecting unauthorized removals from the normal process flow. It is anticipated that any future large-scale MOX facilities would so rely on automated or remotely operated process equipment that the need for direct contact with plutonium would be limited, in most process areas, to maintenance periods. Accordingly, routine hands-on access to plutonium would occur only in loading and unloading, in sampling and inspection areas, and in the analytical laboratories. In process areas, valves on pneumatic transfer lines from storage vessels, as well as portals on gloveboxes, would be monitored, and bulk storage vessels would be monitored for abnormal changes in liquid level or weight. In the loading, unloading, and inspection areas, where personnel handle plutonium in containers, the reference system utilizes personnel surveillance systems to ensure proper procedures (Ref. 7). Item controls that utilize unique container identification and tamper-indicating seals (Refs. 32-34) enable rapid verification of the inventory.

Administrative Procedures. The material control and accounting features of the reference system provide that written procedures be established, maintained, and followed in accordance with the basic material control requirements of 10 CFR Part 70. A description of the key elements of these procedures is presented in the following paragraph.

Material Balance Areas (MBA's) and Item Control Areas (ICA's) are established in a manner and in sufficient numbers to identify and localize losses (Ref. 31). The custody of plutonium within any MBA or ICA is the responsibility of a single designated individual. A system is established for measurement of the plutonium content of all receipts, shipments, discards, and material on inventory (Refs. 36-38). A program of standardization and calibration of measurement equipment and analytical procedures is also established and maintained (Ref. 39). Procedures are established that ensure the accurate identification of receipts and measurement of shipments of SSNM (Ref. 40), the review and evaluation of shipper-receiver differences (Ref. 41), the taking of appropriate investigative and corrective action to reconcile shipper-receiver differences, and the maintenance of appropriate records. A documented system of control over the storage and internal transfer of SSNM within the facility is maintained (Refs. 42 and 43). Procedures for the control of SSNM scrap, including identification and classification (Ref. 44), and for regular processing and recovery, are established. Physical inventory procedures, followed and maintained with a system of records and reports which provide sufficient information to locate SSNM and to close material balances around each MBA and the total plant, are also established (Ref. 45). The system also provides for review of the nuclear materials control and accounting system at least once a year by individuals independent of the material control and accounting organization (Ref. 46).

Measurement Accuracies. The ability of material accounting systems to detect possible thefts by periodic inventories depends primarily upon the accuracy with which the amounts of material entering, leaving, and in process within the facility can be measured. As discussed in Appendix C, process measurement uncertainties of approximately one kilogram (2σ) or less would be necessary within each MBA to provide a high assurance of detecting the removal of two kilograms of plutonium during a single period between inventories. Significantly greater accuracies, of the order of a few hundred grams, would be necessary to detect attempts to accumulate bomb quantities of plutonium by removal of small amounts during each of several accounting periods. As indicated in Appendix C, the process measurement uncertainties obtained with the best available measurement techniques are estimated to range from 100 grams to four kilograms in a model fuel fabrication facility, and from 200 grams to 55 kilograms in a model reprocessing facility. The precise uncertainty within these ranges depends on what portion of the plant is involved and the frequency with which material balances are made.*

---

*The smaller values are the process measurement uncertainties for the material balances in the analytical laboratory of each facility. The four-kg value for the fuel fabrication facility is the process measurement uncertainty for the bimonthly material balance of the process line. The 55-kg value is the process measurement uncertainty for the semiannual material balance of the separations area in the reprocessing facility. Although the 55-kg value is large, it should be noted that access to SSNM within the separation area is limited because the SSNM is remotely handled, behind thick shielding walls, highly radioactive (i.e., large quantities of fission products are present), and not highly concentrated.

Use of material balances to detect the theft of a two-kilogram quantity of plutonium appears to be promising for certain areas of fuel fabrication plants, but not for reprocessing facilities. It is uncertain whether the accuracy needed to detect such amounts can be achieved in the high-throughput facilities of a future MOX industry. The NRC staff does not, however, judge that such high accuracies are necessary for adequate protection of wide-scale MOX facilities. Protection of a MOX industry against theft will be based primarily on detecting and preventing such thefts through improved material control measures, ascess controls and material containment measures.

Despite its limitations, material control and accounting plays a vital role. It assists in deterring and detecting theft or diversion by providing information on the status and amount of SSNM. In the event of theft or diversion, it aids in assessing the extent of loss and it can narrow the search by identifying the place where the loss occurred, and the form and composition of the missing material. It is a basic means for assessing hoaxes or for assessing the extent of loss should a malevolent act occur. Finally, material accounting is a safeguards measure of fundamental importance in international safeguards (Ref. 47).

The material control and accounting elements of the reference system are based on currently available technology and practices and are designed to allow MOX plants to satisfy current regulatory requirements.* Current NRC regulations permit limits of error between book and inventory values of one percent of the semi-annual throughput in the highly radioactive portion of reprocessing plants and 0.5 percent of bi-monthly throughput in other facilities. For the mature MOX industry facilities described in Chapter 3, these limits amount to 20 kilograms in the plutonium inventory of a reprocessing plant and 13 kilograms in the inventory of a fuel fabrication facility.** If the material unaccounted for (MUF) exceeds these measurement uncertainty limits, specific procedures, including investigation and a possible repeat inventory, will be undertaken. The measures selected would be consistent with a prudent assessment of the discrepancy as compared with the regulatory requirements.

Accounting Procedures. Under the reference system procedures, all receipts, shipments, scrap, waste, and inventory would be measured. Weighing, sampling, and chemical or mass spectrometric analysis (Refs. 36, 37, 48 and 49) would be used in MOX fuel fabrication plants to measure and account for plutonium in powder or pellet form. Both sampling and analysis would be performed, according to a random sampling plan, to obtain an accurate average concentration factor for each form of material in the process. After each process step, the material would be weighed and the appropriate concentration factor applied. Because sampling of nonhomogenous materials is not feasible, containers of nonrecyclable scrap powder, pellets, and waste would be measured using non-destructive assaying techniques (Refs. 50 to 54). Plutonium contained in fuel rods would be controlled by pellet count and weight. An additional check would be made via radiometric rod scan, once the rod is sealed, to verify pellet count and composition (Refs. 55)

---

*As research leads to improvement in the accuracy and timeliness of material balance measurement systems and improvement in accounting data analysis methods, and as improved process control techniques are developed, NRC will consider requiring the MOX industry to adopt these improvements.

**These values apply to the year 2000 and are based on the assumption that each facility processed an equal portion of the industry throughput.

and 56). All equipment would be periodically cleaned and material balances computed for components of each MBA, as well as for the entire process (Ref. 45).

In the high radiation area of the reprocessing plant, the volume and weight of the feed and product solutions would be measured (Refs. 38 and 57-59) and the solutions sampled and chemically analyzed. Waste would be accumulated and measured by nondestructive assay. A total measured material balance would be performed at intervals of six months or less by inventorying the solutions in the separation and purification columns (Refs. 45 and 60-62). The imbalance would be controlled to less than one percent of semiannual throughput. Plutonium in the other areas of the facility would be measured and accounted for in a manner similar to that used in MOX fabrication plants (Ref. 17).

Waste and Scrap Streams. Unprotected waste and scrap streams might provide an opportunity to move plutonium to other locations for future diversion (Ref. 63). To protect such materials, low-level waste such as laundry, process trash, and dirty scrap would be collected under controlled conditions in specially marked and identified containers located throughout the plant. At regular intervals, the containers would be spot-checked, sealed, and moved to a central waste and scrap process area. After containers arrived at the process area, seals would be inspected to ensure that they had not been tampered with during transfer, and each container would be nondestructively assayed to determine its plutonium content (Refs. 64 and 65). This measurement would aid material balance accounting and also screen for the presence of abnormally large concentrations of plutonium. If a high concentration is detected, the container would be opened and its contents carefully inspected by material control personnel. After repackaging, the containers would be resealed for storage and shipment.*

Analytical Laboratories. Analytical laboratories within the facilities pose a unique material control problem. Here, skilled technicians performing complex operations would have routine access to small quantities of material. As previously discussed, the reference system would use portal monitors and package searches to control security at the perimeter of all facility operations, and these measures would also contribute to laboratory security. To supplement these measures, a sample control system would be employed between the process lines and the laboratory (Ref. 7).

The reference system requires that all samples be collected under surveillance in standard containers, individually identified and controlled. After the sample is taken, the container would be sealed and transported to the laboratory in a secure manner. Upon receipt at the analytical laboratory, the sealed samples would be inspected for tampering and nondestructively assayed as rapidly as possible to determine the approximate quantity of SSNM in the sample prior to its being released to the laboratory for further division and analysis. After all laboratory tests are completed, any residual material would be nondestructively assayed. Depending on the amount of material, degree of contamination, nature of the process stream, and other related factors, any residual material might be returned to the process. (Any such return must be

---

*For some waste, the original collection container might never be reopened, and the container might simply be moved to a storage area to await shipment. For others, the waste and scrap might undergo segregation, incineration, and solidification processes. The output from these processes would be repackaged for final storage and shipment.

witnessed.) Waste material from the laboratory would be sealed in containers and nondestructively assayed. In this manner, an approximate shift-by-shift material balance can be drawn around the analytical laboratory. As discussed in Appendix C, this type of material balance accounting has adequate sensitivity for protection against thefts of two-kilogram quantities of plutonium.

A summary of the material control features and the number of material accounting system personnel used in the reference system for maintaining material control is given in Table 5.3.

TABLE 5.3

MATERIAL CONTROL AND ACCOUNTING FEATURES AND PERSONNEL

Access Control Measures Within MAA's

Automated or remotely operated process equipment
Glovebox alarms
Valve alarms
Storage vessel level and weight indicators

Material Accounting System

Item Accounting (Pu container handling area)

Analytical Equipment
Weight measurement
Chemical assay
Nondestructive assay

Accounting Personnel (total man-years per facility required for tasks)[a]

SSNM custodians	(8)
SSNM handlers	(8)
Accountants	(7)
Statisticians	(2)
Measurement specialists	(2)
In-house inspection personnel	(5)
Managers	(5)

---

[a] The basis for these estimates is discussed in Appendix A.

5.4.1.4 Surveillance of MAA's and VA's

MAA security is based on limiting access. In addition the processes that occur in MAA's generally involve automated or remote-handling techniques. Nevertheless, in the reference system, those individuals present within MAA's would be under continuous visual observation (Ref. 66), using a combination of CCTV, monitored by a central facility, and the two-man rule (the person needing access would always be accompanied by an observer).

Because automated or remotely operated equipment is normally used, glovebox access to process lines is infrequent. If access is required, the use of monitored indicators on glovebox portals and CCTV would permit effective observation of employee activity. When other normally inaccessible areas, such as process lines, are opened during maintenance periods, direct surveillance by security guards replaces access denial as the primary safeguards measure.

Access to VA's is expected to be infrequent but, when required, a two man-rule and CCTV would both be used.

5.4.1.5 Guard Force: Internal Security Functions

The internal security functions of the guard force are control of the safeguards system including access control, escort, recordkeeping, surveillance, communications, investigations, accident and emergency control, training, and response to detected attempts at diversion or sabotage (Refs. 12 and 67). The number of guards required for such tasks depends on the specific site configuration; the methods selected to achieve access control, material containment, and MAA and VA security; and on the degree of security force reliability.

To protect with high assurance against collusion between security force personnel and other employees, the reference system provides that all guards have a clearance involving a full field background investigation, and that at least two guards be assigned to each of the employee-guard interfaces, i.e., the perimeter portal or the material access portal. Some additional guards are needed to monitor loading and unloading operations, to escort visitors, to monitor the maintenance of alarms and equipment, and to assist in monitoring alarms and CCTV systems. Most of these latter functions are irregular and site-specific, and the exact number of guards required to perform the functions may vary. For the reference system, it was assumed that three additional guards would be adequate.

In order to provide internal security at MOX facilities such as the reprocessing or fuel fabrication plants discussed in Section 3.2.5, the following number of guards per shift has been included in the reference safeguards system for each facility.

Facility Elements	Guards per Shift
Perimeter portal	2
MAA portal	2
Central operations center	2
Auxiliary operations center	1
Intermittent requirement	3
Supervisor	1
TOTAL	11

Every guard in a currently licensed facility must be qualified annually and must demonstrate an understanding of his duties and responsibilities (Ref. 68). Additional regulations are currently being developed for guard selection, training, testing, and evaluation to further ensure their competence and qualifications in the use of security procedures and equipment. This same screening and training of security personnel would be adopted for the MOX industry.

5.4.1.6 Guard Force: Security against External Assault

The normal onsite security force capability generally provided for protection against an external assault depends upon the design and location of the specific facility, the extent to which security forces providing internal security can be diverted to deal with an external

The defense strategy selected for the reference system was to give to the guard force, sized for safe operation and internal security, sufficient supporting measures so that it could defeat a determined armed assault by a small group and delay a larger force until reinforcements could arrive.

The inherent design features of projected MOX facilities maximize the tactical flexibility of their security forces. Many of the containment features already required under 10 CFR 50 to provide protection against internal accidents and natural phenomena, such as thick-walled reinforced concrete structure and heavy steel doors, are also significant obstacles to forced entry. The reference system provides the security force with the added advantage of hardened, defensible posts at strategically located positions along the approach to the nuclear material desired by the invader. The reference system also requires that each member of the security force be well-trained and annually qualified in the use of defense tactics and weapons. The tactics would be based on a comprehensive contingency plan for armed attack individually developed for each specific site. For added assurance, the contingency plan would include procedures for ensuring communication and coordination with local law enforcement agencies or other response forces.

The adequacy of the guard force was assessed by several different but complementary techniques. The results of several general analytic studies of guard force requirements under various conditions were examined, and the physical security practices of other Federal agencies and appropriate sectors of private industry were reviewed (Refs. 12, 23, 69, 70). It was concluded that an internal security force of 11 well-trained, appropriately equipped, and properly supported guards represents a prudent design level for secure protection against determined armed assault by small groups. This conclusion was supported by the following considerations (Ref. 71):

(a) The use of redundant and diverse barriers, sensors, defensive positions, surveillance, and communications equipment at individual sites forces any assault operation to be time-consuming, complex, and vulnerable.

(b) Well-trained guards and a well-developed contingency plan reduce the relative advantage of uninhibited choice of strategy by an assault force.

(c) Hardened defensive positions and reliable and effective sensors and communications reduce the tactical advantage to an attacking force of the element of surprise.

(d) The anticipated arrival of reinforcements places significant time and tactical constraints on any assault.

5.4.1.7 Security Operations

Current regulations, complied with by the reference system, require that there be two security operations centers at each facility to ensure redundant and independent monitoring of all alarms. Each center is capable of monitoring all active detection, surveillance and assessment systems throughout the facility; notifying both onsite and offsite response forces about any unauthorized activity; and directing such forces to where they are needed. In the reference system the main security operations center is located within the MAA building, with an auxiliary center at the protected area perimeter portal (Ref. 12). Features of the security operations centers for the reference system include:

- Offsite base station radios
- Hand-held portable radios
- Hardened security operations center
- Emergency power
- Public address system (two-way capability)
- Central alarm/admit console
- Auxiliary alarm/admit console
- CCTV control console
- Response force paging receivers
- Site signaling system
- Onsite base radio station

Both the main and auxiliary security operations centers have complete surveillance, command, and communications capabilities. Redundancy is required for all vital elements (such as sensor alarms and communications systems) to assure that command and control capabilities are not vulnerable to the failure of any single system or single network of systems. Thus, if one security operations center fails completely, effective control of security force operations can still be maintained.

5.4.1.8 Personnel Clearances

Security clearances are a basic tool for protection of classified information and sensitive items throughout the Federal Government, and are required by both DOD and DOE for all personnel having access to special nuclear materials. Since nuclear weapons are based on highly classified design information, access to such weapons requires both a security clearance and a demonstrated need for access. DOD also has a personnel reliability program under which each individual with access to nuclear weapons is continuously evaluated as to his technical competence, his physical and mental health, and his emotional stability (Ref. 72). DOE requires that any person in a position to divert or to conceal the diversion of SNM possess a DOE "L" or "Q" access authorization or a "Secret" security clearance (Ref. 73).

As described in Section 5.3.5.1, preemployment clearances would be utilized in the MOX industry along with other security measures to protect against employee collaboration in unauthorized actions. The personnel positions requiring clearances would be site-specific, but would certainly include all personnel with access to the area within a facility protected by the dual fences. All those whose jobs provide access to or control over SSNM would require clearance based on a full-field background investigation. Included would be the particularly sensitive positions involved in plutonium accountability procedures and practices, the plant security system, and the management supervision chain. Certain employees, whose positions would involve access to the protected area but who do not require unescorted access to or control over SSNM, would be given a limited clearance based on a national agency check. An estimate of the number of employees requiring clearances in typical MOX facilities has been made for the purpose of costing and impact assessment (Ref. 74). Conclusions drawn from these estimates led to a provision in the reference system that clearances be required for all security guards and for all management, administrative, and production personnel authorized to have access to the protected area of each facility.

5.4.2 Transportation Safeguards

Transportation safeguards include planning and scheduling procedures, measures to protect material during loading and unloading of transports, measures to protect material in transit and contingency plans detailing responses to emergencies. The basic elements for the transportation safeguards of the reference system are contained within the current regulatory base. Additional features considered necessary for a mature MOX industry have also been introduced to supplement the current regulatory requirements. A discussion of the components of the reference system transportation safeguards is presented in the following subsections.

5.4.2.1 Planning and Scheduling

Before any material is packaged or loaded for transport, planning and scheduling of the shipment would have to be provided. A detailed route plan would be prepared, specifying the exact roads to be taken, the rest and refueling stops along the route, and scheduled call-in times or points. Trips would be scheduled on an irregular basis so that there would be no established pattern. Response forces along the planned route would be notified so that a rapid, coordinated response, according to an established contingency plan, could be provided in case of an emergency.

5.4.2.2 Loading and Unloading Procedures

Whenever material is to be loaded for, or unloaded after, transport, specific safeguards procedures would be instituted. A restricted area would be established around the vehicle, and all access to and activities within this area strictly controlled. Security guards would be specifically detailed to monitor the area as well as the loading or unloading process. These guards would be in regular radio communication with the facility's central alarm station.

When a shipment arrives at its destination, the consignee would transmit immediate verification of its arrival to the originator of the shipment as well as preliminary notice that the SSNM containers were properly stowed and intact upon arrival.

5.4.2.3 In-Transit Protection

In-transit safeguards measures specified under the current regulatory base are a private guard escort force, communications, vehicles that resist unauthorized entry, and response forces such as State police, local law enforcement agencies (LLEA's) or dedicated forces. As with fixed sites, a number of alternative strategies could provide equivalent levels of protection. These strategies range from one which employs vehicles designed to delay theft for long periods of time and relies on State police for support, to one which places primary dependence on escort forces.

Reliance on State and local police forces has the advantage that they would not be involved in an initial attack, are normally present throughout the United States, are familiar with roadways, can legally engage in hot pursuit, and, in most States, have good communications systems. Estimates in terms of force size and arrival time have been made of current response capabilities for State and local police along selected routes (Ref. 15). Adequate levels of response can be achieved along some U.S. routes without special arrangements being made with local law enforcement agencies, provided properly designed vehicles (i.e., vehicles which can be immobilized and are designed to be penetration resistant) and proper procedures are used. The study also indicates that effective levels of response by the State or local police would not be possible on many routes unless special arrangements were made. Whether or not such arrangements with the local agencies would be required depends, for example, on the police density along the route, the type of road, the communications available, the procedural arrangements the shipper could make with the State and local police in the jurisdictions involved, and the time of day traveled.

If State or local police were readily available, escort forces could be reduced to two escort vehicles with two guards each, a level which would ensure adequate warning and delay. However, since the availability of outside assistance would vary with the route, the reference system is based on the conservative assumption that such assistance will be minimal (even though PuO_2 and MOX would actually be shipped along many routes where relatively prompt response would be available). Assuming an essentially self-contained protection capability sets an upper bound in estimating the cost and societal impact of safeguarding shipments. Accordingly, the reference system uses 12 armed guards during transport. These guards ride in four escort vehicles, each designed to withstand light weapons fire.

To compensate for any advantage an assault force could have in selecting terrain, timing, and tactics, the reference system includes a specially designed penetration-resistant vehicle to provide the escort guards maximum tactical flexibility in protecting the shipment. The vehicle is one with performance characteristics similar to that of the Integrated Container Vehicle (ICV) described in Section 3.4.3.3 and in References 14 and 15. This vehicle can be immobilized to prevent attackers from driving or towing it away, and a sophisticated multilayered armor system provides significant delay against penetration with explosives, torches or tools. An additional point in favor of such an integrated design is that it would reduce shipping costs, since the vehicle shell can be used instead of special containers for purposes of heat dissipation and radiation protection.

Complementing the protection provided by the vehicle is a communications system for notifying the authorities of an attack. This could be provided either by direct communications into a police network or by a separate, reliable, and rapid communications system via the licensee or his agent. A communications system such as that used by DOE was assumed for costing purposes.*

All personnel in the convoy, including drivers and escort guards, would require a clearance based on a full-field background investigation. As an added precaution for ensuring transport driver reliability and to provide assurance of an immediate alert should an assault be launched on the transport vehicle, one escort vehicle would remain within sight of the transport vehicle at all times.

---

*The DOE communications system, denoted SECOM, is a secure digital radio communications system that permits continuous communication with vehicles anywhere in the continental United States.

5.4.2.4 Contingency Plans

The transportation safeguards of the reference system include provision for contingency plans detailing the appropriate responses to various types of emergencies. The plans would specify the tactics to be utilized in response to attempts at theft or sabotage, as well as the appropriate security force response to other events such as vehicle disablement, unusual weather, natural disasters, and civil disturbance conditions. The plans would be based on established liaison with response forces along the transport route, and would include such reinforcement as they were able to assure.

5.4.2.5 Summary

The reference system in-transit safeguards features include:

Transport Vehicle
ICV
Immobilization capability
Digital radio communications

Escort Force
9 - 12 guards per trip (including 2 transport drivers)*

Escort Vehicles
Armored
2 - 4 per trip
Digital radio communications

These transportation safeguards were assessed on the basis of several differing but complementary approaches. Included were analytic studies of escort force requirements under various conditions (Refs. 15, 23, and 69), a survey of expert opinion, and a review of the physical security practices of private industry and of other Federal agencies. The conclusion of the assessment (Ref. 71) was that in-transit physical protection, like that for fixed sites, would be appropriate for defense against a determined armed assault by a small group armed with automatic weapons. The bases for this assessment are the diverse and redundant protective measures (i.e., penetration-resistant transport vehicles, escort guards, provisions for effective use of local law enforcement), which provide significant obstacles to an assault operation.

5.4.3 Protection of MOX at Reactors

Unirradiated MOX fuel assemblies would be stored at recipient reactor sites for a period of time before insertion into the reactor core. The period of storage would be a function of reactor operational practice. Periods on the order of one month are currently typical for LWR fuels.

---

*The number of guards and escort vehicles is determined by the availability of local law enforcement resources along the convoy route. For costing purposes, a maximum number of escorts and vehicles is included in the reference system.

Safeguards requirements for protecting all licensed LWR reactors against acts of sabotage have recently been introduced (10 CFR 73.55, Ref. 25).* The regulations contain both a general performance requirement and specific prescriptions for equipment, procedures, and security personnel. If a licensee can adequately demonstrate compliance with the general performance requirement through implementation of other safeguards measures which are equivalent to the specific measures prescribed in 10 CFR 73.55 (Ref. 25), the latter may be waived by the NRC.

The general performance requirement, with which the reference system complies, specifies that the licensee shall establish and maintain a safeguards system which protects "with high assurance" against specified external and internal threats. The specified external threats consist of "a determined violent assault, attack by stealth, or deceptive actions, of several persons who are well trained and dedicated, may possess the assistance (active and passive) of a knowledgeable insider, and possess automatic rifles, explosives, hand-held tools, and incapacitating agents." The specified internal threat consists of one employee in any position.

Specific requirements for a complete physical protection system are detailed in 10 CFR 73.55 (Ref. 25) as follow:

> The licensee must establish a security organization, including guards who have been properly trained and qualified. Vital equipment must be located in vital areas which must be surrounded by two physical barriers. The protected area perimeter is also protected by an intrusion detection system. The protected area and the isolation zones at the perimeter must be illuminated during darkness; assessment capability such as CCTV must also be provided. All personnel entering the protected area must present proper identification and are subject to search for weapons, explosives, or other contraband. Regular employees must have picture badges, and visitors must be escorted within the protected area. All vehicles entering the protected area must be searched and visiting vehicles are escorted within the area. The access control function must be housed in bullet-resisting structures."

Two continuously manned alarmed stations are required. One must be hardened and located onsite; the other may be offsite. Every guard must be able to maintain continuous communications with each alarm station, and each alarm station must possess both telephone and radio or microwave voice communications with offsite response forces. All alarm equipment must be tested regularly, and no less often than once a week. All communications equipment must be checked at the beginning of every shift.

The nominal security force requirement consists of 10 armed responders per shift. This number may vary on the basis of site-specific conditions, such as the training and qualifications of the guard force, the availability of defensive positions, and the availability and dependability of local law enforcement response. These site-specific considerations may either increase or decrease the required onsite security force, but a minimum of five guards is always required.

---

*These regulations were published in the Federal Register on February 24, 1977. They became effective on March 28, 1977. Revisions to the remainder of 10 CFR 73 were published in the Federal Register on July 5, 1977. These revisions upgraded the physical protection requirements for fuel cycle facilities and associated transportation activities and provide strengthened physical protection against sabotage that could lead to radiological consequences (radiological sabotage and theft of SNNM).

These recently implemented power reactor safeguards provide a level of physical protection against assaults comparable to that which the reference system requires at fuel cycle facilities. Accordingly, only a few additional measures are indicated for MOX protection when fresh MOX fuel is stored at a reactor site prior to insertion into the reactor core. A hardened and alarmed storage area for storing the MOX assemblies would be necessary. For costing purposes, the reference system provides such an area at the reactor sites. When fresh MOX fuel is being stored at reactors, the system provides for exit searches for plutonium by means of fixed gamma and neutron detectors located at the MAA portal.

5.5 THE APPLICATION OF THE REFERENCE SYSTEM TO ALTERNATIVE LWR FUEL CYCLE OPTIONS

For purposes of assessing the environmental impact of plutonium recycle, five alternative LWR fuel cycle options were defined in NUREG-0002 (Ref. 1). They are briefly described in Section 3.2.7 of this document. A discussion of the application of the reference safeguards system to each of these alternatives follows.

Alternative 1 (prompt fuel reprocessing, prompt uranium recycle, and delayed plutonium recycle) would require implementing the measures prescribed by the reference system for reprocessing facilities. In addition, a plutonium storage facility would have to be protected. A detailed design study of appropriate measures for such a storage facility has not been performed because of configuration uncertainty. However, it is clear that physical security measures similar to those described for reprocessing and fuel fabrication facilities would have to be provided at such a storage facility. For cost and societal impact assessment of the reference system, it was assumed that such a facility would involve physical protection measures similar to those described for reprocessing facilities. Material accounting measures would relate to item control and verification, since the storage facility would deal only with discrete items. Thus, it was assumed that accounting measures equivalent to those used for fuel assembly facilities would be implemented in the plutonium storage facility.

The transportation links from the reprocessing facilities to the storage facility would be protected by the transportation protection measures already described for the reference system.

The other facilities (fuel fabrication and assembly) and transportation links would be protected by the described reference system measures as they became operational.

Alternative 2 (delayed fuel reprocessing, followed by uranium and plutonium recycle) would ultimately require essentially the same level of safeguards as provided under the reference system for immediate reprocessing and recycle. One issue regarding Alternative 2 is the effect that a delay in the initiation of reprocessing would have on the nature of the specific technology available to achieve safeguards for a MOX industry. Delay in reprocessing would improve the prospects for introducing technically advanced safeguards concepts. Although the use of such improved measures might reduce the cost of the reference system, their availability at specific times in the future cannot now be predicted. Accordingly, for costing purposes, it was assumed that MOX safeguards for Alternative 2 would be based on currently available technology and on the measures of the reference system. These measures would be provided at each MOX reprocessing, fuel fabrication, and fuel assembly facility; in the transportation links between them; and at each reactor using MOX fuel as these facilities begin operation after the delay period.

Alternative 3 (prompt uranium and plutonium recycle) is the case discussed in this document. It would require installation of the reference system safeguards measures in all MOX facilities as they become operational.

Alternative 5 (uranium recycle with no plutonium recycle) would require that reference system safeguards measures be installed at reprocessing facilities, at storage facilities for separated plutonium, and in the transportation links between them, only if the plutonium is separated from the spent fuel wastes. If the Pu is left in the spent fuel wastes, no special safeguards measures would be required.

Alternative 6 (no uranium or plutonium recycle) requires no MOX safeguards protection measures.

5.6 COST ASSESSMENT OF THE REFERENCE SYSTEM

As indicated in Section 3.2, the mature MOX industry would contain five reprocessing plants, eight fuel fabrication plants, seven fuel assembly plants, and a complete transportation network linking these plants to 250 reactors that use MOX. The MOX transportation network would include three legs: Leg 1, from the reprocessing plant to the fuel fabrication plant; Leg 2, from the spent fuel fabrication plant to the fuel assembly plant; and Leg 3, from the fuel assembly plant to the reactor.

Cost estimates* for applying the reference safeguards system to this industry are developed in Appendix A. A summary overview of these costs, based on the detailed estimates presented in Appendix A, is given in Tables 5.4, 5.5, 5.6, 5.7 and 5.8.

The estimated initial capital costs and annualized operating costs for the reference safeguards system, as applied to a mature MOX industry, are given in Table 5.4 by individual plant type and for each tranportation leg. Total industry cost, together with the total costs by plant type and for transportation and regulation, is summarized in Table 5.5 for the year 2000. In order to illustrate the added increment in total fuel cycle cost introduced by the safeguards requirements of a MOX industry, the annualized safeguards costs from Table 5.5 are tabulated and compared to the annualized fuel cycle costs in Table 5.6.

As indicated in Table 5.6, the reference safeguards system annualized cost represents, on the average, less than seven percent of the annualized MOX industry fuel cycle costs (based on Alternative 3 of NUREG-0002, Ref. 1). More meaningful to the consumer would be the fact that, as developed in Appendix A (Figure A1.1), the reference safeguards system costs (.09 mills/kWh) would be approximately 0.2 percent of the total cost to the consumer of MOX nuclear electric power (35-60 mills/kWh). It therefore may be concluded that the added cost of safeguarding a future MOX industry, utilizing existing safeguards technology, would not be a pivotal issue in assessing the impact of introducing such an industry into the U.S. economy. Variation in

---

*These estimates are made in terms of 1975 dollars to permit ready comparison with cost figures presented in the Health, Safety, and Environmental portion of the Final Environmental Statement on Mixed Oxide Fuels.

TABLE 5.4

REFERENCE SYSTEM SAFEGUARDS COSTS IN THE YEAR 2000 FOR INDIVIDUAL FACILITIES AND TRANSPORTATION ELEMENTS
(millions of 1975 dollars)

Element	Initial Capital Costs	Annualized Costs[a]
Reprocessing Plant	7.2	6.2
Fuel Fabrication Plant	5.5	7.3
Fuel Assembly Plant	1.3	1.7
Reactor Site[b]	0.1	[c]
Transportation System		
Communications Network	5.5	3.6
Leg 1 - PuO_2 Transport	7.4	3.5
Leg 2 - MOX Rod Transport	9.3	4.7
Leg 3 - MOX Assembly Transport	29.6	24.0

---

[a] Annualized costs include personnel costs, depreciation, return on investment, and operations and maintenance costs.

[b] Reactor safeguards costs are only those associated with the protection of unirradiated MOX fuel when stored at reactor sites.

[c] Less than $50,000.

TABLE 5.5

REFERENCE SYSTEM SAFEGUARDS COSTS IN THE YEAR 2000 FOR THE MOX INDUSTRY
(millions of 1975 dollars)

Element	Initial Capital Costs[a]	Annualized Costs[a,b]
5 Reprocessing Plants	35.8	30.8
8 Fuel Fabrication Plants	44.1	58.3
7 Fuel Assembly Plants	8.8	11.5
250 Reactors at 125 sites[c]	16.6	3.0
Fixed Site Subtotals	105.3	103.6
Transportation	51.7	35.8
Regulation	1.8	1.7
TOTAL	158.8	141.1

---

[a] The physical security equipment costs and the economic assumptions used for all cost estimates were validated by the MITRE Corporation (Ref. 75). If the new item costs recommended in the MITRE Report were substituted for the costs in this report, the total annualized costs would increase by approximately four percent.

[b] Annualized costs include personnel costs, depreciation, return on investment, and operations and maintenance costs.

[c] Reactor safeguards costs are only those associated with the protection of unirradiated MOX fuel when stored at reactor sites.

TABLE 5.6

COMPARISON OF MOX INDUSTRY FUEL CYCLE AND SAFEGUARDS COSTS IN THE YEAR 2000

(millions of 1975 dollars)

Activity	Annualized Safeguards Costs	Annualized Fuel Cycle Costs[a]	Safeguards Costs as % of Fuel Cycle Costs
Reprocessing	30.8	1,586	1.9%
MOX Fabrication and Transport[b]	105.6	534	19.8%
Regulation	1.7	-	-
Reactors[c]	3.0	-	-
Total MOX Fuel Cycle	141.1	2,120	6.7%

---

[a] Fuel cycle costs are for Alternative 3 of NUREG-0002 (Ref. 1, Chapter XI).

[b] Includes costs for fabrication of fuel rods and assemblies and transportation system costs.

[c] Reactor safeguards costs are only those associated with the protection of unirradiated MOX fuel when stored at reactor sites.

assumptions concerning specific site options and in detailed costs of the various safeguarding elements employed does not materially change this observation. Cost assessment and the effect on costs of several modifications to the reference system which might further reduce safeguards concerns or mitigate societal impacts are treated in Chapter 6.

An estimate of the cost of applying, as appropriate, the reference safeguards system to the other industry alternatives discussed in Section 3.2.7 is also included in Appendix A. A summary comparison for all five alternatives of the annualized safeguards costs for the year 2000 and the annualized cumulative costs for a 25-year period (both undiscounted and discounted) is made in Table 5.7. The data indicate that the incremental cost, however viewed, of safeguarding the other industry alternatives considered in NUREG-0002, is no greater than that of Alternative 3 (prompt uranium and plutonium recycle).

As indicated in Section 5.3.5, the safeguards system should be adaptable to possible changes in perceptions of the threat. Accordingly, studies were made to determine the cost sensitivity of the reference system to varying levels of protection. Data presented in Appendix A (Table A1.5) indicate that over half of the annual operating cost for the reference system (64 percent of the total annualized cost) is for personnel, of which the security force constitutes more than half. The balance of the cost is primarily for hardware and equipment and would change only slightly with variations in safeguards capability. For a given installation or transport leg, the major change in the reference system for dealing with an increased (or reduced) level of adversary strength would be a change in the size of the security force. Although the concomitant change in safeguards annual operating costs may be sizable relative to the reference system annual cost, only a minor adjustment to the consumer cost of nuclear electricity would be introduced. (Figures A1.2 to A1.5 of Appendix A show the sensitivity of safeguards system costs to changes in security force numbers.)

TABLE 5.7

ANNUALIZED SAFEGUARDS COSTS OF ALTERNATIVE FUEL CYCLE OPTIONS
(millions of 1975 dollars)

Fuel Cycle Options	Alt. 1	Alt. 2	Alt. 3	Alt. 5[a]	Alt. 6
Year 2000 (Undiscounted)	140	140	140	37	0
Cumulative, 1975-2000 (Undiscounted)	1,350	1,340	1,350	360	0
Cumulative, 1975-2000 (Discounted)	260	220	260	62	0

---

[a] The values listed under Alternative 5 assume plutonium has been separated from the waste. The costs for Alternative 5 are zero if plutonium is left in the waste.

5.7 SUMMARY

Two major issues have been addressed regarding the reference safeguards system:

- the technical and operational feasibility of providing adequate safeguards for a mature MOX industry, and
- the economic feasibility of implementing such safeguards.

It was found that there are no apparent operational or technical barriers in meeting the MOX industry safeguards system design objectives discussed in Section 5.2. The reference safeguards system, which is not necessarily the recommended system, achieves the safeguards design objectives and utilizes measures representative of current technologies and procedures. Future improvements in today's safeguards capability can be anticipated and could, if appropriate, be adopted by the MOX industry.

Cost estimates for safeguarding a future mature MOX industry with currently available safeguards concepts and technology suggest that safeguards costs will have a very minor influence on the total cost of MOX-generated nuclear power. Although the reference safeguards system costs represent almost seven percent of the estimated fuel cycle costs, they would be only 0.2 percent of total electricity costs. As a result, the size of the security force, the level of safeguards provided, and their related cost would not have a pivotal influence on the total cost of MOX-generated power. The size of the security force could be varied greatly (up or down) to accommodate changing perceptions in the size of the threat, and the result would be a relatively insignificant change in the cost of power.

CHAPTER 5

REFERENCES

1. The U.S. Nuclear Regulatory Commission, "Final Generic Environmental Statement on the Use of Recycled Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors," NUREG-0002, August 1976.*

2. Lynn G. Gref and Jack W. Rosengren, R&D Associates, "An Assessment of Evaluation Techniques for MOX Interim Safeguards Rules," Final Report, October 1976.[b]

3. H. A. Bennett et al., Sandia Laboratories, "Safeguards System Effectiveness Modeling," SAND-76-0428, paper, 17th Annual Conference of Institute of Nuclear Materials Management, Seattle, Washington, June 22-24, 1976.[b]

4. T. I. McSweeney et al., "Improved Material Accounting for Plutonium Processing Facilities and a ^{235}U-HTGR Fuel Fabrication Facility," BNWL-2098, UC-16, prepared for NRC by Battelle Pacific Northwest Laboratory, October 1975.[b]

5. Battelle Pacific Northwest Laboratory, "Limitations on Personnnel Access to SNM Records," September 1975. (Confidential)+++

6. Brookhaven National Laboratory, "Limitations on Personnel Access to Special Nuclear Material Records," November 1975.[b]

7. Science Applications, Inc., "An Evaluation of Real-Time Material Control and Accountability in a Model MO_2 Fuel Plant," SAI-75-648-LJ, September 1975.[b] (Section 4, pp. 127-147, "Evaluation of Prompt Theft Indicators," Confidential, has been deleted.)

8. J. P. Indusi et al., "Evaluation of the Impact of Safeguards Measures," Draft Final Report, prepared for ERDA and NRC by Brookhaven National Laboratory, File No. 5.9.3, August 1975.[b]

9. "Executive Summary of the Special Safeguards Study on Material Control and Accounting Systems," Final Report, prepared for NRC by Lawrence Livermore Laboratory and Science Applications, Inc., September 1975.[b]

10. Lawrence Livermore Laboratory, "Technical Appendix for the Special Safeguards Study on Material Control and Accounting Systems," Final Report, September 1975.[b]

11. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. I, "Executive Summary," SAND-75-0457, March 1976.**

12. Harold Bennett et al., "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. II, "Fixed-Site Physical Protection Systems(U)," SAND-75-0457, prepared for NRC by Sandia Laboratories, March 1976. (Confidential)**

13. Kenneth Adams et al., "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. III, "Elements of Physical Protection for Fixed Sites(U)," SAND-75-0457, prepared for NRC by Sandia Laboratories, March 1976. (Secret)**

14. Kenneth Battleson et al., "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. IV, "Transportation Mode Analysis(U)," SAND-75-0457, prepared for NRC by Sandia Laboratories, March 1976. (Confidential)**

15. Kenneth Adams et al., "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. V, "Elements of Physical Protection for Transportation(U)," SAND-75-0457, prepared for NRC by Sandia Laboratories, March 1976. (Secret)**

16. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. VI, "Relocation and Recovery(U)," SAND-75-0457, March 1976. (Secret)**

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

**Unclassified versions of the classified references and copies of the unclassified reference are available in the NRC PDR for inspection and copying, for a fee.

+++This document is not publicly available because it contains national security information.

bAvailable in source file for USNRC Report NUREG-0414, May, 1978.

17. G. R. Bray *et al.*, "Material Control and Accounting for Plutonium Recycle Facilities," SAI-76-539-LJ, prepared for NRC by Science Applications, Inc., March 1976.[b]

18. U.S. Nuclear Regulatory Commission, "Reactor Safety Study--An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," Executive Summary, WASH-1400 (NUREG-75 014), October 1975.*

19. U.S. Energy Research and Development Administration, "Societal Risk Approach to Safeguards Design and Evaluation," ERDA-7, June 1975.*

20. William M. Murphey and John C. Schleter, "Practicality of Diversion Path Analysis," NBSIR 74-524, prepared for ERDA by the National Bureau of Standards, July 1974.++

21. Marcia Maltese, Karl Goodwin, and John Schleter, "Diversion Path Analysis Handbook," 2 vols., prepared for ERDA by the National Bureau of Standards, October 1976.++

22. J.R. NiCastro and R. Liner, "Evaluation and Design Methodology for Generic Safeguard Systems," Interim Technical Memorandum, SAI-76-658-WA, prepared for NRC by Science Applications, Inc., October 1976.[b]

23. Lulejian & Associates, Inc., "The Protection of Nuclear Facilities and Transport against Armed Attacks," December 1976. (Secret)+++

24. The U.S. Nuclear Regulatory Commission, The U.S. Energy Research and Development Administration, "Joint ERDA-NRC Task Force on Safeguards(U)," NUREG-0095, ERDA 77-34, July 1976.**

25. As found in the *Federal Register* *42*, No. 37, 10836-840 (Feb. 24, 1977).***

26. H. Edelhertz, M. Walsh, "White Collar Challenge to Nuclear Safeguards," NUREG-0156, NRC-13, prepared for NRC by Battelle Human Affairs Research Centers, January 1977.*

27. *Federal Register* *42*, No. 52, 14880-883 (March 17, 1977).***

28. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.44, "Perimeter Intrusion Alarm Systems," Revision 1, June 1976.**

29. U.S. Atomic Energy Commission, Regulatory Guide 5.7, "Control of Personnel Access to Protected Areas, Vital Areas, and Material Access Areas," June 1973.**

30. Martin Messinger, U.S. Nuclear Regulatory Commission, "A New Look at Portal Monitoring," NR-NMSS-007, May 1976.**

31. "The Spiking of Special Nuclear Materials as a Safeguards Measure," Vol. 1, prepared for the NRC by Brookhaven National Laboratory, September 1975. (Under classification review--Confidential)+++

32. Cesar Sastre, Nicolas Ovuka, Michael J. Gaitanis, Debbie D. Hill, and Robert J. Sorenson, "Panel Discussion on Use of Security Seals for Safeguards," (15th Annual Meeting of Institute of Nuclear Materials Management, June 19-21, 1974, Atlanta, Georgia), *Proceedings, Institute of Nuclear Materials Management, Inc. III*, No. III (Fall 1974).***

33. U.S. Atomic Energy Commission, Regulatory Guide 5.10, "Selection and Use of Pressure-Sensitive Seals on Containers for Onsite Storage of Special Nuclear Material," July 1973.**

34. U.S. Atomic Energy Commission, Regulatory Guide 5.15, "Security Seals for the Protection and Control of Special Nuclear Material," January 1973.**

35. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.26, "Selection of Material Balance Areas and Item Control Areas," Revision 1, April 1975.**

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

**Available in NRC PDR for inspection and copying, for a fee.

***Available from public technical libraries.

++Available in the DOE (ERDA) PDR.

+++This document is not publicly available because it contains national security information.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

36. U.S. Atomic Energy Commission, Regulatory Guide 5.6, "Standard Methods for Chemical Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Plutonium Dioxide Powders and Pellets and Nuclear-Grade Mixed Oxides [U, Pu] O_2)," May 1973.**

37. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.16, "Standard Methods for Chemical, Mass Spectrometric, Spectrochemical, Nuclear, and Radiochemical Analysis of Nuclear-Grade Plutonium Nitrate Solutions and Plutonium Metal," Revision 1, May 1975.**

38. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.48, "Design Considerations--Systems for Measuring the Mass of Liquids," February 1975.**

39. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.53, "Qualification, Calibration, and Error Estimation Methods for Nondestructive Assay," August 1975.**

40. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.57, "Shipping and Receiving Control of Special Nuclear Material," June 1976.**

41. U.S. Atomic Energy Commission, Regulatory Guide 5.28, "Evaluation of Shipper-Receiver Differences in the Transfer of Special Nuclear Materials," June 1974.**

42. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.24, "Analysis and Use of Process Data for the Protection of Special Nuclear Material," June 1974.**

43. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.49, "Internal Transfers of Special Nuclear Materials," March 1975.**

44. U.S. Atomic Energy Commission, Regulatory Guide 5.2, "Classification of Unirradiated Plutonium and Uranium Scrap," December 1972.**

45. U.S. Atomic Energy Commission, Regulatory Guide 5.13, "Conduct of Nuclear Material Physical Inventories," November 1973.**

46. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.51, "Management Review of Nuclear Material Control and Accounting Systems," June 1975.**

47. J.E. Glancy, Science Applications, Inc., "Safeguards Implementation Practices for a Model Mixed Oxide Recycle Fuel Fabrication Facility," BNL-21409, prepared for ERDA by Brookhaven National Laboratory, May 1976.[b]

48. Clement J. Rodden (ed.), U.S. Atomic Energy Commission, "Selected Measurement Methods for Plutonium and Uranium in the Nuclear Fuel Cycle," TID-7029, 2nd Ed., 1972.*

49. U.S. Atomic Energy Commission, Regulatory Guide 5.40, "Methods for the Accountability of Plutonium Dioxide Powder," December 1974.**

50. Richard L. Bramblett, IRT Corp., "Passive and Active Measurement of SNM in 55-Gallon Drums," (paper, 16th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 18-20, 1975, New Orleans, Louisiana), Proceedings, Institute of Nuclear Materials Management, Inc. IV, No. III, 137-151 (Fall 1975).***

51. P.B. Wallingford, "Safeguards Barrel Scanner," (paper, 16th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 18-20, 1975, New Orleans, Louisiana) prepared for ERDA by E.I. duPont de Nemours and Co., Proceedings, Institute of Nuclear Materials Management, Inc. IV, No. I, 516-521 (February 1975).***

52. Hans J. Weber, Intelcom Rad Tech, "A Fission Multiplicity Detector for Plutonium Waste," (paper, 15th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 19-21, 1974, Atlanta, Georgia), Proceedings, Institute of Nuclear Materials Management, Inc. III, 107-117 (Fall 1974).***

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

**Available in NRC PDR for inspection and copying, for a fee.

***Available from public technical libraries.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

53. E. Ray Martin, David F. Jones, Leslie G. Speir and Alan C. Walker, "Field Assay of Plutonium with a New Computerized Segmented Gamma Scan Instrument," (paper, 15th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 19-21, 1974, Atlanta, Georgia), prepared for the AEC by Nuclear Analysis Research Group and Los Alamos Scientific Laboratory, Proceedings, Institute of Nuclear Materials Management, Inc. III, No. III, 151-170 (Fall 1974).***

54. T. Gozani, Intelcom Rad Tech, "Leached Hull Monitor for Detection of Undissolved Irradiated Nuclear Fuel," (paper, 15th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 19-21, 1974, Atlanta, Georgia), Proceedings, Institute of Nuclear Materials Management, Inc. III, No. III, 203-216 (Fall 1974).***

55. Herman Miller and Stephen H. Shepard, National Nuclear Corporation, "Recent Developments of NNC Multi-Channel 'Fuel Scan'," (paper, 16th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 18-20, 1975, New Orleans, Louisiana), Proceedings, Institute of Nuclear Materials Management, Inc. IV, No. III, 567-576 (Fall 1975).***

56. "High Speed Fuel Rod Scanner," Californium-252 Progress, No. 15, 27-28 (May 1973).***

57. R. G. Gulmacher et al., Lawrence Livermore Laboratory, T. E. Shea and S. P. Turel, U.S. Atomic Energy Commission, "Methods for the Accountability of Plutonium Nitrate Solutions," WASH-1282, February 1974.*

58. U.S. Atomic Energy Commission, Regulatory Guide 5.19, "Methods for the Accountability of Plutonium Nitrate Solutions," January 1974.**

59. F. M. Groth and F. O. Cartan, "Evaluation of Instrumentation for Nuclear Fuels Reprocessing Plant Input Weight Measurements," ICP-1014, prepared for AEC by Allied Chemical Corp., July 1972.b

60. D. W. Wilson, General Electric, "Dynamic Inventory: Dream or Necessity," (paper, 14th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 20-22, 1973, San Diego, California), Proceedings, Institute of Nuclear Materials Management Inc., II, No. 3, 30-40 (Fall 1973).***

61. W. B. Seefeldt, C. H. Bean and G. J. Bernstein, Argonne National Laboratory, "Some Considerations Enabling Dynamic Inventory in Fuel Cycle Facilities," (paper, 14th Annual Meeting, Institute of Nuclear Materials Management, Inc., June 20-22, 1973, San Diego, California), Proceedings, Institute of Nuclear Materials Management, Inc. II, No. 3, 88-109 (Fall 1973).***

62. S. M. Zivi and W. B. Seefeldt, "Temporal Response Methods for Dynamic Measurement of In-Process Inventory of Dissolved Nuclear Materials," (paper, 17th Annual Meeting, Institute of Nuclear Materials Management, Inc., Seattle, Washington, June 22-24, 1976), Proceedings, Institute of Nuclear Materials Management, Inc. V, No. 1, 33-46 (Spring 1976).***

63. U.S. Nuclear Regulatory Commission, Regulatory Guide 5.47, "Control and Accountability of Plutonium in Waste Material," February 1975.**

64. U.S. Atomic Energy Commission, Regulatory Guide 5.11, "Nondestructive Assay of Special Nuclear Material Contained in Scrap and Waste," October 1973.**

65. U.S. Atomic Energy Commission, Regulatory Guide 5.34, "Nondestructive Assay for Plutonium in Scrap Material by Spontaneous Fission Detection," June 1974.**

66. U.S. Atomic Energy Commission, Regulatory Guide 5.14, "Visual Surveillance of Individuals in Material Access Areas," November 1973.**

67. U.S. Atomic Energy Commission, Regulatory Guide 5.43, "Plant Security Force Duties," January 1975.**

68. U.S. Atomic Energy Commission, Regulatory Guide 5.20, "Training, Equipping, and Qualifying of Guards and Watchmen," January 1974.**

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

**Available in NRC PDR for inspection and copying, for a fee

***Availabe in public technical libraries.

bAvailable in source file for USNRC Report NUREG-0414, May 1978.

69. Lawrence Livermore Laboratory, "Comparison of Security Force Concepts fo[illegible]ting Nuclear Facilities," Final Report, and "Nuclear Power Plants," Appendix [illegible]51954, October 1975. (Confidential)+++

70. International Research and Technology Corporation, "Estimates of Security Personnel Required to Protect Nuclear Fuel Cycle Components against Theft of Special Nuclear Materials and Sabotage," IR&T 388-R, August 1975. (Confidential)+++

71. H. W. Hevert, E. Knight, "Net Assessment: Reference Safeguards System vs. Overt Theft Attempts," Final Report, RDA-TR-191300-001, Prepared for NRC by R&D associates, August 1977.[b]

72. U.S. Department of Defense, "Nuclear Weapon Personnel Reliability Program," DOD Directive 5210.42, April 1975.[b]

73. U.S. Energy Research and Development Administration, ERDA Manual, App. 2405, Part 1, "Physical Protection of Unclassified Special Nuclear Material," June 1975.++

74. Science Applications, Inc., Technical Note, SAI-NRC-2, July 1976.[b]

75. The U.S. Nuclear Regulatory Commission, "An Evaluation of Cost Estimates of Physical Security Systems for Recycled Nuclear Fuels, NUREG CR/0040, May 1978.*

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

++Available in DOE (ERDA) PDR.

+++This document is not publicly available because it contains national security information.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

CHAPTER 6
ALTERNATIVE SAFEGUARDS OPTIONS

6.1 INTRODUCTION

Chapter 5 describes and assesses a safeguards system, denoted the reference system, designed to protect the projected MOX industry with currently available technology, under the current regulatory framework. Chapter 6 examines the impacts and relative effectiveness of several possible modifications to that reference system which might further reduce safeguards risks or mitigate societal impacts. It should be noted that these alternative safeguards options could also apply to any of the four GESMO fuel cycle alternatives requiring safeguards (Alternatives 1, 2, 3 and 5) described in Section 3.2.7.

The alternatives either: (1) extend safeguards beyond the current legislative/regulatory framework for SSNM protection; or (2) involve alteration for safeguards purposes of various elements in the projected MOX industry. The discussion in this chapter provides relevant information, including summaries of recent studies, to aid in evaluating the effectiveness of these proposed modifications. It is not the intent to recommend approval or rejection of any of the modifications, but merely to present the major consideration influencing their possible adoption.

Five suggested safeguards modifications were considered of sufficient interest to warrant review. The first two, which focus on the guard force, would require new State or Federal legislation. These two options are: (1) the employment of a Federal guard force; and (2) providing the guard force (Federal or private) with automatic weapons. The other three options examined, unlike the reference system, involve alterations in the industrial procedures envisioned for the future MOX industry. These modifications are: (3) blending plutonium and uranium oxides early in the fuel cycle in order to reduce the presence of pure compounds of plutonium; (4) the collocation of various numbers and types of fuel cycle facilities to reduce the need for shipment of pure plutonium oxides and MOX; and (5) the use of air transportation to eliminate routine road shipment of pure plutonium compounds.

6.2 A FEDERAL GUARD FORCE

This section summarizes the results of a recently completed NRC study (Ref. 1) concerning the desirability of establishing a Federal guard force to protect SSNM handled by private industry. The establishment of such a Federal force would shift from private industry to the Federal Government the major responsibility for the protection of plutonium at licensed facilities and during transit. Such action would require new legislation.

An NRC study of the use of Federal guards to protect SSNM was required by the Energy Reorganization Act of 1974, which specifically directed the newly created NRC Office of Nuclear Material Safety and Safeguards to conduct a study of the "need for, and feasibility of, establishing a security agency within the Office for the purpose of performing safeguards functions." This study became known as the Security Agency Study.

The Security Agency Study was conducted by the NRC staff, augmented by the services of nine special consultants and by commissioned studies on various aspects of the problem by twelve contractor organizations. Advice and assistance were also obtained from ERDA (now DOE), the General Services Administration, and the U.S. Marshals Service. Much of the study group's effort was devoted to onsite visits and meetings with Government and industry groups familiar with nuclear plant and materials security, as well as with legal, academic and public interest groups. In total, more than 300 persons contributed to the assessment.

The study identified 16 criteria that provide a basis for comparing the relative effectiveness of private and Federal guard forces. They are:

1. Ability to apply appropriate legal force against threats
2. Authority to make an arrest
3. General knowledge of security procedures and skills
4. Specific security knowledge concerning site, facility and equipment
5. Psychological fitness for responsibilities
6. Physical fitness
7. Alertness
8. Willingness to endure hardships in performance of duties, including willingness to risk life and use force if necessary
9. Ability to carry arms of various numbers and types
10. Lack of vulnerability to surprise or armed attack
11. Deterrent image
12. Liaison with offsite reaction forces
13. Chain of command and controllability during crisis
14. Compatibility in normal operations
15. Adherence to regulatory requirements
16. Labor stability (e.g., strikes).

The study concluded that guard force effectiveness depends primarily on personal qualities and actions that are determined by regulations and policies and the manner of their implementation, factors that are essentially independent of whether the guard force is Federal or private. For example, regulations equally applicable to Federal or private guards can specify physical and mental requirements, training, weaponry, and duties.

In analyzing the 16 criteria, the study concluded that a Federal guard force would have an inherent advantage over an upgraded private guard force in only one area, criterion 15, adherence to regulatory requirements. It was postulated that private guards, especially those directly employed by facilities as opposed to contract guards, could in theory be subject to improper pressures from facility managers to cut corners or ignore safeguards regulations. Federal guards could be less subject to such pressures. However, the study also pointed out that this potential problem with private guards might be alleviated through careful design of regulatory procedures.

In two areas, criteria 13 and 14, Federal guards at fixed sites appear to pose problems that do not occur with private guards. In a privately owned facility, where everyone else reports through a single chain of command to the plant manager, the presence of a security force that reports to a Federal authority physically removed from the site might complicate normal operations and lead to possible conflict and confusion over chain of command during a crisis. On the other hand, for in-transit security, where the plant organization is not present and primary reliance for support is on agencies of local, State, or Federal governments, Federal guards could have an organizational advantage through their ready identification with governmental agencies and procedures.

In the general area of public policy and administrative considerations, the study found that the disadvantages of a Federal guard force exceed the advantages. If NRC were given direct operating responsibility for security forces in the nuclear industry, a severe organizational imbalance could result as a 2,000-person regulatory agency attempted to absorb a security force three to four times its size. A similar argument exists against incorporating the Federal guard force into the small U.S. Marshals Service. Legal bars would prevent assignment of the task to such existing large organizations as the Department of Defense. On other questions, such as traditional law enforcement relationships and civil liberties, the study found no specific advantage for either Federal or private guards. Similarly, the costs of maintaining Federal or private guard forces would be essentially the same, and provision could be made for industry to absorb the costs of a Federal security force.

Federally provided in-transit security was found to be a special case, in that a group required to provide only transportation security for the projected MOX industry would be relatively small, approximately 500 people, and could be more easily accommodated in existing organizations than a force which would be responsible for fixed-site security. The Security Agency Study concluded, however, that if such an in-transit service were to be provided by the Government, it would be more feasible to contract for use of an expanded version of the existing DOE transportation system than to establish a new security agency to provide in-transit protection for the MOX industry.*

---

*DOE has recently extended its in-transit security system to cover all shipments of DOE-owned SSNM which is currently protected by licensees under NRC or DOE regulations. This decision was based primarily on the lower cost of expanding the present system and not on major differences in effectiveness between Federal or civilian guard forces. This expansion would also reduce management problems for DOE by consolidating all in-transit security forces into one organization to protect all DOE-owned SSNM, whether intended for weapons, reactor fuel, or experimental purposes.

6.3 USE OF AUTOMATIC WEAPONS

Under the reference system, guards would be equipped with .38 caliber handguns, shotguns, or semiautomatic rifles. (This is permitted by most State law.) Since potential attackers could have a wide range of weapons, including fully automatic rifles, it is of interest to investigate the impact that providing automatic weapons to guards would have on safeguards systems. In particular, it is interesting to consider the increase in guard effectiveness that might result from increasing their firepower, since an increase in effectiveness might lead to a reduction in the number of guards required.

Ref. 2 suggests that, under certain conditions, automatic weapons could increase the user's effective firepower by as much as a factor of four. It is important to note that such an increase would be most nearly realized in two basic engagement scenarios. The first is when there are large numbers (tens to hundreds) of relatively massed opposing forces so that area fire is a significant method of producing casualties; the second is when the individuals being fired upon are in relatively exposed positions so that use of automatic weapons significantly increases the probability of these individuals being quickly hit and disabled.

In the case of an ambush of a convoy or a facility, it is plausible that automatic weapons would provide the attackers with an increased capability to produce casualties in at least the first few seconds of surprise, when the guards would be most exposed to attack. It is debatable, however, whether automatic weapons would offer similar advantages to the guards. In the initial confusion of the ambush, they would probably be uncertain where the fire was coming from. After the initial surprise and verification of the location of the attacker fire, rapid, accurately aimed single shots might be a more effective defense than area fire from automatic weapons. In an attack situation, guards with automatic weapons might actually be better off operating their automatic weapons in the semiautomatic mode to avoid rapidly depleting their ammunition.

This does not mean that it is better, other things being equal, not to have automatic weapons. The point is that, from the standpoint of guards under attack, it is difficult to quantitatively determine the increase in guard effectiveness with automatic weapons.* Accordingly, on the basis of current information, it does not seem advisable, as a consequence of any benefit from automatic weapons, to contemplate any reduction in the total number of guards prescribed for the reference system.

Reduction in the number of guards would, without any other changes, clearly reduce the effectiveness of the guard force, and the possible benefits from the guards' possession of automatic weapons are too uncertain to credibly offset such a loss in effectiveness.

---

*For close-range (10-25 meters) ambush situations in Vietnam, so-called fire superiority was not as effective as single, well-aimed shots. Soldiers patrolling the Mekong Delta were trained not to use the full automatic mode on their M-16's and M-14's (Ref. 3).

6.4 BLENDING

6.4.1 Introduction

The reference safeguards system assumes an industry in which pure plutonium oxide is produced at reprocessing plants, shipped to fuel fabrication facilities, and mixed with uranium oxide to form MOX fuel containing an average of three to five percent plutonium. Until the PuO_2 is diluted with UO_2, it represents the most concentrated form of plutonium within the fuel cycle and, as discussed in Section 6.4.4.1, a relatively small amount (30 kg - 70 kg) of this Category I material* could form a critical nuclear mass.

The malevolent use of plutonium may be made more difficult by diluting the plutonium with uranium as soon as it is separated during reprocessing. This dilution or blending of plutonium and uranium can be accomplished either by mechanical mixing of the individual oxides or by chemically forming a solid solution of the two oxides. The major objective of such blending would be to decrease the concentration of the plutonium oxide to avoid the possibility of its direct use in a nuclear explosive. Blending would make malevolent use of plutonium more difficult because:

- A larger weight and bulk of material would have to be acquired to provide sufficient plutonium for a nuclear explosive.

- Added steps would be needed to convert the blended material into one suitable for an explosive device.

There is considerable difference of opinion as to how much blending would add to the difficulty of: (1) stealing the material; or (2) successfully separating the plutonium (as PuO_2) and making an explosive device. These differences occur partly because there is no sharp demarcation between those oxide concentrations that permit direct use as a practical explosive and those that do not. A discussion of the variations in critical mass requirements for different blending levels is presented in Section 6.4.4.1 below.

It should be emphasized that there are no commercial reprocessing facilities presently in operation in the U.S. and, since wide-scale use of mixed oxide fuels in LWR's has not been authorized, no large-scale MOX fuel fabrication plants have been built. All MOX fuel used to date in development and testing programs has been produced in research and development facilities with a combined capacity of approximately 50 tons per year of MOX. In the industry projected for the year 2000 (Ref. 4), each of five large reprocessors would be producing approximately 27 MT/year of PuO_2, which would then be fabricated into about 2600 tons of MOX. It is for these large facilities of a possible future industry that blending would be of interest.

6.4.2 Blending Concepts

MOX fuel specifications would call for a variety of concentrations of fissile plutonium, based on the customer's planned use of the fuel. Because meticulous control would be required to meet such concentration and mixing uniformity specifications, fuel fabricators have indicated a

---

*As defined in Section 3.2, Category I material is material that can be used directly in a nuclear device without further processing.

preference for doing their own final blending. Accordingly, blending would probably involve two stages. The first stage, performed at the reprocessing plant for safeguards purposes, would be designed to produce a "master blend" of standard concentration. The second stage would be "custom blending" (or final dilution) by the fuel fabricator to achieve the MOX fuel specifications called for by the individual customers.

Three "master blends," having PuO_2 concentration levels of approximately 30, 10 and less than one percent (Puechl plan), respectively, have been analyzed from a safeguards viewpoint. These concentrations represent the full range of blending possibilities, the highest level giving the smallest safeguards benefit, but recognizing the special development requirements for breeder reactors, and the lowest level (the Puechl concept) providing both maximum safeguards benefits and maximum costs (Ref. 5). The discussion in Section 6.4.2.1 summarizes the important non-safeguards characteristics of these three blending levels. Safeguards benefits are discussed in Section 6.4.4.

6.4.2.1 Blend Containing 30 Percent PuO_2

Although the future of the U.S. breeder reactor program is uncertain, the highest PuO_2 concentration among the blends considered was based on breeder reactor needs. The Fast Flux Test Facility (FFTF) has Pu concentrations of 22 and 27 percent in its fuel; the Clinch River Breeder Reactor is designed to employ fuels with an average plutonium concentration of about 19 percent and a maximum concentration of about 25 percent. Thus, a 30 percent PuO_2 blend would have breeder utility, should there be some future need.

Whatever the master blend ratio, additional mixing facilities must be introduced, and means for specifying and then verifying master blend acceptability would be required. In addition, the master blend ratio must be acceptable to fuel fabricators. The LWR MOX fuel fabricators have indicated that a 30 percent master blend ratio would be acceptable as their starting material.

Since a detailed design for a large-scale blending operation is not available, only estimates can be made of the capital and operating costs required to handle blends at reprocessing and fuel fabrication plants. For the MOX fuel cycle facilities described in Section 3.2, nearly all the changes required for a 30 percent master blend would be at the reprocessing plant and, as indicated in Appendix A, these changes would add approximately $30 million to the annualized costs of the MOX industry. This would increase by approximately one to two percent the presently projected cost of producing MOX fuel.

6.4.2.2 Blend Containing 10 Percent PuO_2

For LWR fuel using first recycle plutonium, most MOX fuel elements would require plutonium concentrations in the four to five percent range. However, a few of these elements could require concentrations up to 10 percent. With second and third recycle plutonium, the total fissile atom content of the plutonium would be lower, and master blend total Pu concentrations might have to go as high as 12 percent to allow blending to the desired fissile atom content. For this study, a nominal 10 percent master blend for LWR fuels was considered as representative and was used as the basis for analyzing safeguards aspects of the intermediate blending range.

Several fuel fabricators have indicated the acceptability of blends having about 10 percent plutonium oxide concentration. However, one fabricator expressed reservations about any blending at reprocessing plants, particularly in the 10 percent range, because this might limit the use of his uranium fluoride-to-oxide conversion facilities. Other industry reservations about use of 10 percent blends involve potential quality control problems and economic penalties. It is feared, for example, that the 10 percent blends prepared at the reprocessing plants would not allow sufficient dilution during custom blending by the fuel fabricator to ensure feed material with proper particle size and proper sintering and dissolution properties.

The estimates presented in Appendix A indicate that, for an LWR fuel fabrication industry in the year 2000, the total incremental annualized cost of adopting the 10 percent mechanical blend could be as high as $50 million. This represents an estimated increase of about two to three percent in the cost of MOX fuel and is believed to represent an upper bound. The design of future facilities could provide for more efficient integration of blending equipment into the production lines than was contemplated in making this estimate.

6.4.2.3 Very Dilute Blends - 0.12 to 1.0 Percent PuO_2

Nuclear consultant Karl Puechl (Ref. 5) has recommended that all the plutonium formed in LWR's be recovered from the spent fuel and mixed uniformly with all the uranium used to make new fuel for the LWR's. Thus, all LWR fuel would contain a small amount of plutonium, and all recovered plutonium from fuel reprocessing would be promptly blended with low-enriched uranium. The Puechl blending option has been proposed as a means for reducing the risks of theft and misuse of plutonium and also to provide a very dilute mixed oxide fuel which could be fabricated in UO_2 fuel fabrication plants without the expensive facilities normally specified for processing plutonium.

This blending option would produce plutonium concentrations in the range of 0.12 to 1.0 percent, depending on the quantity of plutonium available and the total amount of LWR fuel required. In the early LWR industry, the average PuO_2 content might be as low as 0.12 percent. As the industry matures, the Pu concentration would increase to about 0.6 percent and could eventually reach one percent. In all Puechl blends, enriched uranium would have to be used to adjust the total fissile atom content to the level specified by the customer.

It is Puechl's contention (Ref. 5) that the low concentration of plutonium in this type of mixed oxide fuel would permit it to be processed in UO_2 fuel fabrication plants with only minor modifications and without causing unacceptable health, safety, and environmental effects. Analysis in Ref. 4(Chapter IV, Section L) does not support this view. The regulatory requirements for containment, shielding, and filtration of airborne particles in UO_2 fuel fabrication plants are much less strict than for plutonium-handling operations. In Ref. 4, it was calculated that in the standard UO_2 fuel fabrication plants, even the very dilute mixed blends (less than 0.5 percent) would cause unacceptable health, safety, and environmental effects. Consequently, even if a Puechl blending concept were to be adopted, all fuel cycle facilities would still have to handle blended LWR fuel in accordance with the standards for plutonium-containing materials.

The additional annualized costs to do this are estimated at approximately \$1.3 billion for the MOX industry in the year 2000. This would approximately double the projected price of MOX fuel.*

6.4.3 Blending Methods

A simple way to blend UO_2 and PuO_2 is to mix the ceramic powders of each oxide mechanically. This mixed-oxide powder would be suitable for shipping without further mechanical or chemical alteration. The facilities for packaging the mixed-oxide blend and for loading and shipping would be little changed from those that would have been provided for unblended plutonium, except that larger container capacities would be required because of the UO_2 diluent. Mechanical blending would create no liquid or gaseous wastes. It would, however, involve an additional processing step in which plutonium particles might become airborne outside the processing equipment, and somewhat larger ventilation and high-efficiency particulate air (HEPA) filter systems might be required than without the blending steps.

An alternative to mechanical blending would be the coprecipitation of plutonium and uranium from aqueous solution. Formed in this way, the mixed oxide would be a solid solution of uranium and plutonium and each particle, no matter how small, would contain atoms of both elements in the desired concentration ratio. For a plant designed to produce pure PuO_2, coprecipitation with uranium would require some extra process steps and create some additional contaminated waste streams. For a new plant designed from the start to produce diluted plutonium, the process could be simplified and the added cost lowered.

In making the master blend, it is possible that part of the uranium recovered and purified at the reprocessing plant could be directly recombined with the recovered plutonium. However, the recovered uranium would vary in isotopic enrichment from about 0.8 percent ^{235}U content to perhaps one or two percent (for fuel discharged before reaching full burnup). Because of these enrichment variations, economic considerations would favor not blending with recovered uranium, but returning it instead to the enrichment plant for upgrading to the enrichments desired for future use. Consequently, it is assumed that the fuel reprocessor would return the recovered uranium to the enrichment plant and would use natural uranium for blending with the plutonium.

6.4.4 Safeguards Benefits of Blending

Since PuO_2 separation could be within the capabilities of some malefactors, MOX blends cannot be regarded as self-protecting at any concentration. Accordingly, it is a basic premise of this assessment that lowering the concentration of plutonium through blending should not be used as a basis for reducing the level of safeguards protection. On the other hand, blending could provide additional protection against the threat of clandestine nuclear explosive manufacture in two important ways: first by increasing the difficulty of accumulating the mass of material needed to manufacture an explosive; and second, by increasing the amount of time a malefactor

---

*In the year 2000, 2,600 MT (metric tons) of MOX are projected to be fabricated into MOX fuel rods at a reference-estimated fabrication cost of \$200/kg fuel. (See Ref. 4, p. XI-26.) In addition, 10,900 MT of low-enriched uranium would be fabricated into fuel rods at a reference-estimated fabrication of \$95/kg fuel. (See Ref. 4, p. XI-15.) With the Puechl concept (Ref. 5), all 13,500 MT of fuel would need to be handled as MOX and would require fabrication at a reference-estimated cost of \$200/kg fuel. This represents a \$1.14 billion per year increment in fuel rod fabrication cost. There would be additional cost increases at reprocessing plants for fuel storage and mixing, and further cost increases for transportation, making an estimated total increment of approximately \$1.3 billion per year.

would need to manufacture an explosive after acquiring the requisite material. These two safeguards advantages of blending are discussed in the following subsections.

6.4.4.1 Mass Requirements

The mass required to make an explosive device from plutonium blends depends on whether the blend is used directly or is processed to concentrate the plutonium. It is theoretically impossible to make a nuclear explosive directly from blended plutonium and uranium oxides with a plutonium concentration below about four percent. At higher plutonium concentrations, the MOX blend could in theory be used directly in an explosive device.

The critical mass of unmoderated nuclear materials provides a relative measure of its direct usability for nuclear explosives. The critical mass for MOX blends depends on many variables, such as isotopic composition, impurities, outside reflectors, and, most importantly, density, i.e., whether it is in a powder or a compact solid state. These factors cause the bare sphere critical mass for reactor grade plutonium oxide (PuO_2) to vary from 30 to 70 kg. Bare sphere critical masses for MOX at 30 and 10 percent PuO_2 concentrations vary between 250 to 600 kg and 3,000 to 10,000 kg, respectively. As mentioned above, at four percent PuO_2 concentration and below, no unmoderated critical mass is possible.*

These critical masses suggest that for MOX blends with PuO_2 concentrations lower than the 20 to 30 percent range, impractically large amounts of MOX would be needed for direct manufacture of an illicit nuclear explosive. Although not essential, chemical separation of the PuO_2 would probably be preferred. Although no separation process will be perfectly efficient, it is obvious that separation could lead to substantially lower mass requirements, especially with dilute blends. Table 6.1 compares the weight of material of different blends (with and without separation) which would have to be stolen to have sufficient plutonium to form a bare sphere critical mass.

TABLE 6.1

WEIGHT REQUIRED TO FORM BARE SPHERE CRITICAL MASS

Percent PuO_2 in Blend	Without Separation (kg)	With Separation[a] (kg)
Pure PuO_2	30 - 70	30-70
30%	250 - 600	100 - 230
10%	3,000 - 10,000	300 - 700
4%	None possible	750 - 1,750

---

[a] All weights are 30 to 70 kg after separation into pure PuO_2. These figures make no provision for losses during separation or the additional weight of containers.

Although separation would greatly reduce the amount of material required in the device itself, it is apparent that at the lower blend ratios, the weight and bulk of the required material before separation would be large and unwieldy.

---

*Data on critical masses were supplied by Dr. Robert Selden, Group Leader, B Division, Lawrence Livermore Laboratory.

The additional material required at lower blend ratios would present difficulties to outsiders intent on stealing weapon quantities in a single action, as well as to insiders trying to accumulate the needed quantities by repeated diversion of small amounts. The latter would be handicapped by portal monitors (both neutron and gamma types) whose ability to detect a fixed amount of plutonium in a moderate-sized package would be only slightly affected by blending.

The data in Table 6.1 indicate that blends would need to have concentrations as low as about 10 percent to have significant safeguards advantages. A successful explosive could be assembled directly, with an amount of 30 percent material that is not unreasonably large. At 10 percent concentration, the amount required for direct use in a crude explosive appears so large as to be impractical.

6.4.4.2 Separation Considerations

As indicated above, blending would virtually require malefactors to separate PuO_2 from the blended material to manufacture an illicit nuclear explosive. But this step would introduce an additional degree of difficulty and make the entire assembly operation more costly, more hazardous, and what is particularly important, more time-consuming to the malefactor.

In principle, one plutonium-bearing substance can be converted to another. Moreover, the general principles of plutonium chemistry are described in the unclassified literature, and a technically sophisticated person could learn the theory and basic principles involved in a chemical separation. However, there are substantial practical difficulties and dangers involved in working with plutonium because of its chemical, radiological and nuclear criticality properties. Acute plutonium poisoning, fire, explosions, acid burns and detection by the authorities are among the hazards that would be faced, particularly by a group lacking actual experience in plutonium conversion. In the United States, such experience has been virtually confined to Government-contracted or licensed facilities engaged in the production of nuclear weapons and plutonium-bearing nuclear fuels.

In spite of the difficulties involved, it is possible that a group of dedicated malefactors willing to take substantial risks might obtain the necessary equipment and technical knowledge to accomplish the separation (or enrichment) of plutonium blends. The magnitude of such an effort would depend on the uranium concentration, the amount of plutonium to be separated and the efficiency of the process used (see Ref. 4, Chapter IV, for a description of one separation method). To conduct the separation in a reasonable time, appreciable operating space, good chemical processing equipment, large quantities of supplies such as acid, and at least a several-man work force would be required. The effort might be a garage-size operation.

Experts do not agree on the time malefactors would need for the processing and separation steps to purify blended plutonium to the concentration needed for an illicit explosive. If the malefactors are credited with a substantial facility investment, a willingness to accept high-risk accidents, and an expertise from having previously worked with plutonium, it is estimated that at least three days would be required for a blend in the 20 to 30 percent range (Ref. 6). There is, moreover, a substantial probability that more than three days would be required, and that the effort could fail completely.

The additional time required to separate a blended mixture could be critically important to the recovery operation, should a theft occur. The time could be used to pursue clues on the identity of the individuals involved and on the location of their separation and assembly facility. Many of these clues, e.g., special equipment purchases and radioactive effluents, could be the result of the separation and processing operation itself.

The added problems introduced by a blended mixture--the extra hazards, the skills needed, the greater delay before a weapon could be produced, and the greater risks of process failure, detection, and capture--undoubtedly create a substantial deterrent to any illicit attempt to make a nuclear explosive from blended material.

6.4.5 Summary

The primary purpose of blending plutonium and uranium compounds early in the fuel cycle would be to improve safeguards. It is more difficult to construct nuclear devices with blended material and a larger quantity of material would have to be acquired. The need to extract plutonium oxide from the blend would present an added degree of difficulty, making the endeavor more costly, more time-consuming and more hazardous to the malefactor.

Notwithstanding the fact that additional difficulties would be introduced in either using blended material directly to make an explosive device or in converting blended material into more suitable bomb-quality material, it is still theoretically possible to complete these steps in a relatively short time after acquiring the blended material. If blend separation is required, it is estimated that at least three additional days to locate the stolen materials are available with high assurance that a nuclear explosive has not yet been assembled.

The effectiveness of portal monitors or other radioactive measurement techniques for detecting diversion of plutonium from fixed sites would not be affected appreciably by the use of blends. Moreover, since more blended material would have to be acquired, the frequency of attempted diversion and/or the increased amount of material involved would increase the probability of detection over that for pure PuO_2.

Although blending would offer safeguards advantages, it would also involve an increase in costs because of the need for additional plant personnel and processing capability. It is estimated, for example, that a 10 percent blend, which is about the lowest level acceptable to the LWR industry,* would increase total MOX industry annualized costs by $50 million in the year 2000.

---

*Some fuel elements in some LWR reactors have used concentrations as high as eight to ten percent. It is feasible for the fuel fabricator to further dilute a blend, but it does not appear feasible for the fabricator to concentrate one that is too dilute. Accordingly, a 10 percent blend was considered as the lowest concentration that could meet the requirements of LWR customers.

6.5 COLLOCATION

6.5.1 General

Another MOX industry option with potential safeguards advantages involves collocating (placing on the same site*) facilities performing successive steps in the nuclear fuel cycle. Under such an option, most movements of plutonium compounds would take place within a secured perimeter and under a controlled environment, thus reducing both long-haul transportation and public exposure of these materials. Collocation might also lead to certain economics of scale in fixed-site protection, especially if the reprocessing and fuel fabrication steps were designed as parts of a single integrated facility, possibly in contiguous buildings.

Consideration of the advantages of collocation was undertaken within the context of the following five questions:

1. To what extent would collocation reduce the shipment of plutonium on public highways?
2. What reductions in safeguards costs could be achieved by sharing equipment and personnel between collocated facilities?
3. What additional costs would be introduced by collocations?
4. What other impacts (e.g., market viability) on the plutonium recycle industry would collocation entail?
5. Would collocation reduce the risk that an illicit nuclear device might be constructed and detonated?

These questions are considered in turn in the following subsections.

6.5.2 Collocation as a Means of Reducing SSNM Shipments

The degree to which shipment of SSNM could be reduced by collocation would depend largely on how many steps of the recycle process are collocated. Five alternatives were considered:

1. No collocation--all fuel cycle operations in individual, dispersed plants.
2. Single-line collocation (one fuel reprocessing plant and one fuel fabrication plant with matched capacities).
3. Collocation of two or more fuel reprocessing plants with several fuel fabrication plants in an Integrated Fuel Cycle Facility (IFCF). Fuel rods would be shipped from IFCF's to fuel assembly facilities (see Section 3.2.3).
4. Collocation as in Alternative 3, above, but also including fuel assembly facilities.

---

*For purposes of this discussion of safeguards, "site" means a geographical area in which MOX fuel facilities can be located without requiring the use of public highways for the transport of plutonium and MOX compounds between facilities.

5. Collocation of all the elements of the plutonium recycle industry, plus power reactors, at large Nuclear Energy Centers (NEC's). (The NRC concept is essentially Alternative 4 with reactors also collocated.)

Alternative 5 represents the maximum degree of collocation; it minimizes all transportation links. However, to operate at capacity, a 2,000-MT/year fuel reprocessing plant would require spent fuel from approximately 65 1,000-MWe reactors. The Nuclear Energy Center Site Survey (NECSS) (Ref. 7) projected loads and costs of transmitting electricity over long distances and concluded that only about four 1,000-MWe reactors could presently be economically collocated from the point of view of power supply operations. The NECSS further concluded that an NEC system having more than five to ten reactors would probably not be economically viable in this century. Any system of collocation projected prior to the year 2000 probably would have to provide some transportation of fresh MOX fuel to reactors located apart from the fuel plants. As a result, the maximum degree of collocation considered in any depth in this assessment was the IFCF, including fuel assembly facilities (Alternative 4, above).

Plant shutdowns or outages would influence the degree to which collocation could reduce the transportation of plutonium. If a plant representing one step in the fuel cycle had to be shut down, other elements of the fuel cycle would begin to draw down their inventories. In this regard, a single-line collocated facility would be more vulnerable than an IFCF. In the single-line case, a one- to three-month outage at a reprocessing plant might have little effect on the supply of fuel to the fuel fabricator. A longer outage, however, could deplete the inventories of the fuel fabrication plant, so that it would be forced to shut down unless intersite shipment of plutonium were undertaken. At an IFCF, on the other hand, a fuel fabrication plant whose inventories were exhausted could seek an alternative source of supply within the center. If this could not be arranged, or if intersite plutonium shipments were prohibited, such a plant would ultimately also have to shut down.

The potential reduction in the annual number and ton-mileage of plutonium oxide shipments for the five collocation alternatives is shown in Table 6.2. These estimates are based on the fuel shipment data of Table 3.3. It is assumed that the problem of plant outages in single-line collocation (the NECSS estimated such facility outages at 10 percent of operating time) would be solved by nonroutine transshipment. If such shipments were prohibited except under serious emergency conditions, the quantity shipped and the average number of shipments per year would, at least in principle, be reduced nearly to zero.

As can be observed from Table 6.2, Collocation Alternatives 2 and 3 would reduce the number of shipments and the ton-miles shipped by 10 to 15 percent. This would reduce the societal impacts associated with guarded shipments on public highways by a similar amount. However, the total risk of successful SSNM seizure on a highway and successful fabrication of a nuclear explosive would be reduced by a substantially greater amount, since almost all shipments of pure PuO_2 would be eliminated. Shipments of MOX fuel should be significantly less desirable to a malefactor than those of pure PuO_2.

TABLE 6.2

EFFECT OF COLLOCATION ON PLUTONIUM SHIPPING REQUIREMENTS FOR A MOX INDUSTRY IN THE YEAR 2000

	Collocation Alternatives				
	1 Dispersed Industry	2 Single-Line Collocation	3 IFCF	4 IFCF with Fuel Assembly	5 Nuclear Energy Centers
Shipments/year					
As PuO_2	280	28	0	0	0
As Rods	810	810	810	0	0
As Assemblies	1,310	1,310	1,310	1,310	0
TOTAL[a]	2,400	2,150	2,120	1,310	0
Pu Ton-Miles Shipped[b]					
As PuO_2	37,000	3,700	0	0	0
As Rods	25,000	25,000	25,000	0	0
As Assemblies	123,000	123,000	123,000	123,000	0
TOTAL[a]	185,000	152,000	148,000	123,000	0

---

[a] Figures may not add to totals because of rounding.

[b] See Table 3.3. The weight of Pu metal equivalent shipped per year on each transportation leg is assumed to be 123 MTM (as projected in Ref. 4), whether in the form of pure PuO_2, MOX rods, or MOX assemblies. The average distances involved are assumed to be: leg 1--reprocessing to fuel rod fabrication, 300 miles; leg 2--fuel rod fabrication to fuel assembly, 200 miles; leg 3--fuel assembly to reactor, 1,000 miles.

6.5.3 Collocation Risks

Collocation of reprocessing, fuel fabrication, and fuel assembly plants would not seem to lead to any increased risk of major accidents or sabotage. Appropriate physical separation of plants could preclude the likelihood that an accident at one plant would damage adjacent plants. One concern is that the accidental release of a radioactive effluent from one plant might contaminate and disrupt another plant. This possibility would need investigation in the design of collocated facilities, but it does not appear to argue strongly against collocation. Moreover, the more extensive managerial capabilities and physical resources available at a multi-plant site to cope with an emergency would tend to reduce the risk associated with any given accident. While collocated facilities, especially an IFCF, might appear to offer a more tempting target for sabotage, appropriate safeguards could prevent the risk from being any greater than with separated facilities.

6.5.4 Effects on Safeguards Costs

Some reduction in industry safeguards costs should result from collocation. Clearly the costs of transportation protection would be less. Assuming a 90 percent reduction in the number of PuO_2 shipments with single-line collocation, about a 90 percent reduction in PuO_2 transportation costs would logically result--about \$3.1 million, based on the \$3.5 million figure for annualized PuO_2 transportation (safeguards) costs in Table A1.4.

Certain economies of scale might be realized in the cost of safeguards. For example, collocation could reduce the amount of equipment and the number of guards necessary to maintain a specific level of perimeter security. Two different plants located together could utilize approximately the same number of perimeter portals as either plant located alone. Furthermore, the manpower level needed to provide perimeter security is established primarily by the perimeter length and by the system design, rather than by the number of plants contained within the perimeter. Consequently, the number of guards per plant devoted to perimeter security would be reduced as more plants are collocated at a single site. Economics of scale in the administration and maintenance of safeguards equipment might also be expected. In addition, the complex and expensive equipment used for open highway transport of SSNM from plant to plant would probably not be needed for transportation within a secure perimeter, and the extra guards and escort vehicles required for transport over open highways would be eliminated.

If facilities were under separate ownership, the economies of scale realistically could be achieved only by integrating the management and control of the guard force. The potential cost savings of collocation would not be realized if each facility were to maintain its own complete safeguards system. On the other hand, if such facilities as reprocessing and fuel fabrication facilities were physically collocated, the costs of protecting them with an integrated safeguards system might be only slightly greater than the cost of protecting any one of them.

The NECSS found that collocation would have both positive and negative impacts on industrial operations and practices. Most obvious of the negative impacts would be the constraints on plant location. For example, the greater total size of the collocated plants would tend to remove from consideration some areas with relatively low population that might otherwise have been economically attractive because of low labor costs. This would result in some economic penalty. In the simple case of a matched pair of reprocessing and fabrication plants (collocation Alternative 2, above), the constraints on plant location because of collocation might not be very large. In the case of an IFCF, on the other hand, several MOX-handling firms would be required to locate at a single site whose geographical location might be determined more by fuel reprocessing than by MOX fabrication considerations. In this situation, the resulting economic penalties could be significant.

Collocation would probably require an integrated management organization, which could create some problems. Also internal security requirements within individual plants would probably require the same equipment and security force level as in the non-collocated case.

There might be problems in maintaining a competitive industry with collocated facilities. Separate ownership of the two plants at a single-line collocated site could result in a highly dependent supply-demand relationship between the companies involved. Of course, if shipments of PuO_2 between sites were permitted, the companies could turn to offsite vendors to maintain a competitive environment. This would minimize impact on the free marketplace, but the safeguards advantages of collocation would be dramatically diminished in the process.

In an IFCF, there could be competition onsite between plants performing the same fuel cycle process. However, in the year 2000 the entire reprocessing and MOX fuel fabrication industry could be contained in just two or three IFCF's. Being on the same site with one's competitors may eliminate any geographical marketing advantages, but it may also pose problems in protecting proprietary information, including marketing strategies. (See Section 3.7.3.3, Part IV, Vol. 1 of NECSS, Ref. 7). Nevertheless, it should be noted that there is precedent in the chemical industry and other industries with large, complex production facilities for having plants with different owners at a given site.

The maintenance of a competitive environment could be a continuing issue. At least the appearance of collusion could be a problem, requiring that competitive considerations be kept in mind. This could require that licensing functions be performed with the goal of developing the least restrictive compromise between competitive operations and safeguards objectives.

Collocation would have some beneficial and some deleterious effects on the environmental impacts of the MOX industry. The NECSS found that, subject to site-specific evaluation, total environmental impacts of an energy center probably would be less than those of the same facilities dispersed, and that local impacts of a centralized facility would not be substantially greater than those of dispersed facilities. For some considerations, such as land use and construction "boom or bust" cycles, an IFCF was projected to have greater localized impacts, but possibly a smaller total impact, than a dispersed industry. Chemical and radiological pollution were projected to be no greater in total impact and, with proper design, no greater in local impacts for collocated plants (Collocation Alternative 2) than for single dispersed plants. An IFCF (Collocation Alternatives 3 and 4) was projected to produce a slightly greater local concentration of fluoride effluents than dispersed plants, and also to have potentially greater local radiological impacts, although the latter could be reduced by simple design changes.

6.5.5 Effectiveness of Collocation as a Safeguards Measure

The ultimate object of the safeguards program is to prevent the successful operation of an illicitly made nuclear device, including a device to disperse plutonium particles into the air. Collocation would contribute toward this end in several different ways:

- The reduction in total shipments and ton-miles shipped indicated in Table 6.2 (10 to 15 percent for Collocation Alternatives 2 and 3, more for Alternative 4) would reduce SSNM exposure along public highways, thus reducing somewhat the risk of theft.

- Collocation would reduce shipments of PuO_2 by 90 percent or more and cause the remaining PuO_2 shipments to be less predictable. Collocation could thus either deter attackers or force them to target shipments of MOX (a far less desirable bomb material for reasons indicated earlier). To acquire the 30 to 70 kg of PuO_2 needed for a bare critical mass, the attackers would need to steal two to four PWR MOX assemblies, each containing about 245 kg of MOX plus additional weight structure; or 8 to 19 BWR MOX assemblies, each containing about 190 kg of oxide plus additional weight structure; or an equivalent number of MOX rods. The weight and bulk of these assemblies or rods would make their theft far more difficult than the theft of PuO_2.

The discussion in Section 6.4 on blending indicates the additional hurdles that must be surmounted by a terrorist group contemplating seizing and using MOX fuel to make a weapon. First, the terrorists must steal over 20 times as much MOX as PuO_2, because of the plutonium dilution in MOX. Since the plutonium concentration in MOX rods is too low for direct use in a nuclear device, the PuO_2 must be chemically separated or concentrated. Although this is certainly not an insurmountable obstacle to a terrorist group, it is a significant additional hurdle, necessitating more expertise, more equipment, more time, and more risk. (A plutonium dispersal weapon could be made with MOX fuel, but it would be difficult to make an effective one. The plutonium dilution would require dispersal of more material to achieve the same amount of dispersed plutonium, and, to be effective, the sintered fuel pellets would need to be processed into an appropriate powder.)

- The above problems would tend to deter would-be aggressors from attempting to seize a MOX shipment. Doubts about whether they could steal enough MOX to make a bomb and whether they could successfully separate or concentrate the necessary amount of plutonium would be added to their other uncertainties. Any uncertainties in the exact concentration of plutonium in the final material would complicate the task and add further to the time required to safely construct a nuclear device, since there would be a hazard of unexpected plutonium criticality during construction. PuO_2 shipments, on the other hand, would take place only as a result of unforeseen scheduling, inventory, or production problems, and would probably not be known about long in advance, even to an "insider." Under these conditions, a successful seizure of PuO_2 during shipment could be very difficult to execute.

6.5.6 Summary

A number of safeguards advantages and disadvantages would accrue from the collocation of fuel cycle facilities. The most significant safeguards advantage would be the virtual elimination of pure PuO_2 from the transportation links. Although pure PuO_2 shipments are expected to represent only about 12 percent of the shipments of all plutonium mixes and compounds requiring safeguards, PuO_2 is much more attractive than MOX as a starting material for constructing a nuclear explosive device. It is thus strategically advantageous to restrict PuO_2 shipments. However, with single-line collocation (Alternative 2), a breakdown of either the reprocessing or the fabrication plant could either require some intersite transportation of PuO_2 or inflict an economic penalty on the companion facility. (Another interim possibility would be the intersite transport of a master blend of PuO_2 and UO_2, as discussed in Section 6.4.)

While collocation would be expected to produce savings of over $3 million annually in safeguards transportation costs and some additional savings in fixed site guard force costs, there could be offsetting economic penalties due to decreased flexibility in site location. The strongest argument in favor of collocation is therefore not the economic one, but the reduction in exposure of SSNM on public highways.

6.6 AIR TRANSPORTATION

6.6.1 Introduction

In the reference system, the various forms of plutonium are assumed to be transported commercially by escorted road vehicles. Although the cost of protecting road shipments, even with fairly large escort forces, is relatively small compared to other fuel cycle operating costs, the potential societal impacts of the use of truck-transport convoys with armed escort forces on public highways justify an examination of cargo aircraft as an alternative method of transport. Such aircraft may be used: (1) between private airstrips located at the nuclear facilities; or (2) between public airfields near the nuclear facilities, utilizing road transport to connect the facilities and the airfields.

The potential advantages of air transport include: (1) the relative invulnerability of shipments to theft during flight; (2) lesser public interface and interaction resulting from the reduced use of armed convoys traveling on public highways; (3) lesser exposure to theft or diversion due to the reduced transportation time; (4) reduced probability of successful diversion and hijacking because of the ability of the FAA radar net and communications system to keep the aircraft under continuous surveilliance; and (5) the possibility of limiting transport operations to daylight hours only, thereby increasing an adversary's problems.

6.6.2 Special Restrictions

Air shipment of plutonium-bearing SSNM is currently subject to special restrictions. Public Law 94-79 prohibits the licensing of air shipments of plutonium in any form (except in a medical device designed for individual human application), pending certification by the Joint Committee on Atomic Energy that a safe container has been developed and tested under conditions equivalent to the crash and explosion of a high-flying aircraft. A prototype container for plutonium oxide, weighing approximately 500 pounds, has been designed and tested at Sandia Corporation. This container, which holds 2.0 kg of PuO_2, is designed to withstand ground impacts at 300 to 400 feet per second and to be compatible with fire, immersion, crushing, and penetration requirements for safe and secure air transport. The use of such containers enables approximately 250 kg of plutonium oxide to be transported on a single flight by an L-100 aircraft (the commercial version of the widely used military C-130 cargo aircraft).

A container specifically designed to protect fresh MOX fuel rods or complete fuel assemblies and meeting proposed air crashworthiness requirements is not currently available. Existing container designs for road transport of reactor fuel indicate that a crash-resistant container would have to be heavy and bulky. Payload limitations of the aircraft make questionable the air transport of MOX fuel rods or assemblies. Accordingly, pending further studies concerning container design for MOX fuel rods and assemblies, transportation by air was considered only for the shipment of PuO_2 from reprocessing to fuel fabrication plants. It was assumed that shipments of rods from fabrication to assembly plants and of fuel assemblies from assembly plants to reactors would continue to be made by road or rail.

6.6.3 Risk and Safety Considerations

Basic risks involved in the air transport option include the following: (1) the aircraft might be diverted to some other destination; (2) safeguards risks might occur during cargo commercial airstrips are utilized; and (3) the aircraft might suffer an accident and crash. These risks will be considered in turn in the succeeding paragraphs.

Diversion could occur if one or more members of the flight crew acted in collusion with an adversary group. The likelihood of such collusion by crew members can be minimized by requiring security clearances for all crew members and instituting random personnel assignments and searches for unauthorized weapons prior to takeoff. Further, for aircraft diversion to succeed, it is necessary that there be no calls for assistance during the diversion (the transporter can have special classified frequencies for "Mayday" calls), that the aircraft not be trackable by FAA radar, and that a prepared airstrip be available in a secluded area where the diverters could safely land and remove the plutonium containers. Although further study of this type of diversion is required, appropriate precautionary measures involving communications, ground radar tracking, and coordination with local authorities would seem to make the success of such an attempt within the U.S. (or continental North America, for that matter) very unlikely.

Unplanned diversion might occur due to weather or mechanical trouble. Commercial aircraft data indicate that such diversion may be expected to occur on one to three percent of all flights (Ref. 8). As air shipment of plutonium would not involve regular schedules or particularly long flights, diversion due to weather could be minimized by allowing flights only when the weather over the entire flight path permitted visual flight rules to apply for a period well in excess of the duration of the trip. Furthermore, the range of a cargo aircraft such as an L-100 is adequate in most circumstances to permit it to return to its point of origin if the destination were suddenly closed in by weather.

Regardless of the precautions taken, aircraft transporting plutonium might nevertheless be forced on occasion to divert, because of weather or mechanical problems, to commercial airports. Local law enforcement agencies could probably provide security in such an event. Security problems could be expected to be relatively slight, in any case, since potential adversaries would not ordinarily have prior knowledge of such random diversion.

Air transport is relatively safe from the risk of crashes due to equipment failure or pilot error. The overall accident rate for cargo aircraft is approximately 5.6×10^{-8} accidents per mile flown (Ref. 9). On this basis, the MOX industry could be expected to experience one accident every 180 years, assuming 100,000 transport aircraft miles flown per year. Even this low rate could be reduced substantially if operations were restricted to times when visual flight rule conditions prevailed at the destination airport (Ref. 9). Such restrictions would introduce potential scheduling problems and the need for additional handling and storage capability at nuclear facilities.

Even though statistical evidence suggests that the potential accident risk with air transport of SSNM by cargo aircraft would be very low, there is still a finite possibility that a crash might occur. According to statistics (Ref. 9) the largest proportion of all accidents involving U.S. commercial aircraft occurs during takeoff and landing and while on the ground. If one of these circumstances held for an accident during transport of SSNM, the accident would likely be near a nuclear facility or airport, where adequate guard forces would be available to protect the SSNM. In-flight collision, on the other hand, could result in SSNM containers being scattered many miles from the nearest nuclear facility or airport. In this event, locating and recovering the containers would be a difficult and time-consuming task, and safeguards coverage could be a problem. However, even if adversary forces were able to determine that the aircraft had crashed, they too would have difficulty in locating the containers.

6.6.4 Cost Estimates

The most secure method of using air transport is to construct an aircraft at each reprocessing and fuel fabrication plant, thus eliminating the requirement for loading and unloading outside the secure perimeter of a nuclear facility. This is the first of the two air transportation options for which cost estimates were made (Appendix A). For the projected MOX industry the construction of 13 airstrips at an initial cost of approximately $650,000 each would be required* (assuming general-aviation-type asphalt construction suitable for L-100 type aircraft). There would also be expenditures for airfield equipment, yearly airfield maintenance, and aircraft capital and operating costs, including safeguards provisions to protect loading and unloading operations.

If an aircraft such as the L-100 were to be used, the companies involved in the fuel recycle industry could either purchase the aircraft directly or lease it from an airline company. For cost estimating purposes, it was assumed that one L-100 aircraft would be purchased (ownership not projected for the year 2000 (all separately located). One aircraft flying a total of approximately 1,550 hours per year could handle the 139 MT of PuO_2 projected to be produced by the industry in the year 2000. The flying time estimate includes trips to return empty containers and a contingency factor to cover repairs, maintenance requirements, and additional flights necessitated by bad weather.

As shown in Table 6.3, operation of such an air transport system, including safeguards, would cost approximately $5.6 million per year. This is $2.3 million more than the approximately $3.5 million annualized cost for providing safeguarded ground transportation, using the six hardened transport vehicles and 14 escort vehicles projected for the mature MOX industry in the year 2000. (See Section 5.4.)

Since construction and maintenance of airstrips at nuclear plants would be an important cost item, the use of commercial airfields combined with short haul truck transport between nuclear plants and the airfields has been suggested as an alternative. However, initial cost studies indicate that if local commercial airports were used by all facilities involved, annual industry-wide costs would be approximately $6.0 million, or $0.2 million more than the cost of the system using private airstrips.** This increase would be due to the cost of guards, transporters and escort vehicles required to protect shipments in transit to and from the local airports (average distance 50 miles) and during loading and unloading at the airports. These costs would more than offset the savings from not having airstrips at the nuclear facilities. The comparison is shown in Table 6.3.

---

*See Appendix A, Table A1.2 and Ref. 8, for further breakout of costs.

**See Appendix A, Table A1.8, for further breakout of costs.

TABLE 6.3

COMPARATIVE COST OF AIR TRANSPORT OPTIONS
IN YEAR 2000

Option	Annual Cost $ (millions)
Using airstrips at reprocessing and fabrication plants[a]	5.8
Using commercial airports with truck transport and escort between airports and nuclear plants[b]	6.0

Basis:

Amount of PuO_2 Shipped (PuO_2)	139 MT
Number of Aircraft (L-100-30)	1
Number of Round Trip Flights	557
Average Trip Length (Mi) (One-way)	300
Number of Truck Transport Vehicles	3
Average Distance - Airport to Nuclear Plant (Mi)	50

---

[a] See Appendix A, Table A1.8 for further breakout of the costs.

[b] Additional $0.2 million is for three truck transports with guards--approximate cost $2.2 million--less cost of airstrips and related facilities--$2.0 million (Ref. 8).

6.6.5 Summary

The use of air transportation for the shipment of PuO_2 between reprocessing facilities and fabrication plants would reduce the number of convoys of SSNM on public roadways. Although air transportation of PuO_2 would involve only about 10 percent of the shipments requiring safeguards protection, the shipments involved would be the most sensitive in the MOX industry and would benefit most from the added safeguards protection afforded by air transport. Although air transport would cost slightly more than the road transport it would replace, the added safeguards benefits might justify it.

6.7 SUMMARY: ADVANTAGES AND DISADVANTAGES OF ALTERNATIVES TO THE REFERENCE SYSTEM

Five suggested safeguards alternative options are reviewed in this chapter. The first two focus on the guard force and require changes in State or Federal legislation. These options are: (1) employment of a Federal guard force, and (2) providing the guard force (Federal or private) with automatic weapons similar to those that might be available to potential adversaries. The other three options, unlike the reference system, involve significant alterations to the industrial arrangements considered for the future MOX industry. These alternatives are: (3) reducing the presence of pure compounds of plutonium in the fuel cycle by blending them with uranium compounds early in the cycle; (4) collocation of various numbers and types of fuel cycle facilities to reduce shipments of pure plutonium oxide and MOX and to provide economies of scale in fixed-site protection; and (5) use of air transportation to reduce road shipments of pure plutonium compounds.

The first alternative, use of Federal guard forces, was analyzed in detail in the Security Agency Study (Ref. 1) undertaken at the direction of Congress and published by NRC in August 1976. The major conclusion of this study was that guard force effectiveness is essentially independent of whether the force is Federally or privately employed and depends rather on personal qualifications, particularly motivation and training. Appropriate Federal regulations, guidelines, and implementation procedures influencing these factors are equally applicable to Federal and private guard forces. The study pointed out that Federal guard forces might have possible administrative conflicts with the civilian nuclear industry and concluded that there was no compelling reason to enact new legislation to establish such a force.

From the review of the second alternative, use of automatic weapons by guard forces, it was concluded that there is no firm basis for expecting that a significant increase in guard force effectiveness would result from use of such weapons. A preliminary review of various factors (element of surprise, length of battle, number of defenders and attackers, fixed site protection, etc.) indicates that, whereas automatic weapons might benefit the attackers, such weapons might not provide significant benefit to the guard force. Additional study is desirable before definitive conclusions can be reached on the use of automatic weapons. Pending the outcome of such study, recommendations for legislative changes in State gun laws to permit use of automatic weapons by private guards in the MOX industry do not appear to be warranted.

The third alternative considered was to blend plutonium oxide with uranium oxide early in the fuel cycle so that only dilute mixtures of plutonium would be shipped. Blended plutonium compounds (around 10 percent PuO_2 content) would be much more difficult to fabricate directly into an explosive device than would pure PuO_2, and massive amounts of material would be required.* For a 10 percent blend, a malefactor would probably need to make a chemical separation or concentration of PuO_2 to construct a successful nuclear explosive. This would give the recovery operations additional days, and perhaps weeks, in which to locate stolen blended material before a nuclear device could be assembled. For pure PuO_2, the comparable high assurance time is only a few hours. It was further concluded that, for blends in the 10 to 20 percent range, the additional amount of raw material (assuming subsequent separation) which would have to be stolen to make an explosive would probably not significantly affect the success or failure of an attack. The additional amount of material required could, however, aid in detecting internal thefts and diversions. Incremental annual costs of blends to the MOX industry in the year 2000 were estimated to be $30 million for 30 percent and $50 million for 10 percent blend, in 1975 dollars.

The most significant advantage of the fourth alternative, collocation, would be virtual elimination of pure PuO_2 from the offsite transportation links. Additional advantages include savings in transportation safeguards costs and possible savings in fixed site safeguards costs. If the collocated facility consisted of a single reprocessing plant and a single fabrication plant, possible shutdowns in one plant (due, for example, to process breakdowns or plant maintenance and cleanup) would require plans for intersite transportation of PuO_2, an amount estimated at 10 percent of the PuO_2 shipments required for dispersed facilities.

---

*See Table 6.1.

The fifth alternative, use of air transportation for the shipment of PuO_2 between reprocessing facilities and fabrication plants, would have the virtue of reducing the number of road shipments of PuO_2. Like collocation, however, air transportation of pure plutonium compounds would replace only approximately 10 percent of the plutonium shipments requiring safeguards protection. The costs to implement the air transportation alternative would be higher than road transportation costs, but not significantly so. There does not appear to be any serious question about the technical feasibility of meeting the legal requirements for containers to transport PuO_2 by air.

CHAPTER 6

REFERENCES

1. U.S. Nuclear Regulatory Commission, "Security Agency Study: Report to the Congress on the Need for, and the Feasibility of, Establishing a Security Agency within the Office of Nuclear Material Safety and Safeguards," NUREG-0015, August 1976.*

2. H. W. Hevert, and E. Knight, "Net Assessment: Reference Safeguards System vs. Overt Theft Attempts," Final Report, RDA-TR-191300-001, prepared for NRC by R&D Associates, June 1977.[b]

3. Lt. Gen. Julian J. Ewell, and Maj. Gen. Ira Hunt, Jr., U.S. Department of the Army, "Sharpening the Combat Edge: The Use of Analysis to Reinforce Military Judgment," October 1973.[b]

4. The U.S. Nuclear Regulatory Commission, "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors," NUREG-0002, August 1976.*

5. Karl H. Puechl, "The Case for Low Concentration Plutonium Recycle," <u>Nuclear Engineering International</u>, 687-692 (September 1975).***

6. Letter from George P. Fisher, R&D Associates, to Maurice Eisenstein, NRC, Subject: Conclusions from Meeting on the Difficulty of Separating PuO_2 from Mixed Oxide Blends, with enclosure, dated August 25, 1976. (Confidential)†††

7. U.S. Nuclear Regulatory Commission, "Nuclear Energy Center Site Survey - 1975," NECSS-75, NUREG-0001, 5 vols., Part I of V, "Summary and Conclusions," January 1976.*

8. J. Ericson, L. Greg, E. Knight, R&D Associates, Vol. IV, "Evaluation of Special Nuclear Material Air Transport as a Safeguards Option," RDA-TR-4001-002, December 1976.[b]

9. U.S. Nuclear Regulatory Commission, "Draft Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," NUREG-0034, Docket PR-77, 73, in <u>Federal Register 40</u>, 23768, March 1976.**

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, Va 22161.

**Available in NRC PDR for inspection, and copying, for a fee.

***Available in public technical libraries.

†††This document is not publicly available because it contains national security information.

[b] Available in Source File for USNRC Report NUREG-0414, May 1978.

CHAPTER 7

SOCIETAL IMPACTS

7.1 INTRODUCTION

This chapter addresses the incremental burdens which would be imposed upon society by the additional safeguards which wide-scale use of mixed oxide fuel would require, under the concept of prevailing civil order. As indicated in Chapter 1, this is one of the basic questions which must be addressed in assessing the impact of a MOX industry.

There is little question that plants and materials could be safeguarded with near absolute certainty provided that sufficient resources were concentrated on the problem. There is concern, however, whether such an allocation of resources would be economically acceptable and whether the possible impact of proposed safeguards concepts and measures might entail constraints and intrusions which could have an adverse impact on individual freedoms and other societal values. Accordingly, this chapter treats the impact safeguards could have on individual civil liberties in American society, and the legal issues pertaining to such impact.

In view of the frequently subjective nature of societal issues, the NRC has sponsored conferences and commissioned papers designed to elicit a wide range of opinion from experts and others interested in this field. The content of this chapter represents in large part responses to concerns expressed in such conferences and papers or to concerns which have otherwise been communicated to NRC.

Section 7.2 of this chapter considers the potential impacts of safeguards on the civil liberties of industry employees (who might suffer losses of privacy and First Amendment rights from preemployment screening of their backgrounds and from inspection and searches) and of the general public (who could be affected by surveillance to collect intelligence or by searches and seizures in recovery operations).

Sections 7.3, 7.4 and 7.5 examine, respectively, the potential adverse effects of safeguards on important institutional arrangements in American society; on Federal, State, and local legal frameworks; and on the physical environment. Institutions considered include the free enterprise economic system and the concept of an open society. Legal considerations discussed include the possible use of deadly force by industry guards and restrictions on the weapons they may use. Environmental factors addressed include the potential effect of MOX industry safeguards on the aesthetics of industry facilities and on their use of additional land.

The potential effects of MOX safeguards on the national economy are treated in Section 7.6. The results are based primarily on the detailed cost analyses provided in Appendix A and consider the incremental economic costs to society of safeguards for a mature MOX industry as compared to one with no MOX fuel. Included are the effects of differences in safeguards on employment both at fixed sites and in transportation. Attention is also given to concerns which have been expressed regarding the economic and institutional effects of collocation, including the ability of industry to operate profitably if collocation is mandated.

Section 7.7 considers the possible differences in societal impacts which could result from selecting one of the other alternatives treated in the Health, Safety, and Environment portion of GESMO (NUREG-0002) rather than Alternative 3 (early recycle of plutonium and uranium). It is concluded that the impacts of Alternatives 1 and 2 (which involve some delay in recycle) would differ little from that of Alternative 3; Alternative 5 (uranium recycle with no plutonium recycle) would produce a considerably smaller impact; and Alternative 6 (no recycle) would have no incremental societal impacts as compared with the present situation.

The treatment of most of the societal issues in this chapter is, by the nature of the subject matter, more exploratory than definitive. Individual perceptions regarding the acceptability of societal impacts can be shaped by subjective or intangible factors (e.g., personal value systems). Notwithstanding the difficulty involved, an attempt has been made to identify potential societal impacts and to present the issues they raise. In some instances, particularly with respect to economic matters, it has been possible to present facts, data, or reasoning which suggest answers. In other cases it has not been possible to quantify the subject matter sufficiently to reach numerically demonstrable conclusions. The NRC, however, is cognizant of the importance of societal issues to its decisions and is continuously exploring such issues with the assistance of qualified experts.

7.2 IMPACTS ON CIVIL LIBERTIES

7.2.1 General

The potential impact of safeguards measures upon the entire range of individual rights and freedoms guaranteed by the U.S. Constitution is of great concern to both the Government and the private citizen.* This concern stems not only from the direct effects which might be produced by nuclear safeguarding techniques but also from a fear that erosion of civil liberties might occur generally in society if significant restrictions were permitted in the nuclear area.

In any society, there is a basic conflict between the right of the individual to free action and expression and the need of the community to protect itself.** The nation is currently

---

*The Board of Directors of the American Civil Liberties Union, at its April 1976 meeting, adopted a resolution "opposing the licensing and operation of any facility designed to convert and deliver energy to consumers where governmental suppression of information or the infringement of any constitutional guarantee accompanies the licensing and/or operation of the facility or of associated facilities (e.g., mines, fuel reprocessing plants, waste disposal units and mixed fuel preparation plants). Before a license is granted for the operation of any energy facility a comprehensive statement should be presented showing that protection of civil liberties has been considered and implemented."

**See for example, the New York Times article (Ref. 1) describing four U.S. Supreme Court decisions (Wolff v. Rice, U.S. v. Martinez-Fuente, U.S. v. Janis, and South Dakota v. Opperman) in which the majority reasoned consistently that the needs of society were substantial enough to override the Fourth Amendment protections of the rights of the individual.

in a period of reviewing and reevaluating the issues involved in this complex subject area. Recent disclosures of past government activities which infringed on individual rights have prompted calls for a less intrusive government posture. Simultaneously, increased antisocial activity has created incentives for continued, if not increased, government surveillance and intelligence.[*]

The civil liberties question, then, is not whether adoption of safeguards to protect a MOX fuel cycle affects the balance between individual rights and governmental surveillance--it clearly does, at least to some extent, by changing the context within which that balance is struck. The question to be resolved is whether the change is significant when compared to the national and individual benefits to be derived from the MOX fuel cycle.

Civil liberties considerations can be expected to play a prominent role in the MOX decisionmaking process, both in shaping the requirements for particular safeguards measures and in reaching a decision on the basic issue of whether to authorize wide-scale use of a technology that will require the imposition of those safeguards. The NRC staff has attempted to postulate safeguards concepts which would minimize the impact on civil liberties while simultaneously achieving realistic safeguards goals.

In the past, when constitutional rights were infringed in the name of some real or perceived governmental need, the courts have required a clear showing of that need and have inquired into whether there were alternative, less infringing, means to meet it.[**] This "least restrictive alternative"[†] approach has been used in developing the safeguards programs treated in this report.

The discussion which follows is generally focused on the reference safeguards system set forth in Chapter 5 of this report.

7.2.2 Effects on Industry Employees

7.2.2.1 Inspection and Searches

Routine inspections and searches of employees who have access to sensitive areas of a plant have often been cited as representing an invasion of privacy.[††] Such searches serve the dual functions of monitoring contamination and preventing internal sabotage or theft of

---

[*] Reports of the Senate Select Committee to Study Governmental Operations with Respect to Intelligence Activities (Ref. 2) cited significant intrusions into the private lives of citizens involved in civil rights and other political movements. As a result of these investigations, a new Senate Committee to Establish Permanent Oversight of Intelligence Agencies has been formed (S. Res. 400). It is authorized to propose legislation, as required, to restrict intelligence activities.

[**] U.S. v. Davis 482 F.2d 893 (9th Cir. 1973); U.S. v. Epperson, 454 F.2d 769 (4th Cir.) Cert. denied, 406 U.S. 947 (1972).

[†] See Shelton v. Tucker, 364 U.S. 479, 488 (1960) for the Supreme Court discussion of the "least restrictive alternative" test.

[††] For example, in an extreme case of abuse in which personal searches were carried out in an arbitrary or discriminatory manner, such searches might be considered accusatory, embarrassing, stigmatizing, and in violation of the subject's Fourth Amendment rights.

strategic special nuclear materials (SSNM). In many respects they are not unlike searches and clothing exchanges already conducted by high-precision industries such as the computer and gyroscope industries where assurance is needed that no foreign particles are being introduced.

Several precedents exist for inspections for security reasons, most notably the airlines' searches of passengers and luggage, which have recently been upheld by the Courts.* The precious metals industry also conducts inspections and searches to prevent unauthorized removal of metals from their premises.

The inspection and search procedures selected for the reference safeguards system, as described in Chapter 5, are designed to impact as little as possible on individual privacy and rights. For example, to the maximum extent feasible, technical devices rather than hands-on methods would be used in searches.

7.2.2.2 Personnel Clearances

While security clearances are not at this time required in the nuclear industry under 10 CFR Part 73, the NRC has recommended in Regulatory Guide 5.20 that its licensees conduct checks of prospective employees for prior felony convictions. NRC licensees have found it difficult to comply with the suggested guidelines, however, because local law enforcement agencies are generally reluctant to divulge such information to prospective employers.

Clearance requirements in a future MOX industry could include national agency checks and inquiries, or full field background investigations. In those cases where inconclusive results were obtained by these techniques, or where the employee would be in a particularly sensitive position, structured interviews might also be found useful, both at the time of hiring and periodically thereafter, as one means of assuring continued employee reliability.** It should be noted that clearance procedures for use in the nuclear industry have now been proposed by the NRC quite apart from any MOX decision.†

Such a preemployment clearance program could have an impact on civil liberties through invasion of privacy, through possible infringements of Fifth Amendment rights, and through violation of First Amendment rights, including the right of association.

Invasion of Privacy. Background checks would use a personal history statement as a point of departure, seeking to verify and to supplement statements made by the individual. They would also include inquiries addressed to former employers, educational institutions, and references named by the individual. They might probe the individual's activities, associations, behavior

---

*For example, United States v. Davis, 482 F.2d 893 (9th Cir. 1973); United States v. Epperson, 454 F.2d (4th Cir.), Cert. denied, 406 U.S. 947 (1972).

**One difficulty with the structured interview technique is that the interviewer must have prior familiarity with the type of individual he is dealing with. In practical terms, this means that, to validate the technique for use in the nuclear industry, a general "profile" of the nuclear industry worker would first have to be developed.

†A Commission paper, SECY 76-508 (10/7/76), dealing with possible clearances for NRC licensees handling SNM, has been approved by the Commission and resulted in updating to 10 CFR Parts 11, 50 and 70, as noted in the Federal Register notice of March 17, 1977, Vol. 42-No. 52, p. 14880ff.

traits and beliefs--in short, how he lives. Such inquiries could represent a substantial invasion of privacy. If structured interviews were used, they might constitute a further invasion of privacy.

The fact that an individual consents to being investigated would not lessen any invasion of privacy that might be involved. Mitigating any impact, however, would be the fact that employment in the nuclear industry is a matter of voluntary choice.

Fifth Amendment Rights. Compulsory disclosure requirements in employment applications might raise questions of self-incrimination under the Fifth Amendment. Questions might also arise under the due process clause of the Fifth Amendment if employment were denied on the basis of unjustified presumptions, vague criteria, summary procedures, or adverse information supplied by confidential informants. These issues could be affected by the process of screening, i.e., the investigation or assessments performed to gather information about an individual.

First Amendment Rights. The prime impact of a clearance program on First Amendment rights could be its effect on the exercise of the rights of free association and free speech. The fact that an individual's acceptability for employment is being judged on the basis of his associations and the organizations to which he belongs may represent a strong pressure toward conformity. The degree of such pressure would be related to the criteria against which the information gathered is measured in deciding whether to grant or deny the clearance. Appropriate criteria could be derived from those currently used for the preemployment screening of guards by commercial establishments and protective service companies (e.g., Pinkerton, Wackenhut, Globe, etc.). In addition, careful consideration could be given to utilizing screening criteria that emphasize reliability rather than conformity.

Other Civil Liberties Impacts. The way a clearance program is administered can infringe upon the individual's rights to due process. Denial of a clearance on psychological grounds alone, unsupported by past predictive behavior, e.g., criminal activity of a nature commensurate with the theft of SSNM or industrial sabotage, could be an example of such an infringement.

There is also the problem of the stigma attached to denial of a security clearance. Many employment application forms ask whether the applicant has ever been denied a security clearance. While an affirmative answer to such a question might not, in theory, automatically eliminate an applicant from further consideration, it would undoubtedly raise serious questions regarding the individual's trustworthiness in the minds of many employers. Almost certainly an individual who has been denied a clearance would have difficulty in obtaining a position of trust and responsibility in an industry where clearances are a key requirement. To minimize such possible adverse effects, procedures similar to those in 10 CFR Part 10 would be instituted; e.g., the rights of hearing and appeal would be guaranteed to individuals seeking clearance.*

Numbers Affected. One measure of the civil liberties impact of a preemployment clearance program for a mature MOX industry is the number of people who might be affected. If it were decided to subject to clearance all employees with potential access to plutonium, the number involved would be less than 41,000. If, on the other hand, it were decided to clear only those employees whose duties would afford them the opportunity to commit, aid, or conceal theft or sabotage, the number involved would probably not exceed 21,000.** In either case the number would be relatively small when compared to the nearly 670,000 full-field background investigations and some 4.2 million national agency checks conducted by investigative agencies of the Federal Government in fiscal years 1970 and 1971 (Ref. 7). Indeed, it is estimated that there would be only 14,000 safeguards-related employees in the mature MOX industry. This compares to an estimated 11,700 safeguards-related employees for whom felony conviction checks would have to be performed in the same time frame if the industry were to continue operating under Regulatory Guide 5.20 without recycling. These numbers are small compared to those affected by similar programs in other industries.† (A more detailed analysis of safeguards-related employment is presented in Section 7.6.2.)

7.2.2.3 Impact of Alternatives to the Reference System

Implementation of any of the alternative safeguards measures discussed in Chapter 6 should not introduce societal impacts greatly different from those of the reference system. For example, as mentioned in Section 6.2, Federal guards would be subject to the same clearance requirements as private guards. Also, equivalent training and performance standards would be applied.

---

*References 3, 4, 5, and 6 suggest additional measures to mitigate potential impacts of clearance procedures, including: (1) preventing the applicability of adverse security determination from being extended to less sensitive positions; (2) guaranteeing the confidentiality of security records; (3) establishing narrower, more specific criteria for denying clearances so as to decrease the amount of discretion used by clearance administrators; (4) publication of grounds for dismissal or denial, and the general facts of all cases which lead to nonclearance; (5) right to confront adverse witnesses; and (6) specific guarantees regarding communication with the press and government officials. These suggestions and others will be given detailed examination under the review process which precedes adoption of any new NRC regulations.

**Includes all safeguards personnel plus approximately 25 percent of remaining fuel cycle employees. See Appendix A, p. A1-5.

†Preliminary information has recently been obtained by NRC indicating that a very substantial number of full field background investigations are now performed in certain industries (e.g., precious metals, steamship companies, airlines, department stores, oil producers, insurance, stock exchanges, and many more). Also, the Securities and Exchange Commission has initiated a massive fingerprinting program for securities industry officials and employees, in connection with which the FBI is conducting a search against criminal files. Arrest and conviction records will be sent to brokerage firms and other employers. More than 200,000 securities industry personnel are affected by this measure which became mandatory July 1, 1976, based on legislation enacted in 1975.

7.2.2.4 Summary of Effects on Employees

Compared to current practice in the non-defense portion of the nuclear industry, the proposed inspection and search procedures and proposed personnel clearance measures can be viewed as having potentially adverse effects on the civil liberties of industry employees. In terms of the numbers of employees involved, however, the aggregate impact would probably be small, especially when compared to security programs already in force in a wide variety of business and commercial activities and in the industries in the national defense sector. Mitigating any impact, moreover, are the facts that employment in the nuclear industry is a matter of voluntary choice, and that anyone seeking a job in that industry would do so with the realization that he must subject himself to the industry's procedures.

7.2.3 Effects on the Public

As indicated above, individual employees would have the option of avoiding adverse civil liberty impacts by avoiding employment in the MOX industry. Members of the public may have no such control over the impacts to which they are exposed. Accordingly, careful attention must be given to possible impacts of MOX industry safeguards on individuals not directly involved with the industry. Potential impacts about which concern has been expressed are discussed below.

7.2.3.1 Surveillance to Collect Intelligence

Concern has been expressed over the possible arbitrary extension of the use of surveillance as a tool in exposing domestic dissidents. The basis for this concern is the possibility that investigative agencies might respond to a threat to the MOX fuel industry by extending present domestic covert intelligence activities--with an ultimate impact on First Amendment rights.* It is thought that this could, in the extreme, lead to a nationwide police intelligence network and its associated abuses.** Recent history has shown that surveillance practices are difficult to monitor and control, and that bureaucractic excesses and overreactions,[†] with their potential effects on civil liberties, cannot be entirely eliminated.[††]

---

*Some instances of past abuses of the intelligence functions of the Federal Government have been documented in reports of the Senate Select Committee to Study Governmental Operations with Respect to Intelligence Operations (Ref. 2).

**The American Civil Liberties Union (ACLU) has shown increased concern over such possibilities. ACLU's Northern California affiliate, for instance, expressed the view, in May 1975, that the safeguarding of radioactive wastes at future nuclear facilities and during transport would require massive security measures. ACLU envisioned the creation of massive police forces engaged in undercover intelligence, surveillance, and counterespionage activities, thereby transforming this country into a militarized police state in which civil liberties would be severely threatened. The Kansas Chapter of ACLU is focusing its attention on issues of due process as they relate to societal consequences of police powers granted to protect nuclear plants and their products from terrorists.

[†] As a result of recent criticism levied against the investigative excesses committed by the Army, CIA, and FBI in their surveillance of dissident groups, Government agencies have instituted more stringent self-regulation procedures. Broad authority for the use of undercover agents has been upheld by the courts. It may also be noted that the use of undercover agents is not covered by provisions of the Fourth Amendment. However, the courts have shown increasing concern about the surveillance practices of Federal investigative agencies, and recent judicial decisions have helped circumscribe somewhat the freedom of action previously enjoyed by these agencies.

[††] The need for active NRC attention to the civil liberties costs of domestic surveillance was strongly voiced by participants at an NRC-sponsored working conference on the "Impact of Intensified Nuclear Safeguards on Civil Liberties" (Ref. 8).

Misperceptions as to the actual workings of safeguards and the relationship of the MOX fuel cycle to already existing quantities of SSNM contribute to the public concern. Accordingly, it must be emphasized that the reference safeguards system described in Chapter 5 stresses self-contained defense-in-depth through access denial, barriers, intrusion alarms, armed guards, a trained response force, and internal materials accounting and control procedures that would give indications of theft or diversion. Domestic intelligence activities would contribute but marginally to the capability of such a system and would serve primarily to bolster law enforcement and investigative agencies in their detection and preventive roles.

It is the responsibility of law enforcement and investigative agencies to maintain, within legally permissible boundaries, surveillance of individuals and groups known or thought to have perpetrated illegal acts. The worldwide increases in aircraft hijackings, bombings, and other acts of terrorism have emphasized a need for national and international surveillance of terrorist groups, quite apart from the presence or absence of a MOX fuel industry.*

The present Omnibus Crime Act contains many safeguards against abuse.** Additional Congressional action would be required if it were desired to provide less restrictive standards of probable cause[†] in Title III of the Omnibus Act, and judicial action would be required to expand the national security exception rule to include domestic security threats.[††] Both the legislative and judicial options have civil liberties implications, although the effects of the former might be considered less severe (Ref. 3, p. 98).

Advance warning certainly facilitates defense against hostile acts, and reports from existing surveillance agencies could enhance nuclear industry safeguards. However, the reference safeguards system described in Chapter 5 is designed to function without advance

---

*Increases in the number and severity of violent acts would normally be expected to evoke increased surveillance activity on the part of authorized government investigative agencies (e.g., FBI) since, "...even commentators who are critical of the widespread use of informers agree that they play a vital role in dealing with highly organized groups capable of committing serious crimes." (Ref. 5, p. 404.)

**The Omnibus Crime and Safe Streets Act of 1968 (18 USC §§ 2510-20, 1970) authorizes use of electronic surveillance to investigate a specific set of crimes, including crimes under the Atomic Energy Act relating to misuse of restricted atomic data but not including theft of SSNM.

[†] In the Keith Case (U.S. v. U.S. District Court, 407 U.S. 207; 1972), the Supreme Court acknowledged the difference in investigative approaches between domestic security cases and ordinary crime cases. It noted that domestic security surveillance targets are more difficult to identify than targets of ordinary crimes listed under Title III, that emphasis in surveillance is more on prevention of unlawful activity, and that surveillance is thus necessarily less precise than in ordinary crime. In general, the goal of domestic security surveillance is enhancement of the government's future preparedness to respond.

[††] This has been resisted so far by the courts, e.g., Zweibon v. Mitchell, 516 F. 2d 594 (D.C. Cir. 1974).

warning and would not generate a requirement for increased surveillance by Federal investigative agencies.*

The likelihood that there would be a significant increase in surveillance activity is related less to the existence of a MOX industry than to the broader issues in society of how much surveillance activity is necessary or should be tolerated and what criteria should be satisfied before surveillance activities can be sanctioned by the courts. This is a collective judgment which changes from time to time depending generally on the perception of the stability of society and specifically on judicial decisions by the higher courts. However, because of constitutional interpretations and legal guarantees, these criteria have generally been held within relatively narrow limits.

Whether certain individuals or groups should be placed under surveillance by law enforcement or investigatory agencies without having clearly demonstrated malevolent intentions is one of several issues which must be settled in this broader context. Thus, if a general increase in surveillance activity occurs as the result of possible future changes in or threats to our social structure, there is no reason to believe the MOX industry would share disproportionately in the responsibility for such a change relative to other institutions or facilities needing protection, e.g., office buildings, sports stadia, water suppplies, etc. Further, it is highly unlikely that MOX industry personnel would be singled out as a group for continual surveillance. While they might be subject to periodic background investigations for the purpose of updating their clearances, this would be a routine administrative procedure not motivated by suspicion of malevolent intent.

For perspective on the potential for surveillance problems, it should be noted that a MOX industry would involve only an extension of an existing problem. As indicated in Sections 3.2.6 and 4.4.4, the AEC and ERDA (now DOE) have successfully safeguarded large quantities of SSNM for many years, and licensees under NRC regulatory authority are currently handling appreciable quantities of SSNM. With this experience as a guide, it should be possible to avoid abuses in a MOX industry.

7.2.3.2 Search and Seizure in Recovery Operations

Concern has been expressed about violations of civil liberties and Fourth Amendment rights that might occur in an intense effort to recover missing SSNM after a successful theft or

---

*The evolution of present NRC safeguards thinking and concepts supersedes the preliminary findings of an earlier AEC internal report ("A Special Safeguards Study: Report to the Atomic Energy Commission," by D. Rosenbaum, et al.,) (Ref. 9), which suggested that "The first and one of the most important lines of defense against groups which might attempt to illegally acquire SNM to make a weapon is timely and in-depth intelligence." The study further pointed out that it is the AEC's business to see to it that the intelligence-gathering agencies of the U.S. Government, "including the FBI, CIA and NSA, should focus their attention on this particular threat to our national defense and national security." Under the current concepts, utilization of outside intelligence would be only incidental to the performance of the safeguards systems and would build on principles established during many years of safeguarding weapons-related nuclear materials. Although NRC will not explicitly impose intelligence missions on existing law enforcement elements, neither does it have jurisdiction to bar them. In a March 29, 1976, memorandum to the ACLU Board of Directors, for instance, ACLU's "Special Committee on Nuclear and Other Energy Programs Affecting Civil Liberties" made reference to an article in the August 11, 1974, issue of the New York Times (Ref. 10), which reported that the Texas State Police maintained files on nuclear power plant opponents with the justification that such individuals might wish to commit sabotage.

diversion.* It is conceivable that, because of the severity of the threat, courts would feel compelled to waive particularity requirements for search warrants or to dispense with search warrants entirely.** A legal basis for approving wide-scale searches might be found in opinions[†] in which the courts have accepted law enforcement officials' arguments that searches conducted in enforcement of fire, health, and building code regulations depend on statistical rather than individual probable cause standards. The fear, then, is that citizens innocently caught up in the web of such operations, which could include hot pursuit and dragnets in suspected areas, could suffer a deprivation of their civil liberties and Fourth Amendment rights (Refs. 5 and 11).

The reference safeguards system described in Chapter 5 has been designed to minimize such impacts. It attempts, first, to prevent theft or diversion of SSNM. In the unlikely event that theft or diversion occurs, recovery operations would be based on DOE's current contingency plans. These do not envisage actions which would require wide-scale entry and search of private premises. Under these plans the FBI would have primary field responsibility for recovery operations and would be supported by DOE technical experts trained in the detection and handling of nuclear materials and the disarming of nuclear weapons. DOE's detailed emergency plans for quick deployment of special "Nuclear Emergency Search Teams," established for its own nuclear program, would be activated during an early phase of the emergency. DOE's "Emergency Action Coordination Team" would aid in determining threat credibility. (For further details, see Section 4.3.5.)

Under these operational plans and procedural guidelines for recovery operations, no substantial civil liberties violations are anticipated. While it is not possible to guarantee that no investigative excesses would occur, such excesses could be held to a minimum by requiring that wide-scale searches be approved at the level of the U.S. Attorney General or even the President. Contingency plans would also be continuously updated and refined to minimize their civil liberties impact. This would require continuing coordination among all of the participating agencies.

7.2.3.3 Civil Liberties Impact of a Federal Guard Force

The option of instituting a Federal guard force (FGF) instead of continuing to use private guards (see also Sec. 7.3.4) would in itself not adversely affect civil liberties, so long as the FGF's responsibilities were clearly defined and limited to safeguarding physical facilities from theft, escorting transports of SNM, and providing an initial reaction against any physical attack on a nuclear facility.[††] Under those circumstances, the FGF would not have any general investigative authority and would not participate in later recovery operations. Well-trained,

---

*Such concerns were prevalent among participants in the Conference on the Impact of Intensified Nuclear Safeguards on Civil Liberties (Ref. 8).

**An exhaustive treatment of the legal ramifications and court positions on search and seizure operations can be found in Ref. 5, pp. 412-24. Most of the discussion is based on an assumption of massive sweeps which might affect whole sections of a city.

[†] Camera vs. Municipal Court, 387 U.S. 523, 536-37 (1967); and See vs. Seattle, 387 U.S. 541 (1967).

[††] Qualifications and duties of security guards are noted in References 12 and 13.

well-disciplined, high-quality guards, whether Federal or private, would be expected to fulfill their responsibilities without resort to inefficient, nonselective methods potentially invasive of civil liberties. Although there are substantial issues associated with the establishment and use of a Federal security force, such as comparative effectiveness, costs, and other administrative considerations, civil liberties concerns do not appear to be a governing factor in the decision (Ref 14).

7.2.3.4 Summary of Effects on the Public

The safeguards needed to protect a MOX industry are not likely to include surveillance as an integral part. Should other agencies increase their surveillance activities, it would probably be in response to individuals or groups demonstrating malevolent intent rather than to the existence of MOX facilities. Neither is there reason to believe that the existence of MOX industry facilities would stimulate the formation of additional groups of malefactors which might require surveillance, since the SSNM associated with commercial facilities in the MOX industry would be demonstrably protected to a level equal to or exceeding that currently provided to Government-owned SSNM.

In the unlikely event of an illegal diversion of SSNM from a MOX facility, search and seizure operations could cause localized short-term impacts on the public, but the contingency plans for such operations would be designed to minimize such impacts. Use of a Federal guard force should not threaten civil liberties any more than do private guard forces and could threaten less due to uniformity of training and tighter operational control and discipline.

7.3 INSTITUTIONAL IMPACTS

7.3.1 General

A decision to proceed with MOX fuels could influence to some extent a number of institutional practices, arrangements, or patterns that currently exist in the nuclear power and fuel industries. Prominent among these are the concept of free enterprise, the concept of an open society, and Federal regulatory practices.

7.3.2 Free Enterprise

Imposition of certain safeguards measures could limit industry options in the siting of plants. (An example would be collocation of plants to reduce the transportation of certain plutonium compounds.) This would not be a unique constraint since none of the principal U.S. economic sectors or industries functions entirely free of U.S. Governmental involvement. Regulations, tariffs, quotas, subsidies, and a host of other economic or administrative tools have been employed by the Government to influence the social and economic development of the country. In selecting a site, for example, an enterprise must comply with the provisions of several Federal and State acts, such as the Coastal Zone Management Act, the Clean Air Act, the Federal Water Pollution Control Act, and other recent legislation motivated by environmental considerations. Industry has developed ways to operate successfully under the constraints these acts impose.

The introduction of preemployment clearance requirements and the increased likelihood of terrorist threats against a MOX industry, both of which would increase the role of investigative agencies, could also increase the level of Government involvement in the nuclear fuels industry via a broad range of activities related to rulemaking, adjudicatory proceedings, and actions in other fields where new Federal initiatives might be called for. However, Federal involvement in nuclear matters has been a recognized and accepted fact of life from the beginning of the industry. For example, the Government has provided massive long-term support for nuclear research and development, encouraged nuclear power generation, and defined and enforced health, safety and safeguards standards for radioactive materials.

7.3.3 Open Society

There might be secrecy surrounding certain aspects of a MOX industry which would manifest itself by reducing the availability or ready accessibility of industry-related information, particularly in the area of security operations. Such practices could conflict with the traditional open nature of American society.

If the public is denied the right to be informed and to question and participate in a review of agency actions, the possibility is created that mistakes and inefficiencies might be hidden rather than addressed and corrected. This possibility would not be unlike the situation currently existing in certain defense and foreign policy areas, but would be of a much lesser magnitude.

7.3.4 Impact of Alternatives to the Reference System

If there were a Federal guard force, Federal guards stationed at plants owned and operated by private industry might interfere with plant operation in order to enhance the effectiveness of safeguards.* This might be perceived by some as inconsistent with a free enterprise economy.

Giving a Federal guard force responsibility for protecting private property might also be viewed as a precedent for further Federal intervention in what has previously been considered a function of local law enforcement or of private guards. While States have traditionally resisted the expansion of Federal police powers, some erosion of this resistance has already taken place with the steady growth of civilian Federal agencies charged with statutorily circumscribed law enforcement functions (e.g., FBI, Secret Service, Drug Enforcement Administration, etc.). The use of Federal marshals in the airline industry has set a rather specific precedent for governmental intervention and involvement in providing protective services when unusual security problems are faced by private industry (Ref. 14, p. IV-18.).

If the NRC were to assume direct operational responsibility for a Federal guard force, as has been suggested, considerable organizational imbalances could arise. These would be due to difficulties in assimilating an organization that could grow to more than four times NRC's

---

*The Security Agency Study suggested a possible rationale for division of such responsibility, as follows: "...traditionally, private industry has been required to protect the public only against acts caused by its own negligence or wrongdoing, not against wrongful acts caused by third parties over whom it has no control." (Ref. 14, p. IV-17.)

present size, and whose professional and mission objectives would have little in common with NRC's regulatory orientation. Also, the creation of yet another government bureaucracy, with its own extended career and growth objectives, might lead to suspicion that threat estimates were being exaggerated in order to justify requests for additional Federal resources.

The blending and collocation options could also be viewed as possible constraints on free enterprise, in that they might possibly interfere with more efficient or cost-effective industrial processes and marketing patterns. For instance, the mandatory shipment of blends would constrain fuel fabricators to the use of uranium included in the blends, rather than permit them to select their own uranium sources. Collocation might restrict open markets by forcing separately owned collocated plants to deal only with one other.

7.4 LEGAL FACTORS

7.4.1 Use of Deadly Force

Legal limits on the use of deadly force vary somewhat from State to State. The issue is bound up with the respective State laws regarding homicide, since licensed SSNM has not been granted special status as a form of property justifying the use of greater force than is used to protect other property. The inherent properties of SSNM could, however, bear upon a jury's decision as to whether a guard's use of deadly force in a particular case was justified.

A consistent general thread running through various State statutes and cases is that use of deadly force is legitimate in self-defense and defense of others. Another general line, found for example in California, is the narrowing of the concept of deadly force in prevention of a felony committed by violence and surprise. A third pervasive rule is that deadly force may never be used in misdemeanor situations unless the event turns into one of self-defense (which would generally indicate that the offender has resorted to felonious assault in addition to the misdemeanor).

The use of deadly force would probably be legally justified in most jurisdictions in order: (1) to prevent death or serious bodily injury to self, other guards, or employees and visitors in a nuclear plant; or (2) to repel an adversary attack by armed persons. Deadly force may also be justifiable to counter deadly force offered to resist a lawful arrest for a felony where a guard has acted properly to effect the arrest. It should be noted that, even in States that impose a duty to retreat before the use of deadly force (e.g., Massachusetts), there is normally no duty to retreat if one is performing a lawful duty such as effecting a legal arest. Thus, predicated upon an attempt to arrest and the subsequent conduct of the arrestee, deadly force might be justifiable to: (1) prevent a theft of SSNM; and (2) prevent an act of sabotage resulting in dispersal of SSNM. A more difficult question involves the use of deadly force to prevent an escape with SSNM. If an attempt were made to make an arrest, use of deadly force might be justifiable in response to certain specific actions by the fleeing person. If, however, an opportunity to arrest were not available, then deadly force might not be justifiable.

The principal difference between private guards and Federal officers is in their authority to make arrests, rather than in the rules governing the use of deadly force. All States make a distinction between the circumstances and degree of force permitted to peace officers or private citizens in making an arrest. Peace officers may be justified in using deadly force to make an arrest if reasons exist to believe that a felony has been or is about to be committed which would endanger human life. A private citizen, including a private guard, is immune from liability for the use of deadly force only if such a felony has in fact been committed. It would thus seem that in some situations a Federal status could imbue a guard with a greater sense of confidence in that he would not be held criminally liable for the use of all necessary force in preventing a theft of SSNM.

These considerations apply to the use of deadly force within the context of current law and policy. Protection of SSNM, however, may represent a sufficient departure from this context to justify a fundamental reëxamination of the issue.

7.4.2 Automatic Weapons

Under current laws, private armed guards are generally not permitted to carry weapons more lethal than handguns, shotguns, or rifles. State and Federal laws generally bar the use of automatic weapons. As discussed in Chapter 6, authorization to issue automatic weapons to guards could contribute to their defensive capability, but probably not sufficiently to warrant a reduction in the number of guards.

7.4.3 Liability for Guard Actions

Questions of liability might arise in the event damages were suffered as a consequence of negligent actions or omissions on the part of guards. If private guards were used, questions of liability would be more easily resolved because the traditional employer-employee doctrines of agency law would generally apply (Ref. 14, pp. IV-14, 15). However, if Federal guards were involved and the Government were represented as a third-party intermediary, an acceptable formula for the equitable distribution of liability burdens would need to be built into the enabling legislation.

7.5 ENVIRONMENTAL IMPACTS

7.5.1 Aesthetics

It has been suggested that future nuclear fuel fabrication and reprocessing plants would look like World War II concentration camps, replete with vehicle barricades and barbed wire fences patrolled by gun-carrying security guards. Nothing in the safeguards measures described in Chapters 4, 5 and 6 requires that the facilities be laid out in such a manner, and experience does not support such a premise. The use of optical and other perimeter sensors, for example, would reduce direct dependence on outside armed patrols. Trees and other vegetation are already used successfully to shield unsightly buildings or fences from the view of passers-by. Individual environmental impact statements for each facility would, of course, address this issue.

7.5.2 Other Environmental Issues

The safeguards-related visible changes for dispersed facilities would probably be confined to adding a strip of ground of perhaps 15 meters in width around the perimeter fence. If collocation were implemented, individual sites would tend to be slightly larger but, since there would be fewer sites, the total environmental impact would not be expected to increase. If air transportation were selected as one of the required safeguards measures, additional land requirements and other environmental considerations would result from the construction and operation of separate airstrips.* These would be governed by applicable local and State ordinances, licenses, and permits, as is the case with any other industrial construction project.

No other significant safeguards-related changes affecting the physical environment are foreseen at this time. The Health, Safety, and Environment portion of GESMO (NUREG-0002) addresses other construction-related impacts not directly attributable to safeguards.

7.6 EFFECTS ON THE NATIONAL ECONOMY

7.6.1 Aggregate Costs of Safeguards

The potential impact on society of safeguards costs, especially the impact on electric power bills and the indirect cost of administering a complex safeguards system, is a matter of considerable interest. Based on the estimates presented in Chapters 5 and 6 and in Appendix A of this report, annualized costs for safeguarding a mature MOX industry (including amortization of fixed investment, return on capital, salary of guard forces, costs of screening and clearances, etc.) would range from $141 million per year for the reference system to a high of $191 million per year if a 10 percent blend were undertaken.**

It is probable that these costs would all be borne initially by the nuclear power industry and then be passed on to the consumer through increases in utility rates. Preliminary estimates show that the average additional cost for electric power (over a non-MOX nuclear system) would be about $1.89 per customer per year for the reference system.† Location of a nuclear fuel facility in a community would place an additional burden on local public services, a burden which might be only partially offset by increased revenues from the additional tax base.

More difficult to measure are indirect costs. Most significant among them would be the added costs of financing regulatory activities at the Federal level. Preliminary estimates place the increment at about $1.7†† million per year in annualized operating costs.

In summary, estimates suggest that the cost of MOX-related safeguards in the reference system would not be substantially greater than the costs of safeguards required for the non-MOX nuclear industry under existing regulations covering the handling and safeguarding of enriched uranium and high-level wastes (see also Section 5.4).

---

*E.g., the design of facilities would, of course, seek to minimize the likelihood of damage to facilities due to a possible aircraft crash.

**See Chs. 5 and 6 and App. A for a more complete explanation of the basis for cost and employment estimates for the MOX and non-MOX industries.

†A utility customer (e.g., a household) consumed an average of 22,000 kWh in 1970. If he were to consume only MOX-generated power, his annual cost attributable to MOX safeguards would be .086 mills/kWh (see App. A) x 22,000 kWh/yr, or roughly $1.89/year. Naturally, if some of the power he consumed originated in non-MOX nuclear generating plants his share of the cost attributable to MOX safeguards would be correspondingly less. (To place safeguards costs in perspective, it should be noted that the annual per-capita costs of police protection in metropolitan areas of the United States range from $30 to $150.) (Refs. 15,16.)

††See Table A1.4, p. A1-8 of Appendix A.

The differential costs added by most of the safeguards alternatives considered in Chapter 6 would be small and would not be an overriding consideration in selection or rejection of a specific alternative. A summary compilation reflecting the incremental costs of the several alternatives is presented in Table 7.1.

7.6.2 Effects on Employment

7.6.2.1 Employment at Fixed Sites

Nominal safeguards employment at all reactor sites under proposed amendments to 10 CFR 73 would be 10 guards per shift.* Thus, the total nominal number of guards required under the NUREG-0002 industry model for the year 2000 (507 reactors at 250 separate sites) would be 11,500 guards.** It is estimated (Ref. 17) that there would be 47,000 non-safeguards reactor site employees at that time. Thus, adding the safeguards personnel required by the proposed amendment would increase the total reactor site employment by 24 percent. No additional safeguards personnel would be required for those reactors converted to MOX fuel.

Each fuel reprocessing, fabrication, and assembly plant in a MOX industry is projected to employ 10 guards and one supervisor per shift, and about 11 security support personnel. Fuel reprocessing and fabrication plants would also need an estimated 58 positions each for material control functions including accounting. Assembly facilities would not require materials accounting personnel, since all material in these facilities would be tracked by item count. (Item count is required in both uranium oxide and MOX facilities.) Industry-wide, safeguards-related employment based on these estimates is summarized in Table 7.2. (Transportation employment, discussed in Section 7.6.2.2, is also shown in Table 7.2.)

Employment increases in a MOX industry relative to a non-MOX industry are presented in Table 7.3 for both safeguards and total industry employment. As shown, the increase amounts to about 10,650 people, i.e., an increase of 14 percent over a non-MOX industry.

7.6.2.2 Employment in Transportation

In the reference system set forth in Chapter 5 the total number of guards employed for transportation of material is a function of the protection levels sought, the average distance traveled on a given transportation leg, and the number of hours required to travel each leg. It is estimated that a total of 416 guards would be thus employed plus an additional 122 employees devoted to communications and administrative duties.

---

*As few as five guards per shift might be permitted at a specific site under appropriate conditions, after review and upon approval by the NRC.

**Ten guards per shift at each site times a factor of 4.6 to account for three-shift operation, annual and sick leave, and administrative/supervisory support.

TABLE 7.1

SAFEGUARDS COSTS AND THEIR EFFECT ON COSTS OF GENERATING ELECTRICITY[a]

Alternative	Estimated Annual Safeguards Costs $ millions	 Mills per kWh[b]	 % of Cost of Generating Electricity[c]
Reference System	141	0.086	0.72
Reference System with:			
Collocation	138	0.084	0.70
Blending			
30%	170	0.103	0.86
10%	191	0.116	0.97
Air Transport	144	0.087	0.73

[a] Source: App. A

[b] Assumes 250 1,000-MWe reactors, each generating 6.57 x 10^9 kWh/reactor/year, with a load factor of 75 percent of capacity. (Costs at the reactor are bus-bar costs before distribution of electricity.)

[c] Assumes total generating cost to be approximately 12 mills per kilowatt-hour, 1975 dollars. This is derived from Ref. 18, page 20, Table 1-5, by deflating the 22.6 mills per kWh cost figure shown there for the year 1972 back to 1975 using an 8 percent discount rate.

TABLE 7.2

PROJECTED SAFEGUARDS EMPLOYMENT IN THE MOX NUCLEAR INDUSTRY IN THE YEAR 2000

INDUSTRY COMPONENTS	SAFEGUARDS PERSONNEL
Reactor Sites	11,500[a]
Reprocessing	580[b]
MOX Fuel Fabrication	790[c]
Fuel Assembly	460[d]
Transportation	540[e]
Regulation (NRC)	80
Total Employment	13,950

---

[a] 10 guards/shift x 4.6 equivalent shifts x 250 reactor sites (assuming average of 2 reactors per site).

[b] 5 facilities x [58 (material control and accounting) + 57 (security force)].

[c] 7 facilities x [58 (material control and accounting) + 57 (security force)].

[d] 8 facilities x 57 (security force).

[e] 416 guards/drivers + 42 administrative support (~10%) + 80 communications personnel.

TABLE 7.3

SAFEGUARDS AND OTHER EMPLOYMENT[a] FOR MOX AND NON-MOX NUCLEAR INDUSTRY ALTERNATIVES, YEAR 2000

Industry Alternative	Total Safeguards Employment	Reactors	Fuel Cycle	Total Industry
Non-MOX Industry (THROWAWAY Cycle)	11,700[b]	47,060[c]	18,400[d]	77,160
MOX Industry (Alternatives 1, 2, or 3) w/Reference Safeguards System	13,950	47,060	26,800[e]	87,810

---

[a] Other employment refers primarily to process and production employment. Safeguards employment would not be expected to differ if collocation, air transport, Federal guard force or automatic weapons were incorporated into the safeguards system. Blending would be likely to increase safeguards employment only by 100.

[b] Includes physical security force for reactors plus about 200 additional employees for material control at UO_2 fuel fabrication facilities.

[c] Ref. 19 and Table 3.4. This figure includes no safeguards security personnel, referring primarily to operating and administrative personnel.

[d] Ref. 19. This fuel cycle value is assumed equal to the fuel rod assembly personnel value.

[e] Ref. 17, Vol III, Table 1, p. III-78. This figure includes reprocessing (6,000), fuel rod fabrication (2,400), and fuel rod assembly (18,400).

7.6.2.3 Impact of Alternatives On Employment

The collocation of matched fuel reprocessing and fabrication facilities in the mature MOX industry would essentially eliminate the first transportation leg, thereby eliminating most of the 23 guards employed in the reference system for this purpose. Impacts on other phases of employment would be quite negligible, as revealed by an examination of the employment data underlying Tables 7.2 and 7.3.

If the blending option were adopted, the transportation cycle would remain the same as in the reference system, except for the first leg where the ton-miles would be increased by the addition of UO_2 to the PuO_2. Since all plutonium-containing materials in the transportation cycle of a mature MOX industry are considered to require the same level of protection, the first transportation leg, for all blending levels considered, would require the same number of guards per shipment as in the reference system. The only identifiable increase in safeguards-related employment would be in the reprocessing part of the cycle. That increase, however, would be very small, amounting to not more than 100 people.

Air transport of plutonium compounds would be expected to reduce somewhat the number of safeguards-related personnel employed on the first transportation leg. In place of the 23 ground transport guards needed in the reference system, air transport would require 16 people. (For each flight the plane would have a crew of three, plus five guards.) Beyond that, no other safeguards-related employment changes have been identified for this alternative.

7.6.3 Other Implications of Collocation

Because of the interdependence between collocated reprocessing and fuel fabrication plants, an investment of more than $600 million in collocated facilities may be seen by some as a greater business risk than an equal investment in dispersed plants. For the most part, however, the problems of acquiring and financing collocated reprocessing and fabrication facilities appear little different than those of dispersed facilities.

While there is no exact parallel, there are numerous examples in other industries--aerospace, chemical, and petrochemical, for example--involving the construction and operation of jointly owned facilities. Collocated nuclear fuel reprocessing and fabrication facilities would, at the most, involve only a moderate extension of the scope of such arrangements. Existing private institutions and financial channels are believed capable of raising the necessary capital over the projected time period.

An alternative approach involves having the Federal Government provide the capital for the high front-end construction costs and then licensing the facilities or selling them to an investor-owned company to operate.* Such an arrangement would reduce economic uncertainty and still preserve the role of investor-owned companies in the industry. Special legislation would probably be required. If profitable and stable markets can be established within the framework of effective regulations and licensing procedures, Federal involvement might be unnecessary.

Inasmuch as MOX users would insist on timely fuel shipments, there might be a need for contingency provisions to permit access to alternate offsite sources should a plant in a collocated facility break down. Prolonged or repeated breakdowns which required use of such offsite sources, of course, would reduce the long-run attractiveness of collocation.

To protect against the business risks associated with a possible breakdown of one plant in a collocated facility, some industry officials have argued in favor of multicompany partnership arrangements covering the entire fuel cycle process, i.e., vertical integration by technology of all plants at each site. Industry-generated figures presented in the Nuclear Energy Center Site Survey (NECSS) suggest that such an approach could result in savings of 10 percent in investment costs and 20 percent in operating costs.** It has also been suggested that such arrangements might give the appearance of collusion or of restraining competition (especially by "unconnected" prospective entrants). Since, under the collocation options considered, utilities would be required to contract for a combined reprocessing-fabrication package from the nearest site, as opposed to being able to shop separately for all materials on the basis of the lowest price, close Government supervision would be needed to avoid higher utility rates. Any constraints thus imposed might dampen industry's enthusiasm for collocation.

---

*This issue was addressed in the Nuclear Energy Center Site Survey (NECSS) (Ref. 20) for power centers in relation to land improvement and central fabrication facilities.

**These estimates were not independently confirmed by the NRC in Ref. 20.

The NECSS study concluded that collocation could probably be accommodated within the antitrust laws and regulations which presently govern the electric power industry. The study pointed out that antitrust enforcement efforts, which normally focus on preventing the misuse of market power, permit the realization of scale and integration economies so long as competitive rivalry is preserved to the maximum extent possible. For example, vertical organizational structures would be permissible if significant economies could be demonstrated, but the firms involved would be prohibited from using their market position to prevent other entities from having an opportunity to compete.

In sum, the most important societal concerns related to collocation appear to center on the following two issues: (1) whether the Government's role in facilitating a shift from a dispersed to a collocated industry would be too intrusive, and (2) the ability of the industry to operate profitably within the accompanying legal and regulatory constraints. At present, neither issue appears significant enough to rule out collocation as a safeguards alternative.

7.7 SOCIETAL IMPACTS OF GESMO ALTERNATIVES 1, 2, 5 AND 6

The Health, Safety, and Environment portion of the final GESMO, NUREG-0002, discusses five alternatives:

Alternative 1: prompt fuel reprocessing, prompt uranium recycle, delayed plutonium recycle

Alternative 2: delayed fuel reprocessing followed by uranium and plutonium recycle

Alternative 3: prompt uranium and plutonium recycle

Alternative 5: uranium recycle, no plutonium recycle

Alternative 6: no uranium or plutonium recycle

The societal impacts discussed thus far in this chapter have focused on Alternative 3. The impacts of the remaining alternatives are discussed below.

7.7.1 Alternatives 1 and 2

As indicated in some detail in Sections 3.2 and 5.5, the costs and composition of the safeguards systems and the total quantities of plutonium processed for GESMO Alternatives 1, 2 and 3 would be essentially the same in the year 2000. The safeguards costs would be essentially the same when calculated on a 26-year (1975-2000) cumulative undiscounted basis. Since societal impacts other than economic costs would be a function of the amount of SSNM processed, the nature of the safeguards systems used, and the number of people involved, they also would be essentially the same for Alternatives 1, 2 and 3 in the year 2000.

There would, however, be differences in the time phasing of societal impacts, since Alternatives 1 and 2 contemplate a later start on plutonium recycle than does Alternative 3. This delay could provide time for developing safeguards systems with reduced societal impacts. It is also to be noted that, on a cumulative basis, more plutonium would have to be safeguarded, under Alternative 1, because of the large accumulation of unused reprocessed plutonium.

7.7.2 Alternative 5

Under Alternative 5 (recycle of uranium only), if plutonium were stored for possible future use, it would have to be safeguarded at the reprocessing plant and the plutonium storage facility, as well as during transportation to storage. For this modest level of protection the annualized safeguards costs for the year 2000 would be about one-third those of Alternative 3, and the discounted 1975-2000 cumulative costs slightly more than one-third. Other factors leading to societal impacts, such as number of shipments, number of employee clearances and opportunity for theft or diversion, would be reduced in similar proportion. On the other hand, if plutonium were left in the spent fuel wastes, no plutonium safeguards would be required, there would be no societal impact, and waste disposal would proceed in a manner similar to that for Alternative 6.

7.7.3 Alternative 6

By definition, Alternative 6 (no uranium or plutonium recycle) would have no identifiable incremental societal impacts, since it would be basically an expanded version of the current industry. It is the "zero base" against which the incremental impact of the other alternatives is measured.

7.7.4 Safeguards Cost Comparisons

Dollar costs of safeguards might be used as a rough measure of the relative societal impacts of the various alternatives, since the costs reflect variations in the components which determine those impacts: e.g., amounts of plutonium processed, numbers of shipments, and numbers of guard force personnel. Table 7.4 shows the incremental costs for the various alternatives relative to Alternative 6. It can be noted that Alternative 5 would have the lowest costs, with only inconsequential cost differences among Alternatives 1, 2 and 3.

Table 7.4

INCREMENTAL SAFEGUARDS COSTS FOR GESMO ALTERNATIVES
RELATIVE TO ALTERNATIVE 6 (Ref. 21)
(in millions of 1975 dollars)

	ALT. 1	ALT. 2	ALT. 3	ALT. 5[a]
Year 2000, undiscounted	150	150	150	40
26-Year cumulative, undiscounted	1,500	1,500	1,500	500
26-Year cumulative, discounted	280	240	290	90

Source: Adapted from App. A, Pt. 3, and rounded off to the nearest 10M.

[a] These costs assume that plutonium is stored separately for possible future use. If the plutonium were left in the spent fuel, there would be no incremental safeguards costs for Alternative 5.

7.8 CONCLUSIONS

Safeguards attendant to the wide-scale introduction of MOX fuels for LWR's can be expected to have impacts of a societal nature, both within the nuclear industry and on the public at large. The actual significance and extent of such effects, however, must be considered in the context of current efforts to upgrade the overall level and quality of protection accorded the nuclear industry, quite independent of any decision to introduce wide-scale use of MOX fuels.

The analysis in this document leads to the conclusion that neither the safeguards measures associated with the reference system discussed in Chapter 5 nor the alternative options discussed in Chapter 6 would be likely to introduce severe societal effects. Most of the safeguards measures discussed are already in use in one form or another in private industry and in government operations.

Indeed, there is every prospect that the contemplated measures would be required in the nuclear industry even without plutonium recycle. The introduction of MOX fuels would thus appear to give rise to incremental impacts of a quantitative rather than a qualitative nature. These would stem from the extension in the scope of safeguards measures by the year 2000 to some 20 additional fuel cycle facilities and to 250 reactors during MOX fuel loading and storage; an increase of 2,400 shipments of SSNM per year; and an increase from approximately 11,500 to 14,000 in safeguards employment.

The concern about the potential adverse impacts that safeguarding MOX fuels would exert on traditional U.S. values revolves primarily around the question of the acceptability of the slight extension in safeguards coverage which would be involved. The related issues of qualitative impacts on individual citizens and on the public of safeguards measures such as searches, preemployment clearances, and recovery operations should be treated separately from the broader question of the possible presence or absence of MOX in the economy, since such measures would apply equally to a non-MOX U.S. nuclear industry whose safeguards are now being upgraded.

Chapter 7 References

1. "Justices Reduce Power of Courts over Convictions," New York Times, p. 1, July 7, 1976.†

2. Final Report of the Select Committee to Study Government Operations with Respect to Intelligence Activities, United States Senate, 94th Congress, 2nd Session, Book II, Intelligence Activities and the Rights of Americans and Book III, Supplementary Detailed Staff Reports on Intelligence Activities and the Rights of Americans, Senate Report No. 94-755, April 1976.†

3. Timothy R. Dyk, Daniel Marcus, and William J. Kolasky, Jr., Wilmer, Cutler, & Pickering, "Civil Liberties Implications of a Safeguards Program for Special Nuclear Material in the Private Nuclear Power Industry," Report to the Nuclear Regulatory Commission, October 1975.**

4. W.H. Clune, III, University of Wisconsin Law School," Standards and Decision Rules for Evaluating Trade-Offs between Civil Liberties and Nuclear Materials Safeguards," Report submitted to the Nuclear Regulatory Commission, October 1975.**

5. R.W. Ayres, "Comments--Policing Plutonium: The Civil Liberties Fallout," Harvard Civil Rights -- Civil Liberties Law Review 10, 369-443 (1975).***

6. Frederick S. Wyle, Esq., "Plutonium Recycling, Safeguards, and Civil Liberties--Conclusions and Recommendations," memorandum for the Nuclear Regulatory Commission, December 1975.[b]

7. U.S. General Accounting Office, "Personnel Security Investigations: Inconsistent Standards and Procedures," B-132376, December 1974.[b]

8. Robert Bartkus and Gail Block, "Rapporteurs' Report on the Conference on the Impact of Intensified Nuclear Safeguards on Civil Liberties," sponsored by Nuclear Regulatory Commission, Stanford Law School, Stanford, California, October 17-18, 1975.**

9. D. Rosenbaum et al., "A Special Safeguards Study: Report to the Atomic Energy Commission," Congressional Record 120, No. 59, S6623-S6628 (1970).†

10. "Texas Police Have A List For Dissenters," p. 4 of Sec. 4, New York Times, August 11, 1974.†

11. John H. Barton, "Intensified Nuclear Safeguards and Civil Liberties," paper for Conference on the Impact of Intensified Nuclear Safeguards on Civil Liberties, sponsored by Nuclear Regulatory Commission, Stanford Law School, Stanford, California, October 31, 1975, Nuclear Regulatory Commission Contract No. AT (49-24)-0190.**

12. U.S. Atomic Energy Commission, AEC Appendix 2401, "Physical Protection of Classified Matter and Information," Part IV, "Protective Personnel," pp. 19-24a, December 1974.**

13. U.S. Atomic Energy Commission, Regulatory Guide 5.43, "Plant Security Force Duties," January 1975.**

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

**Available in NRC PDR for inspection and copying, for a fee.

***Available in public technical libraries.

†Available in public libraries.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

Chapter 7 References (cont.)

14. U.S. Nuclear Regulatory Commission, "Security Agency Study: Report to the Congress on the Need for, and the Feasibility of, Establishing a Security Agency within the Office of Nuclear Material Safety and Safeguards," NUREG-0015, August 1976.*

15. U.S. Department of Commerce, *Statistical Abstract of the United States--1975*, 94th Congress, 1st Session, House Document No. 94-267, 1976.[†]

16. U. S. Department of Justice/U.S. Department of Commerce, *Expenditure and Employment Data for the Criminal Justice System 1974*, February 1976.[b]

17. Aerospace Corporation, "Effectiveness of Safeguards Programs for LWR Plutonium Recycling," Final Supplement, January 1976.[b]

18. U.S. Atomic Energy Commission, "The Nuclear Industry--1974," WASH-1174-74, 1974.*

19. R&D Associates, "RDA Support on GESMO Supplement," Vol. III, RDA-TR-4001-002, December 1976.[b]

20. U.S. Nuclear Regulatory Commission, "Nuclear Energy Center Site Survey--1975 (Summary and Conclusions)," (NECSS-75) NUREG-0001, 5 vols., January 1976.*

21. U.S. Nuclear Regulatory Commission, "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors," NUREG-0002, Vol. IV, August 1976.*

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

[†] Available in public libraries.

BIBLIOGRAPHY

1. Atomic Industrial Forum, "Technical Options for Plutonium Safeguards: A Report of a Forum Study Group on Fuel Cycle Safeguards," 1975.

2. International Atomic Energy Agency, "The Physical Protection of Nuclear Material," INFCIRC/225, September 1975.

3. Larson, Howard J., Assistant Deputy Director for Fuels and Materials, Nuclear Regulatory Commission, "The Nuclear Fuel Cycle," paper, The Atomic Industrial Forum Public Affairs Workshop, Knoxville, Tennessee, October 9, 1974.

4. Speth, Gus, Arthur Tamplin and Thomas Cochran, "Plutonium recycle or civil liberties? We can't have both," Environmental Action 6, No. 15, 10-13 (1974).

5. U.S. Department of Defense, Directive Number 5210.41, "Security Criteria for Protecting Nuclear Weapons," July 1974.

6. U.S. Atomic Energy Commission, "Proposed Final Environmental Statement: Liquid Metal Fast Breeder Reactor Program," WASH-1535, Vol. 4 of 7, December 1974.

7. Willrich, Mason, and Theodore B. Taylor, Nuclear Theft: Risks and Safeguards, Ballinger Publishing Company, Cambridge, 1974.

APPENDIX A

SAFEGUARDS COST DATA AND ANALYSIS

TABLE OF CONTENTS
APPENDIX A

APPENDIX A TABLES

Table Page

Summary Tables

Source Data Tables

Reprocessing Plants:

APPENDIX A TABLES (Cont'd)

Fuel Fabrication Plants:

APPENDIX A TABLES (Cont'd)

Table Page

Fuel Assembly Plants:

Other Source Data:

Safeguards Costs for GESMO Alternatives:

APPENDIX A FIGURES

APPENDIX A
SAFEGUARDS COST DATA AND ANALYSIS
Part 1: Cost Analysis

A1.1 INTRODUCTION

Several recent studies have presented cost estimates for safeguards systems to protect plutonium if the mixed oxide fuel cycle is adopted by the nuclear power industry (Ref. 1; Ref. 2, Vol. IV, Section 7.4; and Ref. 3). Since each of these studies uses somewhat different assumptions, a comparison between them reveals a fairly wide range of cost estimates. However, an important conclusion highlighted by these studies is that the total costs of a safeguards program for the MOX fuel cycle would be relatively small on a percentage basis when compared to either the costs associated with providing fuel for light water reactors or the total cost, capital or operating, of producing electricity from nuclear power plants. While such percentages are small, the absolute value of the incremental safeguards costs would be in the hundred million dollar range and thus warrants careful analysis.

The objective of this cost analysis, therefore, is to identify the incremental costs associated with safeguarding plutonium as it would appear in various forms during the principal steps in the MOX fuel cycle, including reprocessing, MOX fuel rod fabrication, MOX fuel rod assembly and transportation. Costs associated with Federal regulatory activities relating to the plutonium recycle industry are also identified.

It should be noted that none of the safeguards activities from the time the fresh MOX assemblies are inserted into the reactor core until the irradiated fuel assemblies are received at the reprocessing facility would be attributable to safeguarding plutonium. Once the MOX assemblies are in the core of the reactor, they no longer pose a safeguards threat unique to plutonium; safeguarding them would be similar to safeguarding all other irradiated fuels. During the transportation of the irradiated assemblies to the reprocessing facilities, the hazardous nature of the spent fuel and the difficulty of its conversion to a material suitable for use in weapons would provide built-in safeguards against the general problem of theft or sabotage.*

The safeguards analysis is based on a mature MOX industry as it would exist more than 20 years in the future. Estimates of the size of the industry in the year 2000 are taken from NUREG-0002. For such a large extrapolation in time, it is impossible to obtain highly accurate cost estimates. Uncertainties in precise equipment specifications and site-specific requirements for future facilities preclude precise cost measurement. Other major uncertainties such as the specific mode of operations, cost of capital, or technological breakthroughs in the next 20 years further complicate the cost estimating process. Given such uncertainties, this study

---

*It is possible that safeguards measures may be required for spent fuel shipments at some point in the future as a result of agreements between the United States Government and the IAEA or some other international agency.

attempts to treat each of the safeguards program alternatives in a consistent fashion to avoid possible biases. Emphasis is placed on the relative costs of the various safeguards alternatives considered for the MOX fuel cycle rather than on their absolute costs.

This Appendix identifies, analyzes, and compares the costs of each of the safeguards program alternatives (blending, collocation, air transport, reference system) that are described in Chapters 5 and 6 of this Technical Report and presents conclusions based on this analysis. The actual cost data are based on studies done by NRC Staff and NRC contractors. Part 2 of this Appendix includes a compilation of detailed safeguards cost data and a list of study references. The nuclear fuel cycle costs and the MOX fuel cycle costs presented herein are drawn from NUREG-0002. These industry costs are used in Tables A1.9 and A1.10 as a basis for comparison with safeguards costs. In Part 3 of this Appendix, the NUFUEL Computer Program used in Chapter XI of NUREG-0002 is used to obtain cumulative and year 2000 safeguards costs for the five fuel cycle alternatives (1, 2, 3, 5, and 6) of NUREG-0002.

A1.2 DEFINITIONS

This section defines some of the terms used in this Appendix.

Reprocessing Facility: A fixed site where spent fuel assemblies from reactors are processed to recover the uranium and plutonium. The plutonium is recovered as plutonium nitrate and converted to plutonium oxide. The uranium is recovered as uranyl nitrate and converted to uranium hexafluoride.

Mixed Oxide (MOX) Fuel Fabrication Facility: A fixed site where a mixture of uranium oxide and plutonium oxide is compacted into small fuel pellets, which are then inserted into fuel rods.

Fuel Assembly Facility: A fixed site where fuel rods are "bundled" into fuel assemblies.

Transportation: Movement of plutonium (either as PuO_2 or as MOX) between fixed sites.

Control and Recovery: A Federal Government function that includes the investigation of the theft of stolen nuclear material and the coordination of recovery efforts among the military, the FBI, and local law enforcement agencies. (This function will exist for any nuclear industry and as a result is not charged to MOX recycle safeguards costs.)

Regulation: A Federal Government function that includes the initial inspection and licensing of an applicant's safeguards program, the periodic inspection and enforcement of that program to ensure compliance, and the recurring analysis and development effort associated with upgrading safeguards systems. (Only those regulation costs associated directly with MOX recycle are included in this Appendix.)

Initial Capital Costs: The initial purchase price of the equipment, facility, or service, plus the cost of installation.

Annualized Costs: Annual costs of depreciation, return on investment, and operation and maintenance.

A1.3 ASSUMPTIONS

Constant Dollars: To facilitate comparisons, all costs are in constant 1975 dollars. This avoids projecting inflationary trends, changes in the cost of capital, technological breakthroughs, etc.

Ownership: Private industry is assumed to own and operate all fixed sites and the transportation network, while the Federal Government provides the resources for the control and recovery function and the regulation function.

Residual Value: All hardware and vehicular equipment are assumed to have a zero residual value at the end of their depreciated lives.

Reactor-to-Reprocessing-Facility Transportation Link: It is assumed that the safeguards associated with the transportation link that carries irradiated fuel from reactor sites will be required whether or not there is plutonium recycle. Thus, no additional safeguards costs would be chargeable to the MOX fuel cycle for this link.

Facility Age: All the reprocessors, MOX fabrication and assembly plants, and related facilities are assumed to be new. Although costs of lost production or changes in production as a result of backfitting of safeguards hardware might be significant for existing facilities such as AGNS, these costs are ignored in this discussion for the sake of simplicity.

Facility Size: Within a facility type, all units are assumed to be of the same scale. Any economies of scale that may accrue to facilities of different size have been ignored. The safeguards costs for the reprocessing plant were initially estimated for a 1,500-MTHM per year capacity plant and the safeguards costs for the MOX fuel fabrication plant were initially estimated for a 200-MT per year capacity plant. However, NUREG-0002 selected a reprocessing plant of 2,000 MT/year capacity and a MOX fuel fabrication plant of 360 MT/year capacity. (See page XI-20 of NUREG-0002.) To deal with this difference in size, all safeguards costs pertaining to reprocessing and fuel fabrication plants were scaled up on a linear basis in Part 1 of this Appendix. This approach is consistent with that taken in NUREG-0002.

Personnel salaries: Salary assumptions are provided in Table A1.1. The average salary of the guard force is taken as $15,000 per year plus $7,500 in fringe benefits. This is a key input since guards (and other safeguards-related personnel) make up approximately 64 percent of yearly safeguards operating costs. A $15,000 salary should attract a high caliber of individual since it is significantly above current industry averages and is at the high end of the range paid by the Federal Government for similar positions with FAA airport security and U.S. Customs operations.

Personnel Turnover Rates: The turnover rate for all safeguards personnel is assumed to be 10 percent per year.

TABLE A1.1

PERSONNEL SALARIES (UNIT COSTS)

Job Category	Basic Salary	Burdened Salary[a]
Fixed-Site Personnel		
Security and Resource Forces		
Supervisors	$18,500	$27,000
Guards	15,000	22,500
Technicians	14,900	22,400
Clerks	9,000	14,000
Material Accounting		
Supervisors	22,500	33,750
Accountants	15,000	22,500
Clerks	9,000	14,000
Transportation Network		
Supervisors	18,500	34,500[b]
Guards/Drivers	15,000	30,000[b]
Communications Network		
Station Manager	20,750	31,000
Radio Operators	14,500	22,000
Guards	15,000	22,500
Clerks	9,000	14,000
Regulation		
Licensing		
Inspectors	22,500	33,700
Enforcement		
Administrators	37,800	56,700
Enforcement Officials	30,000	45,000
Clerks	9,000	14,000

[a] Includes fringe benefits and general and administrative expenses.

[b] Includes $5,000 for per diem ($25/day X 200 days/year) and $2,500 for overtime pay.

Shift Factor: All fixed-site guard posts are assumed to be manned on a 24-hour-per-day, 7-day-per-week basis. A shift factor of 4.6, which includes an allowance for vacation, sick time, training, etc., is used to convert the number of guard posts to required guard manpower levels.

Training: Training for guard personnel is assumed to cost $700 per year. This includes initial training as well as required refresher training each year. Training costs include such items as classroom instruction and ammunition for annual range qualification.

Configuration: All safeguards alternatives discussed in Chapter 6 are configured for the mature MOX industry.

Full Incremental Costs: All alternatives are estimated on a full incremental cost basis; that is, costs for each alternative program represent the total additional safeguards cost that would be incurred as a result of the decision to recycle plutonium.

Joint Costs: Joint costs (such as for a resource serving both safety and safeguards functions) are charged entirely to safeguards when a reasonable allocation algorithm does not exist. For example, specially designed transport vehicles, which serve a safety function as well as a safeguards function, are charged entirely to safeguards.

Security Clearances: Full-field background investigations (FFBI's) are assumed for all guards and for 25 percent of the rest of the personnel at each fixed facility. Costs for clearances for all plant and transportation personnel will be changed in accordance with the final decision on proposed rule changes to 10 CFR Parts 11, 50, and 70 that are related to security clearances.

A1.4 ANNUALIZED COSTS

The initial capital costs and the annual operating costs for each safeguards physical item and worker are listed in Part 2 of this Appendix. The description and source of the cost data are also included. The individual safeguards costs have been aggregated to the physical security, material control and accounting, security force, and transportation levels. At that point, financial factors were applied to capital costs to convert them to annualized costs. The factors selected were:

Useful Life:

Fixed-site safeguards hardware: 20 years
Transport vehicles (integrated container vehicle): 1,000,000 miles
Escort vehicles: 500,000 miles

All depreciation is computed on a straight-line basis.

Rates of Return: The rates of return on outstanding capital investment in safeguards are intended to represent the minimum pre-tax rates of return necessary to attract private capital to this type of venture, which has a long investment period and high risk from a financial standpoint (Ref. 4). The rate figures are assumed to cover cost of capital and related profit. The pre-tax rate of return on the reprocessing facility, the MOX fuel fabrication facility, the fuel assembly facility, and the MOX transportation network would all be 25 percent, while the rate of return after taxes would be approximately 13 percent. The pre-tax rate of return for the reactors would be 16 percent owing to the assumed public utility rate structure.

Methodology: There are several methods that can be used to determine return on investment. As indicated above, the rate of return has been selected at 25 percent in order to attract private capital to this type of venture. The 25 percent rate applies to the return during any one year and it does not take into account the depreciation of assets over the life of the assets. The outstanding balance method of calculating an average rate of return was selected to overcome the problem of depreciation. This method calculates the annual return based on the value of the original investment less cumulative depreciation (see Table A1.2).

TABLE A1.2

ILLUSTRATIVE CALCULATIONS OF
RETURN ON OUTSTANDING BALANCE
(Based on $100 of Original Investment)

No. of Years	Outstanding Undepreciated Balance[a]	Annual Return on Outstanding Balance[b]
1	$ 100	$ 25
2	95	23.75
3	90	22.5
4	85	21.25
5	80	20
6	75	18.75
7	70	17.5
8	65	16.25
9	60	15
10	55	13.75
11	50	12.5
12	45	11.25
13	40	10
14	35	8.75
15	30	7.5
16	25	6.25
17	20	5
18	15	3.75
19	10	2.5
20	5	1.25
		$262.5
Average Annual Return on Outstanding Balance		$ 13.125[c]

[a] Depreciation at $5 per year

[b] 25 percent rate of return on outstanding undepreciated balance

[c] This number will vary with the number of years over which the investment is depreciated and with the rate of return on outstanding undepreciated balance.

Maintenance: For simplicity, annual maintenance costs (labor and repair parts) for fixed-site hardware resources are estimated as a percentage of initial procurement cost as follow:

Construction items: 2 percent
Mechanical and electronic items (except computer hardware): 10 percent
Computer hardware: 20 percent.

For vehicular resources, annual operation and maintenance costs (labor, repair parts, and fuel, as applicable) are provided in the source data tables on road transportation in Part 2 of this Appendix.

A1.5 SUMMARY COST DATA FOR EACH PROGRAM ALTERNATIVE

The summary of annualized costs for each safeguards program alternative is contained in Table A1.3.

TABLE A1.3

ANNUALIZED COST BY SAFEGUARDS ALTERNATIVE
($, Thousands)

		Reference System With			
			Blending		
Facility or System	Reference System	Collocation[a]	30%	10%	Air Transport
5 Reprocessing Plants	30,850	30,850	54,350	70,200	30,850
8 Fuel Fabrication Plants	58,270	58,270	63,480	68,590	58,270
7 Fuel Assembly Plants	11,530	11,530	11,530	11,530	11,530
250 MOX Reactors (at 125 reactor sites)	3,000	3,000	3,000	3,000	3,000
Transportation	35,760	32,640	35,760[b]	35,760[b]	38,110
Regulation	1,710	1,710	1,710	1,710	1,710
Total Costs	141,120	138,000	169,830	190,790	143,470

---

[a] Collocation indicates the placement of one reprocessing plant and one MOX fuel fabrication plant at the same site.

[b] It is assumed that the ICV would be redesigned to carry blended fuel if the blending option is selected. Thus, the interior of the ICV would be enlarged to accommodate the increased volume of blended fuel for either the 30 percent case or the 10 percent case. The net result would be no change to the number of trips or number of ICV's from the reference system alternative to the blending alternative.

A1.5.1 Individual Facilities, Transportation, and Other Costs

In Part 2 of this Appendix, itemized safeguards equipment and personnel costs are identified for the reference system and then aggregated to the plant and transportation system level. The safeguards costs for individual plants and the transportation system are repeated in Table A1.4.

TABLE A1.4

SAFEGUARDS COSTS - INDIVIDUAL ELEMENTS
($, Thousands)

Facility/System	Initial Capital Costs[g]	Annualized Costs[g]
Reprocessing Plant[a]	7,160	6,170[b]
Fuel Fabrication[a] Plant	5,510	7,280b
Fuel Assembly Plant	1,260	1,650[b]
Reactor[c]	130	25
Transportation System[d]		
Communications Network	5,480	3,550
Leg 1 - PuO_2 Transport	7,410	3,470[e]
Leg 2 - MOX Rod Transport	9,260	4,740[e]
Leg 3 - MOX Assembly Transport	29,580	24,000[e]
Regulation[d]	1,840[f]	1,710

---

[a] It is estimated that present requirements (10 CFR Parts 70 and 73) would result in an initial capital investment of approximately $2 million (in 1975 dollars) for safeguards for a new reprocessing or fuel fabrication plant and that each type of plant would require approximately $1 million in annual operating costs. (The initial capital and annualized plant costs are scaled up from the Part 2 values of Table A2.1 in the manner described in Section A1.3.)

[b] Includes $107,600 per guard on shift, which is the annualized cost per guard multiplied by a factor of 4.6 to obtain 24-hour-per-day, 7-day-per-week operations.

[c] Reactor costs assume a hardened storage vault with alarms and a fixed SNM detector at each MOX reactor site.

[d] Transportation system costs and regulation costs are included here for the sake of completeness. However, these costs refer to the entire MOX fuel cycle, and cannot be allocated to individual plants.

[e] Includes $30,400 per guard, which is the annualized cost of a guard/driver (includes pay, training, equipment, and clearances).

[f] One-time costs, covering initial review, inspection, and licensing, are treated as capital costs. Additional information is provided in Part 2 of this Appendix.

[g] The physical security development costs and the economic assumptions used for all cost estimates were validated by the MITRE Corporation (Ref. 10). If the new item costs recommended in the MITRE report were substituted for the costs in this appendix, the total annualized costs would increase by approximately four percent.

A1.5.2 Reference System*

The reference system is composed of five reprocessing plants, eight fuel fabrication plants, seven fuel assembly plants, and a complete transportation network linking these plants to the 250 reactors that use MOX. The transportation network consists of three legs: Leg 1 from the reprocessing plant to the fuel fabrication plant; Leg 2 from the fuel fabrication plant to the fuel assembly plant; and Leg 3 from the fuel assembly plant to the reactor. (See Figures A2.1 and A2.2 in Part 2 of this Appendix.) The total reference system costs are given in Table A1.5.

TABLE A1.5

REFERENCE SYSTEM SAFEGUARDS COSTS
($. Thousands)

Element	Initial Capital Costs	Annualized Costs
5 Reprocessing Plants	35,800	30,850
8 Fuel Fabrication Plants	44,080	58,270
7 Fuel Assembly Plants	8,820	11,530
250 Reactors at 125 Sites	16,570	3,000
Fixed-Site Subtotals	105,270	103,650
Transportation	51,730	35,760
Regulation	1,840	1,710
TOTAL	158,840	141,120

In terms of functional elements, the reference system total annualized costs can be subdivided as follows:

Personnel Pay	64.0%
Operations and Maintenance	10.6%
Depreciation	10.5%
Return on Investment	14.9%
	100%

A1.5.3 Collocation

Based on the discussion in Chapter 6 of this Technical Report the collocation alternative assumes collocated reprocessing and fuel fabrication facilities having the same total fixed-site safeguards costs as the reference system. However, the safeguards costs for the transportation leg from the reprocessing plant to the fuel fabrication plant would be drastically reduced. Because of stoppages caused by unpredictable events, the output of the reprocessing plant would not always match the input of the fuel fabrication plant. Therefore, PuO_2 would sometimes be shipped to the fuel fabrication plant from outside sources. Also, some plutonium would be shipped to research facilities. The annualized costs for transportation safeguards on this leg are assumed to be reduced by 90 percent instead of 100 percent to account for these factors. (Thus, they would be reduced from $3,470 thousand to about $350 thousand.) Safeguards costs for transportation under the collocation alternative would be as shown in Table A1.6.

---

*Although the mature MOX fuel industry considered here is based on the one described in Chapter 3 of this report and in Chapter III of NUREG-0002, other projections of nuclear industry growth exist, as discussed in Appendix B to Chapter III of NUREG-0002.

TABLE A1.6

TRANSPORTATION COSTS WITH COLLOCATION
($, Thousands)

	Initial Capital Costs	Annualized Costs
Reprocessing to fuel fabrication	740	350
Fuel fabrication to fuel assembly	9,260	4,740
Fuel assembly to reactors	29,580	24,000
Communications network	5,480	3,550
Totals	45,060	32,640

A1.5.4 Blending

The safeguards costs for the blending alternative would depend on which dilution case is selected for implementation: the 30 percent blend or the 10 percent blend. In either case, the blend could be produced by a mechanical mixing process or a precipitation process at the reprocessing plant. Blending would not affect the safeguards costs at fuel assembly plants. It would cause the costs of safeguards at each reprocessing plant and each fuel fabrication facility to increase because the cost of additional construction and equipment needed for the blending alternative would be charged to safeguards. The additional (incremental) initial capital and annualized costs for fixed facilities for the 30 percent mix and the 10 percent mix for the mechanical mix process are presented in Table A1.7.

A1.5.5 Air Transport

The air transport alternative assumes that all PuO_2 is moved directly by air from the reprocessing plants to the fuel fabrication plants or by a combination of air and surface means. Thus Leg 1 in the reference transportation system (from fuel reprocessing to fuel fabrication) would be deleted in this alternative, and an air leg would replace it. Safeguards costs for the other two legs and for the fixed-site facilities in the system would not change. The safeguards costs for the direct air transport* of plutonium between the reprocessing and the fuel fabrication plants are presented in Table A1.8.

A1.6 COST SENSITIVITY ANALYSIS

An analysis was made to estimate the sensitivity of the reference system costs to some of the assumptions. The following variations in the assumptions were considered:

---

*The air transport alternative assumes the use of C-100-130 aircraft because this craft is available today, has the requisite carrying capability, and has proven reliability with modest cost. However, several types of short takeoff and landing (STOL) aircraft are under development and could reach an operational stage in the next 10 years. Several types of these STOL could be similarly well suited for this type of transport mission. The selection of one of the STOL aircraft could result in marked savings in the cost of establishing suitable airfields.

TABLE A1.7

INCREMENTAL FIXED FACILITIES BLENDING COSTS
($, Thousands)

Reprocessing Plants	30% Mix	10% Mix
Initial capital costs per plant		
Mixing station[a]	13,300	20,000
MOX storage[b]	3,300	8,400
Total	16,600	28,400
Annualized costs per plant		
Depreciation and return on investment	3,020	5,150
Maintenance[c]	1,000	1,700
Personnel[d]	610	740
UO_2 inventory costs[e]	70	280
Total	4,700	7,870
Total annualized costs for 5 reprocessing plants	23,500	39,350
Fuel Fabrication Plants		
Initial capital costs per plant		
MOX storage	2,500	6,300
Annualized costs per plant		
Depreciation and return on investment	450	1,140
Maintenance	50	10
Personnel[f]	140	140
Total	640	1,290
Total annualized costs for 8 fuel fabrication plants	5,120	10,320
Total annualized industry costs	28,620	49,670

---

[a] Mechanical mix based on one additional bay at the end of the plutonium line.

[b] Scaled up by $(Vol)^{0.4}$ from $10 million to obtain incremental costs for storing the increased volume of the various blends.

[c] Maintenance cost for the additional mixing station and MOX storage is estimated to be 10 percent per year on 50 percent of the initial capital costs and two percent per year on the other 50 percent of the initial capital costs.

[d] Pay for 27 additional workers for 30 percent mix and 33 for 10 percent mix.

[e] Assumes UO_2 with unreprocessed U is used to blend additional UO_2 inventory.

[f] Pay for six additional workers.

TABLE A1.8

ESTIMATED AIR TRANSPORT COSTS FOR LEG 1
($, Thousands)

	Initial Capital Costs	Annual Costs	
One Aircraft (L-100, C-130 Type)[a]	8,000		
Operations and Maintenance			
Crew[b]		275	
Oil, Fuel, Insurance[c]		400	
Maintenance[c]		445	
Guards[d]	10	110	
Containers (1950 @ $1000 ea)[e]	1,950		
Container Usage[f]		195	
Airstrips (13 @ $0.65M)[g]	8,450		
Airstrip Ops. and Maint. (O&M)		260	
Airstrip Facilities & Equipment (13 @ $50,000)[i]	650		
Airstrip Equipment O & M (10% of inital costs)		65	
	19,060	1,750	(Subtotal)
Annualized Cost			
Return on Investment		2,565	
Depreciation			
Aircraft (10 years)		800	
Containers (10 years)		195	
Airstrips (20 years)		425	
Equipment (10 years)		65	
		4,050	(Subtotal)
Total Air Transportation Costs (Leg 1)		5,800	
Less Ground Transport Costs (Leg 1)		-3,470	
Net increase in annualized safeguards costs due to air transport		2,370	

---

[a] Lockheed Corporation quote taken from Reference 5.

[b] Based on Lockheed analysis of Saturn Airlines operating data taken from Reference 5.

[c] Based on Lockheed-Georgia modified ATA DOC cost method and block time/fuel curves.

[d] Three guards per aircraft @ $27,000/year each (resulting cost multiplied by 1.36 to allow for sickness, vacations, scheduling, etc.). Initial capital costs for guards include training, clearances, and equipment.

[e] SANDIA PARC container. Container is a 65-gallon drum with redwood filling and an inner container enclosing 2.25 kg of PuO_2. The total container weighs 450 lb and can survive a 222-fps impact on a steel plate supported by a concrete slab. About 150 containers at each of the 13 plant sites were judged to be sufficient for anticipated usage requirements, taking into account variations in scheduling, inventories at plants, etc.

[f] Includes costs of decontamination after each usage cycle. The average number of cycles per container is estimated at 32.

[g] Runway is general aviation type with a 4-inch asphalt surface measuring 100 feet x 5000 feet. Costs include excavation, grass seeding, grading, gravel access road, drainage piping, tiedowns, and wind cone. Annual air field maintenance costs estimated at $20,000 per field. Data obtained from telephone conversation with personnel at State of Minnesota, Department of Aeronautics. See also Reference 6.

[h] Airport operating personnel not included.

[i] Airstrip facilities and equipment include landing lights, communication equipment, and materials handling equipment.

Guard Pay: a change in guard and guard supervisor costs of 33 percent would add or subtract approximately $12.2 million per year to the annualized reference system safeguards costs, a change of 8.6 percent. A change of 33 percent in the costs of all safeguards-related personnel would cause a change of approximately $22.9 million per year, or 16.2 percent.

Operations and Maintenance Costs: a variation in all O&M costs of 50 percent would change the annualized reference system safeguards costs by $5.7 million, a fluctuation of only 4.0 percent.

Useful Life: a 50 percent decrease or increase in the useful life of safeguards hardware, facilities, and vehicular equipment would add approximately $11.3 million per year, an increase of 8.0 percent, or subtract approximately $5.7 million per year, a decrease of 4.0 percent.

Rate of Return: an increase in the rate of return from 25 to 35 percent or a decrease from 25 to 15 percent would add or subtract approximately $4.6 million per year, a change of 3.3 percent.

If all of the above changes were taken together so that their effects are in the same direction (a 33 percent change in the salary of all personnel; a 50 percent change in all operations and maintenance costs; a 50 percent change in the useful life of all hardware, facilities, and vehicles; and a change of 10 percent in the rate of return for non-regulated components (from 25 percent to 35 percent or to 15 percent), the annualized reference system safeguards costs would be increased by approximately $44.6 million (31.6 percent) per year or decreased by $38.9 million (27.6 percent) per year.

A1.7 COST COMPARISON

The calculations illustrated in Tables A1.9 through A1.11 and Figure A1.1 show the costs of alternative safeguards systems for the mature plutonium recycle industry to be of relatively minor importance when compared to total nuclear power costs.

A1.8 CONCLUSIONS

The MOX safeguards costs determined in this study are generally consistent with those derived in other studies (Refs. 1-3). The annualized safeguards costs will probably total between one hundred and forty and two hundred million dollars per year for a mature MOX industry. Roughly 64 percent of those costs are estimated to be in salaries of safeguards personnel.

As has been concluded from other analyses, safeguards costs are no more than a few tenths of a percent of the total costs of generating nuclear electric power. They will, however, be an important cost factor in the MOX fuel cycle industry.

A1.9 VARIATIONS IN GUARD FORCES

As explained in Subsection 5.6 of Chapter 5, the number of guard positions in the reference system guard force could be adjusted up or down to meet perceived requirements and changing technology. The relationship between safeguards costs as a function of the number of guard positions is shown in Figure A1.5. The starting point for the number of guard positions

TABLE A1.9

COMPARISON OF SAFEGUARDS COSTS WITH SELECTED FUEL CYCLE COST COMPONENTS

	Reprocessing $/kg-HM	MOX Fuel Fabrication[b] $/kg-HM	Pu Transportation[c] $/gm-TOT
Component Cost[a]	154.70	200.00	0.04
Safeguards Costs for Reference System[a]	3.10	38.57	0.03
Safeguards Costs as a Percentage of Component Estimates	2.0%	19.3%	N/A

---

[a] NUREG-0002 estimates represent the assumed price for each of the identified services. Included in the price would be the estimated cost of present safeguards (source: Chapter XI of NUREG-0002). This Technical Report's estimates represent engineering design cost estimates, including a rate of return on investment (source in Section A1.5.1 of this Appendix). All estimates are based on the industry of year 2000 using constant 1975 dollars.

[b] MOX fuel fabrication estimates for both systems include the MOX fuel fabrication facility, the fuel assembly activity for MOX, Legs 2 and 3 and the communications network of the transportation system described in Section A1.5.1 of this Appendix.

[c] All plutonium transportation estimates are charged to safeguards. This report estimate is lower than the FES estimate, owing to economies of scale realized by the use of the larger ICV transporter.

TABLE A1.10

COMPARISON OF INCREMENTAL SAFEGUARDS COSTS FOR PLUTONIUM-URANIUM RECYCLE OPTION WITH MOX FUEL CYCLE COSTS FOR THE YEAR 2000

	($, millions)	
	MOX Fuel Cycle Costs[a]	Total Fuel Cycle Costs[b]
Total Annual Costs, NUREG-0002 Alternative 3	2,120	11,923
Safeguards Annualized Costs for the Reference System	141	141
Safeguards Costs as a Percentage of Total	6.7%	1.18%

---

[a] For purposes of this discussion, the MOX fuel cycle is deemed to include spent fuel reprocessing, MOX fuel rod fabrication, MOX fuel assembly fabrication, and the MOX transportation network.

[b] Total fuel cycle costs include all costs that go into the production of finished fuel assemblies (including mining and transportation costs) plus all costs pertaining to waste fuel transportation, storage, and reprocessing. The total fuel cycle costs include the MOX cycle costs.

TABLE A1.11

COMPARISON OF SAFEGUARDS COSTS WITH COSTS OF GENERATING ELECTRICITY AT THE REACTOR[a]

Safeguards Alternative	Safeguards Costs $, Million	Safeguards Costs Mills/kWh[b]	Safeguards Costs as % of Cost of Generation[c]
Reference System	141.1	0.086	0.72%
Reference System with Collocation	138.0	0.084	0.70%
Reference System with Blending:			
30% Blend	169.8	0.103	0.86%
10% Blend	190.8	0.116	0.97%
Reference System with Air Transport	143.5	0.087	0.73%

---

[a] Costs at the reactor are busbar costs before distribution of electricity.

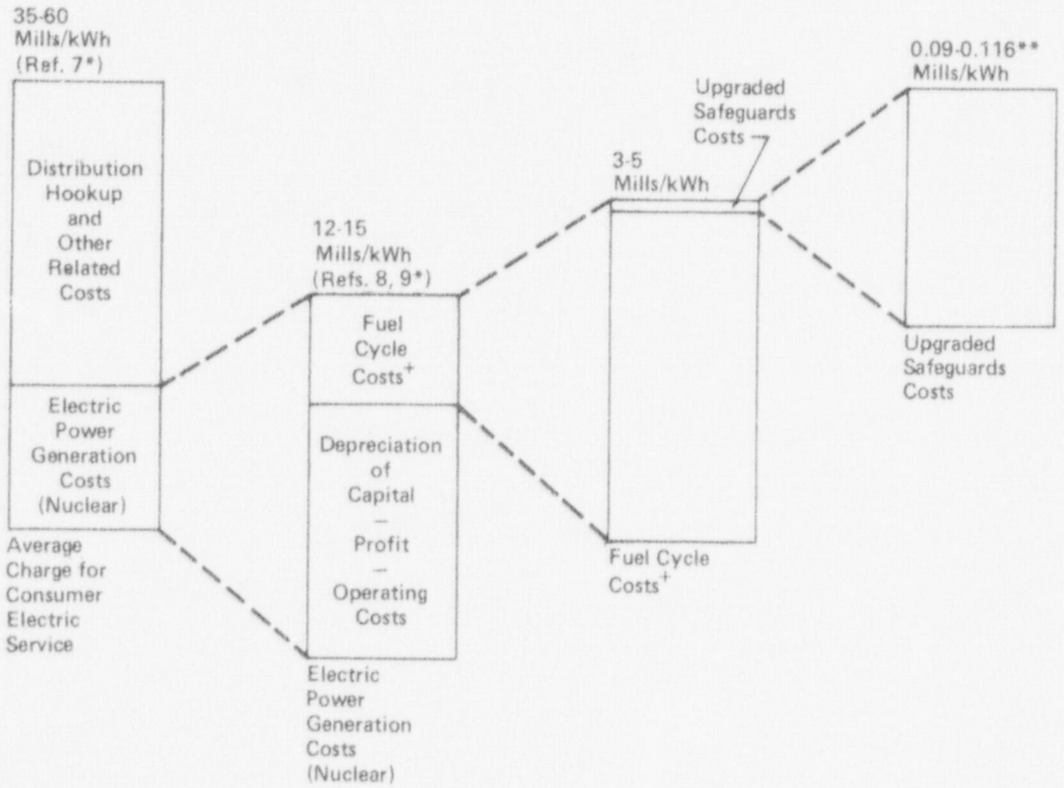
[b] Assumes 250 1,000-MWe reactors each generating 6.57 X 10^9 kilowatt hours per day. The reactor load factor is 75 percent capacity.

[c] Assumes approximately 12 mills per kilowatt hour (Ref. 10, page 20--de-escalated from 1982 to 1975 dollars) as the cost of generating electricity at the reactor.

Because of the large number of reactors compared to MOX fuel cycle facilities, safeguards against reactor sabotage (not associated with MOX fuel) are a major factor in the total safeguards costs, and the security requirements at the reactors have the potential for driving safeguards costs up or down much more quickly than any item associated with the MOX fuel cycle.

The annualized safeguards costs of $141 million are about 5 percent of the projected $2.6 billion annual savings from Pu-U recycle, circa the year 2000 (NUREG-0002), a relationship which is consistent with that for earlier years. Thus, even doubling the cost of safeguards would not make safeguards cost a determining factor in the decision on possible wide-scale use of MOX fuel.

Figure A1.1 Upgraded Safeguards Costs Related to Cost of Nuclear Electric Power to the Consumer



---

*And NRC Staff estimate

**Represents all options to Reference System

+Includes all steps from Mining through Spent Fuel Disposal is the reference system, the annualized cost of which is $141.12 million. Costs are then added or subtracted. The guard position costs above and below the reference system costs are different because the reactor guard costs are added to the reference system costs but are not subtracted from the reference system costs. The reason for this is that, while the current requirement for reactor guard positions has been established for non-MOX reactors, the current requirements are considered sufficient to protect MOX reactors. Thus, although guard positions may be added to MOX reactors if it is determined that additional security is needed, guard positions will not be subtracted from MOX reactors if it is determined that less security is needed than provided by the reference system. The basis for the determination of Figure A1.5 is presented below.

The relationships between the annualized costs of guard positions and the number of guard positions for reactors, for the MOX fuel cycle and for the MOX transportation system are shown in Figures A1.2, A1.3 and A1.4 respectively.

Figure A1.2 for reactors is based on the addition of $2.24 million and 96 guards each time a guard position is added to a MOX reactor.

Figure A1.3 is based on the addition or subtraction of 92 guards and $2.15 million each time a guard position is added to or subtracted from a MOX fuel cycle plant.

Figure A1.4 is based on the addition of or subtraction of 35 guards and $1.77 million each time a guard position is added to or subtracted from a MOX convoy. The costs for guard positions are higher for MOX convoys than for fixed facilities because each time a guard position is added to a convoy one-third of the annualized cost of a special escort vehicle and its communication equipment is also added to the guard force.

To determine the amount of annualized guard force costs to add to the reference system for each additional guard position in Figure A1.5 first add the guard force costs from Figures A1.2, A1.3, and A1.4 for the guard position selected and then add the total costs to the reference system costs in Figure A1.5.

To determine the amount of annualized guard force costs to subtract from the reference sytem for each decrease in a guard position from the reference system in Figure A1.5 first add the guard force costs from Figures A1.3 and A1.4 for the guard position selected and then subtract the total from the reference system costs in Figure A1.5. Do not include reactor guard force costs in the determination of total annualized safeguards costs for guard positions less than the number of positions required by the reference system.

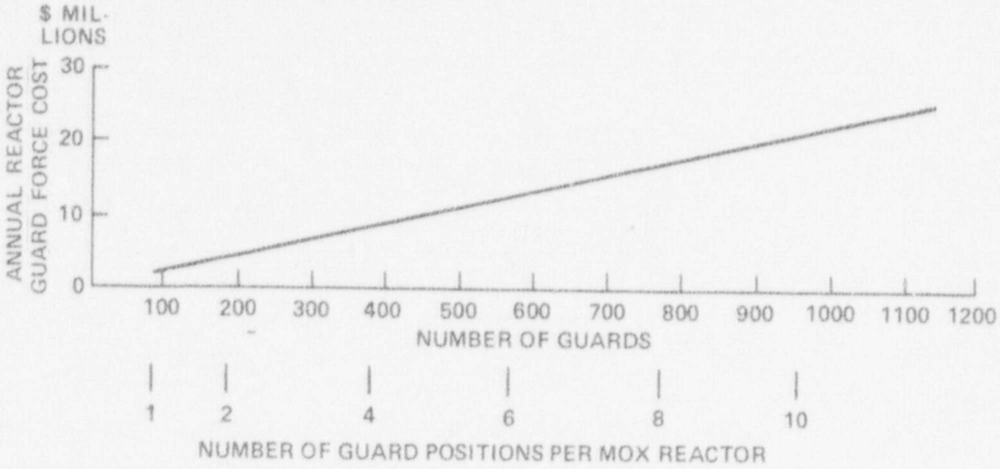


Figure A1.2 Annual MOX Reactor Guard Force Cost as a Function of Number of Guards Per MOX Reactor

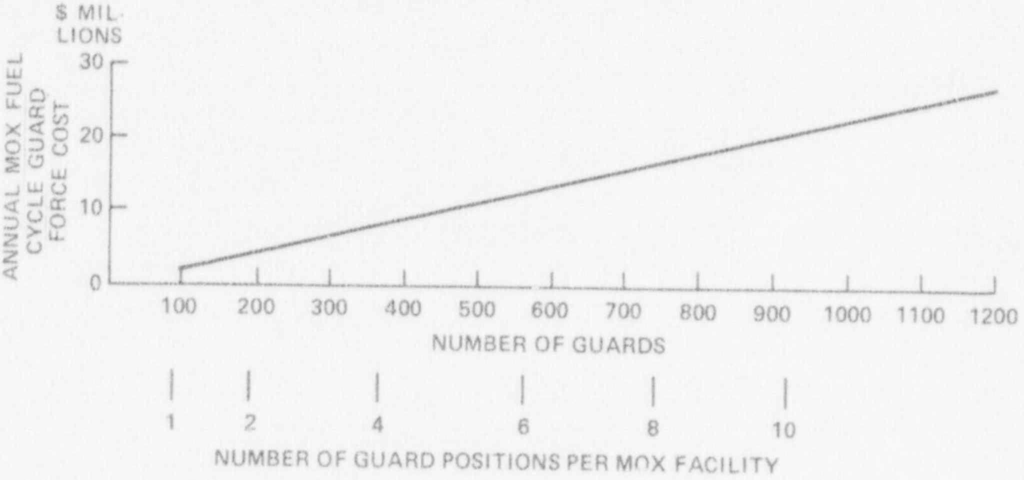


Figure A1.3 Annual MOX Fuel Cycle Guard Force Cost as a Function of Number of Guards Per MOX Facility

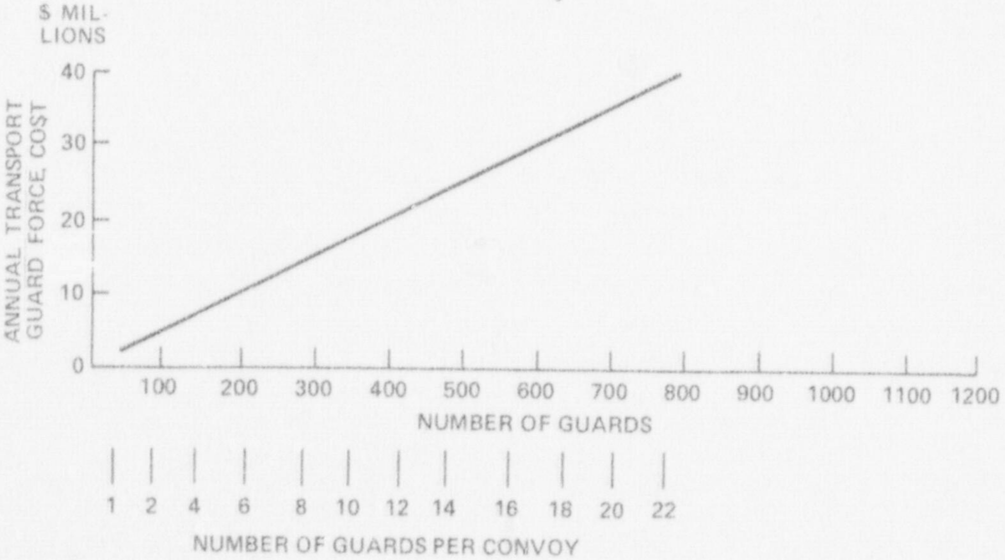


Figure A1.4 Annual Transport Guard Force Cost as a Function of Number of Guards Per Convoy

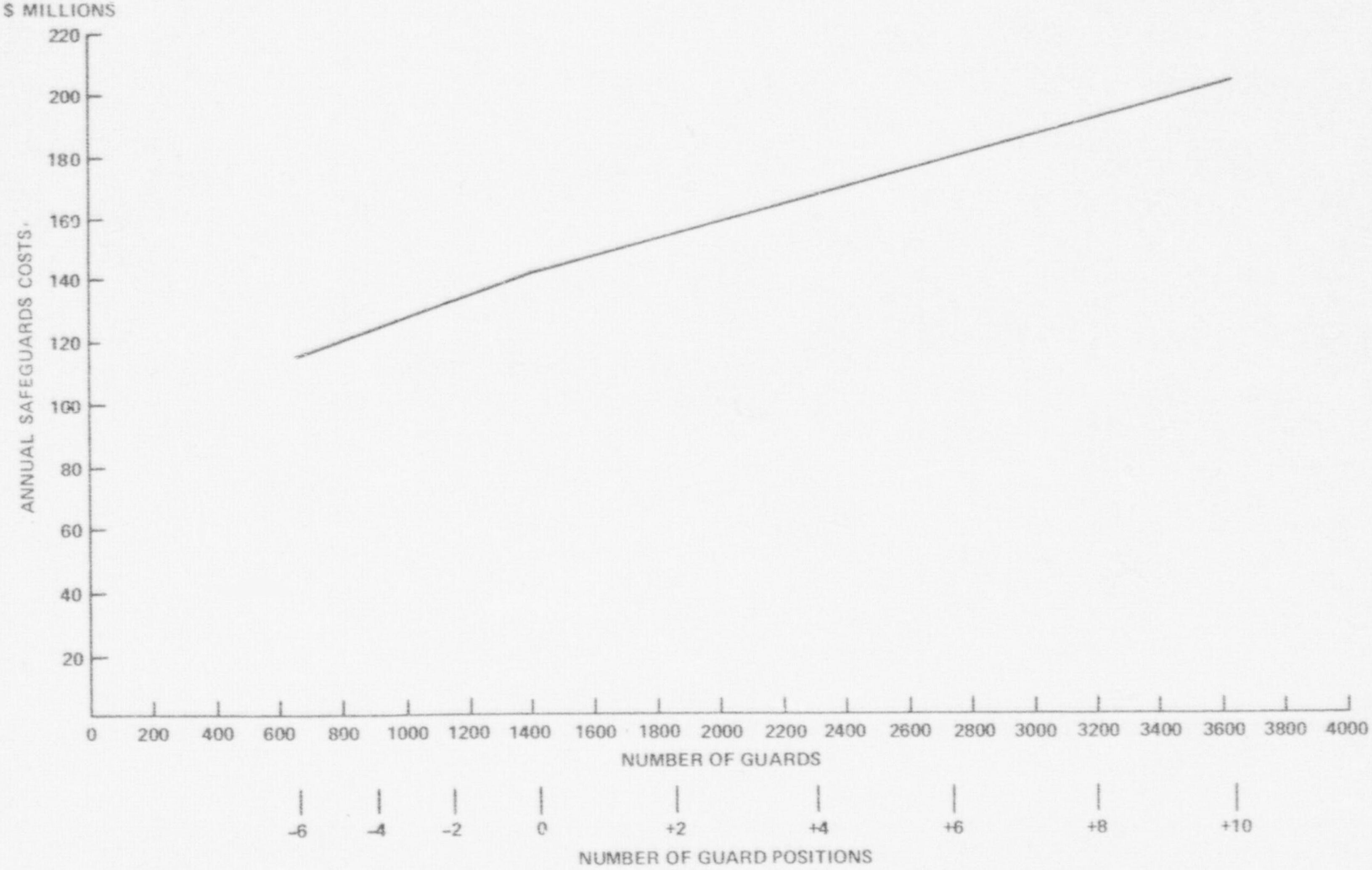


Figure A1.5 Total Annualized Safeguards Costs as a Function of Guard Force Size

APPENDIX A, PART 1

REFERENCES

1. E. R. Johnson Associates, Inc., Atomic Industrial Forum, "An Upper Estimate of Safeguards for Handling Plutonium," prepared for the Atomic Industrial Forum, July 1975.***

2. U.S. Atomic Energy Commission, "Proposed Final Environmental Statement: Liquid Metal Fast Breeder Reactor Program," WASH-1535, Vol. IV, December 1974.**

3. Sandia Laboratories, "Physical Protection of Spent Nuclear Material in the Commercial Fuel Cycle," Vol. I, "Executive Summary," SAND-75-0457, March 1976.**

4. Sidney M. Stoller, Leonard Geller, and Robert W. Kupp, Edison Electric Institute, "Report on Reprocessing and Recycle of Plutonium and Uranium: Task VII of EEI Nuclear Fuels Supply Study Program," December 1975.[b]

5. R&D Associates, "Evaluation of Special Nuclear Material Air Transport as a Safeguards Option," RDA TR-4001-002, Vol. IV, December 1976.[b]

6. Nevins D. Baxter, E. Philip Howrey, and Rudolph G. Penner, Mathematica, "Public Investment in General Aviation Airports: An Application of Cost-Benefit Economics," FAA Contract No. FA66WA-1549, May 1967.[b]

7. U.S. Federal Power Commission, "Typical Electric Bills 1976," FPC R88, pp. xi, xxiii, and xxviii, 1976.[b]

8. American Nuclear Society, "Nuclear Power and the Environment, Questions and Answers," pp. 5-11, April 1976.***

9. U.S. Atomic Energy Commission, "The Nuclear Industry - 1974," "Economics of Nuclear Power," WASH-117474, pp. 17-21, 1974.*

10. The U.S. Nuclear Regulatory Commission, "An Evaluation of Cost Estimates of Physical Security Systems for Recycled Nuclear Fuel," NUREG CR/0040, May 1978. Available for purchase from the National Technical Information Service (NTIS), Springfield, VA 22161.

---

*Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

**Available in NRC PDR for inspection and copying, for a fee.

***Available in public technical libraries.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

Appendix A
Part 2
Cost Data

A2.1 INTRODUCTION

The safeguards cost figures presented in Part 1 of this Appendix are based on the source data, detailed assumptions and item descriptions contained in this part.* The sources of the data include the NRC staff, safeguards studies sponsored by NRC, studies of safeguards systems made by members of the nuclear community, operating experience in the nuclear transportation industry, and information provided by other Government agencies. Specific sources are identified opposite the cost items in the tables.

The two principal sources are the work of Sandia Laboratories and the NRC staff. The extensive Sandia work is in a series of volumes entitled "Physical Protection of SNM in the Commercial Fuel Cycle" dated March 1976.

The individual plant costs developed from the data are summarized in Table A2.1. Road transportation costs are shown in Tables A2.2 and A2.3 and the associated communications costs in Table A2.4. These tables are followed by figures describing the industry model and the road transport model (Figures A2.1 and A2.2) and by Table A.2.5, which gives the amounts of equipment and manning for road transport. Costs for the systems (Physical Security, Material Control and Accounting, and Security Force) that make up the plant costs are presented next (Tables A2.6 through A2.11). Costs of regulation for the industry are summarized in Table A2.12. The intent of this sequence of presentation is to provide the reader first with an overall view of the costs and then to present successively lower levels of cost aggregation, so that the dominant costs can be traced to their origin in the basic data (Tables A2.13 through A2.44).

A2.2 FIXED-SITE SAFEGUARDS COSTS

The safeguards costs for fixed-site facilities are first estimated for individual plants and then converted to an industry-wide basis. The plant safeguards costs are made up of three systems: Physical Security, Material Control and Accounting, and Security Force. The security clearance costs for fixed-site personnel other than guards were obtained by assuming that 1/4th of all the non-guard personnel would require security clearances. (These costs could not readily be allocated to the three systems and are consequently shown separately.) It was judged that there was no need for large numbers of non-guard personnel to be cleared at fuel assembly plants. At reprocessing and fabrication plants, the two types where special material control and accounting systems are required, the material control and accounting system is the dominant safeguards cost. A special MC&A system is not required in a fuel assembly plant, where fuel enters in rod form and standard inventory methods are therefore adequate. The dominant annualized operating cost in facility security is the cost of personnel pay.

---

*All other capital and operating costs for the facilities in the projected industries (MOX and non-MOX) described in Chapter 3 are drawn from NUREG-0002.

A2.3 ROAD TRANSPORTATION SAFEGUARDS COSTS

Unlike the fixed-site facilities, the costs of transportation cannot be estimated for individual plants. The basic cost data are therefore presented on an industry-wide basis. The industry model adopted for calculating road transport costs is summarized in Figure A2.1. The distances between plants represent averages for pairs of plants in the total industry. The nuclear material flow rates agree with those defined in the industry description, Section 3.1. The cost of transporting spent fuel from reactors to reprocessing plants is not included in the safeguards costs treated in this section. This leg would exist even without a recycle industry.

Figure A2.2 shows the payload capacity for the transporter vehicle/container combination adopted for this study and the number of annual trips resulting from the combination of this capacity and the industry nuclear material flow rate. The integrated container vehicle (ICV) transporter provides roughly twice the payload capacity of some current road transport equipment (thus reducing costs) together with a high degree of nuclear safety and threat security. Development work on this equipment has established its feasibility. Research and development costs ($2,500,000) to translate the proven concept for the vehicle into commercial equipment are included in the PuO_2 transport leg cost (Table A2.3). Additional information on this vehicle is available in the Sandia report. The number of ICV's for Legs 1 and 2 resulted from the assumption that each reprocessing and fabrication plant should have one ICV assigned to it, plus one spare shared between plants of each given type. ICV's assigned to the reprocessing plants (plus one spare) are assigned to Leg 1 transportation costs, and ICV's assigned to the fabrication plants (plus one spare) are assigned to Leg 2 transportation costs. The number of ICV's for Leg 3 is controlled by the total number of trips required for the industry on that leg. Figure A2.2 also shows the convoy makeup adopted for each transport leg. The special escort vehicle (SEV) is essentially a conventional armored vehicle, often equipped to customer specification, available on order from small manufacturing firms. All vehicles are fitted with the communications equipment identified in Table A2.42.

The equipment list and manning levels shown in Table A2.5 were used for cost estimating purposes. These numbers are based on work loading, utilization rates, availabilities, and scheduling/pipeline considerations. The key numbers are listed below and are based on system studies and ERDA/transportation industry operating procedures.

Convoy Speed:	50 mph
Guards:	Total time on job 2,400 hr/yr
Containers	
PuO_2:	6 trips/yr
MOX:	2 trips/yr
ICV's	100,000 miles/yr
SEV's	50,000 miles/yr

The road transportation safeguards costs (Table A2.3), are composed of two groups, the road equipment and personnel costs and the communications network facilities costs. The most expensive transportation leg is that between the fuel assembly plant and the reactors because of the long distances between these facilities. Container costs for MOX and PuO_2 are the principal equipment investment in the transportation system. The major annualized operating cost in MOX transportation is the cost of personnel pay.

A2.4 REGULATION COSTS

As with transportation costs, the costs of regulation are estimated on an industry-wide basis. These costs consist of the one-time costs associated with the initial review, inspection, and licensing process and the continuing costs associated with inspection and license updating. Although both of these costs consist predominantly of salaries, the one-time costs are treated as capital costs. In the conversion to annualized costs, however, no return on investment is considered because regulation is a cost to the Federal Government.

SUMMARY TABLES AND FIGURES

Table

Page

Figure

TABLE A2.1

SAFEGUARDS COSTS BY PLANT TYPE

Item	Reprocessing Plant		Fabrication Plant		Assembly Plant	
	Initial Investment	Annualized Cost	Initial Investment	Annualized Cost	Initial Investment	Annualized Cost
Physical Security System	$2,036,406	$ 516,500	$1,810,501	$ 467,926	$1,126,360	$ 291,647
Material Control & Accounting	3,072,000	2,742,000	1,093,000	2,220,587	—	—
Security Force	133,730	1,355,881	133,730	1,355,881	133,730	1,355,881
Non-Guard Clearances*	127,600	12,760	21,750	2,175	—	—
TOTAL	$5,369,736	$4,627,141	$3,058,981	$4,046,569	$1,260,090	$1,647,528

---

*These non-guard clearance costs are based on a policy of issuing full field background clearances to all guards and to one quarter of the remaining MOX fuel cycle facility employees. A proposed clearance program for fuel cycle facilities and reactors that requires some type of clearance for all personnel in protected areas has been issued for public comment by NRC as proposed amendments to 10 CFR Parts 11, 50, and 70. The cost of the changes to the current program that would be required by the proposed amendments will add less than one percent (1%) to the reference system annualized costs. (See Section 5.4.1.8, Chapter 5.)

TABLE A2.2

ROAD TRANSPORTATION SAFEGUARDS COSTS
ROAD EQUIPMENT & PERSONNEL
INITIAL INVESTMENT & OPERATING COSTS

Item	PuO_2 Transport Leg 1		Rod Transport Leg 2		Assembly Transport Leg 3	
	Initial Investment	Annual Operating	Initial Investment	Annual Operating	Initial Investment	Annual Operating
ICV's	$ 4,150,000	$ 99,360	$ 2,475,000	$ 195,360	$ 7,425,000	$ 1,569,600
SEV's	700,000	158,976	1,350,000	312,576	10,500,000	2,511,360
Communications	240,000	24,000	432,000	43,200	2,844,000	284,400
Containers	2,254,000	644,000	4,884,000	488,400	7,848,000	784,800
Pay		690,000		1,320,000		10,470,000
Individual Guard Equip.	30,590	3,059	58,520	5,852	464,170	46,417
Training	16,100	16,100	30,800	30,800	244,300	244,300
Clearances						
Initial	16,675		31,900		253,025	
Annual Turnover		1,668		3,190		25,303
TOTAL	$ 7,407,365	$ 1,637,163	$ 9,262,220	$2,399,378	$29,578,495	$15,936,180

TOTAL ALL LEGS
INITIAL INVESTMENT
$46,248,080
ANNUAL OPERATING
$19,972,721

TABLE A2.3

ROAD TRANSPORTATION SAFEGUARDS COSTS
ANNUALIZED COSTS

Item	Leg 1	Leg 2	Leg 3	Total	Communications Network
Annual Operating	$ 1,637,163	$ 2,399,378	$15,936,180	$19,971,721	$ 2,554,000
Depreciation	814,400	1,065,300	3,986,100	5,865,800	274,000
Return on Investment	1,019,800	1,275,788	4,075,388	6,370,976	719,000
TOTAL	$ 3,471,363	$ 4,740,466	$23,996,668	$32,208,497	$ 3,547,000

COMBINED TOTAL
ANNUALIZED COST
$35,755,497

TABLE A2.4

COMMUNICATIONS NETWORK COSTS

	Initial Investment	Annual Operating Costs
Facilities	$ 1,250,000	$ 50,000
Communications Equipment	4,000,000	400,000
Communications Workers Pay	0	1,778,000
Security Clearances and Individual Training	58,000	9,000
Security Equipment	169,000	17,000
Other	0	300,000
TOTAL	$ 5,477,000	$2,554,000

ANNUALIZED COSTS

Annual Operating	$ 2,554,000
Depreciation of Initial Investment (20 yr)	274,000
Return on Undepreciated Assets	719,000
TOTAL	$ 3,547,000

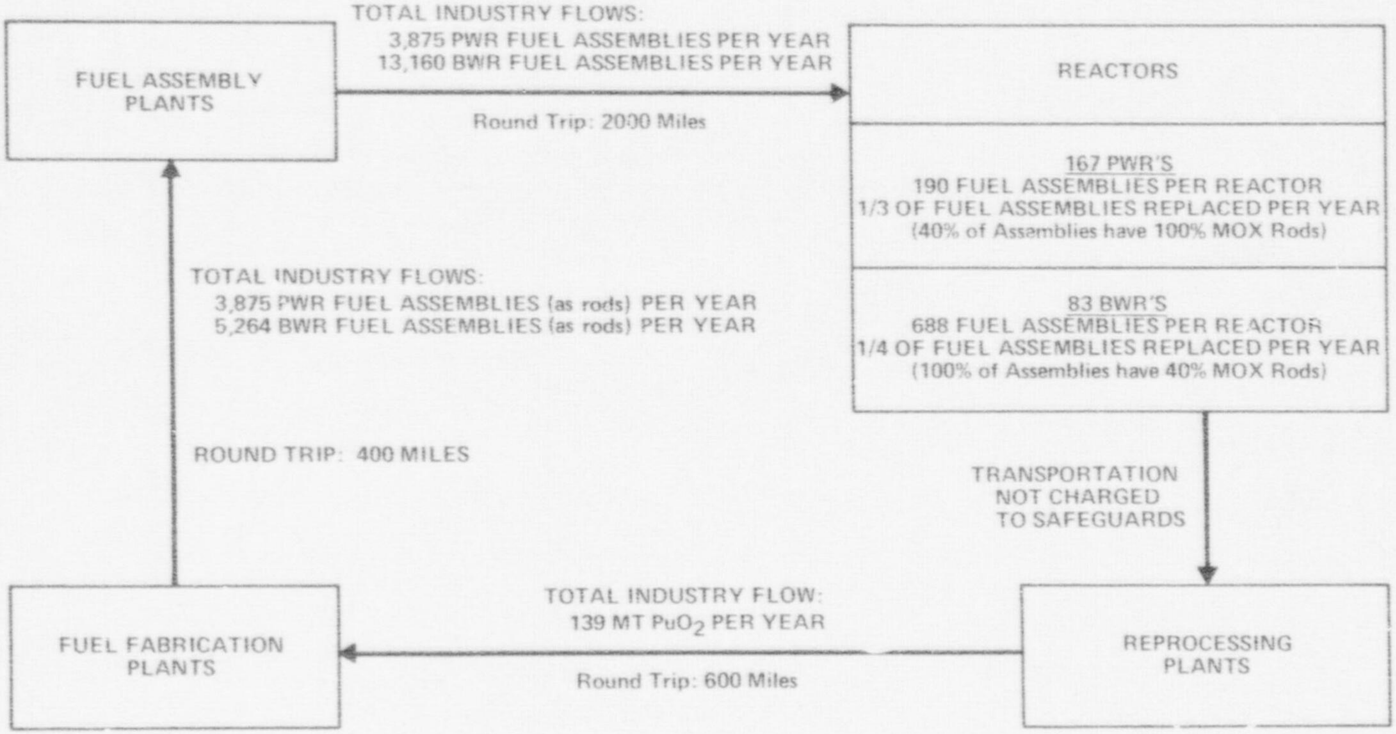
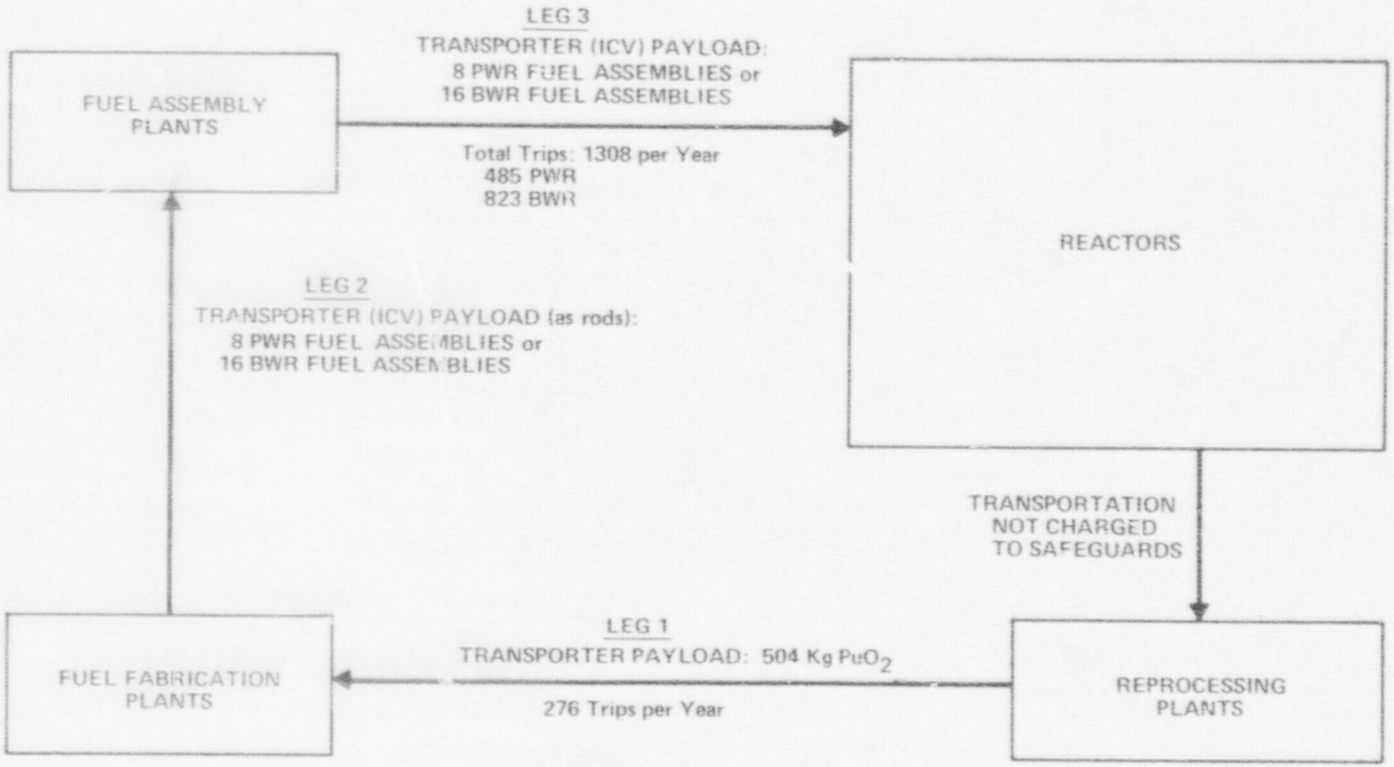


Figure A2.1 Industry Model Used to Calculate Road Transportation Costs



ALL CONVOYS CONSIST OF:
1 TRANSPORTER (ICV)
4 SPECIAL ESCORT VEHICLES (SEV)
12 GUARD/DRIVERS

Figure A2.2 Road Transportation Model; Trips and Convoy Size

TABLE A2.5

ROAD TRANSPORT EQUIPMENT AND MANNING

Item	Reprocessing to Fuel Fab Leg 1	Fuel Fab to Fuel Assembly Leg 2	Fuel Assembly to Reactors Leg 3	Total
Vehicles				
ICV Transporter	6	9	27	42
Escort Vehicles (SEV)	14	27	210	251
Container Sets	46	407	654	1,107
Guard/Drivers	23	44	349	416

TABLE A2.6

FIXED SITE PHYSICAL SECURITY SYSTEM INITIAL INVESTMENT AND OPERATING COSTS

Item	Reprocessing Plant		Fabrication Plant		Assembly Plant	
	Initial Investment	Annual Operating	Initial Investment	Annual Operating	Initial Investment	Annual Operating
Perimeter Control	$ 585,700	$ 33,410	$ 404,590	$ 26,950	$ 263,400	$ 19,812
Protected Area Portal	66,000	4,760	66,000	4,360	66,000	4.360
MAA Portals	152,000	12,640	152,000	12,640	152,000	12,640
MAA Containment	286,150	18,667	272,066	19,616	143,830	10,877
Vital Area Portals	143,480	12,790	143,480	12,790	—	—
Vital Area Containment	194,526	15,384	163,815	13,666	—	—
Command & Control	600,050	49,561	600,050	49,561	497,550	39,711
Miscellaneous	8,500	190	8,500	190	3,580	94
TOTAL	$ 2,036,406	$ 147,402	$ 1,810,501	$ 139,773	$ 1,126,360	$ 87,494

TABLE A2.7

PHYSICAL SECURITY SYSTEM
ANNUALIZED COSTS

Item	Reprocessing Plant	Fabrication Plant	Assembly Plant
Depreciation of Fixed Assets (20 year straight line)	$101,820	$ 90,525	$ 56,318
Return on Undepreciated Assets (25%)	267,278	237,628	147,835
Annual Operating Costs	147,402	139,773	87,494
TOTAL	$516,500	$467,926	$291,647

TABLE A2.8

MATERIAL CONTROL AND ACCOUNTING SYSTEM INITIAL INVESTMENT AND OPERATING COSTS

Item	Reprocessing Plant		Fabrication Plant	
	Initial Investment	Annual Operating	Initial Investment	Annual Operating
Measurement Equipment	$2,897,000		$ 918,000	
Accounting Equipment	175,000		175,000	
Personnel				
Measurement		$ 533,000		$ 481,000
Accounting		1,480,000		1,480,000
TOTAL	$3,072,000	$2,013,000	$1,093,000	$1,961,000

TABLE A2.9

MATERIAL CONTROL AND ACCOUNTING SYSTEM
ANNUALIZED COSTS

Item	Reprocessing Plant	Fabrication Plant
Depreciation of Fixed Assets (10 yr S/L)	$ 307,200	$ 109,300
Return on Fixed Assets (25% Pre-tax)	422,400	150,287
Annual Operating Costs	2,013,000	1,961,000
TOTAL	$2,742,600	$2,220,587

TABLE A2.10

SECURITY FORCE
INITIAL INVESTMENT AND OPERATING COSTS

Items	Reprocessing Plant		Fabrication Plant		Assembly Plant	
	Initial Investment	Annual Operating	Initial Investment	Annual Operating	Initial Investment	Annual Operating
PAY (Includes Burden)						
Guards		$1,035,000		$1,035,000		$1,035,000
Shift Supervisor		108,000		108,000		108,000
Clerical		42,000		42,000		42,000
Technicians		44,800		44,800		44,800
Assistant Security Director		30,100		30,100		30,100
Security Director		35,000		35,000		35,000
TOTAL		$1,294,900		$1,294,900		$1,294,900
EQUIPMENT AND OTHER						
Individual Guard Equipment	$ 61,180	$ 6,118	$ 61,180	$ 6,118	$ 61,180	$ 6,118
Patrol Vehicle	7,000	700	7,000	700	7,000	700
Clearances (guards)						
Initial	33,350		33,350		33,350	
Annual Turnover		3,335		3,335		3,335
Training	32,200	32,200	32,200	32,200	32,200	32,200
TOTAL	$ 133,730	$ 42,353	$ 133,730	$ 42,353	$ 133,730	$ 42,353

TABLE A2.11

SECURITY FORCE
ANNUALIZED COSTS

Item	Reprocessing Plant	Fabrication Plant	Assembly Plant
Depreciation of Fixed Assets (10-yr S/L) (no training)	$ 10,153	$ 10,153	$ 10,153
Return on Undepreciated Assets	9,375	9,375	9,375
Annual Operating Costs			
Pay	1,294,000	1,294,000	1,294,000
Equipment	42,353	42,353	42,353
TOTAL	$1,355,881	$1,355,881	$1,355,881

TABLE A2.12

REGULATION COSTS

	Initial Investment	Annual Operating Costs
Initial Inspection and Licensing	$1,823,000	0
Annual Inspection	2,000	$ 181,000
Enforcement	17,000	1,038,000
Safeguards Analysis and Development	0	400,000
TOTAL	$1,842,000	$1,619,000

ANNUALIZED COST	
Annual Operating	$1,619,000
Depreciation of Initial Investment (20 yr)	92,000
Return on Undepreciated Assets	0
TOTAL	$1,711,000

SOURCE DATA TABLES

Table | Page

Reprocessing Plants:

Fuel Fabrication Plants:

SOURCE DATA TABLES (CON'T)

Fuel Assembly Plants:

TABLE A2.13

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
PERIMETER CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Outer Clear Zone Terrain Cleared of Places of Concealment for Distance of 15 Meters from Outer Fence	NOT CHARGED TO SAFEGUARDS			Ref. 1 pp. 32-34
2.	Outer Fence 7-Foot Chain Link with 1-Foot Barbed Wire Topping	$55/Meter	1,500	$ 82,500	Ref. 1 pp. 32-34
3.	Soil Stabilization Grading and Homogenization of Soil	$80/Meter	1,500	120,000	Ref. 1 pp. 32-34
4.	Microwave Sensors BI-Static System	$31/Meter	1,400	43,400	Ref. 1 pp. 32-34
5.	Seismic Sensors Buried Pressure-Sensitive Cable	$57/Meter	1,400	79,800	Ref. 1 pp. 32-34
6.	Alarm/Assessment CCTV Fixed-Focus Silicon Diode Array Cameras in Environmental Housing	$10,000	10	100,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
7.	Inner Fence Same as Item #2	$55/Meter	1,400	77,000	Ref. 1 pp. 32-34
8.	Lighting Pole-Mounted Incandescent Lights Directed Outwards	$1,000	35	35,000	Ref. 1 pp. 32-34
9.	Inner Clear Zone No Structures or Places of Concealment within 15 Meters of Inner Fence	NEGLIGIBLE SAFEGUARDS COST			Ref. 1 pp. 32-34
10.	Remote Control CCTV (mounted in P.A.) Silicon Diode Cameras in Environmental Housing with Remote Pan/Tilt/Zoom	$12,000	4	48,000	Ref. 1 pp. 32-34
			TOTAL	$585,700	

TABLE A2.14

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
PROTECTED AREA PORTAL

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Personnel Gate/Turnstile Floor-to-Ceiling Turnstile/Steel Door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2. Electric Vehicle Gate/Barrier Remotely Operated Chain Link Gate with Two Steel Rails Attached for Vehicle Barrier	$ 2,500	2	5,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
3. Protected Guard Position Guard Position Hardened to Provide Protection against Small-Arms Fire	$10,000	1	10,000	NRC Staff Estimate
4. Remotely Operated Train Gate/Barrier Same As Item #2	$10,000	1	10,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
5. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	1	6,000	Ref. 1 pp. 32-34
6. Card Reader On-Line System	$ 3,000	2	6,000	Ref. 1 p. 121
7. Fixed Metal Detector Active Magnetic Field Metal Detector (MFMD)	$ 5,000	1	5,000	Ref. 2 p. 85
8. Hand-Held Explosives Detector Electron Capture	$10,000	1	10,000	Ref. 1 p. 127
9. •Hand-Held SSNM Detector Gamma Detector	$10,000	1	10,000	Ref. 1 p. 125 & NRC Staff Estimate
10. Hand-Held Metal Detector Active MFMD	$ 500	2	1,000	Ref. 2 p. 85
		TOTAL	$66,000	

TABLE A2.15

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MAA PORTALS

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
I. Continuous/Personnel Portal				
1. Portal Doors/Turnstiles Floor-to-Ceiling Turnstile on Steel Door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2. Protected Guard Position Guard Position Hardened to Provide Protection Against Small-Arms Fire	$10,000	1	10,000	NRC Staff Estimate
3. Exchange Badges Picture Badge/Card Key	$ 2	500	1,000	NRC Staff Estimate
4. Change Room	NOT A SAFEGUARDS COST			
5. Fixed Metal Detector Active MFMD	$ 5,000	1	5,000	Ref. 2 p. 85
6. Hand-Held Metal Detector Active MFMD	$ 500	2	1,000	Ref. 2 p. 85
7. Fixed SSNM Detector Neutron and Gamma Detector	$60,000	1	60,000	Ref. 2 p. 68 & NRC Staff Estimate
8. Card Reader On-Line System	$ 3,000	4	12,000	Ref. 1 pp. 121

TABLE A2.15 (Continued)

REPROCESSING PLANT
MAA PORTALS

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
9. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	2	12,000	Ref. 1 pp. 32-34
10. Fixed Explosive Detector Electron Capture	$20,000	1	20,000	Ref. 1 pp. 123
II. Intermittent/Material Portal				
11. Portal Door Steel Door	$ 750	4	3,000	Ref. 2 p. 208
12. Hand-Held SSNM Detector Gamma Detector	$10,000	1	10,000	Ref. 1 p. 125 & NRC Staff Estimate
13. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	2	12,000	Ref. 1 pp. 32-34
14. Card Reader On-Line System	$ 3,000	1	3,000	Ref. 1 pp. 121
		TOTAL	$152,000	

TABLE A2.16

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MAA CONTAINMENT

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Vehicle Barrier (Rail) Three-Foot Rail Sections	$165/Meter	630	$103,950	Ref. 2 p. 208
2.	Exterior CCTV Fixed-Focus Silicon Diode Array Camera in Environmental Housing	$10,000	4	40,000	Ref. 1 pp. 32-34
3.	Exterior Lighting Pole Mounted Incandescent	$ 1,000	8	8,000	Ref. 1 pp. 32-34
4.	Emergency Exits Floor-to-Ceiling Turnstile Plus Steel Door	$ 2,000	4	8,000	NRC Staff Estimate
5.	Door Opening Alarms Balanced Magnetic Door Switches	$ 120	20	2,400	Ref. 1 pp. 32-34
6.	Storage Area Rolling Door Steel Door of Rollup Variety	$ 2,000	1	2,000	Ref. 2 p. 208
7.	Volumetric Sensors Active Ultrasonic Sensors	$3/Meter	600	1,800	Ref. 1 pp. 32-34
8.	Internal CCTV Fixed-Focus Silicon Diode Array	$ 6,000	20	120,000	Ref. 1 pp. 32-34
			TOTAL	$286,150	

TABLE A2.17

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
VITAL AREA PORTALS

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Portal Door/Turnstile Floor-to-Ceiling Turnstile Steel Door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2.	Fixed Explosive Detector Electron Capture	$ 20,000	4	80,000	Ref. 1 p. 123
3.	Fixed Metal Detector Active MFMD	$ 5,000	4	20,000	Ref. 2 p. 85
4.	Card Reader On-Line System	$ 3,000	4	12,000	Ref. 1 p. 121
5.	Vehicle Gate/Barrier Chain Link Gate with Attached Steel Rails	$ 2,000	2	4,000	NRC Staff Estimate
6.	Door Opening Alarm Balanced Magnetic Door Switches	$ 120	4	480	Ref. 1 pp. 32-34
7.	CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	4	24,000	Ref. 1 pp. 32-34
			TOTAL	$ 143,480	

TABLE A2.18

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
VITAL AREA CONTAINMENT

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Vehicle Barrier (Rail) Three-Foot Rail Sections	$165/Meter	270	$ 44,550	Ref. 2 p. 208
2. Exterior CCTV Fixed Focus Silicon Diode Array in Environmental Housing, Pole Mounting	$ 10,000	8	80,000	Ref. 1 pp. 32-34
3. Volumetric Alarms Active Ultrasonic	$3/meter^2	1,512	4,536	Ref. 1 pp. 32-34
4. Interior CCTV Fixed-Focus Silicon Diode Array	$ 6,000	8	48,000	Ref. 1 pp. 32-34
5. Exterior Lighting Pole-Mounted Incandescent	$ 1,000	8	8,000	Ref. 1 pp. 32-34
6. Emergency Exits Inner Floor-to-Ceiling Turnstile and Outer Steel Door	$ 2,000	4	8,000	NRC Staff Estimate
7. Door Opening Alarms Balanced Magnetic Door Switches	$ 120	12	1,440	Ref. 1 pp. 32-34
		TOTAL	$ 194,526	

TABLE A2.19

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
COMMAND AND CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Offsite Base Station Radios Two-Channel Radio plus Antenna (40-100 Watts)	$ 4,000	2	8,000	Ref. 1 pp. 32-34
2.	Hand-Held Portable Radios Two-Channel Radio and Battery and Charger (1.5-5 Watts)	$ 1,000	40	40,000	NRC Staff Estimate
3.	Vehicle/Portable Radios AC/DC 10-15 Watt Portable/ Vehicle Radio and Antenna	$ 1,500	1	1,500	NRC Staff Estimate
4.	Hardening (Walls and Roofs) of Security OPS Center	$930/meter	85	79,050	NRC Staff Estimate
5.	Emergency Power Uninterruptible Power and Generator	$ 30,000	1	30,000	Ref. 1 pp. 32-34
6.	Public Address System With 2-Way Capability	$ 20,000	1	20,000	NRC Staff Estimate
7.	Central Alarm/Admit Console Either Multiplex System with Mini-Computer or Direct Wire. Either With High-Security Line Supervision (Includes Wiring to Sensors) (Includes Control over Card-Key Reader System)	$ 260,000	1	260,000	NRC Staff Estimate

TABLE A2.19 (Continued)

REPROCESSING PLANT
COMMAND AND CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
8.	Alternate/Redundant Alarm/Admit Console Backup Display and Control of Alarm and Admit Functions	$ 84,000	1	84,000	NRC Staff Estimate
9.	CCTV Control Console with Motion Detection Rack Mounted 12" or Larger Monitors with Video Motion Detection Control Unit	$ 50,000	1	50,000	NRC Staff Estimate
10.	Portal Doors Steel Doors	$ 750	2	1,500	Ref. 2 p. 208
11.	RF Paging Receivers Tone Encoder Plus Tone-Only Paging Receivers	$ 300	40	12,000	NRC Staff Estimate
12.	Site Signaling System Klaxon, Siren, etc.	$ 10,000	1	10,000	NRC Staff Estimate
13.	Onsite Base Radio Station Single-Channel Radio Plus Antenna (40-100 Watts)	$ 4,000	1	4,000	Ref. 1 pp. 32-34
			TOTAL	$ 600,050	

TABLE A2.20

REPROCESSING PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MISCELLANEOUS

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Barriers for Vents/Drains Steel Grids	$ 100	*	*	NRC Staff Estimate
2. ID Badge Costs Combination Card-Key/Picture Badge	$ 2	500	$ 1,000	NRC Staff Estimate
3. ID Badge Fabrication Equipment Photographic and Laminating Equipment	$ 1,500	1	1,500	NRC Staff Estimate
4. Duress Alarms	$ 300	20	6,000	NRC Staff Estimate
5. SSNM Alarms for Vents/Drains "Panic Button" - Either Handwired or RF	$ 5,000	*	*	NRC Staff Estimate
		TOTAL	$ 8,500	

* Site specific; not costed for reference system

TABLE A2.21

REPROCESSING PLANT
MATERIAL CONTROL AND ACCOUNTING: EQUIPMENT AND FACILITIES
(CAPITAL COST OF EQUIPMENT)

A. Measurements

Item/Description	Unit Cost	Number of Units	Safeguards Fraction	NDA Standards* Increment	Total	Cost References
1. Weight and Volume						
Lab. Scales	$ 5,000	10	0.5	-	$ 25,000	Ref. 3
Pu Product and Waste Scales	$ 10,000	5	0.25	-	12,500	Ref. 3
Pu Product Load Cells	$ 20,000	2	0	-	0	Ref. 3
Vessel Dip Tubes and Manometers	$ 5,000	30	0	-	0	Ref. 3
2. Analytical						
Titrimeter (amperometric)	$ 20,000	2	0.5	-	20,000	Ref. 3
Mass Spectrometer	$ 200,000	1	0	-	0	Ref. 3
Alpha Spectrometer	$ 20,000	1	0.5	-	10,000	Ref. 3
3. Samplers		(NO SAFEGUARDS COST)				
4. Nondestructive Assay						
Neutron Counter (small containers)	$ 40,000	1	1.0	$ 16,000	56,000	Ref. 3
Barrel Assay (γ,n, Cf-252)	$ 750,000	2	0.5	$100,000	850,000	Ref. 3
Leached Hull γ-Assay	$ 50,000	1	0.5	$ 20,000	45,000	Ref. 3
γ-Survey	$ 10,000	2	1.0	$ 8,000	28,000	Ref. 3
n-Survey	$ 20,000	2	1.0	$ 16,000	56,000	Ref. 3
Small Sample Assay	$ 50,000	1	1.0	$ 20,000	70,000	Ref. 3
5. Laboratories and Counting Rooms						
Barrel Assay Facility	$3,000,000	1	0.5	-	1,500,000	Ref. 3
Leached Hull Assay Facility	$ 250,000	1	0.5	-	125,000	Ref. 3
Other	$ 50/ft^2	4,000 ft^2	0.5	-	100,000	Ref. 3
TOTAL MEASUREMENT COSTS (Equipment and Facilities)					$2,897,500	

---

*Required for Calibration and Measurement Control.

TABLE A2.21 (Continued)

REPROCESSING PLANT
MATERIAL CONTROL AND ACCOUNTING: EQUIPMENT AND FACILITIES

B. Accounting

Item/Description	Unit Cost	Number of Units	Safeguards Fraction	NDA Standards* Increment	Total	Cost References
Computer, Desk Calculators, and Peripherals	$ 100,000	One Total	1.0	-	100,000	Ref. 3
Computer Terminals	$ 15,000	5	1.0	-	75,000	Ref. 3
TOTAL ACCOUNTING COSTS					$ 175,000	
TOTAL INITIAL INVESTMENT COSTS					$3,072,500	

TABLE A2.22

REPROCESSING PLANT
MATERIAL CONTROL AND ACCOUNTING: PERSONNEL
(ANNUAL OPERATING COSTS)

A. Measurements

Item/Description (Personnel Function)	Unit Cost	Number of Units		Total	Cost References
		Routine	Measurement Control		
1. Weight					
Lab. Scales	$ 26,000/MY	0.5 MY	0.25 MY	$ 19,500	Ref. 3
Pu Product and Waste Scales	$ 26,000/MY	0.5 MY	0	13,000	Ref. 3
Pu Load Cells	$ 26,000/MY	0	0	0	Ref. 3
Vessel Dip Tubes and Manometers	$ 26,000/MY	0	0.25	6,500	Ref. 3
2. Analytical					
Titrimeter (amperometric)	$ 26,000/MY	2.0 MY	0.5 MY	65,000	Ref. 3
Mass Spectrometer	$ 26,000/MY	3.0 MY	1.5 MY	117,000	Ref. 3
Alpha Spectrometer	$ 26,000/MY	0.5 MY	0	13,000	Ref. 3
3. Samplers		(NO SAFEGUARDS COST)			
4. Nondestructive Assay					
Neutron Counter (small containers)	$ 26,000/MY	2.0 MY	0.25 MY	58,500	Ref. 3
Barrel Assay (γ, n, Cf-252)	$ 26,000/MY	4.0 MY	1.0 MY	130,000	Ref. 3
Leached Hull γ-Assay (NaI)	$ 26,000/MY	2.0 MY	0	52,000	Ref. 3
γ-Survey	$ 26,000/MY	0.5 MY	0.5 MY	26,000	Ref. 3
n-Survey	$ 26,000/MY	0.5 MY	0	13,000	Ref. 3
Small Sample Assay	$ 26,000/MY	0.5 MY	0.25 MY	19,500	Ref. 3
5. Laboratories and Counting Rooms		(NO PERSONNEL COSTS)			
TOTAL MEASUREMENT COSTS (Personnel Costs)				$ 533,000	

TABLE A2.22 (Continued)

REPROCESSING PLANT
MATERIAL CONTROL AND ACCOUNTING: PERSONNEL

B. Accounting

Item/Description (Personnel Function)	Unit Cost	Number of Units		Total	Cost References
		Routine	Measurement Control		
SSNM Custodians	$ 40,000/MY	8.0 MY	0	320,000	Ref. 3
SSNM Transfer Operators	$ 40,000/MY	8.0 MY	0	320,000	Ref. 3
Accountants and Clerks	$ 40,000/MY	7.0 MY	0	280,000	Ref. 3
Statisticians	$ 40,000/MY	2.0 MY	0	80,000	Ref. 3
Measurement Specialists	$ 40,000/MY	2.0 MY	0	80,000	Ref. 3
Compliance Inspectors	$ 40,000/MY	5.0 MY	0	200,000	Ref. 3
Supervisors	$ 40,000/MY	4.0 MY	0	160,000	Ref. 3
Manager	$ 40,000/MY	1.0	0	40,000	Ref. 3
TOTAL ACCOUNTING COSTS				$1,480,000	
TOTAL ANNUAL OPERATING COSTS				$2,013,000	

TABLE A2.23

REPROCESSING PLANT SECURITY FORCES

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Guards Uniformed Force	$ 22,500	46	$ 1,035,000	NRC Staff Estimate
2. Shift Supervisors Uniformed Supervisors	$ 27,000	4	108,000	NRC Staff Estimate
3. Clerical Both Clerks and Secretaries	$ 14,000	3	42,000	NRC Staff Estimate
4. Technicians For Maintenance of Security Equipment	$ 22,400	2	44,800	NRC Staff Estimate
5. Security Director Non-Uniformed	$ 35,000	1	35,000	NRC Staff Estimate
6. Assistant Security Director Also Functions as Chief Investigator	$ 30,100	1	30,100	NRC Staff Estimate
7. Individual Guard Equipment Uniforms, Sidearms, Shoulder Weapons, Ammunition, Helmets, Flak Vests, etc.	$ 1,330	46	61,180	NRC Staff Estimate
8. Guard Training Both Initial and Inservice Training	$700/Guard/yr	46	32,200	NRC Staff Estimate
9. 4 WD Patrol Vehicle	$ 7,000	1	7,000	NRC Staff Estimate
10. Guard Clearances	$ 725	46	33,350	NRC Staff Estimate
		TOTAL	$ 1,428,630	

TABLE A2.24

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
PERIMETER CONTROL

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Outer Clear Zone Terrain Cleared of Places of Concealment for Distance of 15 Meters from Outer Fence	NOT CHARGED TO SAFEGUARDS			Ref. 1 pp. 32-34
2. Outer Fence 7-Foot Chain Link with 1-Foot Barbed Wire Topping	$55/meter	1,000	$ 55,000	Ref. 1 pp. 32-34
3. Soil Stabilization Grading and Homogenization of Soil	$80/meter	1,000	80,000	Ref. 1 pp. 32-34
4. Microwave Sensors BI-Static System	$31/meter	900	27,900	Ref. 1 pp. 32-34
5. Seismic Sensors Buried Pressure-Sensitive Cable	$57/meter	900	51,300	Ref. 1 pp. 32-34
6. Alarm/Assessment CCTV Fixed-Focus Silicon Diode Array Cameras in Environmental Housing	$ 10,000	10	100,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
7. Inner Fence Same as Item #2	$55/meter	900	49,500	Ref. 1 pp. 32-34
8. Lighting Pole-Mounted Incandescent Lights Directed Outwards	$ 1,000	18	18,000	Ref. 1 pp. 32-34
9. Inner Clear Zone No Structures or Places of Concealment within 15 Meters of Inner Fence	NEGLIGIBLE			Ref. 1 pp. 32-34
10. Remote Control CCTV (located in P.A.) Silicon Diode Cameras in Environmental Housing with Remote Pan/Tilt/Zoom	$ 12,000	4	48,000	Ref. 1 pp. 32-34
		TOTAL	$ 429,700	

TABLE A2.25

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
PROTECTED AREA PORTAL

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Personnel Gate/Turnstile Floor-to-Ceiling Turnstile/Steel Door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2. Electric Vehicle Gate/Barrier Remotely Operated Chain Link Gate with Two Steel Rails Attached for Vehicle Barrier	$ 2,500	2	5,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
3. Protected Guard Position Guard Position Hardened to Provide Protection against Small-Arms Fire	$ 10,000	1	10,000	NRC Staff Estimate
4. Remotely Operated Train Gate/Barrier Same as Item #2	$ 10,000	1	10,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
5. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	1	6,000	Ref. 1 pp. 32-34
6. Card Reader On-line System	$ 3,000	2	6,000	Ref. 1 p. 121
7. Fixed Metal Detector Active Magnetic Field Metal Detector (MFMD)	$ 5,000	1	5,000	Ref. 2 p. 85
8. Hand-Held Explosives Detector Electron Capture	$ 10,000	1	10,000	Ref. 1 p. 127
9. Hand-Held SSNM Detector Gamma Detector	$ 10,000	1	10,000	Ref. 1 p. 125 & NRC Staff Estimate
10. Hand-Held Metal Detector Active MFMD	$ 500	2	1,000	Ref. 2 p. 85
		TOTAL	$ 66,000	

TABLE A2.26

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MAA PORTALS

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
I. Continuous/Personnel Portal				
1. Portal Doors/Turnstile Floor-to-Ceiling Turnstile on Steel Door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2. Protected Guard Position Guard Position Hardened to Provide Protection Against Small-Arms Fire	$10,000	1	10,000	NRC Staff Estimate
3. Exchange Badges Picture Badge/Card Key	$ 2	500	1,000	NRC Staff Estimate
4. Change Room		NOT A SAFEGUARDS COST		
5. Fixed Metal Detector Active MFMD	$ 5,000	1	5,000	Ref. 2 p. 85
6. -Hand-Held Metal Detector Active MFMD	$ 500	2	1,000	Ref. 2 p. 85
7. Fixed SSNM Detector Neutron and Gamma Detector	$60,000	1	60,000	Ref. 2 p. 68 & NRC Staff Estimate
8. Card Reader On-Line System	$ 3,000	4	12,000	Ref. 1 pp. 121

TABLE A2.26 (Continued)

FUEL FABRICATION PLANT
MAA PORTALS

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
9. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	2	12,000	Ref. 1 pp. 32-34
10. Fixed Explosive Detector Electron Capture	$20,000	1	20,000	Ref. 1 p. 123
II. Intermittent/Material Portal				
11. Portal Door Steel Door	$ 750	4	3,000	Ref. 2 p. 208 & NRC Staff Estimate
12. Hand-Held SSNM Detector Gamma Detector	$10,000	1	10,000	Ref. 1 p. 125 & NRC Staff Estimate
13. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	2	12,000	Ref. 1 pp. 32-34
14. Card Reader On-Line System	$ 3,000	1	3,000	Ref. 1 p. 121
		TOTAL	$152,000	

TABLE A2.27

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MAA CONTAINMENT

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Vehicle Barrier (Rail) 3-Foot Sections of Rail	$165/meter	400	$ 66,000	Ref. 2 p. 208
2.	Exterior CCTV Fixed-Focus Silicon Diode Array Camera in Environmental Housing	$ 10,000	4	40,000	Ref. 1 pp. 32-34
3.	Exterior Lighting Pole-Mounted Incandescent	$ 1,000	8	8,000	Ref. 1 pp. 32-34
4.	Emergency Exits Floor-to-Ceiling Turnstile Plus Steel Door	$ 2,000	8	16,000	NRC Staff Estimate
5.	Door Opening Alarms Balanced Magnetic Door Switches	$ 120	24	2,880	Ref. 1 pp. 32-34
6.	Storage Area Rolling Door Steel Door of Rollup Variety	$ 2,000	1	2,000	Ref. 2 p. 208
7.	Volumetric Sensors Active Ultrasonic Sensors	$\$3/\text{meter}^2$	1,728	5,184	Ref. 1 pp. 32-34
8.	Internal CCTV Fixed-Focus Silicon Diode Array	$ 6,000	22	132,000	Ref. 1 pp. 32-34
			TOTAL	$272,064	

TABLE A2.28

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
VITAL AREA PORTALS

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Portal Door/Turnstile Floor-to-Ceiling Turnstile Steel Door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2.	Fixed Explosive Detector Electron Capture	$ 20,000	4	80,000	Ref. 1 p. 123
3.	Fixed Metal Detector Active MFMD	$ 5,000	4	20,000	Ref. 2 p. 85
4.	Card Reader On-Line System	$ 3,000	4	12,000	Ref. 1 p. 121
5.	Vehicle Gate/Barrier Chain Link Gate with Attached Steel Rails	$ 2,000	2	4,000	Ref. 2 p. 208 & NRC Staff Estimate
6.	Door Opening Alarm Balanced Magnetic Door Switches	$ 120	4	480	Ref. 1 pp. 32-34
7.	CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	4	24,000	Ref. 1 pp. 32-34
			TOTAL	$143,480	

TABLE A2.29

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
VITAL AREA CONTAINMENT

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Vehicle Barrier Three-Foot Rail Section	\$165/meter	100	\$ 16,500	Ref 2 p. 208
2.	Exterior CCTV Fixed-Focus Silicon Diode Array in Environmental Housing	\$ 10,000	8	80,000	Ref. 1 pp. 32-34
3.	Volumetric Alarms Active Ultrasonic	\$3/meter^2	625	1,875	Ref. 1 pp. 32-34
4.	Interior CCTV Fixed-Focus Silicon Diode Array	\$ 6,000	8	48,000	Ref. 1 pp. 32-34
5.	Exterior Lighting Pole-Mounted Incandescent	\$ 1,000	8	8,000	Ref. 1 pp. 32-34
6.	Emergency Exits Floor-to-Ceiling Turnstile and Steel Door	\$ 2,000	4	8,000	NRC Staff Estimate
7.	Door Opening Alarms Balanced Magnetic Door Switches	\$ 120	12	1,440	Ref. 1 pp. 32-34
			TOTAL	\$163,815	

TABLE A2.30

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
COMMAND AND CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Offsite Base Station Radios Two-Channel Radio plus Antenna (40-100 Watts)	$ 4,000	2	8,000	Ref. 1 pp. 32-34
2.	Hand Held Portable Radios Two-Channel Radio and Battery and Charger (1.5-5 Watts)	$ 1,000	40	40,000	NRC Staff Estimate
3.	Vehicle/Portable Radios AC/DC 10-15 Watt Portable/ Vehicle Radio and Antenna	$ 1,500	1	1,500	NRC Staff Estimate
4.	Hardening (Walls and Roofs) of Security OPS Center	$930/meter	85	79,050	NRC Staff Estimate
5.	Emergency Power Uninterruptible Power and Generator	$ 30,000	1	30,000	Ref. 1 pp. 32-34
6.	Public Address System With 2-Way Capability	$ 20,000	1	20,000	NRC Staff Estimate
7.	Central Alarm/Admit Console Either Multiplex System with Mini-Computer or Direct Wire. Either With High-Security Line Supervision (Includes Wiring to Sensors) (Includes Control over Card-Key Reader System)	$260,000	1	260,000	NRC Staff Estimate

TABLE A2.30 (Continued)

FUEL FABRICATION PLANT
COMMAND AND CONTROL

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
8. Alternate/Redundant Alarm/Admit Console Backup Display and Control of Alarm and Admit Functions	$ 84,000	1	84,000	NRC Staff Estimate
9. CCTV Control Console with Motion Detection Rack Mounted 12" or Larger Monitors with Video Motion Detection Control Unit	$ 50,000	1	50,000	NRC Staff Estimate
10. Portal Doors Steel Doors	$ 750	2	1,500	Ref. 2 p. 208 & NRC Staff Estimate
11. RF Paging Receivers Tone Encoder Plus Tone-Only Paging Receivers	$ 300	40	12,000	NRC Staff Estimate
12. Site Signaling System Klaxon, Siren, etc.	$ 10,000	1	10,000	NRC Staff Estimate
13. Onsite Base Radio Station Single-Channel Radio plus Antenna (40-100 Watts)	$ 4,000	1	4,000	Ref. 1 pp. 32-34
		TOTAL	$600,050	

TABLE A2.31

FUEL FABRICATION PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MISCELLANEOUS

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Barriers for Vents/Drains Steel Grids	$ 100	*	*	NRC Staff Estimate
2.	ID Badge Costs Combination Card Key/Picture Badge	$ 2	500	$ 1,000	NRC Staff Estimate
3.	ID Badge Fabrication Equipment Photographic and Laminating Equiment	$ 1,500	1	1,500	NRC Staff Estimate
4.	Duress Alarms "Panic Button" - Either Handwired or RF	$ 300	20	6,000	NRC Staff Estimate
5.	SSNM Alarms for Vents/Drains	$ 5,000	*	*	NRC Staff Estimate
			TOTAL	$ 8,500	

*Site-specific; not costed for reference system.

TABLE A2.32

FUEL FABRICATION PLANT
MATERIAL CONTROL AND ACCOUNTING: EQUIPMENT AND FACILITIES
(CAPITAL COST OF EQUIPMENT)

A. Measurements

	Item/Description	Unit Cost	Number of Units	Safeguards Fraction	NDA Standards* Increment	Total	Cost References
1.	Weight						
	Scales	\$ 10,000	15	0.25	-	\$ 37,500	Ref. 3
	Laboratory Scales	\$ 5,000	10	0.5	-	25,000	Ref. 3
	Load Cells and Electronics	\$ 20,000	18	0	-	0	Ref. 3
2.	Analytical						
	Titrimeter (Amperometric)	\$ 20,000	4	0.5	-	40,000	Ref. 3
	Mass Spectrometer	\$ 200,000	1	0	-	0	Ref. 3
	Alpha Spectrometer	\$ 20,000	2	1.0	-	40,000	Ref. 3
3.	Samplers		NO	SAFEGUARDS	COSTS		
4.	Laboratories and Counting Room	\$ 50/ft^2	4,000 ft^2	0.5	-	100,000	Ref. 3
5.	Nondestructive Assay						
	Neutron Counter	\$ 40,000	1	1	\$ 16,000	56,000	Ref. 3
	Waste γ-Assay (GELI, Small Containers)	\$ 70,000	1	1	28,000	98,000	Ref. 3
	Waste γ-Assay (GELI, 55-Gallon Barrels)	\$ 60,000	1	1	\$ 24,000	84,000	Ref. 3
	Rod Scanner	\$ 250,000	1	0.5	\$ 50,000	175,000	Ref. 3
	Small Sample Assay System	\$ 50,000	1	1	\$ 20,000	70,000	Ref. 3
	γ-Survey	\$ 10,000	5	0.75	\$ 15,000	52,500	Ref. 3
	n-Survey	\$ 20,000	5	1	\$ 40,000	140,000	Ref. 3
	TOTAL MEASUREMENT COSTS (Equipment and Facilities)					\$ 918,500	

*Required for Calibration and Measurement Control

TABLE A2.32 (Continued)

FUEL FABRICATION PLANT
MATERIAL CONTROL ACCOUNTING: EQUIPMENT AND FACILITIES

B. Accounting

Item/Description	Unit Cost	Number of Units	Safeguards Fraction	NDA Standards* Increment	Total	Cost References
Computer, Desk Calculators, and Peripherals	-	-	1.0	-	100,000	Ref. 3
Computer Terminals	$ 15,000	5	1.0	-	75,000	Ref. 3
TOTAL ACCOUNTING COSTS					$ 175,000	
TOTAL INITIAL INVESTMENT COSTS					$1,093,000	

TABLE A2.33

FUEL FABRICATION PLANT
MATERIAL CONTROL AND ACCOUNTING: PERSONNEL
(ANNUAL OPERATING COSTS)

A. Measurements

Item/Description (Personnel Function)	Unit Cost	Number of Units		Total	Cost References
		Routine	Measurement Control		
1. Weight					
Scales	$ 26,000/MY	1.5 MY	0.25 MY	$ 45,500	Ref. 3
Laboratory Scales	$ 26,000/MY	0.5	0	13,000	Ref. 3
Load Cells and Electronics	$ 26,000/MY	0	0	0	Ref. 3
2. Analytical					
Titrimeter	$ 26,000/MY	4.0	1.5	143,000	Ref. 3
Mass Spectrometer	$ 26,000/MY	1.5	0.5	52,000	Ref. 3
Alpha Spectrometer	$ 26,000/MY	0.5	0	13,000	Ref. 3
3. Samplers		NO SAFEGUARDS COSTS			
4. Nondestructive Assay					
Neutron Counter	$ 26,000/MY	2.0 MY	0	52,000	Ref. 3
Waste γ, small containers	$ 26,000/MY	1.0 MY	1.0 MY	52,000	Ref. 3
Waste γ, 55-gallon barrels	$ 26,000/MY	0.5	0	13,000	Ref. 3
Rod Scanner	$ 26,000/MY	0.5 MY	0.25 MY	19,500	Ref. 3
Small Sample Assay System	$ 26,000/MY	0.5 MY	0	13,000	Ref. 3
γ-Survey	$ 26,000/MY	1.0 MY	0	26,000	Ref. 3
n-Survey	$ 26,000/MY	1.0 MY	0.5 MY	39,000	Ref. 3
5. Laboratories and Counting Rooms	0	0	0	0	
TOTAL MEASUREMENTS COST (PERSONNEL COSTS)				$ 481,000	

TABLE A2.33 (Continued)

FUEL FABRICATION PLANT
MATERIAL CONTROL AND ACCOUNTING: PERSONNEL

B. Accounting

Item/Description (Personnel Function)	Unit Cost	Number of Units		Total	Cost References
		Routine	Measurement Control		
Computer, etc.	0	0	0	0	
Computer Terminals	0	0	0	0	
SSNM Custodians	$ 40,000/MY	8.0 MY	0	$ 320,000	Ref. 3
SSNM Transfer Operators	$ 40,000/MY	8.0 MY	0	320,000	Ref. 3
Accountants and Clerks	$ 40,000/MY	7.0 MY	0	280,000	Ref. 3
Statisticians	$ 40,000/MY	2.0 MY	0	80,000	Ref. 3
Measurement Specialists	$ 40,000/MY	2.0 MY	0	80,000	Ref. 3
Compliance Inspectors	$ 40,000/MY	5.0 MY	0	200,000	Ref. 3
Supervisors	$ 40,000/MY	4.0 MY	0	160,000	Ref. 3
Manager	$ 40,000/MY	1.0 MY	0	40,000	Ref. 3
TOTAL ACCOUNTING COSTS				$1,480,000	
TOTAL ANNUAL OPERATING COSTS				$1,961,000	

TABLE A2.34

FUEL FABRICATION PLANT
SECURITY FORCES

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Guards Uniformed Force	$ 22,500	46	$1,035,000	NRC Staff Estimate
2. Shift Supervisors	$ 27,000	4	108,000	NRC Staff Estimate
3. Clerical Both Clerks and Secretaries	$ 14,000	3	42,000	NRC Staff Estimate
4. Technicians For Maintenance of Security Equipment	$ 22,400	2	44,800	NRC Staff Estimate
5. Security Director Non-Uniformed	$ 35,000	1	35,000	NRC Staff Estimate
6. Assistant Security Director Also Functions as Chief Investigator	$ 30,100	1	30,100	NRC Staff Estimate
7. Individual Guard Equipment Uniforms, Sidearms, Shoulder Weapons, Ammunition, Helmets, Flak Vests, etc.	$ 1,330	46	61,180	NRC Staff Estimate
8. Guard Training Both Initial and Inservice Training	$700/Guard/yr	46	32,200	NRC Staff Estimate
9. 4 WD Patrol Vehicle Standard Vehicle	$ 7,000	1	7,000	NRC Staff Estimate
10. Guard Clearances	$ 725	46	33,350	NRC Staff Estimate
		TOTAL	$1,428,630	

TABLE A2.35

FUEL ASSEMBLY PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
PERIMETER CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Outer Clear Zone Terrain Cleared of Places of Concealment for Distances of 15 Meters from Outer Fence.	NEGLIGIBLE SAFEGUARDS COST			Ref. 1 pp. 32-24
2.	Outer Fence 7-Foot Chain Link with 1 Foot Barbed Wire Topping	$55/meter	410	$ 22,550	Ref. 1 pp. 32-34
3.	Soil Stabilization Grading and Homogenization of Soil	$80/meter	410	32,800	Ref. 1 pp. 32-34
4.	Microwave Sensors BI-Static System	$31/meter	350	10,850	Ref. 1 pp. 32-34
5.	Seismic Sensors Buried Pressure Sensitive Cable	$57/meter	350	19,950	Ref. 1 pp. 32-34
6.	Alarm/Assessment CCTV Fixed-focus Silicon Diode Array Cameras in Environmental Housing	$ 10,000	10	100,000	Ref. 1 pp. 32-34 & NRC Staff Estimate

TABLE A2.35 (Continued)
FUEL ASSEMBLY PLANT
PERIMETER CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
7.	Inner Fence Same as Item #2	$55/meter	350	19,250	Ref. 1 pp. 32-34
8.	Lighting Pole-mounted	$ 1,000	10	10,000	Ref. 1 pp. 32-34
9.	Inner Clear Zone No Structures or Places of Concealment within 15 meters of Inner Fence	NEGLIGIBLE SAFEGUARDS COST			Ref. 1 pp. 32-34
10.	Remote Control CCTV Silicon Diode Cameras in Environmental Housing with Remote Pan/Tilt/Zoom	$12,000	4	48,000	Ref. 1 pp. 32-34
			TOTAL	$263,400	

TABLE A2.36

FUEL ASSEMBLY PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
PROTECTED AREA PORTAL

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Personnel Gate/Turnstile Floor-to-Ceiling Turnstile/Steel Door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2. Electric Vehicle Gate/Barrier Remotely Operated Chain Link Gate with Two Steel Rails Attached for Vehicle Barrier	$ 2,500	2	5,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
3. Protected Guard Position Guard Position Hardened to Provide Protection against Small-Arms Fire	$ 10,000	1	10,000	NRC Staff Estimate
4. Remotely Operated Train Gate/Barrier Same as Item #2	$ 10,000	1	10,000	Ref. 1 pp. 32-34 & NRC Staff Estimate
5. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	1	6,000	Ref. 1 pp. 32-34
6. Card Reader On-Line System	$ 3,000	2	6,000	Ref. 1 p. 121
7. Fixed Metal Detector Active Magnetic Field Metal Detector (MFMD)	$ 5,000	1	5,000	Ref. 2 p. 85
8. Hand-Held Explosives Detector Electron Capture	$ 10,000	1	10,000	Ref. 1 p. 127
9. Hand-Held SSNM Detector Gamma Detector	$ 10,000	1	10,000	Ref. 1 p. 125 & NRC Staff Estimate
10. Hand-Held Metal Detector Active MFMD	$ 500	2	1,000	Ref. 2 p. 85
		TOTAL	$ 66,000	

TABLE A2.37

FUEL ASSEMBLY PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MAA CONTAINMENT

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Vehicle Barrier (Rail) Three-Foot Rail Sections	$165/Meter	190	$ 31,350	Ref. 2 p. 208
2.	Exterior CCTV Fixed-Focus Silicon Diode Array Camera in Environmental Housing	$ 10,000	4	40,000	Ref. 1 pp. 32-34
3.	Exterior Lighting Pole-Mounted Incandescent	$ 1,000	8	8,000	Ref. 1 pp. 32-34
4.	Emergency Exits Floor-to-Ceiling Turnstile Plus Metal Door	$ 2,000	2	4,000	NRC Staff Estimate
5.	Door Opening Alarms Balanced Magnetic Door Switches	$ 120	4	480	Ref. 1 pp. 32-34
6.	Internal CCTV Fixed-Focus Silicon Diode Array	$ 6,000	10	$ 60,000	Ref. 1 pp. 32-34
			TOTAL	$143,830	

TABLE A2.38

FUEL ASSEMBLY PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MAA PORTALS

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
I. Continuous/Personnel Portal				
1. Portal Doors/Turnstiles Floor-to-Ceiling Turnstile or Steel door	$ 750	4	$ 3,000	Ref. 2 p. 208 & NRC Staff Estimate
2. Protected Guard Position Guard Position Hardened to Provide Protection Against Small-Arms Fire	$ 10,000	1	10,000	NRC Staff Estimate
3. Exchange Badges	$ 2	500	1,000	NRC Staff Estimate
4. Change Room		NO SAFEGUARDS COST		
5. Fixed Metal Detector Active MFMD	$ 5,000	1	5,000	Ref. 2 p. 85
6. Hand Held Metal Detector Active MFMD	$ 500	2	1,000	Ref. 2 p. 85
7. Fixed SSNM Detector Neutron and Gamma Detector	$ 60,000	1	60,000	Ref. 2 p. 68 & NRC Staff Estimate

TABLE A2.38 (Continued)
FUEL ASSEMBLY PLANT
MAA PORTALS

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
8. Card Reader On-Line System	$ 3,000	4	12,000	Ref. 1 p. 121
9. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	2	12,000	Ref. 1 pp. 32-34
10. Fixed Explosives Detector Electron Capture	$ 20,000	1	20,000	Ref. 1 p. 123
II. Intermittent/Material Portal				
11. Portal Door Steel Door	$ 750	4	3,000	Ref. 2 p. 208 & NRC Staff Estimate
12. Hand-Held SSNM Detector Gamma Detector	$ 10,000	1	10,000	Ref. 1 p. 125
13. CCTV Camera Fixed-Focus Silicon Diode Array	$ 6,000	2	12,000	Ref. 1 pp. 32-34
14. Card Reader On-Line System	$ 3,000	1	3,000	Ref. 1 p. 121
		TOTAL	$152,000	

TABLE A2.39

FUEL ASSEMBLY PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
COMMAND AND CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Offsite Base Station Radios Two-Channel Radio Plus Antenna (40-100 Watts)	$ 4,000	2	$ 8,000	Ref. 1 pp. 32-34
2.	Hand Held Portable Radio Two-Channel Radio and Battery and Charger (1.5 - 5 Watts)	$ 1,000	20	20,000	NRC Staff Estimate
3.	Hardening of S.O.C.	$930/Meter	85	79,050	NRC Staff Estimate
4.	Emergency Power Uninterruptible Power and Generator	$ 30,000	1	30,000	Ref. 1 pp. 32-34
5.	Public Address System With 2-Way Capability	$ 15,000	1	15,000	NRC Staff Estimate
6.	Central Alarm/Admit Console Either Multiplex System with Mini-Computer or Direct Wire. Either with High-Security Line Supervision. (Includes Wiring to Sensors) (Includes Control over Card-Key Reader System)	$215,000	1	215,000	NRC Staff Estimate

TABLE A2.39 (Continued)
FUEL ASSEMBLY PLANT
COMMAND AND CONTROL

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
7.	Alternate/Redundant Console Backup Display and Control of Alarm/Admit functions	$ 64,000	1	$ 64,000	NRC Staff Estimate
8.	CCTV Control Console with Motion Detection Rack-Mounted 12" or Larger Monitors with Video Motion Detection Control Unit	$ 45,000	1	45,000	NRC Staff Estimate
9.	Portal Doors Steel Doors	$ 750	2	1,500	Ref. 2 p. 208 & NRC Staff Estimate
10.	RF Paging Receivers Tone Encoder plus Tone-Only Paging Receivers	$ 300	20	6,000	NRC Staff Estimate
11.	Site Signaling System Klaxon, Siren, etc.	$ 10,000	1	10,000	NRC Staff Estimate
12.	Onsite Base Radio Station Single-Channel Radio plus Antenna (40-100 Watts)	$ 4,000	1	4,000	Ref. 1 pp. 32-34
			TOTAL	$497,550	

TABLE A2.40

FUEL ASSEMBLY PLANT
PHYSICAL SECURITY EQUIPMENT AND FACILITIES
MISCELLANEOUS

	Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1.	Barriers for Vents/Drains Steel Grids	$ 100	*	*	NRC Staff Estimate
2.	ID Badge Costs Combination Card Key/Picture Badge	$ 2.00	60	$ 180	NRC Staff Estimate
3.	ID Badge Fabrication Equipment Photographic and Laminating Equipment	$ 1,500	1	1,500	NRC Staff Estimate
4.	Duress Alarms	$ 300	10	3,000	NRC Staff Estimate
5.	SSNM Alarms for Vents/Drains "Panic Button" - Either Handwired or RF	$ 5,000	*	*	NRC Staff Estimate
			TOTAL	$ 4,620	

*Site-specific; not costed for reference system.

TABLE A2.41

FUEL ASSEMBLY PLANT
SECURITY FORCES

Item/Description	Unit Cost	Number of Units	Total Cost	Cost References
1. Guards Uniformed Force	$ 22,500	46	$1,035,000	NRC Staff Estimate
2. Shift Supervisors Uniformed Supervisors	$ 27,000	4	108,000	NRC Staff Estimate
3. Clerical Both Clerks and Secretaries	$ 14,000	3	42,000	NRC Staff Estimate
4. Technicians For Maintenance of Security Equipment	$ 22,400	2	44,800	NRC Staff Estimate
5. Security Director Non-Uniformed	$ 35,000	1	35,000	NRC Staff Estimate
6. Assistant Security Director Also Functions as Chief Investigator	$ 30,100	1	30,100	NRC Staff Estimate
7. Individual Guard Equipment Uniforms, Sidearms, Shoulder Weapons, Ammunition, Helmets, Flak Vests, etc.	$ 1,330	46	61,180	NRC Staff Estimate
8. Guard Training Both Initial and Inservice Training	$700/Guard/yr	46	32,200	NRC Staff Estimate
9. 4 WD Patrol Vehicle Standard Vehicle	$ 7,000	1	7,000	NRC Staff Estimate
10. Guard Clearances	$ 725	46	33,350	NRC Staff Estimate
		TOTAL	$1,428,630	

TABLE A2.42

TRANSPORTATION SAFEGUARDS COST ELEMENTS
ROAD TRANSPORT

Item	Cost References
Integrated Container Vehicle (ICV) (PuO_2 or MOX) $275,000; 10 year life; 100,000 miles per year utilization; Operating & Maintenance Cost $0.60/mile	Ref. 4 p. 117 & NRC Staff Estimate
Communications Amortization SECOM-II plus VHF $12,000 Cost; 5-year life; Maintenance $1,200 per year	Ref. 4 p. 129 & NRC Staff Estimate
Containers PuO_2 ICV Safeguards and locator device; capacity 504 kg; initial cost 7 x $7,000 = $49,000/set; 10-year life; maintenance $14,000/set/yr; 6 trips/yr	Ref. 4 Table B-111-1 & NRC Staff Estimate
MOX ICV Locator device PWR 4 Ctrs. x $3,000 = $12,000/set; 10-year life; maintenance $1,200/set/yr; 2 trips/yr	Ref. 4 Table B-111-1 & NRC Staff Estimate
BWR 8 Ctrs. x $1,500 = $12,000/set; 10-year life maintenance $1,200/set/yr; 2 trips/yr	

TABLE A2.42 (Continued)

TRANSPORTATION SAFEGUARDS COST ELEMENTS
ROAD TRANSPORT

Item	Cost References
Special Escort Vehicle (SEV) Cost $50,000 each: $10,000 chassis & engine, 2-yr life; 5 replacements over 10 years; $40,000 body & armor, 10-yr life. Amortization: $90,000, 10-year life; 50,000 miles per year utilization. Operating and maintenance: 1.5 x conventional escort vehicle, $0.24/mile.	NRC Staff Estimate
Escort Guards & Drivers Cost: $30,000 per year per guard/driver; includes overtime & per diem. Personnel Utilization: 2400 total duty hours estimated 75% hours on road = 1800 hr at 50 miles per hour. Number Convoy Personnel = $\frac{\text{(round trip distance)}}{\text{50 mph}} \; \frac{\text{(trips/yr)(personnel/convoy)}}{\text{1800 hr}}$ or 1.4 (personnel/convoy) whichever is larger.	NRC Staff Estimate

TABLE A2.43

COMMUNICATIONS NETWORK COST DATA

(5 Sites)

Reference: NRC Staff Estimate

	Initial Investment (Unit Cost)	Annual Operating (Unit Cost)	Number of Units	Total Investment Cost	Total Annual Operating
Facilities					
Building	$ 200,000	$ 10,000	5	$1,000,000	$ 50,000
Land Purchase and Site Improvement	$ 50,000	0	5	250,000	0
Total Facilities				$1,250,000	$ 50,000
Communications Equipment					
Receiver/Transmitter/ Antenna	$ 750,000	$ 75,000	5	$3,750,000	$ 375,000
Central Computer	$ 250,000	$ 25,000	1	250,000	25,000
Total Communications				$4,000,000	$ 400,000
Controller Pay					
Station Manager	0	$ 31,000	5	0	$ 155,000
Radio Operators	0	$ 22,000	45	0	990,000
Guards	0	$ 22,500	25	0	562,500
Clerks	0	$ 14,000	5	0	70,000
Total Controller Pay				0	$1,777,500
Security Clearances and Individual Training					
Initial Clearances	$ 725	0	80	$ 58,000	0
Replacement Clearances	0	$ 725	12	0	$ 8,700
Initial Training	0	0	80	0	0
Replacement Training	0	0	12	0	0
Total Security Clearances				$ 58,000	$ 8,700

TABLE A2.43 (Continued)

COMMUNICATIONS NETWORK COST DATA

	Initial Investment (Unit Cost)	Annual Operating (Unit Cost)	Number of Units	Total Investment Cost	Total Annual Operating
Security Equipment					
Entrance ID Portal	$ 25,000	$ 2,500	5	$ 125,000	$ 12,500
Sidearms	150	$ 15	25	3,750	375
Intrusion Alarms	$ 8,000	$ 800	5	40,000	4,000
Total Security Equipment				$ 168,750	$ 16,875
Other					
Utilities, Communications, etc.	0	$ 60,000	5	0	$ 300,000
Total Other				0	$ 300,000

TABLE A2.44

REGULATION COST DATA

Reference: NRC Staff Estimate

Initial Inspection and Licensing	Initial Investment (Unit Cost)	Annual Operating (Unit Cost)	Number of Units	Total Investment Cost	Total Annual Operating
Inspector Pay					
Reprocessing Facility	$ 33,750/man-yr	0	14 man-yr	$ 472,500	0
Fuel Fabrication Facility	$ 33,750	0	10	337,500	0
Fuel Assembly Facility	$ 33,750	0	9	303,750	0
Power Reactor Facility	$ 33,750	0	15	506,250	0
Security Clearances and Individual Training					
Initial Clearances	$ 725	0	48	34,800	0
Initial Training	0	0	48	0	0
Other					
Travel and Subsistence	$ 3,500	0	48	168,000	0
Inicial Training	0	0	48	0	0
Total Initial Inspection				$1,822,800	0
Annual Inspection					
Inspector Pay					
Reprocessing Facility	0	$ 33,750/man-yr	1 man-yr	0	$ 33,750
Fuel Fabrication Facility	0	$ 33,750	1	0	33,750
Fuel Assembly Facility	0	$ 33,750	1	0	33,750
Power Reactor Facility	0	$ 33,750	2	0	67,500
Security Clearances and Individual Training					
Initial Clearances	$ 725	0	3.5	2,537	0
Replacement Clearances	0	$ 725	0.5	0	362
Initial Training	0	0	3.5	0	0
Replacement Training	0	0	0.5	0	0

TABLE A2.44 (Continued)

REGULATION COST DATA

Reference: NRC Staff Estimate

	Initial Investment (Unit Cost)	Annual Operating (Unit Cost)	Number of Units	Total Investment Cost	Total Annual Operating
Other					
Travel and Subsistence	0	$ 3,500	3.5	0	12,250
Total Annual Inspection				$ 2,537	$ 181,362
Enforcement					
Pay					
Administrators	0	$ 56,700	5	0	$ 283,500
Enforcement Officials	0	$ 45,000	15	0	675,000
Clerks	0	$ 14,000	3	0	42,000
Security Clearances and Individual Training					
Initial Clearances	$ 725	0	23	$ 16,675	0
Replacement Clearances	0	$ 725	3	0	2,175
Initial Training	0	0	20	0	0
Replacement Training	0	0	3	0	0
Other					
Travel and Subsistence	0	$ 1,750	20	0	$ 35,000
Total Enforcement				$ 16,675	$ 1,037,675
Safeguards Analysis and Development					
In-House Effort	0	$100,000	1	0	$ 100,000
Contractural Effort	0	$300,000	1	0	$ 300,000
Total Analysis and Development					$ 400,000

Appendix A, Part 2

REFERENCES

1. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. II, "Fixed-Site Protection System (U)," SAND-75-0457, March 1976. (Confidential)**

2. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. III, "Elements of Physical Protection for Fixed Sites (U)," SAND-75-0457 March 1976. (Secret)**

3. Science Applications, Inc., Technical Note, SAI-NRC-1, July 20, 1976.[b]

4. Sandia Laboratories, "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle," Vol. IV, "Transportation Mode Analysis (U)," SAND-75-0457, March 1976. (Confidential)**

** Unclassified versions available in NRC PDR for inspection and copying, for a fee.

[b] Available in source file for USNRC Report NUREG-0414, May, 1978.

APPENDIX A

Part 3: Safeguards Costs for NUREG-0002 Alternatives and Total Fuel Cycle Costs (Including Upgraded Safeguards)

In Parts 1 and 2 of this Appendix, safeguards costs were obtained for the reference safeguards system (NUREG-0002 Alternative 3) in the year 2000.* In this Part, the total fuel cycle flows and costs with upgraded safeguards are presented for each alternative (Tables A3.1 - A3.5), and the safeguards costs for each alternative for the year 2000 are calculated. The cumulative discounted and undiscounted safeguards costs for each alternative are also calculated.

The total fuel cycle flows and costs with upgraded safeguards were determined by taking the reference system safeguards costs in the year 2000 from Part 1 of this Appendix and the estimated safeguards systems costs for the other NUREG-0002 alternatives for the year 2000 (in terms of dollars per kilogram) and adding these costs to their respective NUREG-0002 alternative fuel cycle flows and costs as presented in Tables XI-28 through XI-32 of NUREG-0002.

The safeguards system costs for Alternatives 1, 2, and 5 for the year 2000 were based on the safeguards systems descriptions in Chapters 3 and 5 of this Technical Report. The NUFUEL computer program was then used to calculate the year-by-year total costs with upgraded safeguards for each alternative as well as the 26-year cumulative discounted and undiscounted total costs. The specific safeguards costs for each alternative were calculated by subtracting the fuel cycle costs of NUREG-0002 Chapter XI (Tables 28-32) from the total fuel cycle costs of the appropriate alternative in this part. The reactor safeguards costs and the regulation safeguards costs (4.7 million) could not be put into the NUFUEL computer program but they were added to the year 2000 costs for each alternative after the NUREG-0002 costs were subtracted from the costs presented in the Tables in this section. The reactor and regulation safeguards costs could not be added to the 26-year cumulative discounted or undiscounted costs. The resulting safeguards costs for each alternative are shown below:

Annualized Safeguards Costs (Millions of Dollars)

	Alt. 1	Alt. 2	Alt. 3	Alt. 5**	Alt. 6
Year 2000	140	141	139	37	0
26-Year Cumulative (Discounted)	259	220	261	62	0
26-Year Cumulative (Undiscounted)	1,352	1,338	1,346	357	0

---

*Although the mature MOX fuel industry identified here is based on the mature MOX fuel industry described in Chapter 3 of this report and in Chapter III of NUREG-0002, there exist other projections of nuclear industry growth. These are discussed in Appendix B to Chapter III of NUREG-0002.

**The three safeguards costs for Alternative 5 assume that plutonium is separated from the waste fuel at the reprocessing plant. All three would be zero if the plutonium is left in the spent fuel wastes at the reprocessing plant.

The differences in costs between Alternatives 1, 2, and 3 are accounted for by the storage costs in Alternative 1 and the difference in the starting times of the three alternatives.

The costs for the year 2000 for Alternative 3 were calculated as 139 million per year rather than the 141 million per year shown in Part 1 of this Appendix owing to rounding carried out by the NUFUEL model.

TABLE A3.1 FUEL CYCLE FLOWS AND COSTS WITH UPGRADED SAFEGUARDS - ALTERNATIVE I

SECTION 1 PROCESS FLOW

SAFEGUARD RUN T-2 ALT I CASE 31 - LOW GROWTH - 70' CF - 1978 REPROCESSING - 1983 RECYCLE - NO FDATE 25-MAY-77 TIME 12:32

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919	0	0	0	0	0	[illegible]	0	0	0
76	11.4	10.4	4.8	1337	0	0	0	0	0	[illegible]	0	0	0
77	14.8	11.5	5.7	1758	500	0	0	0	0	[illegible]	0	0	0
78	16.7	13.0	5.9	1972	999	500	0	1928	0	[illegible]	0	0	0
79	20.1	14.7	7.6	2345	1499	999	0	5918	0	[illegible]	0	1000	0
80	23.3	17.6	9.0	3181	1498	1499	0	14913	0	[illegible]	0	1200	0
81	26.3	19.2	10.5	2826	1748	1498	0	25047	0	[illegible]	0	1200	0
82	26.9	20.3	11.4	4162	1998	1748	8981	29021	148	[illegible]	0	1000	0
83	31.1	21.6	11.1	4138	2249	1998	21255	23726	402	[illegible]	500	800	0
84	37.1	26.0	14.7	5066	2248	2249	25412	16308	542	[illegible]	999	750	0
85	38.7	29.2	15.7	5212	2849	2248	27749	8293	608	[illegible]	1499	400	0
86	42.4	31.3	16.5	5239	3549	2849	29787	2639	710	[illegible]	1498	200	0
87	47.5	35.7	19.4	5982	4249	3549	32508	336	721	[illegible]	1748	250	0
88	51.7	38.2	21.1	6816	4249	4249	35169	65	687	[illegible]	1998	250	0
89	55.4	41.3	23.0	6984	4846	4249	39189	0	893	[illegible]	2249	250	0
90	58.6	43.6	24.2	7699	5545	4846	48669	0	1008	[illegible]	2248	250	0
91	61.7	45.1	25.9	8152	6248	5545	58416	165	1292	[illegible]	2849	250	0
92	65.1	48.2	27.4	8553	6848	6248	65103	87	1411	[illegible]	3549	250	0
93	68.0	50.6	29.3	9115	7548	6848	71214	146	1577	[illegible]	4249	250	0
94	70.1	51.0	30.5	9469	8248	7548	31084	210	1774	[illegible]	4249	250	0
95	73.1	53.4	31.7	9608	8248	8248	87471	141	2026	9611	4846	250	0
96	76.1	56.5	33.4	10082	9248	8248	89271	0	2009	10152	5545	250	0
97	76.7	57.0	34.6	10508	10248	9248	94350	0	2044	10470	6248	250	0
98	77.2	56.8	34.7	10613	10248	10248	110429	1764	2288	[illegible]	6848	250	0
99	78.9	57.7	35.4	10678	10248	10248	117872	2493	2538	[illegible]	7548	250	0
0	80.5	59.3	36.1	10842	10248	10248	122798	2850	2650	[illegible]	8248	250	0
TOT	1241.9	915.5	521.3	163248	125406	115158	1166724	136547	25328	[illegible]	66918	10150	0

SECTION 2 PROJECTED UNIT COST

SAFEGUARD RUN T-2 ALT I CASE 31 - LOW GROWTH - 70' CF - 1978 REPROCESSING - 1983 RECYCLE - NO FDATE 25-MAY-77 TIME 12:32

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W/O PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
79	15.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	17.62	100.0
80	17.8	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	19.13	100.0
81	19.9	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	20.25	100.0
82	21.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	20.84	100.0
83	21.8	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	21.27	100.0
84	22.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	21.65	100.0
85	23.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	22.16	100.0
86	25.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	23.25	100.0
87	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	24.86	100.0
88	28.5	3.5	75.0	95.0	15.1	5.0	154.2	0.03	2.06	238.6	50.0	24.86	100.0
89	28.5	3.5	75.0	95.0	15.3	5.0	155.8	0.03	2.06	238.6	50.0	24.86	100.0
90	28.5	3.5	75.0	95.0	15.3	5.0	156.1	0.03	2.06	238.6	50.0	24.86	100.0
91	28.5	3.5	75.0	95.0	15.3	5.0	156.3	0.03	2.06	238.6	50.0	24.86	100.0
92	28.5	3.5	75.0	95.0	15.4	5.0	156.8	0.03	2.06	238.6	50.0	24.86	100.0
93	28.5	3.5	75.0	95.0	15.3	5.0	156.4	0.03	2.06	238.6	50.0	24.86	100.0
94	29.9	3.5	75.0	95.0	15.3	5.0	155.9	0.03	2.06	238.6	50.0	25.61	100.0
95	32.5	3.5	75.0	95.0	15.3	5.0	156.6	0.03	2.06	238.6	50.0	27.00	100.0
96	33.0	3.5	75.0	95.0	15.3	5.0	156.6	0.03	2.06	238.6	50.0	27.25	100.0
97	33.0	3.5	75.0	95.0	15.4	5.0	157.3	0.03	2.06	238.6	50.0	27.26	100.0
98	33.0	3.5	75.0	95.0	15.4	5.0	157.4	0.03	2.06	238.6	50.0	27.26	100.0
99	33.0	3.5	75.0	95.0	15.4	5.0	157.6	0.03	2.06	238.6	50.0	27.25	100.0
0	33.1	3.5	75.0	95.0	15.5	5.0	157.9	0.03	2.06	238.6	50.0	27.30	100.0
WT AVE	28.1	3.5	75.0	95.0	15.3	5.0	156.2	0.03	2.06	238.6	50.0	22.22	0.0

TABLE A3.1 (Continued) - ALTERNATIVE 1

```
                                   SECTION 3  PROJECTED COSTS FOR MATERIALS AND SERVICES
                                             (IN MILLIONS OF 1975 DOLLARS)
SAFEGUARD RUN  T-2 ALT I  CASE 31 - LOW GROWTH - 70' CF - 1978 REPROCESSING - 1983 RECYCLE - NO FDATE: 25-MAY-77  TIME: 12:32:3
YEAR   MINING  UF6  ENRICHMNT  U FUEL   SPENT     REPRO    PU      INCR PU      MOX  INCR SPENT   WASTE   PU SALES  SPENT     TO
      MILLING CONVR             FAB   FUEL TRAN           TRANS    STORAGE      FAB  FUEL STOR  DISPOSAL          FUEL DISP
                                                                                                 W/O PU
 75    224.7    22.     267.     87.       0.       0.    0.00       0.00        0.        6.        0.      0.        0.     6
 76    286.2    36.     359.    127.       0.       0.    0.00       0.00        0.       10.        0.      0.        0.     8
 77    325.2    40.     430.    167.       7.       0.    0.00       0.00        0.       15.        0.      0.        0.     9
 78    401.5    46.     446.    187.      15.      77.    0.00       3.97        0.       18.       16.      0.        0.    12
 79    601.5    52.     572.    223.      22.     153.    0.00      12.19        0.       19.       21.    -18.        0.    16
 80    830.2    61.     674.    302.      22.     229.    0.00      30.72        0.       18.       47.    -23.        0.    21
 81   1045.5    67.     786.    268.      26.     229.    0.00      51.60        0.       18.       47.    -24.        0.    25
 82   1127.8    71.     856.    395.      30.     268.    0.27      59.78       35.       18.       54.    -21.        0.    28
 83   1355.6    76.     835.    392.      34.     306.    0.64      48.87       96.       20.       62.    -17.        0.    32
 84   1671.1    91.    1102.    481.      34.     344.    0.76      33.59      129.       21.       70.    -16.        0.    39
 85   1817.1   102.    1174.    495.      43.     344.    0.83      18.11      145.       24.       70.     -9.        0.    42
 86   2161.1   110.    1240.    498.      53.     436.    0.89       5.44      169.       27.       88.     -7.        0.    47
 87   2708.9   125.    1455.    568.      64.     543.    0.98       0.69      172.       30.      110.     -6.        0.    57
 88   2944.7   134.    1581.    648.      64.     655.    1.06       0.13      164.       32.      132.     -6.        0.    63
 89   3159.0   145.    1729.    663.      74.     662.    1.18       0.00      213.       35.      132.     -6.        0.    68
 90   3340.0   153.    1818.    731.      85.     756.    1.46       0.00      241.       38.      150.     -6.        0.    73
 91   3518.3   158.    1941.    774.      96.     867.    1.75       0.34      308.       41.      172.     -6.        0.    78
 92   3711.3   169.    2057.    813.     105.     979.    1.95       0.18      337.       44.      194.     -6.        0.    84
 93   3876.2   177.    2196.    866.     116.    1071.    2.14       0.30      376.       45.      213.     -6.        0.    89
 94   4193.8   178.    2204.    900.     126.    1177.    2.43       0.43      423.       46.      234.     -6.        0.    94
 95   4753.9   187.    2380.    913.     127.    1291.    2.62       0.29      483.       47.      256.     -7.        0.   104
 96   5020.9   198.    2507.    958.     142.    1292.    2.68       0.00      479.       51.      256.     -7.        0.   109
 97   5065.1   200.    2592.    998.     158.    1455.    2.83       0.00      488.       52.      287.     -7.        0.   112
 98   5098.4   199.    2602.   1006.     158.    1613.    3.31       3.63      546.       51.      318.     -7.        0.   115
 99   5208.8   202.    2656.   1014.     158.    1615.    3.54       5.14      606.       53.      318.     -7.        0.   118
  0   5325.9   208.    2706.   1030.     159.    1618.    3.68       5.87      632.       56.      318.     -7.        0.   120
TOT  69772.8  3204.   39244.  15509.    1917.   17982.   35.00     281.29     6043.      836.     3575.   -226.        0.  1581.
                                       SECTION 4  DISCOUNTED PROCESS COSTS
                                          (IN MILLIONS OF 1975 DOLLARS)
SAFEGUARD RUN  T-2 ALT I  CASE 31 - LOW GROWTH - 70' CF - 1978 REPROCESSING - 1983 RECYCLE - NO FDATE: 25-MAY-77  TIME: 12:22:3
DISCOUNT RATE =0.100

YEAR   MINING  UF6  ENRICHMNT  U FUEL   SPENT     REPRO    PU      INCR PU      MOX  INCR SPENT   WASTE   PU SALES  SPENT     TO
      MILLING CONVR             FAB   FUEL TRAN           TRANS    STORAGE      FAB  FUEL STOR  DISPOSAL          FUEL DISP
                                                                                                 W/O PU
 75    224.7    22.     267.     87.       0.       0.    0.00       0.00        0.        5.        0.      0.        0.     6
 76    260.2    33.     326.    115.       0.       0.    0.00       0.00        0.        9.        0.      0.        0.     7
 77    268.8    33.     356.    138.       6.       0.    0.00       0.00        0.       12.        0.      0.        0.     8
 78    301.6    34.     335.    141.      11.      58.    0.00       2.98        0.       13.       12.      0.        0.     9
 79    410.8    35.     391.    152.      15.     104.    0.00       8.33        0.       13.       21.    -12.        0.    11
 80    515.5    38.     418.    188.      14.     142.    0.00      19.08        0.       11.       29.    -14.        0.    13
 81    590.1    38.     443.    152.      15.     129.    0.00      29.13        0.       10.       26.    -14.        0.    14
 82    578.8    36.     439.    203.      15.     137.    0.14      30.68       18.        9.       28.    -11.        0.    14
 83    632.4    35.     389.    183.      16.     143.    0.30      22.80       45.        9.       29.     -8.        0.    14
 84    708.7    39.     467.    204.      14.     146.    0.32      14.25       55.        9.       30.     -7.        0.    16
 85    700.6    39.     453.    191.      16.     133.    0.32       6.98       56.        9.       27.     -3.        0.    16
 86    757.5    38.     434.    174.      19.     153.    0.31       1.91       59.       10.       31.     -2.        0.    16
 87    863.1    40.     464.    181.      20.     173.    0.31       0.22       55.       10.       35.     -2.        0.    18
 88    853.0    39.     458.    188.      19.     190.    0.31       0.04       47.        9.       38.     -2.        0.    18
 89    831.9    38.     455.    175.      19.     174.    0.31       0.00       56.        9.       35.     -2.        0.    17
 90    799.6    37.     435.    175.      20.     181.    0.35       0.00       58.        9.       36.     -1.        0.    17
 91    765.7    34.     422.    169.      21.     189.    0.38       0.07       67.        9.       37.     -1.        0.    17
 92    734.3    33.     407.    161.      21.     194.    0.39       0.04       67.        9.       38.     -1.        0.    16
 93    697.2    32.     395.    156.      21.     193.    0.38       0.05       68.        8.       38.     -1.        0.    16
 94    685.7    29.     373.    147.      21.     192.    0.40       0.07       69.        8.       38.     -1.        0.    15
 95    706.6    28.     354.    136.      19.     192.    0.39       0.04       72.        7.       38.     -1.        0.    15
 96    678.5    27.     339.    129.      19.     175.    0.36       0.00       65.        7.       35.     -1.        0.    14
 97    622.2    25.     318.    123.      19.     179.    0.35       0.00       60.        6.       35.     -1.        0.    13
 98    569.4    22.     291.    113.      18.     180.    0.37       0.41       61.        6.       36.     -1.        0.    12
 99    528.8    21.     270.    103.      16.     164.    0.36       0.52       61.        5.       32.     -1.        0.    12
  0    491.6    19.     250.     95.      15.     149.    0.34       0.54       58.        5.       29.     -1.        0.    11
TOT  15777.2   845.    9951.   3977.     410.    3670.    6.39     138.13     1097.      228.      734.    -88.        0.   367
NET GENERATION    35357. , BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH
        1.935   0.104   1.228   0.480    0.050    0.450   0.001      0.017     0.135     0.028     0.090  -0.011     0.000    4.
```

TABLE A3.2 FUEL CYCLE FLOWS AND COSTS WITH UPGRADED SAFEGUARDS - ALTERNATIVE 2

SECTION 1 PROCESS FLOW

```
SAFEGUARD RUN  T-2 ALT II      - CASE  33        - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIDATE: 25-MAY-77  TIME: 12:33:0

YEAR   MINING     UF6   ENRICHMNT  U FUEL    SPENT   REPROCESS      PU      INCR PU    MOX  INCR SPENT  WASTE   PU SALES    SPENT
       MILLING   CONVR     1000      FAB   FUEL TRAN              TRANS    STORAGE    FAB  FUEL STOR  DISPOSAL  KG FISS  FUEL DISP
       1000 ST 1000 MTU   MT-SWU     MTU     MT-HM     MT-HM     KG-TOT     KG-TOT  MT-HM    MT-HM     MT-HM               MT-HM
                                                                                                     W/O PU
 75      10.5      6.2      3.6      919.       0.        0.         0.         0.     0.    1167.        0.        0.        0.
 76      13.4     10.4      4.8     1337.       0.        0.         0.         0.     0.    1962.        0.        0.        0.
 77      15.0     11.5      5.7     1758.       0.        0.         0.         0.     0.    2917.        0.        0.        0.
 78      17.8     13.5      6.0     1972.       0.        0.         0.         0.     0.    4014.        0.        0.        0.
 79      21.8     16.1      7.8     2345.       0.        0.         0.         0.     0.    5236.        0.        0.        0.
 80      25.3     19.1      8.9     3181.       0.        0.         0.         0.     0.    6566.        0.        0.        0.
 81      29.4     21.3     10.4     2826.       0.        0.         0.         0.     0.    8140.        0.        0.        0.
 82      32.2     24.1     12.1     4310.       0.        0.         0.         0.     0.    9930.        0.        0.        0.
 83      38.0     27.1     12.7     4532.       0.        0.         0.         0.     0.   12193.        0.        0.        0.
 84      44.9     32.6     16.6     5608.       0.        0.         0.         0.     0.   14634.        0.        0.        0.
 85      46.2     36.2     17.9     5820.    1348.        0.         0.         0.     0.   17575.        0.        0.        0.
 86      46.8     35.7     18.4     5889.    3397.     1348.      5187.         0.    61.   19721.        0.     2200.        0.
 87      46.8     36.5     20.0     6280.    5843.     3397.     21408.         0.   424.   20427.        0.     2200.        0.
 88      45.8     34.4     20.2     6687.    7245.     5843.     44741.         0.   816.   19192.        0.     1550.        0.
 89      46.9     35.1     21.2     6571.    7849.     7245.     61976.         0.  1306.   16874.        0.      700.        0.
 90      51.2     37.1     22.5     7243.    8249.     7849.     69344.         0.  1463.   14497.        0.      500.        0.
 91      56.0     40.1     25.3     8011.    8241.     8249.     67887.        45.  1433.   12379.     1348.      500.        0.
 92      60.2     43.6     26.8     8219.    8248.     8241.     73092.       404.  1745.   10807.     3397.      500.        0.
 93      64.3     46.8     28.5     8868.    8248.     8248.     80457.       419.  1823.    9709.     5843.      250.        0.
 94      68.2     49.1     29.7     9189.    8248.     8248.     89363.       323.  2054.    9260.     7245.      250.        0.
 95      72.4     53.0     31.0     9477.    8248.     8248.     93416.        71.  2157.    9413.     7849.      250.        0.
 96      75.9     56.3     32.7     9980.    9248.     8248.     95321.        57.  2111.   10154.     8249.      250.        0.
 97      76.7     56.8     34.0    10461.   10248.     9248.     99581.       156.  2092.   10472.     8241.      250.        0.
 98      77.1     56.4     34.4    10482.   10248.    10248.    112287.      1613.  2419.   10297.     8248.      250.        0.
 99      78.9     57.5     35.3    10642.   10248.    10248.    118658.      2156.  2573.   10559.     8248.      250.        0.
  0      80.6     59.6     35.8    10805.   10248.    10248.    124931.      2685.  2687.   11226.     8248.      250.        0.
TOT    1242.2    916.0    522.2   163412.  125404.   115156.   1157655.      7926. 25164.  279323.    66916.    10150.        0.
```

SECTION 2 PROJECTED UNIT COST

```
SAFEGUARD RUN  T-2 ALT II      - CASE  33        - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIDATE: 25-MAY-77  TIME: 12:33:04

YEAR    U308       U     SEP WORK  U  FAB    SPENT   INCR SPENT   REPRO      PU     INCR PU     MOX     WASTE  PU VALUE     SPENT
     AS BURNED   CONVR                     FUEL TRAN  FUEL STOR             TRAN    STORAGE     FAB   DISPOSAL            FUEL DISP
       $/LB     $/KG-U    $/SWU    $/KG-U   $/KG-HM  $/KG-HM-YR  $/KG-HM  $/G-TOT   $/G-TOT   $/KG-HM  $/KG-HM   $/G FISS   $/KG-HM
                                                                                                        W/O PU
 75     10.7      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.66     238.6     50.0      0.00      100.0
 76     10.7      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 77     11.0      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 78     12.0      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 79     15.2      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 80     18.2      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 81     20.3      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 82     21.3      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 83     22.2      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 84     22.9      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0      0.00      100.0
 85     25.0      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.5     50.0     24.83      100.0
 86     28.5      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0     24.86      100.0
 87     28.5      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0     24.86      100.0
 88     28.5      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0     24.86      100.0
 89     28.5      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0     24.86      100.0
 90     28.5      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0     24.86      100.0
 91     28.5      3.5      75.0     95.0     15.0       5.0      153.1     0.03      2.06     238.6     50.0     24.86      100.0
 92     28.5      3.5      75.0     95.0     15.0       5.0      153.4     0.03      2.06     238.6     50.0     24.86      100.0
 93     28.5      3.5      75.0     95.0     15.2       5.0      155.0     0.03      2.06     238.6     50.0     25.65      100.0
 94     30.0      3.5      75.0     95.0     15.3       5.0      156.4     0.03      2.06     238.6     50.0     27.03      100.0
 95     32.6      3.5      75.0     95.0     15.5       5.0      158.2     0.03      2.06     238.6     50.0     27.26      100.0
 96     33.0      3.5      75.0     95.0     15.5       5.0      158.2     0.03      2.06     238.6     50.0     27.26      100.0
 97     33.0      3.5      75.0     95.0     15.5       5.0      157.7     0.03      2.06     238.6     50.0     27.26      100.0
 98     33.0      3.5      75.0     95.0     15.5       5.0      158.5     0.03      2.06     238.6     50.0     27.26      100.0
 99     33.0      3.5      75.0     95.0     15.5       5.0      158.3     0.03      2.06     238.6     50.0     27.26      100.0
  0     33.1      3.5      75.0     95.0     15.5       5.0      158.7     0.03      2.06     238.6     50.0     27.30      100.0
 WT
AVE.    28.1      3.5      75.0     95.0     15.3       5.0      156.0     0.03      2.06     238.6     50.0     25.22        0.0
```

TABLE A3.2 (Continued) - ALTERNATIVE 2

```
                                          SECTION 3  PROJECTED COSTS FOR MATERIALS AND SERVICES
                                                     (IN MILLIONS OF 1975 DOLLARS)
SAFEGUARD RUN  T-2 ALT II       - CASE  33        - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIDATE: 25-MAY-77  TIME: 12:33:0
YEAR    MINING   UF6  ENRICHMNT  U FUEL     SPENT     REPRO      PU      INCR PU        MOX  INCR SPENT    WASTE   PU SALES  SPENT      TO
       MILLING  CONVR             FAB   FUEL TRAN             TRANS     STORAGE        FAB  FUEL STOR  DISPOSAL            FUEL DISP
                                                                                                        W/O PU
 75     224.7    22.     267.      87.        0.        0.     0.00       0.00         0.       6.        0.        0.        0.      60
 76     286.2    36.     359.     127.        0.        0.     0.00       0.00         0.      10.        0.        0.        0.      81
 77     330.0    40.     430.     167.        0.        0.     0.00       0.00         0.      15.        0.        0.        0.      9
 78     426.6    47.     447.     187.        0.        0.     0.00       0.00         0.      20.        0.        0.        0.      11
 79     661.9    56.     585.     223.        0.        0.     0.00       0.00         0.      26.        0.        0.        0.      15
 80     921.1    67.     670.     302.        0.        0.     0.00       0.00         0.      33.        0.        0.        0.      19
 81    1195.3    74.     780.     268.        0.        0.     0.00       0.00         0.      41.        0.        0.        0.      23
 82    1370.2    84.     905.     409.        0.        0.     0.00       0.00         0.      50.        0.        0.        0.      28
 83    1685.0    95.     954.     431.        0.        0.     0.00       0.00         0.      61.        0.        0.        0.      32
 84    2055.3   114.    1244.     533.        0.        0.     0.00       0.00         0.      73.        0.        0.        0.      40
 85    2308.4   127.    1340.     553.       20.        0.     0.00       0.00         0.      88.        0.        0.        0.      44
 86    2664.0   125.    1378.     559.       51.      206.     0.16       0.00        15.      99.       42.      -55.        0.      50
 87    2667.8   128.    1503.     597.       88.      520.     0.64       0.00       101.     102.      105.      -55.        0.      57
 88    2608.9   120.    1519.     635.      109.      895.     1.34       0.00       195.      96.      181.      -39.        0.      63
 89    2673.0   123.    1588.     624.      118.     1109.     1.86       0.00       312.      84.      225.      -17.        0.      68
 90    2920.7   130.    1688.     688.      124.     1202.     2.08       0.00       349.      72.      244.      -12.        0.      740
 91    3193.7   140.    1896.     761.      124.     1263.     2.04       0.09       342.      62.      256.      -12.        0.      80
 92    3431.9   153.    2011.     781.      124.     1264.     2.19       0.83       416.      54.      256.      -12.        0.      84
 93    3667.2   164.    2136.     842.      125.     1279.     2.41       0.86       435.      49.      256.       -6.        0.      89
 94    4087.9   172.    2225.     873.      126.     1290.     2.68       0.66       490.      46.      256.       -6.        0.      95
 95    4717.1   185.    2329.     900.      128.     1305.     2.80       0.15       515.      47.      256.       -7.        0.      103
 96    5010.3   197.    2450.     948.      143.     1305.     2.86       0.12       504.      51.      256.       -7.        0.      108
 97    5060.3   199.    2547.     994.      158.     1459.     2.99       0.32       499.      52.      287.       -7.        0.      112
 98    5089.9   198.    2583.     996.      159.     1624.     3.37       3.32       577.      51.      318.       -7.        0.      115
 99    5205.9   201.    2645.    1011.      159.     1622.     3.56       4.44       614.      53.      318.       -7.        0.      118
  0    5331.0   209.    2685.    1026.      159.     1626.     3.75       5.53       641.      56.      318.       -7.        0.      120
TOT   69794.5  3206.   39163.   15524.     1915.    17969.    34.73      15.33      6004.    1397.     3575.     -256.        0.      1583
                                          SECTION 4  DISCOUNTED PROCESS COSTS
                                            (IN MILLIONS OF 1975 DOLLARS)
SAFEGUARD RUN  T-2 ALT II       - CASE  33        - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSIDATE: 25-MAY-77  TIME: 12:33:0
DISCOUNT RATE =0.100
YEAR    MINING   UF6  ENRICHMNT  U FUEL     SPENT     REPRO      PU      INCR PU        MOX  INCR SPENT    WASTE   PU SALES  SPENT      TO
       MILLING  CONVR             FAB   FUEL TRAN             TRANS     STORAGE        FAB  FUEL STOR  DISPOSAL            FUEL DISP
                                                                                                        W/O PU
 75     224.7    22.     267.      87.        0.        0.     0.00       0.00         0.       6.        0.        0.        0.      60
 76     260.2    33.     326.     115.        0.        0.     0.00       0.00         0.       9.        0.        0.        0.      74
 77     272.7    33.     356.     138.        0.        0.     0.00       0.00         0.      12.        0.        0.        0.      81
 78     320.5    36.     336.     141.        0.        0.     0.00       0.00         0.      15.        0.        0.        0.      84
 79     452.1    38.     399.     152.        0.        0.     0.00       0.00         0.      18.        0.        0.        0.      10
 80     571.9    42.     416.     188.        0.        0.     0.00       0.00         0.      20.        0.        0.        0.      12
 81     674.7    42.     440.     152.        0.        0.     0.00       0.00         0.      23.        0.        0.        0.      13
 82     703.1    43.     464.     210.        0.        0.     0.00       0.00         0.      25.        0.        0.        0.      14
 83     786.1    44.     445.     201.        0.        0.     0.00       0.00         0.      28.        0.        0.        0.      15
 84     871.7    48.     528.     226.        0.        0.     0.00       0.00         0.      31.        0.        0.        0.      17
 85     890.0    49.     517.     213.        0.        0.     0.00       0.00         0.      34.        0.        0.        0.      17
 86     933.7    44.     483.     196.       18.       72.     0.05       0.00         5.      35.       15.      -19.        0.      178
 87     850.1    41.     479.     190.       28.      166.     0.20       0.00        32.      33.       34.      -17.        0.      18
 88     755.7    35.     440.     184.       31.      259.     0.39       0.00        56.      28.       53.      -11.        0.      183
 89     703.9    32.     418.     164.       31.      292.     0.49       0.00        82.      22.       59.       -5.        0.      18
 90     699.2    31.     404.     165.       30.      288.     0.50       0.00        84.      17.       58.       -3.        0.      17
 91     695.0    31.     413.     166.       27.      275.     0.44       0.02        74.      13.       56.       -3.        0.      174
 92     679.0    30.     398.     154.       25.      250.     0.43       0.16        82.      11.       51.       -2.        0.      16
 93     659.6    29.     384.     152.       23.      230.     0.43       0.16        78.       9.       46.       -1.        0.      161
 94     668.4    28.     364.     143.       21.      211.     0.44       0.11        80.       8.       42.       -1.        0.      156
 95     701.2    28.     346.     134.       19.      194.     0.42       0.02        77.       7.       38.       -1.        0.      154
 96     677.0    27.     331.     128.       19.      176.     0.39       0.02        68.       7.       35.       -1.        0.      14
 97     621.6    24.     313.     122.       19.      179.     0.37       0.04        61.       6.       35.       -1.        0.      138
 98     568.4    22.     288.     111.       18.      181.     0.38       0.37        64.       6.       36.       -1.        0.      129
 99     528.5    20.     268.     103.       16.      165.     0.36       0.45        62.       5.       32.       -1.        0.      12
  0     492.0    19.     248.      95.       15.      150.     0.35       0.51        59.       5.       29.       -1.        0.      111
TOT   16261.2   872.   10071.    4029.      347.     3089.     5.64       1.86       966.     433.      618.      -67.        0.      3662
NET GENERATION    35357. , BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH
        1.994   0.107   1.235    0.494     0.043     0.379    0.001      0.000      0.119    0.053     0.076   -0.008     0.000     4.4
```

TABLE A3.3 FUEL CYCLE FLOWS AND COSTS WITH UPGRADED SAFEGUARDS - ALTERNATIVE 3

SECTION 1. PROCESS FLOW

SAFEGUARD RUN T-2 ALT III - CASE 36 - LOW GROWTH - 70' CF - 1978 REP - 1981 REC - NO FBR DATE: 25-MAY-77 TIME: 12:33:41

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919	0	0	0	0	0	1167	0	0	0
76	13.4	10.4	4.8	1337	0	0	0	0	0	1962	0	0	0
77	14.8	11.5	5.7	1758	500	0	0	0	0	2317	0	0	0
78	16.7	13.0	5.9	1972	999	500	0	1928	0	3514	0	0	0
79	19.6	14.6	7.6	2345	1499	999	0	5918	0	3737	0	1000	0
80	21.7	16.5	8.6	3106	1498	1499	4665	10247	75	3968	0	1200	0
81	24.2	17.3	9.5	2570	1748	1498	12930	7452	255	3644	0	1200	0
82	26.6	19.2	10.5	3896	1998	1748	20406	0	413	3886	0	1000	0
83	32.2	22.5	11.6	4137	2249	1998	15960	0	395	3951	500	800	0
84	38.3	27.1	15.3	5230	2248	2249	17996	0	378	4143	999	750	0
85	39.7	30.2	16.2	5383	2849	2248	20535	140	437	4836	1499	400	0
86	42.8	32.0	16.9	5347	3549	2849	25527	222	602	5483	1498	300	0
87	47.6	35.9	19.4	6012	4249	3549	33039	39	692	6035	1748	250	0
88	51.8	38.3	21.0	6787	4249	4249	36675	0	716	6394	1998	250	0
89	55.6	41.4	23.1	6991	4846	4249	37983	0	886	7072	2249	250	0
90	58.6	43.7	24.3	7725	5545	4846	47090	30	981	7698	2248	250	0
91	61.7	45.1	26.0	8193	6248	5545	56937	362	1251	8284	2849	250	0
92	65.1	48.2	27.5	8577	6848	6248	64161	200	1387	8705	3549	250	0
93	68.0	50.6	29.3	9126	7548	6848	71174	141	1565	9007	4249	250	0
94	70.1	51.0	30.5	9471	8248	7548	80981	116	1771	9258	4249	250	0
95	73.1	53.4	31.8	9612	8248	8248	87090	200	2022	9411	4846	250	0
96	76.1	56.5	33.5	10087	9248	8248	88971	0	2004	10152	5545	250	0
97	76.7	57.0	34.6	10512	10248	9248	94142	0	2040	10470	6248	250	0
98	77.3	56.8	34.7	10620	10248	10248	110231	1893	2281	10295	6848	250	0
99	78.9	57.7	35.4	10683	10248	10248	117752	2640	2532	10557	7548	250	0
0	80.5	59.3	36.1	10846	10248	10248	122637	2996	2647	11224	8248	250	0
TOT	1241.9	915.5	523.2	163242	125406	115158	1166879	34520	25330	167170	66918	10150	

SECTION 2. PROJECTED UNIT COST

SAFEGUARD RUN T-2 ALT III - CASE 36 - LOW GROWTH - 70' CF - 1978 REP - 1981 REC - NO FBR DATE: 25-MAY-77 TIME: 12:33:41

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W/O PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	153.1	6.03	2.06	238.6	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
79	15.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	17.62	100.0
80	17.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	19.08	100.0
81	19.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	20.14	100.0
82	20.8	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	20.75	100.0
83	21.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	21.22	100.0
84	22.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	21.63	100.0
85	23.4	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	22.13	100.0
86	25.5	3.5	75.0	95.0	15.1	5.0	153.8	0.03	2.05	238.6	50.0	23.23	100.0
87	28.5	3.5	75.0	95.0	15.3	5.0	155.9	0.03	2.06	238.6	50.0	24.86	100.0
88	28.5	3.5	75.0	95.0	15.3	5.0	156.0	0.03	2.06	238.6	50.0	24.86	100.0
89	28.5	3.5	75.0	95.0	15.3	5.0	155.8	0.03	2.06	238.6	50.0	24.86	100.0
90	28.5	3.5	75.0	95.0	15.2	5.0	155.2	0.03	2.06	238.6	50.0	24.86	100.0
91	28.5	3.5	75.0	95.0	15.2	5.0	155.4	0.03	2.06	238.6	50.0	24.86	100.0
92	28.5	3.5	75.0	95.0	15.3	5.0	156.2	0.03	2.06	238.6	50.0	24.86	100.0
93	28.5	3.5	75.0	95.0	15.3	5.0	156.3	0.03	2.06	238.6	50.0	24.86	100.0
94	29.9	3.5	75.0	95.0	15.3	5.0	156.0	0.03	2.06	238.6	50.0	25.61	100.0
95	32.5	3.5	75.0	95.0	15.3	5.0	156.5	0.93	2.06	238.6	50.0	27.00	100.0
96	33.0	3.5	75.0	95.0	15.3	5.0	156.6	0.03	2.06	238.6	50.0	27.26	100.0
97	33.0	3.5	75.0	95.0	15.4	5.0	157.2	0.03	2.06	238.6	50.0	27.26	100.0
98	33.0	3.5	75.0	95.0	15.4	5.0	157.4	0.03	2.06	238.6	50.0	27.26	100.0
99	33.0	3.5	75.0	95.0	15.4	5.0	157.6	0.03	2.06	238.6	50.0	27.26	100.0
0	33.1	3.5	75.0	95.0	15.5	5.0	157.9	0.03	2.06	238.6	50.0	27.30	100.0
WT AVE	28.1	3.5	75.0	95.0	15.3	5.0	156.2	0.03	2.06	238.6	50.0	22.19	0.0

TABLE A3.3 (Continued) - ALTERNATIVE 3

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

SAFEGUARD RUN T-2 ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR DATE: 25-MAY-77 TIME: 12:33:41

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	5.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	325.2	40.	430.	167.	7.	0.	0.00	0.00	0.	15.	0.	0.	0.	985.
78	401.5	46.	446.	187.	15.	77.	0.00	3.97	0.	18.	16.	0.	0.	1209.
79	587.5	51.	572.	223.	22.	153.	0.00	12.19	0.	19.	31.	-18.	0.	1653.
80	7[illegible]9.2	58.	646.	295.	22.	229.	0.14	21.11	18.	18.	47.	-23.	0.	2101.
81	954.6	61.	709.	244.	26.	229.	0.39	15.35	61.	18.	47.	-24.	0.	2341.
82	1108.1	67.	789.	370.	30.	268.	0.61	0.00	99.	18.	54.	-21.	0.	2783.
83	1396.7	79.	866.	393.	34.	306.	0.48	0.00	94.	20.	62.	-17.	0.	3234.
84	1723.2	95.	1146.	497.	34.	344.	0.54	0.00	90.	21.	70.	-16.	0.	4004.
85	1859.2	106.	1217.	511.	43.	344.	0.62	0.29	104.	24.	70.	-9.	0.	4271.
86	2180.6	112.	1267.	508.	53.	438.	0.77	0.46	144.	27.	88.	-7.	0.	4813.
87	2716.0	125.	1455.	571.	65.	553.	0.99	0.08	165.	30.	110.	-6.	0.	5780.
88	2955.2	134.	1574.	645.	65.	663.	1.10	0.00	171.	32.	132.	-6.	0.	6366.
89	3167.6	145.	1734.	664.	74.	662.	1.14	0.00	211.	35.	132.	-6.	0.	6820.
90	3343.0	153.	1826.	734.	84.	752.	1.41	0.06	234.	38.	150.	-6.	0.	7318.
91	3518.2	158.	1948.	778.	95.	862.	1.71	0.74	298.	41.	172.	-6.	0.	7868.
92	3709.2	169.	2061.	815.	105.	976.	1.92	0.41	331.	44.	194.	-6.	0.	8393.
93	3875.7	177.	2196.	867.	116.	1070.	2.14	0.29	373.	45.	213.	-6.	0.	8928.
94	4195.6	179.	2284.	900.	126.	1178.	2.43	0.24	423.	46.	234.	-6.	0.	9561.
95	4755.0	187.	2382.	913.	127.	1291.	2.61	0.41	482.	47.	256.	-7.	0.	10437.
96	5021.6	198.	2509.	958.	142.	1291.	2.67	0.00	478.	51.	256.	-7.	0.	10900.
97	5065.4	200.	2593.	999.	158.	1453.	2.82	0.00	487.	52.	287.	-7.	0.	11299.
98	5098.5	199.	2603.	1009.	158.	1613.	3.31	3.90	544.	51.	318.	-7.	0.	11594.
99	5209.2	202.	2656.	1015.	158.	1615.	3.53	5.44	604.	53.	318.	-7.	0.	11833.
0	5326.3	208.	2707.	1030.	159.	1618.	3.68	6.17	632.	56.	318.	-7.	0.	12057.
TOT	69774.0	3204.	39242.	15508.	1918.	17986.	35.01	71.11	6044.	836.	3575.	-225.	0.	157968.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

SAFEGUARD RUN T-2 ALT III - CASE 36 - LOW GROWTH - 70% CF - 1978 REP - 1981 REC - NO FBR DATE: 25-MAY-77 TIME: 12:33:41
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	9.	0.	0.	0.	744.
77	268.0	33.	356.	130.	6.	0.	0.00	0.00	0.	12.	0.	0.	0.	814.
78	301.6	34.	335.	141.	11.	58.	0.00	2.98	0.	13.	12.	0.	0.	909.
79	401.3	33.	391.	152.	15.	104.	0.00	8.33	0.	13.	21.	-12.	0.	1129.
80	477.6	36.	401.	183.	14.	142.	0.09	13.11	11.	11.	29.	-14.	0.	1306.
81	538.9	34.	400.	138.	15.	129.	0.22	8.67	34.	10.	26.	-14.	0.	1322.
82	568.6	35.	405.	190.	15.	137.	0.31	0.00	51.	9.	28.	-11.	0.	1428.
83	651.6	37.	404.	183.	16.	143.	0.22	0.00	44.	9.	29.	-8.	0.	1509.
84	730.8	40.	406.	211.	14.	146.	0.23	0.00	38.	9.	30.	-7.	0.	1693.
85	716.8	41.	469.	197.	16.	133.	0.24	0.11	40.	9.	27.	-3.	0.	1647.
86	764.3	33.	444.	178.	19.	154.	0.27	0.16	50.	10.	31.	-2.	0.	1687.
87	865.4	40.	464.	182.	21.	176.	0.32	0.03	53.	10.	35.	-2.	0.	1844.
88	856.0	39.	456.	187.	19.	192.	0.32	0.00	49.	9.	38.	-2.	0.	1841.
89	834.1	38.	457.	175.	19.	174.	0.30	0.00	56.	9.	35.	-2.	0.	1796.
90	808.3	37.	437.	176.	20.	180.	0.34	0.01	56.	9.	36.	-1.	0.	1750.
91	765.7	34.	424.	165.	21.	180.	0.37	0.16	65.	9.	37.	-1.	0.	1712.
92	733.0	33.	400.	161.	21.	193.	0.38	0.08	65.	9.	38.	-1.	0.	1662.
93	697.1	32.	395.	156.	21.	192.	0.38	0.05	67.	8.	38.	-1.	0.	1606.
94	686.0	29.	373.	147.	21.	193.	0.40	0.04	69.	8.	38.	-1.	0.	1567.
95	706.9	28.	354.	136.	19.	192.	0.39	0.06	72.	7.	38.	-1.	0.	1551.
96	678.6	27.	339.	129.	19.	174.	0.36	0.00	65.	7.	35.	-1.	0.	1473.
97	622.3	25.	319.	123.	19.	179.	0.35	0.00	60.	6.	35.	-1.	0.	1387.
98	569.4	22.	291.	113.	18.	180.	0.37	0.44	61.	6.	36.	-1.	0.	1295.
99	528.9	21.	270.	103.	16.	164.	0.36	0.55	61.	5.	32.	-1.	0.	1201.
0	491.6	19.	250.	95.	15.	149.	0.34	0.57	58.	5.	29.	-1.	0.	1113.
TOT	15741.2	842.	9913.	3966.	410.	3673.	6.55	35.35	1126.	228.	734.	-88.	0.	36593.

NET GENERATION 35357., BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH

	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W/O PU	PU SALES	SPENT FUEL DISP	TOTAL
	1.930	0.103	1.216	0.406	0.088	0.450	0.001	0.004	0.130	0.020	0.090	-0.011	0.000	4.487

TABLE A3.4 FUEL CYCLE FLOWS AND COSTS WITH UPGRADED SAFEGUARDS - ALTERNATIVE 5

SECTION 1 PROCESS FLOW

SAFEGUARD RUN T-2 ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSDATE: 25-MAY-77 TIME: 12:34:18

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	915.	0.	0	0	0.	0	1167	0.	0	0.
76	13.4	10.4	4.8	1337.	0.	0	0	0.	0	1962	0.	0	0
77	15.0	11.5	5.7	1758.	0.	0	0.	0.	0	2917	0.	0	0.
78	17.8	13.5	6.0	1972.	0.	0	0.	0	0	4014	0.	0	0
79	21.8	16.1	7.8	2345.	0	0	0.	0	0	5236	0.	0	0
80	25.3	19.1	8.9	3181.	0.	0	0	0.	0	6566	0.	0	0.
81	29.4	21.3	10.4	2826.	0.	0	0.	0.	0	8140	0.	0	0.
82	32.2	24.1	12.1	4310.	0.	0	0.	0.	0.	9930	0.	0	0
83	38.0	27.1	12.7	4532.	0	0	0	0.	0	12193	0.	0	0
84	44.9	32.6	16.6	5608.	0.	0.	0	0	0.	14634	0.	0	0
85	46.7	36.4	17.9	5820.	1348.	0	0.	0	0.	17575	0.	0	0
86	49.3	37.5	18.8	5949.	3397.	1348	0	0	0	19723	0	0	0
87	52.7	40.6	21.7	6704.	5843.	3397	0	0	0	20427	0	0	0.
88	55.0	41.9	23.8	7503.	7245.	5843	0	0	0	19192	0.	0	0
89	58.0	43.9	26.1	7877.	7849.	7245	0.	0	0	16874	0.	0	0.
90	62.7	47.2	28.0	8707.	8249.	7849	0.	0	0	14437	0.	0	0
91	67.8	50.9	30.7	9444	8241.	8249	0.	0	0	12[illegible]	1348.	0	0
92	72.8	54.7	32.6	9964.	8248.	8241	0	0	0	10[illegible]	3397.	0	0
93	77.8	59.1	34.8	10692.	8248.	8248	0	0.	0	9[illegible]	5843.	0	0
94	82.1	62.2	36.7	11242.	8248.	8248	0	0.	0	9268	7245.	0	0.
95	86.2	65.3	38.4	11634.	8248.	8248	0	0	0	9413	7849.	0	0
96	89.9	68.8	40.2	12091.	9248.	8248	0	0	0.	10154	8249.	0	0
97	92.2	70.5	41.8	12552.	10248.	9248	0	0	0.	10472	8241.	0	0
98	94.3	71.0	43.2	12901.	10248.	10248	0.	0	0	10397	8248.	0	0.
99	96.7	73.9	44.5	13216.	10248.	10248	0.	0	0.	10559	8248.	0.	0
0	98.0	75.5	45.5	13492.	10248.	10248.	0	0.	0.	11226	8248.	0.	0.
TOT	1431.1	1082.2	613.4	188576.	125404.	115156.	0.	0.	0.	279323.	66916.	0	0

SECTION 2 PROJECTED UNIT COST

SAFEGUARD RUN T-2 ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSDATE: 25-MAY-77 TIME: 12:34:18

YEAR	U3O8 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
79	15.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
80	18.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
81	20.3	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
82	21.3	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
83	22.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
84	22.9	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
85	25.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
86	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
87	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
88	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.0	2.06	238.6	50.0	0.00	100.0
89	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
90	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
91	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
92	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
93	30.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
94	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
95	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
96	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
97	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
98	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
99	33.9	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
0	34.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238	50.0	0.00	100.0
WT AVE.	28.9	3.5	75.0	95.0	15.0	5.0	153.1	0.00	0.00	0.0	50.0	0.00	0.0

TABLE A3.4 (Continued) - ALTERNATIVE 5

SECTION 3. PROJECTED COSTS FOR MATERIALS AND SERVICES
(IN MILLIONS OF 1975 DOLLARS)

SAFEQUARD RUN T-2 ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSDATE: 25-MAY-77 TIME: 12:34:18

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	6.	0.	0.	0.	606.
76	286.2	36.	359.	127.	0.	0.	0.00	0.00	0.	10.	0.	0.	0.	818.
77	330.0	40.	430.	167.	0.	0.	0.00	0.00	0.	15.	0.	0.	0.	982.
78	426.6	47.	447.	187.	0.	0.	0.00	0.00	0.	20.	0.	0.	0.	1128.
79	661.9	56.	585.	223.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1552.
80	921.1	67.	670.	302.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1993.
81	1195.3	74.	780.	268.	0.	0.	0.00	0.00	0.	41.	0.	0.	0.	2359.
82	1370.2	84.	905.	409.	0.	0.	0.00	0.00	0.	50.	0.	0.	0.	2818.
83	1685.0	95.	954.	431.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	3226.
84	2055.3	114.	1244.	533.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	4019.
85	2234.0	127.	1340.	553.	20.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	4462.
86	2808.1	131.	1409.	565.	51.	206.	0.00	0.00	0.	[illegible]	42.	0.	0.	5311.
87	3004.3	142.	1631.	637.	88.	520.	0.00	0.00	0.	[illegible]	105.	0.	0.	6229.
88	3133.2	147.	1784.	713.	109.	895.	0.00	0.00	0.	[illegible]	181.	0.	0.	7058.
89	3307.1	154.	1958.	748.	118.	1109.	0.00	0.00	0.	[illegible]	225.	0.	0.	7703.
90	3575.2	165.	2103.	827.	124.	1202.	0.00	0.00	0.	[illegible]	244.	0.	0.	8312.
91	3867.2	178.	2303.	897.	124.	1263.	0.00	0.00	0.	[illegible]	256.	0.	0.	8950.
92	4147.0	192.	2447.	947.	124.	1262.	0.00	0.00	0.	[illegible]	256.	0.	0.	9427.
93	4666.9	207.	2613.	1016.	124.	1263.	0.00	0.00	0.	[illegible]	256.	0.	0.	10194.
94	5415.4	218.	2754.	1068.	124.	1263.	0.00	0.00	0.	[illegible]	256.	0.	0.	11144.
95	5691.6	229.	2883.	1105.	124.	1263.	0.00	0.00	0.	[illegible]	256.	0.	0.	11598.
96	5930.3	241.	3016.	1149.	139.	1263.	0.00	0.00	0.	[illegible]	256.	0.	0.	12044.
97	6086.5	247.	3133.	1192.	154.	1416.	0.00	0.00	0.	[illegible]	287.	0.	0.	12568.
98	6223.9	251.	3248.	1226.	154.	1569.	0.00	0.00	0.	[illegible]	318.	0.	0.	13023.
99	6555.8	259.	3338.	1256.	154.	1569.	0.00	0.00	0.	[illegible]	318.	0.	0.	13501.
0	6756.8	264.	3415.	1282.	154.	1569.	0.00	0.00	0.	[illegible]	318.	0.	0.	13815.
TOT	82659.7	3788.	46007.	17915.	1881.	17630.	0.00	0.00	0.	[illegible]	3525.	0.	0.	174852.

SECTION 4. DISCOUNTED PROCESS COSTS
(IN MILLIONS OF 1975 DOLLARS)

SAFEQUARD RUN T-2 ALTERNATE V - CASE 39 - LOW GROWTH - 70' CF - NO FBR - 1986 REPROCESSDATE: 25-MAY-77 TIME: 12:34:18
DISCOUNT RATE =0.100

YEAR	MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W PU	PU SALES	SPENT FUEL DISP	TOTAL
75	224.7	22.	267.	87.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	606.
76	260.2	33.	326.	115.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	744.
77	272.7	33.	356.	138.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	812.
78	320.5	36.	336.	141.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	848.
79	452.1	38.	399.	152.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1060.
80	571.9	42.	416.	188.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1237.
81	674.7	42.	440.	152.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1332.
82	703.1	43.	464.	210.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1446.
83	786.1	44.	445.	201.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1505.
84	871.7	48.	528.	226.	0.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1705.
85	899.9	49.	517.	213.	8.	0.	0.00	0.00	0.	[illegible]	0.	0.	0.	1720.
86	984.2	46.	494.	198.	18.	72.	0.00	0.00	0.	[illegible]	15.	0.	0.	1861.
87	957.3	45.	520.	203.	28.	166.	0.00	0.00	0.	[illegible]	34.	0.	0.	1985.
88	907.6	43.	517.	206.	31.	259.	0.00	0.00	0.	[illegible]	53.	0.	0.	2044.
89	870.9	40.	516.	197.	31.	292.	0.00	0.00	0.	[illegible]	59.	0.	0.	2028.
90	855.9	40.	503.	198.	30.	288.	0.00	0.00	0.	[illegible]	58.	0.	0.	1990.
91	841.6	39.	501.	195.	27.	275.	0.00	0.00	0.	[illegible]	56.	0.	0.	1948.
92	820.5	38.	484.	187.	24.	250.	0.00	0.00	0.	[illegible]	51.	0.	0.	1865.
93	839.4	37.	470.	183.	22.	227.	0.00	0.00	0.	[illegible]	46.	0.	0.	1833.
94	885.5	36.	450.	175.	20.	206.	0.00	0.00	0.	[illegible]	42.	0.	0.	1822.
95	846.0	34.	429.	164.	18.	188.	0.00	0.00	0.	[illegible]	38.	0.	0.	1724.
96	801.4	33.	408.	155.	19.	171.	0.00	0.00	0.	[illegible]	35.	0.	0.	1628.
97	747.7	30.	385.	146.	19.	174.	0.00	0.00	0.	[illegible]	35.	0.	0.	1544.
98	695.1	28.	362.	137.	17.	175.	0.00	0.00	0.	[illegible]	36.	0.	0.	1456.
99	665.6	26.	339.	127.	16.	159.	0.00	0.00	0.	[illegible]	32.	0.	0.	1371.
0	623.6	24.	315.	118.	14.	145.	0.00	0.00	0.	[illegible]	29.	0.	0.	1275.
TOT	18379.7	969.	11186.	4414.	343.	3047.	0.00	0.00	0.	[illegible]	618.	0.	0.	39389.

NET GENERATION 35357., BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH

MINING MILLING	UF6 CONVR	ENRICHMNT	U FUEL FAB	SPENT FUEL TRAN	REPRO	PU TRANS	INCR PU STORAGE	MOX FAB	INCR SPENT FUEL STOR	WASTE DISPOSAL W PU	PU SALES	SPENT FUEL DISP	TOTAL
2.254	0.119	1.372	0.541	0.042	0.374	0.000	0.000	0.000	0.053	0.076	0.000	0.000	4.830

TABLE A3.5 FUEL CYCLE FLOWS AND COSTS WITH UPGRADED SAFEGUARDS - ALTERNATIVE 6

SECTION 1. PROCESS FLOW

SAFEGUARD RUN T-2 ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE DATE: 25-MAY-77 TIME: 12:34:30

YEAR	MINING MILLING 1000 ST	UF6 CONVR 1000 MTU	ENRICHMNT 1000 MT-SWU	U FUEL FAB MTU	SPENT FUEL TRAN MT-HM	REPROCESS MT-HM	PU TRANS KG-TOT	INCR PU STORAGE KG-TOT	MOX FAB MT-HM	INCR SPENT FUEL STOR MT-HM	WASTE DISPOSAL MT-HM W/O PU	PU SALES KG FISS	SPENT FUEL DISP MT-HM
75	10.5	6.2	3.6	919.	0.	0.	0	0.	0.	[illegible]	0.	0.	0
76	13.4	10.4	4.8	1337.	0.	0.	0.	0.	0.	1962.	0.	0.	0.
77	15.0	11.5	5.7	1758.	0.	0.	0.	0.	0.	2917.	0.	0.	0.
78	17.8	13.5	6.8	1972.	0.	0.	0.	0.	0.	4014.	0.	0.	0.
79	21.0	16.1	7.8	2345.	0.	0.	0.	0.	0.	5236.	0.	0.	0.
80	25.3	19.1	8.9	3181.	0.	0.	0.	0.	0.	6566.	0.	0.	0.
81	29.4	21.3	10.4	2826.	0.	0.	0.	0.	0.	8140.	0.	0.	0.
82	32.2	24.1	12.1	4310.	0.	0.	0.	0.	0.	9930.	0.	0.	0.
83	38.0	27.1	12.7	4532.	0.	0.	0.	0.	0.	12193.	0.	0.	0.
84	44.9	32.6	16.6	5608.	0.	0.	0.	0.	0.	14634.	0.	0.	0.
85	47.1	36.4	17.9	5820.	0.	0.	0.	0.	0.	17575.	0.	0.	0.
86	51.7	38.6	18.7	5949.	3500.	0.	0.	0.	0.	17571.	0.	0.	3500.
87	57.9	44.1	21.0	6704.	3500.	0.	0.	0.	0.	18172.	0.	0.	3500.
88	63.0	47.8	23.5	7503.	3500.	0.	0.	0.	0.	19208.	0.	0.	3500.
89	68.3	51.8	25.8	7877.	3500.	0.	0.	0.	0.	20707.	0.	0.	3500.
90	73.8	55.7	27.7	8707.	3500.	0.	0.	0.	0.	22679.	0.	0.	3500.
91	79.3	59.7	30.2	9444.	3571.	0.	0.	0.	0.	25239.	0.	0.	3571.
92	84.7	64.0	32.2	9964.	4101.	0.	0.	0.	0.	27807.	0.	0.	4101.
93	89.8	68.5	34.5	10692.	4608.	0.	0.	0.	0.	30349.	0.	0.	4608.
94	94.0	71.5	36.3	11242.	4927.	0.	0.	0.	0.	33221.	0.	0.	4927.
95	98.2	74.7	38.0	11634.	5472.	0.	0.	0.	0.	36159.	0.	0.	5472.
96	102.4	78.0	39.8	12091.	6131.	0.	0.	0.	0.	[illegible]	0.	0.	6131.
97	105.9	80.9	41.4	12552.	6669.	0.	0.	0.	0.	41565.	0.	0.	6669.
98	109.0	83.2	42.8	12901.	7150.	0.	0.	0.	0.	44828.	0.	0.	7150.
99	111.7	85.6	44.0	13216.	7799.	0.	0.	0.	0.	47539.	0.	0.	7799.
0	113.9	87.3	45.0	13492.	8401.	0.	0.	0.	0.	50053.	0.	0.	8401.
TOT	1599.1	1209.8	608.2	108576.	76329.	0.	0.	0.	0.	558842.	0.	0.	76329.

SECTION 2. PROJECTED UNIT COST

SAFEGUARD RUN T-2 ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE DATE: 25-MAY-77 TIME: 12:34:30

YEAR	U308 AS BURNED $/LB	U CONVR $/KG-U	SEP WORK $/SWU	U FAB $/KG-U	SPENT FUEL TRAN $/KG-HM	INCR SPENT FUEL STOR $/KG-HM-YR	REPRO $/KG-HM	PU TRAN $/G-TOT	INCR PU STORAGE $/G-TOT	MOX FAB $/KG-HM	WASTE DISPOSAL $/KG-HM W/O PU	PU VALUE $/G FISS	SPENT FUEL DISP $/KG-HM
75	10.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
76	10.7	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
77	11.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
78	12.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
79	15.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
80	18.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
81	20.3	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
82	21.3	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
83	22.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
84	22.9	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
85	25.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
86	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
87	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
88	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
89	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
90	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
91	28.5	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
92	29.6	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
93	32.4	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
94	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
95	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
96	33.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
97	33.2	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
98	34.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
99	35.0	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
0	37.6	3.5	75.0	95.0	15.0	5.0	153.1	0.03	2.06	238.6	50.0	0.00	100.0
WT AVE.	29.8	3.5	75.0	95.0	15.0	5.0	0.0	0.00	0.00	0.0	0.0	0.00	100.0

TABLE A3.5 (Continued) - ALTERNATIVE 6

```
                                          SECTION 3  PROJECTED COSTS FOR MATERIALS AND SER   ES
                                                (IN MILLIONS OF 1975 DOLLARS)

SAFEGUARD RUN  T-2 ALT VI - CASE 40 - LOW GROWTH - 70% CF - NO FBR - NO REPROCESSING OR RECYCLE  DATE: 25-MAY-77  TIME: 12:34:30

YEAR   MINING   UF6  ENRICHMNT  U FUEL   SPENT     REPRO    PU     INCR PU   MOX  INCR SPENT     WASTE   PU SALES  SPENT     TOTAL
      MILLING CONVR              FAB   FUEL TRAN          TRANS    STORAGE   FAB  FUEL STOR   DISPOSAL          FUEL DISP
                                                                                              W/O PU
 75    224.7     22.    267.     87.       0.        0.   0.00      0.00     0.           6.       0.       0.        0.      606.
 76    286.2     36.    359.    127.       0.        0.   0.00      0.00     0.          10.       0.       0.        0.      818.
 77    330.0     40.    430.    167.       0.        0.   0.00      0.00     0.          15.       0.       0.        0.      982.
 78    426.6     47.    447.    187.       0.        0.   0.00      0.00     0.          20.       0.       0.        0.     1128.
 79    661.9     56.    585.    223.       0.        0.   0.00      0.00     0.          26.       0.       0.        0.     1552.
 80    921.1     67.    670.    302.       0.        0.   0.00      0.00     0.          33.       0.       0.        0.     1993.
 81   1195.3     74.    780.    268.      33.        0.   0.00      0.00     0.          41.       0.       0.      217.     2609.
 82   1370.2     84.    905.    409.      33.        0.   0.00      0.00     0.          50.       0.       0.      217.     3068.
 83   1685.0     95.    954.    431.      33.        0.   0.00      0.00     0.          61.       0.       0.      217.     3476.
 84   2055.3    114.   1244.    533.      33.        0.   0.00      0.00     0.          73.       0.       0.      217.     4269.
 85   2359.4    127.   1340.    553.      33.        0.   0.00      0.00     0.          88.       0.       0.      217.     4717.
 86   2945.9    135.   1406.    565.      33.        0.   0.00      0.00     0.          88.       0.       0.      222.     5395.
 87   3302.9    154.   1634.    637.      38.        0.   0.00      0.00     0.          91.       0.       0.      255.     6112.
 88   3593.2    167.   1765.    713.      43.        0.   0.00      0.00     0.          96.       0.       0.      286.     6663.
 89   3894.0    181.   1934.    748.      46.        0.   0.00      0.00     0. [illegible]       0.       0.      306.     7214.
 90   4207.9    195.   2081.    827.      51.        0.   0.00      0.00     0. [illegible]       0.       0.      340.     7815.
 91   4522.4    209.   2263.    897.      57.        0.   0.00      0.00     0.         126.       0.       0.      381.     8455.
 92   5009.9    224.   2414.    947.      62.        0.   0.00      0.00     0. [illegible]       0.       0.      414.     9210.
 93   5822.3    240.   2584.   1016.      67.        0.   0.00      0.00     0.         152.       0.       0.      444.    10324.
 94   6204.5    250.   2723.   1068.      73.        0.   0.00      0.00     0.         166.       0.       0.      484.    10969.
 95   6482.3    261.   2852.   1105.      78.        0.   0.00      0.00     0.         181.       0.       0.      522.    11482.
 96   6756.5    273.   2987.   1149.      84.        0.   0.00      0.00     0.         195.       0.       0.      558.    12002.
 97   7042.2    283.   3109.   1192.      89.        0.   0.00      0.00     0.         210.       0.       0.      594.    12519.
 98   7415.0    291.   3207.   1226.      94.        0.   0.00      0.00     0.         224.       0.       0.      625.    13083.
 99   7998.5    300.   3301.   1256.      98.        0.   0.00      0.00     0.         238.       0.       0.      653.    13843.
  0   8569.8    305.   3378.   1282.     102.        0.   0.00      0.00     0.         250.       0.       0.      678.    14565.
TOT  95283.7   4234.  45619.  17915.    1177.        0.   0.00      0.00     0.        2794.       0.       0.     7847.   174870.

                                          SECTION 4  DISCOUNTED PROCESS COSTS
                                             (IN MILLIONS OF 1975 DOLLARS)

SAFEGUARD RUN  T-2 ALT VI - CASE 40 - LOW GROWTH - 70% CF --NO FBR - NO REPROCESSING OR RECYCLE  DATE: 25-MAY-77  TIME: 12:34:30
DISCOUNT RATE =0.100

YEAR   MINING   UF6  ENRICHMNT  U FUEL   SPENT     REPRO    PU     INCR PU   MOX  INCR SPENT     WASTE   PU SALES  SPENT     TOTAL
      MILLING CONVR              FAB   FUEL TRAN          TRANS    STORAGE   FAB  FUEL STOR   DISPOSAL          FUEL DISP
                                                                                              W/O PU
 75    224.7     22.    267.     87.       0.        0.   0.00      0.00     0.           6.       0.       0.        0.      606.
 76    260.2     33.    326.    115.       0.        0.   0.00      0.00     0.           9.       0.       0.        0.      744.
 77    272.7     33.    356.    138.       0.        0.   0.00      0.00     0.          12.       0.       0.        0.      812.
 78    320.5     36.    336.    141.       0.        0.   0.00      0.00     0.          15.       0.       0.        0.      848.
 79    452.1     38.    399.    152.       0.        0.   0.00      0.00     0.          18.       0.       0.        0.     1060.
 80    571.9     42.    416.    188.       0.        0.   0.00      0.00     0.          20.       0.       0.        0.     1237.
 81    674.7     42.    440.    152.      18.        0.   0.00      0.00     0.          23.       0.       0.      123.     1473.
 82    703.1     43.    464.    210.      17.        0.   0.00      0.00     0.          25.       0.       0.      112.     1574.
 83    706.1     44.    445.    201.      15.        0.   0.00      0.00     0.          28.       0.       0.      101.     1621.
 84    871.7     48.    528.    226.      14.        0.   0.00      0.00     0.          31.       0.       0.       92.     1811.
 85    909.6     49.    517.    213.      13.        0.   0.00      0.00     0.          34.       0.       0.       84.     1819.
 86   1032.5     47.    493.    198.      12.        0.   0.00      0.00     0.          31.       0.       0.       78.     1891.
 87   1052.4     49.    521.    203.      12.        0.   0.00      0.00     0.          29.       0.       0.       81.     1947.
 88   1040.0     48.    511.    206.      12.        0.   0.00      0.00     0.          28.       0.       0.       83.     1930.
 89   1025.6     48.    509.    197.      12.        0.   0.00      0.00     0.          27.       0.       0.       81.     1900.
 90   1007.3     47.    498.    198.      12.        0.   0.00      0.00     0.          27.       0.       0.       81.     1871.
 91    984.2     46.    492.    195.      12.        0.   0.00      0.00     0.          27.       0.       0.       83.     1840.
 92    991.2     44.    478.    187.      12.        0.   0.00      0.00     0.          28.       0.       0.       82.     1822.
 93   1047.2     43.    465.    183.      12.        0.   0.00      0.00     0.          27.       0.       0.       80.     1857.
 94   1014.5     41.    445.    175.      12.        0.   0.00      0.00     0.          27.       0.       0.       79.     1793.
 95    963.6     39.    424.    164.      12.        0.   0.00      0.00     0.          27.       0.       0.       78.     1707.
 96    913.0     37.    404.    155.      11.        0.   0.00      0.00     0. [illegible]       0.       0.       75.     1622.
 97    865.1     35.    382.    146.      11.        0.   0.00      0.00     0.          26.       0.       0.       73.     1538.
 98    828.1     33.    358.    137.      10.        0.   0.00      0.00     0.          25.       0.       0.       70.     1461.
 99    812.0     30.    335.    127.      10.        0.   0.00      0.00     0.          24.       0.       0.       66.     1405.
  0    791.0     28.    312.    118.       9.        0.   0.00      0.00     0.          23.       0.       0.       63.     1344.
TOT  20415.9   1046.  11120.   4414.     250.        0.   0.00      0.00     0.         625.       0.       0.     1664.    39534.
NET GENERATION    35357. , BILLIONS KWH
LEVELIZED FUEL CYCLE COST, MILLS/KWH
        2.504   0.120  1.364   0.541    0.031    0.000  0.000     0.000  0.000       0.077    0.000    0.000    0.204     4.840
```

APPENDIX B

EFFECTIVENESS OF RADIATION DETECTORS

TABLE OF CONTENTS
APPENDIX B

APPENDIX B FIGURES

APPENDIX B

EFFECTIVENESS OF RADIATION DETECTORS

Recycled plutonium emits sufficient neutron and gamma radiation to activate sensors for indicating its presence. Such detection represents a basic tool in controlling the containment of plutonium and in revealing its movement through portals leading from material access areas. The reference safeguards system discussed in Chapter 5 uses such a system for searching employees, vehicles and waste containers for concealed plutonium. The effectiveness of radiation detection systems in detecting the radiation emitted by recycled plutonium is summarized in this Appendix.

NRC Regulatory Guide 5.27 (Ref. B-1) states that doorway monitors acceptable to NRC must detect with a 90 percent confidence the radiation emitted by 0.5 gram of plutonium encased in three millimeters of brass. This requirement can easily be met by commercially available gamma detectors. In addition, Refs. B-2 and B-3 indicate that neutron sensors could exhibit detection sensitivities in the range of 0.3 to three grams of unshielded plutonium.

The major difference between the effectiveness of gamma and neutron detector technologies, from a safeguards point of view, is in the possible methods of shielding SSNM to prevent detection. Gamma radiation is severely attenuated by lead or lead compounds, while neutron radiation can be shielded by an absorber such as cadmium used with a neutron moderator such as water or boronated polyethylene. While doorway monitors are expected to contain both gamma and neutron detectors, the calculations that follow are conservatively based on the detection of neutrons only.

Mathematical models were developed in a supporting study to assess the probability of detecting the presence of unshielded plutonium as a function of sensor technology, the amounts of material involved, the operational procedures utilized, and shielding (Ref. 2). Utilizing these mathematical formulations, Figure B.1 illustrates the effectiveness of a neutron sensor in terms of probability of detecting an attempted removal of SSNM as a function of the amount of material involved. This figure is based on representative alarm thresholds of 3 and 4 standard deviations above the mean background count (a false alarm rate of 1 out of every 740 or 1 out of every 31,560 measurements, respectively) and a representative detector sensitivity g (standard deviation of the alarm probability function) corresponding to 1 gram-second of unshielded recycled plutonium.* (This curve may be adapted to other sensitivities, for example, g = 0.3, by linear scaling of the abscissa.)

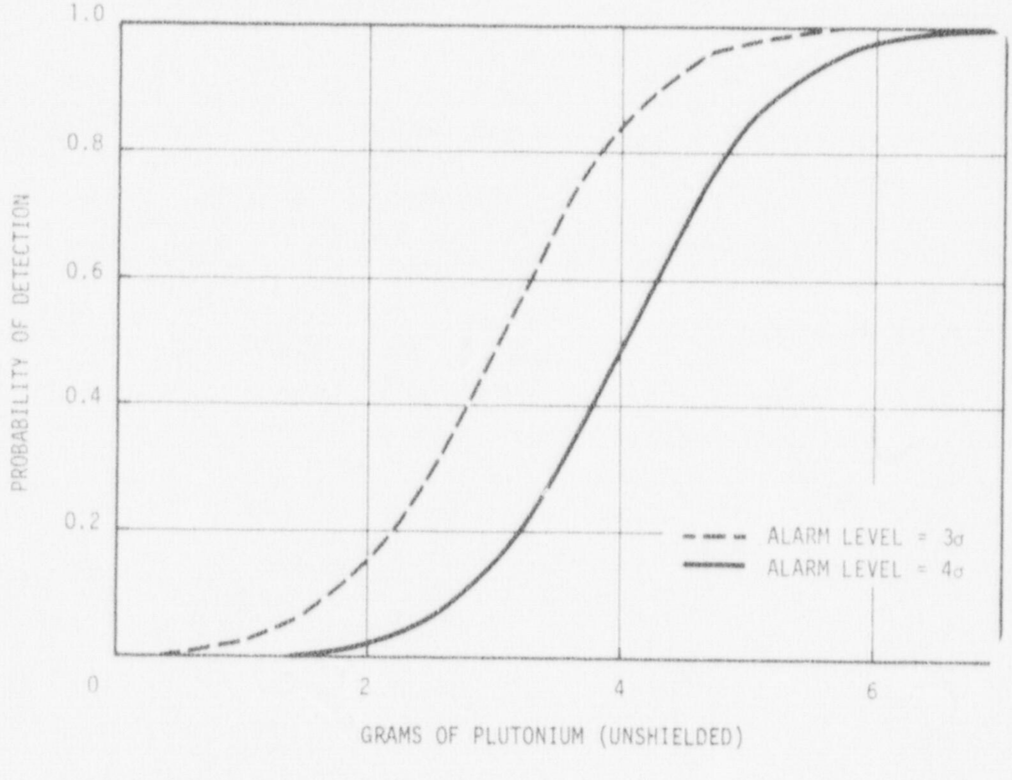


Figure B.1 Detection Sensitivity of Neutron Sensor

As can be observed, attempts to acquire more than four or five grams of plutonium will be detected with high confidence by such sensors. In contrast, quantities of less than a gram cannot be detected with high confidence by projected neutron sensors if alarm thresholds are set to make false alarms relatively infrequent (as they are in Figure B.1). If a very small amount can be taken past such a sensor with some confidence of not being detected, the

---

*These parameter values are based on the data presented in Ref. 2.

possibility arises that a diversion attempt might consist of a series of thefts of such very small amounts until a sufficiently large quantity, perhaps as much as a strategic quantity (defined as two kilograms) is accumulated.

Figures B.2, B.3, and B.4 reflect the calculated effectiveness of neutron detectors in combination with random searches in protecting against such a strategy. These figures were also developed using the methodologies presented in Ref. 2. In constructing these figures, it was assumed that employees attempting to remove the plutonium would know the performance of the sensors and would pass through the portal with optimally selected quantities of SSNM. It was conservatively assumed for the calculations that the adversary would somehow be able to shield the plutonium to some extent using a 10-centimeter-thick layer of boronated polyethylene with a thin cadmium outer shell.

Three cases for an alarm level of 4σ are shown in Figure B.2: one employee with a time limit of one year to accumulate the desired material quantities; four employees with a one-year time limit; and any number of employees with an unlimited time to accumulate the material (which is the bounding case and the optimal strategy for those attempting diversion against this system). The curve for one employee with a time limit of one year against an alarm level of 3σ is shown for comparison.

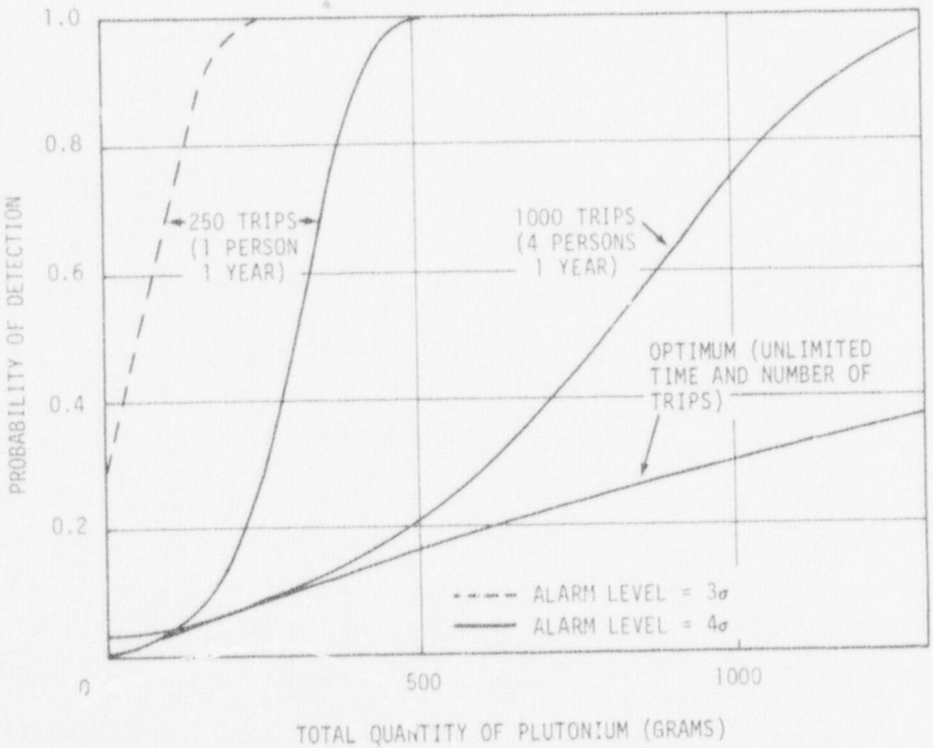


Figure B.2 Portal Sensor Effectiveness--Multiple Passage ; Shielded

Additional curves for an alarm level of 3σ are shown in Figure B.3. While an alarm level of 3σ produces higher probabilities of detection against any diversion strategy than does an alarm level of 4σ, it also produces a higher false alarm rate owing to its greater sensitivity to background radiation. The calculations reflected in these figures show that the chances that one to four people can successfully accumulate two or more kilograms of plutonium within a year are extremely small. However, these amounts can be accumulated with small probabilities of detection if substantially larger numbers of people are involved or if accumulation can take place over many years.

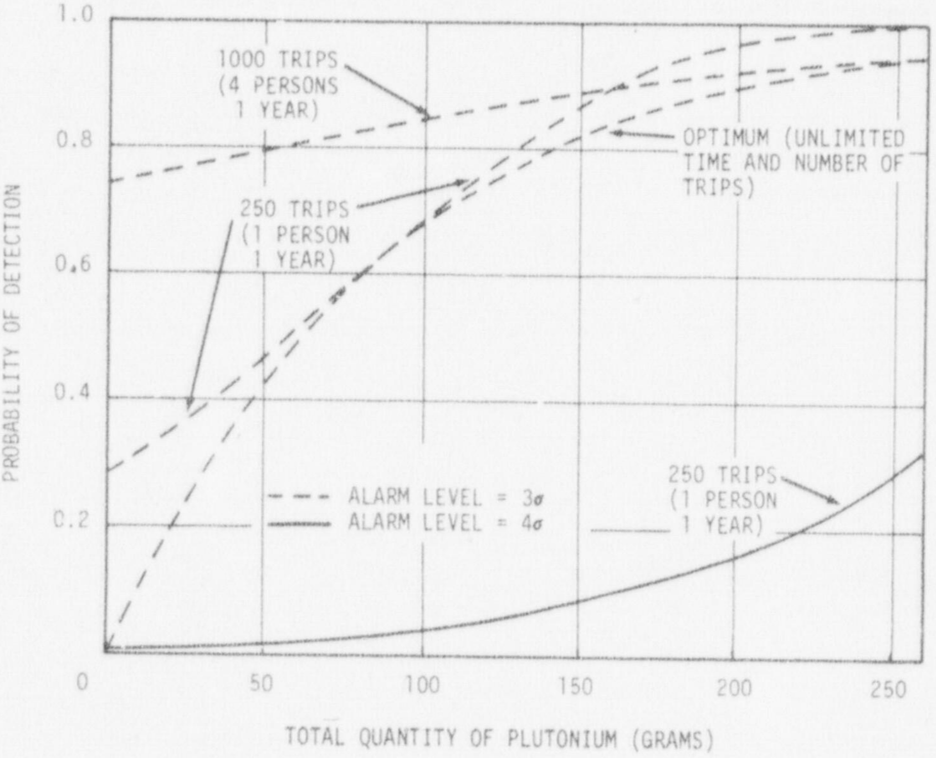


Figure B.3 Portal Sensor Effectiveness--Multiple Passage; Shielded

Although such a possibility would seem unlikely, protection against even long-term accumulation by large numbers of people can be effectively achieved if fixed doorway sensors are augmented by random searches using highly sensitive hand-held equipment. Figure B.4 illustrates the result of using a 4σ alarm level plus a random search of 1 percent of those passing through the portal sensor. The combination of a 4σ alarm level and a random search produces a detection capability equivalent to the 3σ alarm level, but with a substantially reduced false alarm rate. Thus portal sensors, particularly when coupled with random searches, are an effective means of detecting the unauthorized removal of all but very small quantities of plutonium from a plant, whether in a single passage or in a series of multiple small thefts.

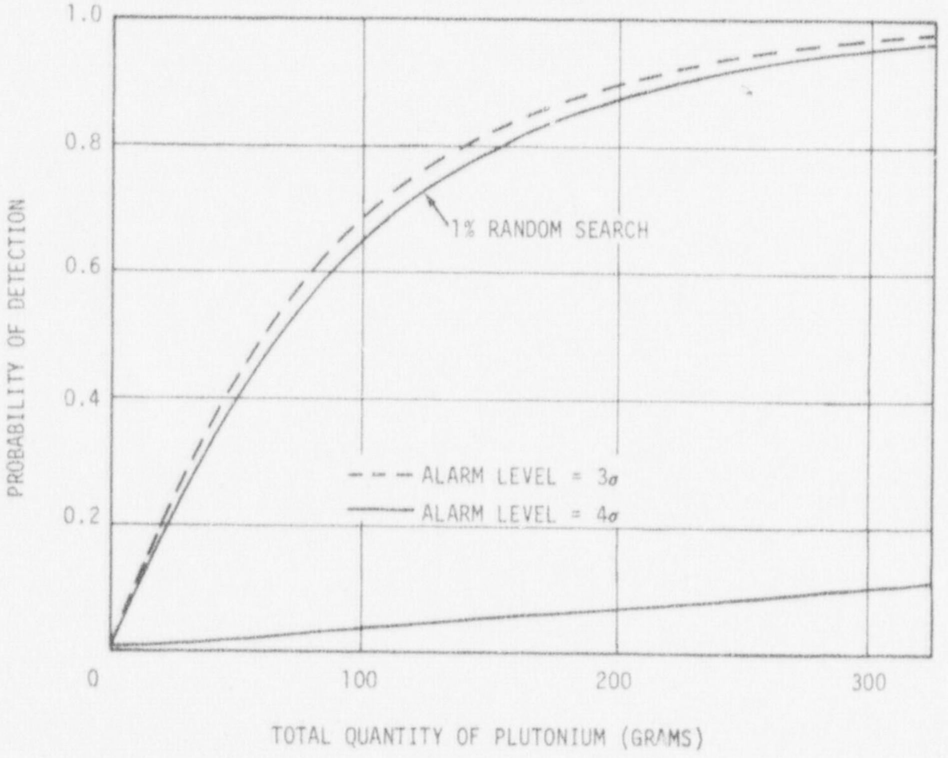


Figure B.4 Portal Sensor Effectiveness--Multiple Passage: Influence of Random Search (Unlimited Time and Unlimited Number of Trips)

APPENDIX B

REFERENCES

B-1 U.S. Nuclear Regulatory Commission, Regulatory Guide 5.27, "Special Nuclear Material Doorway Monitors," Washington, D.C., June 1974.**

B-2 U.S. Nuclear Regulatory Commission, "A New Look at Portal Monitoring," NR-NMSS-007, Washington, D.C., May 1976.**

B-3 Brookhaven National Laboratory, "The Spiking of Special Nuclear Materials as a Safeguards Measure," Upton, N.Y., September 1975.[b]

**Available in NRC PDR for inspection and copying, for a fee.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

APPENDIX C

THE ACCURACY AND PRECISION OF MATERIAL BALANCE ACCOUNTING

TABLE OF CONTENTS
APPENDIX C

APPENDIX C TABLES

APPENDIX C FIGURES

APPENDIX C

THE ACCURACY AND PRECISION OF MATERIAL BALANCE ACCOUNTING

The purpose of this Appendix is to summarize the results of analyses conducted for NRC (Refs. C-1, C-2, C-3, and C-4) to estimate the precision with which material balance inventories could be measured in future MOX facilities.

Within an item control area (ICA) and some process areas, material is either in controlled containers or discrete forms. Since the integrity of these containers and forms can be maintained, accounting for individual items can reliably determine if any have been removed. With material in nondiscrete form, however, there can be uncertainties in flow measurements, inventories, and hold-up. When an inventory is taken for a material balance area (MBA), measurement uncertainties can cause inventory discrepancies (material unaccounted for (MUF)). The calculation is based on material measurements at the beginning of the material inventory and additions during the accounting period minus the ending inventory and removals. The MUF can be either positive or negative, and can be expected to have a normal distribution about its mean value with a standard deviation, σ, which depends on the type and quantity of material processed, the type of process, and the accuracy of the measurements performed.

A diversion might involve an attempt to remove all the material desired in a single period between material balance inventories or in a series of small diversions over many accounting periods. An analytical model was developed to estimate the likelihood that either of such actions would be detected by material balance inventories (Ref. C-1).

It was assumed that discrepancy limits were set at twice the standard deviation (2σ) of the material balance discrepancy calculated on the basis of process measurement uncertainties. This is in keeping with the "limit of error for MUF" (LEMUF) defined in 10 CFR 70. With such a threshold, false alarms would normally occur in 1 out of 44 inventories.

Using this model, Figure C.1 indicates how precise the material balance must be to achieve a specified confidence of detection of an attempt to accumulate two kilograms of plutonium. The three cases shown assume that two kilograms are accumulated by diversion in one, five, or an unlimited number of accounting intervals. The curve related to diversion over an unlimited number of intervals assumes that the person attempting the diversion is aware of the accounting accuracy and removes the fractional amount during each accounting period that maximizes his overall probability of accumulating two kilograms without causing the inventory balance discrepancy to ever exceed the alarm threshold. As such, this curve depicts an upper bound on the probability that a diversion will remain undetected.

The figure shows that, for accounting to provide a high confidence (defined as 90 percent) of detecting that a diversion has occurred, a 2σ accounting period process measurement uncertainty of no more than 0.28 kilogram of plutonium is required to protect against diversion of small amounts over numerous accounting periods to obtain two kilograms, and an uncertainty of no more than 1.2 kilograms of plutonium is required to detect the removal of two kilograms in one accounting period.

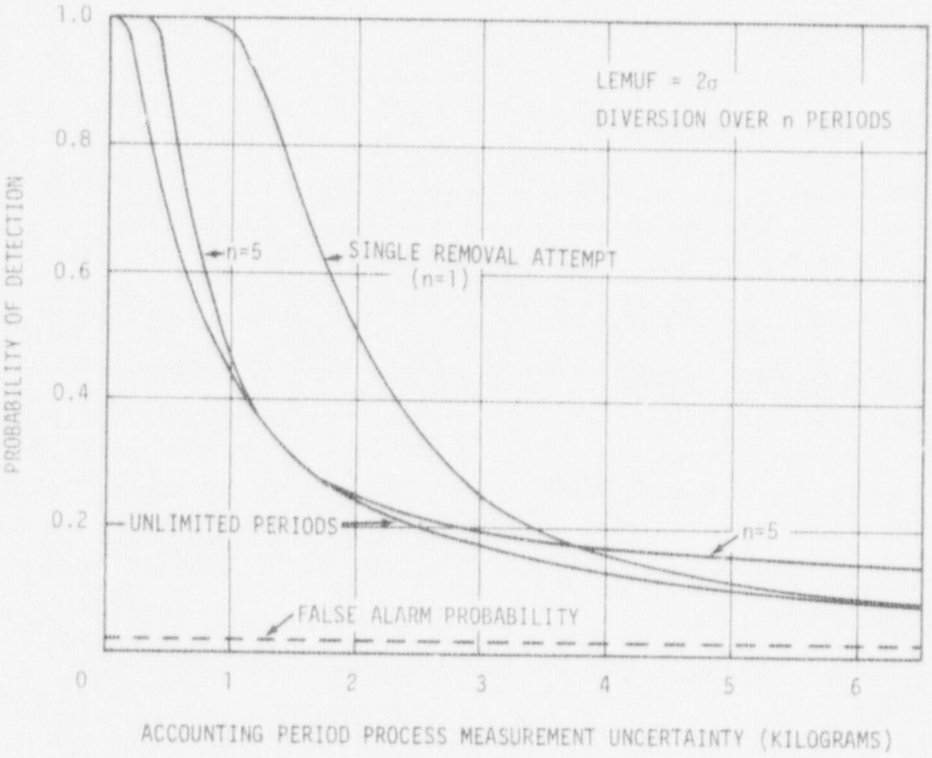


Figure C.1 ACCOUNTING PERIOD ACCURACY REQUIRED TO DETECT DIVERSION OF 2 KILOGRAMS OF PLUTONIUM

Estimates of the actual process measurement uncertainties achievable under various circumstances for future MOX facilities were calculated in Refs. C-2, C-3, and C-4. Tables C.1 and C.2, obtained from Refs. C-2 and C-3, summarize material balance uncertainties for various areas of reprocessing and fuel fabrication facilities. The computations utilized model facilities based on the process lines proposed for the AGNS reprocessing plant and the Westinghouse fuel fabrication facility and the best methods and measurement technologies expected to be available.* The results of these computations show that for most MBA's in a fuel fabrication plant, but only the analytical laboratory in a reprocessing plant, a weekly (or less) material balance could reliably detect a diversion of two kg of plutonium during that period. If the two kg were accumulated over several inventory periods, the diversion would be reliably detected by material balances in only a few MBA's.

Measures to increase the accuracy of material measurements in fuel fabrication facilities by fundamentally altering the material processing methods were examined in Ref. C-4. This study involved an evaluation of the feasibility, advantages, disadvantages, and costs associated with a concept of providing large homogeneous batches of input material for the production requirements of future plants processing plutonium. Of primary importance was the impact on measurement capability of using thoroughly blended isotopically homogeneous plutonium, which would improve the accuracy of material measurements, in particular, that of calorimetric assay measurements. The study indicated, however, that only negligible improvements in the accuracy of the material balance would occur.

---

*These technologies and procedures are included as part of the reference system discussed in Chapter 5.

TABLE C.1

MATERIAL BALANCE UNCERTAINTIES FOR THE LWR FUEL FABRICATION PLANT (2σ)[a]

Material Balance Area	Inventory Interval		
	End of 8-Hour Shift (kg)	Weekly After Runout (kg)	Monthly After Cleanout (kg)
PuO_2 Unloading, Blending, and Storage	1.36	1.60	2.38
MOX Blending and Storage	2.09	3.74	2.31
Pelletizing	0.64	0.79	2.05
Green Boat Storage and Pellet Sintering	0.10	0.55	2.02
Sintering Pellet Storage Pellet Grinding	0.43	0.77	1.95
Pellet Inspection and Storage Fuel Rod Loading	0.45	0.67	1.89
Fuel Rod Repair and Dismantling	0.21	0.37	0.13
Clean Scrap Recovery System	0.52	0.49	0.44
Analytical Services Facility	0.283	0.283	0.283

---

[a] From Reference C-2.

TABLE C.2

MATERIAL BALANCE UNCERTAINTIES FOR THE LWR REPROCESSING PLANT (2σ)[a]

Material Balance Area	Inventory Interval[b]			
	Daily (kg)	One Month (kg)	Two Months (kg)	Six Months (kg)
Separations	21.9	10.7	15.2	27.3
Pu Nitrate Blending and Storage	6.8	9.5	11.7	18.9
Pu Nitrate-to-Oxide Conversion	26.8	5.8	8.7	18.0
Analytical Laboratory	0.3	0.4	0.5	1.4

---

[a] From Reference C-3.

[b] Daily inventories tabulated involve estimates for in-process Pu. For other inventory periods shown, a cleanout is presumed prior to inventory.

APPENDIX C

REFERENCES

C-1 U.S. Nuclear Regulatory Commission, "A New Look at Portal Monitoring," NR-NMSS-007, Washington, D.C., May 1976.**

C-2 E. E. Bain, Jr., et al., "An Evaluation of Real-Time Material Control and Accountability in a Model MO_2 Fuel Plant," SAI-75-648-LJ, Science Applications, Inc., La Jolla, Calif., September 1975.[b]

C-3 G. R. Bray, et al., "Material Control and Accounting for Plutonium Recycle Facilities," SAI-76-539-LJ, Science Applications, Inc., La Jolla, Calif., March 1976.[b]

C-4 W. W. Rodenburg, "Plutonium Isotopic Control," Mound Laboratory, Monsanto Research Corporation, Miamisburg, Ohio, September 1975. Addendum, October 1975, pp. 64-72.[b]

**Available in NRC PDR for inspection and copying, for a fee.

[b] Available in source file for USNRC Report NUREG-0414, May 1978.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
U.S. NUCLEAR REGULATORY
COMMISSION

U.S. MAIL