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International Safeguards for Fast Critical Facilities

Donald O. Gunderson, James L. Todd

Sandia Laboratories

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INTERNATIONAL SAFEGUARDS
FOR
FAST CRITICAL FACILITIES*

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ABSTRACT

A study was conducted to investigate various approaches to providing international safeguards for high-inventory fast critical facilities. Twenty-eight options were considered, ranging from technology intensive to inspector intensive. One option, believed to be a reasonable compromise between the number of inspectors and level of technological sophistication, was further investigated for its application to a hypothetical model reference facility.

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CONTENTS

	<u>Page</u>
Executive Summary	4
I Introduction	6
II Objectives of International Safeguards	7
III Safeguards Approach	9
Basic Assumptions	9
Current IAEA Safeguards	10
Proposed Approach	11
IV Development and Evaluation of Safeguards Options	14
Introduction	14
Overview of System Alternatives	14
Category 1, Resident IAEA Inspectors	14
Category 2, Periodic IAEA Inspections	15
Category 3, Unattended Containment/ Surveillance	15
Category 4, Containment/Surveillance and Resident Inspectors	15
Category 5, Containment/Surveillance and Periodic IAEA Inspections	15
Identification of Options	16
Preliminary Option Evaluation	18
Preferred Options Evaluation	22
V Reference Facility Safeguards System	28
Introduction	28
Material Accountancy and Inspection	28
Containment/Surveillance	29
Corridor to Control Room	30
Corridor to Material Storage Area	31
Escape Exit	32
Abnormal Exits	32
Procedural Restrictions	33
SNM Detection	33
Special Inventory and Inspection	35
VI Conclusion	38
References	39

CONTENTS (Continued)

	<u>Page</u>
APPENDIX A -- Survey of Past Critical Facilities	40
APPENDIX B -- Model Reference Facility	44
APPENDIX C -- Diversion Analysis	48
Potential Diversion Goals	48
Diversion Strategies and Scenario Elements	51
Path Specifics	55

ILLUSTRATIONS

<u>Figure</u>		
1.	Current IAEA Safeguards	10
2.	International Safeguards	11
3.	The Alarm/Assessment Approach	12
4.	Typical Detection Trends	13
5.	Option Identification	18
6.	Explanation of Table IV	20
7.	Evaluation Scatter Charts	21
8.	Estimated Response Profiles	25
9.	Detection Capabilities of Option 8	27
10.	Conceptual Design of Model Reference Containment/Surveillance System	30
11.	Estimated Inspection Capability at Model Reference Facility	37
B.1.	Plot Plan of Model Reference Facility	44
B.2.	Fuel Storage Container	45
B.3.	Material Flow in the MAA	46
B.4.	Fuel Drawer	47
C.1.	Diversion Goals	51
C.2.	Diversion Sequence	56

TABLES

<u>Table</u>	<u>Page</u>
I IAEA Guidelines for Timeliness	8
II Inspection Options	16
III Equipment Options	17
IV Preliminary Option Evaluation	20
V Preferred Options	22
VI Detection Time Comparison	24
VII Inspection Activity for a Typical Reactor Loading and SNM Inventory	36
A.1 Summary of Fast Critical Reactors	41
C.1 Potential Diversion Goals	49
C.1.1 Scenario Elements for Concealment	52
C.1.1.1 Scenario Elements for Substitution	53
C.IV Scenario Elements for Record Falsification	54
C.V Scenario Elements for Actual/Staged Abnormalities	54
C.VI Path Specific Variables	55

EXECUTIVE SUMMARY

A study was undertaken to investigate various approaches for providing international safeguards for fast critical facilities. Only high-inventory fast critical facilities were considered. The objective was to define methods for detecting and verifying the protracted or abrupt diversion of 8 kilograms of plutonium or 25 kilograms of the uranium isotope 235 within seven days of the diversion. The general international safeguards alternatives considered were (1) continuous inspection by resident inspectors, with varying degrees of comprehensiveness, (2) periodic inspections by regional inspectors at varying time intervals, (3) unattended containment/surveillance techniques, and (4) various combinations of the above.

It was concluded that it is possible to achieve an effective international safeguards system by employing a method of continuously monitoring those facility activities which could lead to diversion. This method is in addition to the periodic inspections typical of the international safeguards currently employed. Monitoring detects inventory discrepancies and violations of agreed-upon procedural restrictions, as well as unauthorized removal of Special Nuclear Materials (SNM). Following the detection of such discrepancies, a special inventory is performed to verify any suspected diversion.

The comparison of 28 different safeguards options led to the selection of a system which uses what is believed to be a reasonable compromise between technology and the number of inspectors required. Included in the selected system is a combination of surveillance and inspection by resident IAEA personnel, containment/surveillance by unattended equipment, and routine inventory sampling.

The key elements of the selected international safeguards system are:

1. Routine material accountancy and inventory verification on a sampling basis,
2. Containment of nuclear material by unattended SNM portal monitors,
3. Inspector presence during movement of any material that cannot pass through portal monitors,
4. Visual inspection of the facility to detect unusual activity or structural alterations,
5. Use of seals on containers of stored SNM to reduce inventory verification requirements, and
6. Special inventory verification when unauthorized actions or indications of diversion occur.

A survey of fast critical facilities was made and a model reference facility was chosen as a basis for this study of international safeguards. It was concluded that the generic features of this reference facility are sufficiently broad to allow identification of key international safeguards elements which are applicable to actual fast critical facilities.

INTERNATIONAL SAFEGUARDS FOR FAST CRITICAL FACILITIES

I. INTRODUCTION

Nuclear critical facilities have been and continue to be used extensively in support of both thermal and fast reactor research. These facilities play a major role in evaluating and characterizing new reactor designs and configurations. Studies on reactor safety, reactor kinetics, neutron spectra, and many other areas pertinent to nuclear research and development have been conducted using nuclear critical facilities. The intent of this study is to identify options and to develop concepts for an international safeguards system which would be applicable to critical facilities. A survey of fast critical facilities is contained in Appendix A.

The impetus for this effort came from two sources. The first source was a series of discussions within the Department of Energy, Office of Safeguards and Security (DOE/OSS) Technical Advisory Committee, during which it was concluded that more effort should be applied to developing international safeguards for protecting nuclear material at fast critical facilities. The second was a request by the International Atomic Energy Agency (IAEA) through the United States International Safeguards Project Office (ISPO) for assistance in developing a safeguards approach for large-inventory, critical experiment facilities.

Therefore, Sandia Laboratories and the Los Alamos Scientific Laboratory (LASL) were tasked by DOE/OSS and ISPO with developing effective system concepts for application to critical facilities.^{1,2} The model reference zero power fast critical facility used in this study is described in Appendix B.

II. OBJECTIVES OF INTERNATIONAL SAFEGUARDS

The stated IAEA objective of international safeguards has been set forth as "The timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities . . . and the deterrence of such diversion by risk of early detection."³

There is general agreement within the IAEA on the meaning of "significant quantities" as related to existing IAEA safeguards practices which involve periodic inventory verification and, to some extent, containment/surveillance of nuclear material. This "significant quantity" is defined as 8 kilograms of plutonium or of the uranium isotope 233 (^{233}U) and 25 kilograms of the uranium isotope 235 (^{235}U).

The IAEA definition of timeliness is detection before the fabrication of a nuclear explosive from diverted material. This time is a function of the physical and chemical form of the material. IAEA guidelines for timeliness are based on the estimated times required to convert the diverted material to material suitable for the manufacture of nuclear devices. These IAEA guidelines are reproduced in Table I.

Table I IAEA Guidelines for Timeliness		
Required conversion of nuclear material to the form suitable for the manufacture of nuclear explosive devices	Material Form	Approximate range of times required to convert nuclear materials to a form suitable for manufacture of nuclear explosive devices
Physical change or chemical and physical change but no purification	Plutonium and highly enriched uranium such as metal, oxide or solution	Days to weeks
Chemical and physical change with purification	Irradiated fuel, radioactive solution, and cold scrap	Weeks to months
Isotopic, chemical, and physical change	Natural and low enriched uranium	Less than one year

Source: IAEA Safeguards Technical Manual IAEA-174, Part A.

Recent statements by L. Scheinman, of the United States Department of State, concerning timeliness, suggest an even more stringent requirement for timeliness, namely detection of diversion within a week if the material is in any form other than irradiated fuel." For the purposes of this study, the goal established is the ability to detect and to verify diversion of 8 kilograms of plutonium or 25 kilograms of ^{235}U within 7 days of the completion of the diversion. Both protracted diversion of small quantities of material in multiple attempts and abrupt diversion of large quantities of material in one attempt are considered.

III. SAFEGUARDS APPROACH

Basic Assumptions

This study assumes that an international authority will require verification of a suspected diversion by means of a physical inventory check before any statement is made concerning diversion. An accusation that a state has diverted fissile material for nonpeaceful purposes is a very serious step--one that would not be taken lightly by the IAEA. Hence the assumed need for high assurance through physical inventory verification.

It is also assumed that on-site inspection activities are basic to an international safeguards system. This not only follows directly from the need for physical verification but also from the number of activities which must be performed by an inspector. These activities may include such functions as safeguards equipment maintenance, the verification of tamper-safe features, the observation of abnormal operations, Special Nuclear Materials (SNM) shipment and receipt, and the monitoring of unusual activities such as the movement of very large equipment in and out of SNM areas. Several desirable benefits may also accrue by virtue of on-site inspection activities. These include the improved timeliness of detection, assessment of the cause of alarms, and surveillance for unauthorized activity. An option analysis is used to identify and evaluate alternatives for accomplishing these activities in the context of a complete safeguards system.

An acceptable international safeguards system must clearly demonstrate the capability to meet a number of basic functional requirements and conditions. Those assumed to be most important include:

1. High confidence in detecting diversion,
2. Timely detection of diversion,
3. Low false alarm rate,

4. Minimum interference with facility operations,
5. Acceptable cost, and
6. High reliability and easy maintenance.

The intent throughout this study is to develop a safeguards system that meets these overall objectives. However, some compromises must be made since a number of these requirements tend to be mutually exclusive. These compromises are considered in later sections of this report.

Current IAEA Safeguards

International safeguards inspections conducted by the IAEA now rely on routine reporting by the state and periodic inspection by IAEA personnel. The procedures and the frequency and levels of inspection are negotiated with the state and are documented in a basic agreement (NPT, bilateral or multilateral). Site specific information and agreements are documented in a Facility Attachment. Figure 1 illustrates the timing of the current international safeguards procedures. Generally, the state provides routine monthly reports. Periodic inspection by the IAEA occurs quarterly to annually, depending on the type of facility inspected. The negotiated inspection level and frequency are actually couched in terms of inspector days per year per facility with the IAEA having some discretion in the allocation of the effort.

Figure 1. Current IAEA Safeguards

Review of Figure 1 reveals two important facts about current IAEA safeguards. First, the points at which statements are made concerning diversion or the lack thereof (safeguards decision points) occur periodically and often are months apart. Thus, the timeliness

goal stated for this study is not achieved. Secondly, the routine report from the state is not of value in the timely detection of diversion if the diversion is being attempted by the state itself.

Proposed Approach

Figure 2 outlines the international safeguards system approach which is used as a basis for the options considered in this study.

Figure 2. International Safeguards

"Continuous" monitoring bridges the time between safeguards decision points now associated with periodic inspections. This monitoring may be accomplished by inspector surveillance, by instrumentation, by routine inventory, or by a combination of these methods. Unauthorized actions which could indicate a diversion are sensed by the monitors, thereby causing an alarm to be generated. The alarm in turn is received by the international authority. Response to such an alarm is a special inventory verification procedure which assesses the alarm and also

includes a sampling of the inventory. This sequence will provide the information necessary to reach a safeguards decision. The "timeliness" factor in this approach is the interval from the unauthorized action to the safeguards decision point at the end of the special inventory verification. The times between the unauthorized action, the alarm, the receipt of alarm, and the beginning of the special inventory are system variables that depend upon inspection procedures, communication, and safeguards equipment.

This safeguards system approach, since it depends upon physical inventory procedures which may be disruptive to the normal operation of the facility, must have a very low likelihood of false alarm to be acceptable to the facility operator. Cooperation by the operator in following procedures to minimize false alarms can and should be encouraged by the safeguards system. The approach pursued is to establish agreed-upon administrative procedures which are monitored by the safeguards system. Any violation of these procedures would result in an alarm. Figure 3 illustrates the sequence leading to a special inventory. A sensor trip and a deliberate facility exit, a procedural violation, or a discrepancy in routine inventory can cause an alarm. If assessed as a real alarm by the inspector, a special inventory verification is performed and a subsequent statement concerning diversion is made. The degree of this inspection effort will depend upon the circumstances,

Figure 3. The Alarm/Assessment Approach

e.g., the number of alarms, the type of violations detected, or the amount of time the operator had available to divert material.

The confidence of verifying a suspected diversion by means of a special inventory will in general be a function of the time that is available for the special inventory and the amount of material that is presumed to be diverted. Figure 4 illustrates the trends that generally occur. It is important to recognize that for a given inspection procedure and time there is a continuum of statements that can be made concerning the confidence of detection and the amount of material diverted. For example, in Figure 4 the results of the same inventory verification (indicated in the figure by the constant time lines) could be considered as low confidence in detection of the diversion of a small amount of material or as high confidence in detection of the diversion of a large amount of material. Thus a system that is adequate to detect an abrupt removal of large amounts of material may have limited capability for timely detection during a protracted diversion of small quantities of SNM.

Figure 4. Typical Detection Trends
(time from start of special inventory as parameter)

IV. DEVELOPMENT AND EVALUATION OF SAFEGUARDS OPTIONS

Introduction

The international safeguards approach described in the preceding section is the basis for the system options considered in this study. Material accountancy, which may include item sampling and count, nondestructive assay (NDA), and reactivity and other reactor measurements, is a necessary part of all options since quantitative measurements may be required both routinely and during special inventory verification. Preliminary concepts for a material accountancy system have been developed for critical facilities⁵ and a more detailed analysis is to be published.⁶ This is expected to result in a plan not only for special inventory verification in response to a monitor alarm but also for recommendations for both continuous and/or periodic routine inventory. Preliminary results from this effort suggest that timely special inventory verification can be achieved and that routine inventory can detect protracted diversion.

Overview of System Alternatives

The options for international safeguards systems that are potentially capable of meeting the requirement of timely detection can be classified into five categories. These range from inspector-intensive systems to those relying heavily on containment/surveillance technology. They are briefly described and evaluated in the following paragraphs in the context of safeguards for high-inventory fast critical facilities.

Category 1, Resident IAEA Inspectors -- Resident inspectors without the benefit of containment/surveillance equipment could be used to keep the facility under strict surveillance. Typical duties of the inspector might include (1) routine inventory verification on a continuing basis, (2) performance of some NDA tests to confirm isotopic content of the fuel pieces, (3) reactivity and other reactor measurements, (4) visual inspection of the facility for unusual/unauthorized activity, and (5) verification of seal integrity when seals are used to secure SNM.

Category 2, Periodic IAEA Inspections -- In this category, IAEA personnel would make periodic inspections of the facility at regular intervals (weekly, monthly, or yearly). No containment/surveillance equipment would be used and the inspector would have duties similar to those described in Category 1. However, since the time between inspections is longer, there would be an expected reduction in detection capability and less timeliness.

Category 3, Unattended Containment/Surveillance -- Containment and/or surveillance equipment can be installed at each exit of the Material Access Area (MAA) to detect the unauthorized flow of SNM. Surveillance techniques can also be used to detect the flow of nuclear material through abnormal paths including tunneling through the walls, ceiling, or floor and removal through existing ducts, vents, or pipes. This category excludes on-site inspection activities, but IAEA personnel would be required to maintain equipment and could be employed to periodically collect safeguards records from the equipment. Alternatively, a remote reporting capability could be used to transfer information to international authorities. Although operationally attractive, this option requires technology which is not currently available.

Category 4, Containment/Surveillance and Resident Inspectors -- Resident inspectors and containment/surveillance techniques, as described above, can be combined into a single safeguards system. Joint usage of the two techniques could result in a less complicated containment/surveillance system since remote data transmission and much of the surveillance equipment would not be required.

Category 5, Containment/Surveillance and Periodic IAEA Inspections -- Another possibility is the use of a combination of containment/surveillance and periodic inspections. Satisfying the timeliness criteria requires a more sophisticated containment/surveillance system than does Category 4. The complexity will depend on the inspection interval. Closed circuit television (CCTV) surveillance, more sophisticated tamper-safing, and remote data transmission would probably be required.

Within each of these categories, there can be a wide range of system complexity depending upon the inspection effort and instrumentation choice. Clearly, options in each of these categories must be identified and more fully analyzed.

Identification of Options

The options selected for preliminary analysis are combinations generated by combining several inspection options with equipment options. Table II briefly describes the inspection options considered. More intense options could include, as an extreme example, an inspector for every operator. However, it was judged by the authors that the on-site 24-hour case of one or possibly several inspectors would be the maximum effort an international agency could reasonably be expected to field.

Table II	
Inspection Options	
On-Site 24 Hrs	-- Assumes at least one inspector on duty 24 hours a day, seven days a week. Dependent upon equipment, the inspector responds to alarms and visually inspects and performs routine inventory procedures.
On-Site 8 Hrs	-- Assumes at least one inspector on duty during working hours and daily visits on non-working days. Activities are similar to 24-hour coverage but less intense.
Weekly Inspection	-- Assumes a weekly visit of one or two days by an inspector from a regional IAEA center. In addition, the regional inspector would respond to alarms and nonroutine inspection needs.
Monthly Inspection	-- Assumes monthly visits of several days duration by inspectors from a regional center who would respond to nonroutine requests and to alarms.
Annual Inspection	-- Assumes a procedure similar to that currently in use. Personnel from international headquarters perform physical inventory and inspection.

Table III lists the equipment options and brief descriptions of the functions that the equipment would be expected to perform. The specifics of the equipment design and its mode of implementation depend strongly upon the inspection option under which the equipment is operated. For example, the sophistication of tamper-safing features required for containment/surveillance equipment would be considerably greater in the case of monthly inspection than that required in the case of 24-hour on-site inspection.

TABLE III	
Equipment Options	
No Equipment	-- The inspector relies only on visual inspection, record review, piece count, and possible use of operator's equipment. Seals may be used to assist in verifying an inventory.
Hand-Held Search Instruments	-- These include portable radiation monitoring instruments that could be used to search for concealed fissile material.
Unattended Containment/Surveillance	-- This category may include SNM and metal detectors at portals, cameras, CCTV, and sealing devices. Tamper-safe features are included. Data readout is assumed to be at the instrument or possibly at a central station at the facility.
Remote Reporting	-- This category assumes real-time data transmission, including possible CCTV information to a regional center or to IAEA headquarters.

Figure 5 illustrates the matrix used to generate the 28 options selected for preliminary evaluation. For example, Option 28 assumes annual inspection with hand-held search instrumentation, unattended containment/surveillance, and remote reporting capability. All of these options lie within four of the five categories used to classify the overall options. Category 3, Unattended Containment/Surveillance, which excludes inspection, is not represented because, as previously

noted, current technology does not permit full implementation of a safeguards system that depends solely on unattended instrumentation and equipment.

EQUIPMENT OPTIONS	INSPECTION OPTIONS (ALL INCLUDE MATERIAL ACCOUNTANCY)																											
	ON-SITE 24 HRS ONE INSPECTOR ON DUTY TOTAL OF 5-7 REQUIRED				ON-SITE 8 HRS ONE INSPECTOR WORKING HOURS DAILY VISITS NONWORKING HOURS				WEEKLY INSPECTION ONE INSPECTOR REGIONAL OFFICE ON CALL				MONTHLY INSPECTION SEVERAL INSPECTORS REGIONAL OFFICE ON CALL				ANNUAL INSPECTION TEAM HEADQUARTERS ON CALL											
	UNDEQUIPPED OBSERVATION ONLY																											
	HAND-HELD SEARCH INSTRUMENTS ADDING COUNTING EQUIPMENT																											
	UNATTENDED CONTINUOUS SURVEILLANCE PERSONNEL & MATERIAL MONITORS, CAMERAS, CCTV																											
	REMOTE REPORTING REAL TIME TRANSMISSION MONITORING OF DATA & CCTV																											
	OPTION NUMBER																											

Figure 5. Option Identification

Preliminary Option Evaluation

The 28 options were evaluated to identify several of the more promising ones which would be analyzed in more detail. A ranking technique based on the judged relative merit of the options was used in the evaluation. It must be recognized that options selected on the basis of relative merit may ultimately be judged as unacceptable when measured on an absolute scale. Estimates of actual cost and operational impact were not attempted in this analysis.

Several criteria have been proposed for evaluating and ranking international safeguards systems.⁷ Generally, effectiveness and acceptability are considered paramount, where acceptability includes cost and operational impact not only to the IAEA but also to the facility and the state. The analysis performed on these 28 options

measured effectiveness in terms of ability to counter three diversion strategies, namely, concealment, substitution, and actual/staged abnormalities. These strategies are detailed in the Division Analysis presented in Appendix C. The scenario of record falsification was not considered as it is part of the inventory verification procedure. Acceptability was subdivided into operational acceptability, excluding cost considerations, and cost acceptability. The relative merit of these criteria was again considered for the IAEA, the facility, and the state.

Table IV presents the 28 options and individual ranks which are assigned as measures of the various criteria. Included are effectiveness, acceptability, and cost-ranking, with the larger numbers indicating higher desirability. Figure 6 is a partial reproduction of Table IV, with explanatory notes added. An arbitrary option number appears at the bottom of each column to delineate the option. Also shown are the overall effectiveness, operational acceptability, and cost acceptability rankings, which are the average of the individual item ranks, as well as a combined ranking which is the average of all individual ranks for the particular option. The latter is an unweighted subjective measurement of the overall options quality.

The general trends and the selection of options to be pursued in more detail are demonstrated by the scatter charts shown in Figure 7. The effectiveness, operational acceptability, and cost acceptability rankings are plotted separately against the combined ranking, with each point representing an option. The rationale for option selection is based upon the belief that the prime requirement for an international safeguards system is effectiveness; therefore, only the options with effectiveness rankings of three or above are considered viable. These are indicated in the upper plot of Figure 7 where they are individually numbered to correspond to option numbers assigned in Table IV. A total of seven options are included, three of which have an effectiveness ranking of four or greater. The enclosed regions on each of the plots contain the points representing these seven options. Note that the

Preliminary Option Evaluation

		INSPECTION OPTIONS (Single Inspector)																												
		On-Site 24 Hours				On-Site 8 Hours				Weekly Inspection				Monthly Inspection				Annual Inspection												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
E D C U P I N I M O N E N S I	No Equipment	X				X				X				X				X				X				X				
	Hand Held Search		X	X			X	X	X	X					X	X	X			X	X				X	X	X	X	X	
	Instruments										X											X								
	Unattended Containment/Surveillance			X	X				X	X	X	X	X					X	X	X	X				X	X	X	X	X	
	Remote Reporting									X	X			X	X						X	X					X	X		
R A N K S E V A L U E I N F O R M A T I O N	Effectiveness	2	3	4	5	1	2	3	4	6	5	1	1	1	1	2	4	1	1	1	1	2	4	1	1	1	1	1	1	
	Corcealment	2	3	4	5	1	2	2	3	5	2	5	1	1	1	1	2	4	1	1	1	1	2	4	1	1	1	1	1	
	Substitution	2	3	4	5	1	2	2	3	5	2	5	1	1	1	1	2	4	1	1	1	1	2	4	1	1	1	1	1	
	Actual/Stage	2	3	4	5	1	2	2	3	5	2	5	1	1	1	1	2	4	1	1	1	1	2	4	1	1	1	1	1	
	Abnormalities	2	3	4	5	1	2	2	3	5	2	5	1	1	1	1	2	4	1	1	1	1	2	4	1	1	1	1	1	
Effectiveness Ranking	2	3	3.7	4.7	1	2	2.3	4.0	2.7	4.3	1	1	1	1	2	3.3	1	1	1	1	2	3.3	1	1	1	1	1	1		
Operational Acceptability (without cost)																														
IAEA Facility/State	2	2	2	2	3	3	3	3	2	2	2	2	2	2	2	2	2	4	4	2	2	3	3	5	4	2	2	3	3	
Cost Acceptability	3	3	2	2	4	4	3	3	3	3	3	2	2	2	1	1	1	2	2	2	1	1	1	2	2	1	1	1	1	
Cost Acceptability Ranking	2.3	2.3	1.7	1.7	3	3	2.3	2.3	2	2	2	1.3	1.3	1.3	1.3	1.3	3.3	3.3	2	2	2	2	4	3.7	2	2	2	2		
IAEA Facility/State	2	2	2	2	3	3	2	2	1	1	3	3	2	2	1	1	1	4	4	2	2	1	1	5	5	3	3	3	2	
Cost Acceptability Ranking	3	3	2.5	2.5	3.5	3.5	2.5	2.5	2.5	2.5	2.5	3	3	2	2	2	2	3	3	2	2	1.5	1.5	4	4	3	3	2.5	2.5	
Cr. iined Ranking	2.4	2.8	2.5	3.0	2.4	2.8	2.4	3.0	2.4	3.0	1.9	1.9	1.4	1.4	1.0	2.3	2.4	2.4	1.6	1.6	1.9	2.4	2.9	2.8	1.9	1.9	1.6	1.8		
OPTION NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28		
		High														Low														
		Effectiveness														Cost Acceptability														
		Operational Acceptability														Cost Acceptability														

				INSPECTION OPTIONS			
				On-Site 24 Hours		On-Site 8 Hours	
CO	No Equipment						
UP	Hand Held Search						
IN	Instruments		1				
PS	Unattended Containment/Surveillance						
EN	Remote Reporting		1				
H							
S	Effectiveness						
I	(Concurrence)		2	3			
A	Substitution		2	3	4		
R	Anal/Scraped		2	3	3		
K	Anomalities						
E	Effectiveness						
V	Ranking		2	3	3.7		
A	Operational Acceptability						
L	(Without cost)						
E	IEA		2	2	2	2	
E	Facility/State		2	2	1	1	
C	Cost Acceptability Ranking		2.3	2.3	1.7		
O	Cost Acceptability						
N	IEA		2	2	2		
G	Facility/State		4	4	3		
T	Cost Acceptability Ranking		2.3	2.3	2.5		
P	Combined Ranking		2.4	2.8	2.9		
M	OPTION NUMBER		1	2			

Option Definitions, e.g., inspector on duty 24 hours a day, having hand-held search instruments and unattended containment/surveillance

Rank Number - Based on Relative merit of option as follows:

High	Median	Low
Effectiveness 5	3	1
Acceptability 5	3	1
Cost acceptability 5	3	1

Average of Effectiveness Ranks $\frac{5+3+1}{3} = 3$

Average of Acceptability Ranks $\frac{2+2+1}{3} = 1.7$

Average of Cost Ranks $\frac{2+2}{2} = 2.5$

Average of All Ranks $\frac{3+3+3+2+2+2+2}{8} = 2.7$

Figure 6. Explanation of Table IV.

Figure 7. Evaluation Scatter Charts

effective systems tend to be ranked below mid-value both in operational and cost acceptability, with no single system being an obvious standout. Table V presents these seven preferred options in the same format used for option evaluation.

Table V Preferred Options							
I C O U N T R Y P R O J E C T N O M E N T	E Q U I P M E N T N E E D S A N D O T H E R C O N S I D E R A T I O N S	INSPECTION OPTIONS (Single Inspector)					R A N K
		On-Site		Weekly			
		24 Hours	8 Hours	Inspection	Inspection	Monthly Inspection	
I C O U N T R Y P R O J E C T N O M E N T	No Equipment						
	Hand-Held Search Instruments	X	X	X	X	X	
	Unattended Containment/Surveillance	X	X	X	X	X	
	Remote Reporting			X	X	X	
	Effectiveness						
	Concealment	3	4	5	4	4	
	Substitution	3	4	5	4	4	
	Actual/Stage	3	3	4	2	2	
	Abnormalities						
	Effectiveness Ranking	3	3.7	4.7	3.3	3.3	
I C O U N T R Y P R O J E C T N O M E N T	Operational Acceptability (Without Cost)						
	Site	2	2	2	2	2	
	Facility	2	2	2	1	1	
	State	2	1	1	1	2	
	Cost Acceptability Ranking	2	3	7	1.7	2	
	Cost Acceptability (Cost)						
	Facility/State	2	2	2	1	1	
	Cost Acceptability Ranking	4	3	3	3	2	
	Cost Acceptability Ranking	3	2.5	2.5	2	1.5	
	Continuous Working	2	2	2.5	2.2	2.4	
OPTION NUMBER		2	3	4	10	16	22
		High Medium Low					
		Effectiveness					
		Operational Acceptability					
		Cost Acceptability					

Preferred Options Evaluation

The selection of one of the seven preferred options is based in part upon two considerations not included in the relative ranking used to evaluate the original 28 options. The first of these is the unmeasurable but necessary consideration of international policies. Currently, there are no IAEA inspectors who are permanently assigned to nuclear facilities and only recently has the establishment of IAEA regional centers been considered. It was concluded that the assignment of a staff of five to seven inspectors to a single facility to assure 24-hour surveillance is well beyond the expected near-term capabilities and resources of the IAEA.* On this basis, Options 2, 3, and 4 were eliminated from further consideration.

*It should also be noted that the use of permanent international inspectors may impose an additional burden on facility operations since it may be necessary to continuously escort the inspectors both for their personal safety and for site security purposes. The impact of this consideration is strongly dependent on the policies of the operator and the host country and therefore is not directly addressed in this study.

The second consideration that is not included in the relative ranking previously described in this report is an assessment of the technical difficulty, including the associated risk and economic cost, of developing practical unattended surveillance systems. However attractive a remote monitor system might seem to appear, technology currently available does not allow the implementation of a practical system that will detect, with high levels of confidence, the diversion of nuclear materials from a zero power, high-inventory fast critical facility. Detection, if it were to occur in a totally unattended system, would certainly be timely, but assuring detection at this type of facility would require essentially total surveillance both internal and external to the facility. Furthermore, it should be noted that an inspector's duties include other necessary functions that must be performed at the site. For these types of facilities, routine inventory tasks, monitoring the movement of large equipment, and other nonstandard activities require frequent attention by the inspector. Accordingly, those system options that require remote surveillance to assure timeliness are considered unattractive. Since Options 16 and 22 (weekly and monthly inspection, respectively) each require remote surveillance to meet the 7-day timeliness criterion, they are not considered further in this study.

Options 8 and 10 both assume on-site inspection during working hours and at least one inspection every 24 hours during nonworking days. Each of these options includes hand-held search instruments and unattended containment/surveillance; however, only Option 10 includes remote reporting capability. The technical requirements for tamper-safe, remote containment/surveillance monitoring are considerably less demanding when the inspector absence is measured in terms of days rather than in terms of weeks. Hence, there is not a clear-cut choice between these options, and additional analysis will be required before a preference can be established.

Comparison of the detection time capabilities of Options 8 and 10 are presented in Table VI. The activities of diversion, alarm, inspector receipt of alarm, and beginning of special inventory are also illustrated in this table as an adapted version of Figure 2 (International Safeguards Approach). The table shows the detection capabilities of Options 8 and 10 and the delays that could occur prior to commencement of the special inventory verification. The time from unauthorized action to receipt of alarm is the time between inspections for both inspector monitoring and unattended monitoring unless there is remote readout capability, in which case alarm is immediate. It is argued that since part of the monitoring must be performed by an inspector, e.g., looking for unauthorized structural changes that might provide a diversion path, a remote readout capability in other parts of the system is unnecessary.

Table VI Detection Time Comparison					
D E T E C T I O N M E T H O D	MINIMUM DELAY				
	Offsite Remote Readout of Unattended Instruments (Option 10)	No Delay	No Delay	Time for Inspectors to Reach Facility	Time (No scale)
	Onsite Inspector Reads Unattended Instruments (Option 8)	No Delay	Time Between Inspections	No Delay For Start of One-Man Effort. Otherwise, Time For Inspectors to Reach Facility	
	Onsite Inspector Observes Evidence of Unauthorized Action (Options 8 & 10)	Time Between Inspections	No Delay		
	Onsite Inspector Observes Unauthorized Action (Options 8 & 10)	No Delay	No Delay		
	Unauthorized Action	Alarm	Inspector Receives Alarm	Beginning Of Special Inventory	

Quantitative estimates of response times are shown in Figure 8 where it is assumed that a total of seven inspectors would be required for the special inventory verification.* Based on these assumptions, both options could have a full inspection team at the facility in 2 to 3 days, leaving 4 to 5 days for inventory verification. Some variation in these times is to be expected due to the diverse locations and details of specific fast critical facilities.

The profile shown for Option 10 assumes that there is no delay between the diversion attempt and inspector receipt of alarm. If this condition were to prevail for all diversion scenarios, this would be an optimum system. In cases where there is a delay in receiving the alarm, the Option 10 profile will be more like

Figure 8. Estimated Response Profiles

*The IAEA recently used a seven-man team to inspect a high-inventory fast critical facility. The effort took approximately 4 days.

that presented for Option 8. However, as previously noted, the technology does not exist to implement a practical, high-confidence, totally unattended containment/surveillance system for these types of facilities. Therefore, since Option 10 provides no major response advantage over Option 8, and there is no standout difference in performance between these options, least cost should be the deciding factor. Remote reporting of containment/surveillance information clearly requires more equipment with its associated maintenance and replacement cost, thus making Option 10 less attractive.

The detection capabilities of Option 8 are reviewed in Figure 9, which presents a flowchart related to the generic sequence of actions required for successful diversion (see Appendix C). Routine inventory provides the primary means for detecting inventory discrepancies both within the MAA and during shipping and receiving operations. A backup capability is provided by inspector surveillance. Diversion strategies involving a material substitution and/or record falsification can be detected only through routine inspection. Detection by routine inventory may not always be timely but it does provide high confidence in assuring that protracted diversion has not occurred.

On-site inspector surveillance provides the principal capabilities to detect unauthorized structural changes which could facilitate removal of material along abnormal exits such as holes in the reactor containment or modifications of the ventilation system. Inspector surveillance also provides valuable secondary capabilities for detecting abnormal activities which might occur during allegedly normal operations.

Unattended containment/surveillance is the primary means for detecting removal of SNM through facility exits either by concealment or during actual/staged emergencies. This capability effectively increases the capability of the on-site inspector by providing unattended monitoring of these exits at times when the inspector is

engaged in other activities such as routine inventory or observation of large item movement.

The preferred options evaluation indicated that the recommended international safeguards system for high-inventory fast critical facilities should be modeled after Option 8. This option provides for 8-hour, daily on-site inspection, unattended containment/surveillance, routine inventory verifications, and special inventory verifications that result from an alarm trip from a continuous monitoring system.

Figure 9. Detection Capabilities of Option 8

V. REFERENCE FACILITY SAFEGUARDS SYSTEM

Introduction

A model facility based on the generic features of several actual installations was used as the reference for this study. A description of the model is contained in Appendix B. The development of Option 8 for this reference facility is described in the following paragraphs. Detection measures used in this option are (1) material accountancy (inventory verification), (2) material control (containment/surveillance), and (3) monitored administrative and procedural restrictions. These are implemented by resident IAEA inspection and unattended instrumentation.

Material Accountancy and Inspection

Material accountancy is a necessary and fundamental part of any safeguards system. Since each piece of SNM is assumed to be uniquely identifiable by serial number and isotopic content, item verification provides a method for determining whether nuclear material has been diverted. However, the typical large SNM inventory at fast critical facilities makes it impractical to perform a complete inventory verification on a timely basis because of the time and effort required to perform such an inspection. Consequently, a compromise must be made on both the timeliness and the confidence level of inventory verification. For international safeguards, this means that inventory verification should be performed routinely on a sampling basis. This verification must be such that it minimizes interference with reactor operation while remaining timely. A proposed inventory verification procedure follows. A comprehensive discussion of inventory verification is to be presented in a companion document prepared by LASL.⁶

When IAEA safeguards are first implemented, a baseline inventory must be established. All SNM not expected to be used between inspections can be sealed in containers with IAEA-approved secure seals. On

subsequent inspections by the resident inspector, inventory verification can be performed on a sampling basis. All SNM in sealed containers is exempt from sampling. There are two basic sampling plans, one corresponding to routine inventory and the other to special inventory verification. Routine inventory verification remains in effect until audit discrepancies, violations in procedures, or indications of SNM diversion from the monitoring system occur, at which time special inventory procedures become effective.

Duties of the IAEA inspector, many of which should be performed daily, typically include the following:

1. Verify the integrity of SNM containers secured with IAEA-approved seals. If a seal has been opened or compromised, the contents of that container must be included in the overall population from which verification samples are drawn.
2. Randomly select the samples to be inspected.
3. Count individual fuel elements in sampled reactor drawers or storage containers. When possible, the inspector will make use of time-saving techniques such as autoradiography.
4. Count by visual inspection other nuclear material (such as plutonium and uranium foils) as required.
5. Perform nondestructive assay tests on a portion of the sample to verify isotopic content.
6. Compare inspection results with facility records and verify that facility records are correct.
7. Visually inspect the facility for evidence of unauthorized structural modifications which might be indicative of attempts to divert material through abnormal paths.
8. Inspect all containment/surveillance equipment for alarm indications or for evidence of tampering.
9. Initiate special inventory verification if required.

Containment/Surveillance

The reactor containment and structure provides a natural safeguards perimeter which includes three exits through which SNM might be diverted. A containment/surveillance method for safeguarding these exits and for verifying the integrity of the reactor

containment is described below. All personnel and material moving out of the MAA are monitored for SNM. Items that are too large for the SNM detection equipment require the presence of an IAEA inspector to monitor the flow of material. Routine inspections of the facility structure for evidence of diversion through abnormal paths are required. A diagram of the conceptual design is shown in Figure 10. It should be emphasized that these containment/surveillance techniques complement the material accountability safeguards and that failure of containment/surveillance, though degrading to the effectiveness of the safeguards system, may not result in complete inability to detect diversion.

Figure 10. Conceptual Design of Model Reference Containment/Surveillance System

Corridor to Control Room -- The greatest flow of traffic in and out of the MAA, shown in Figure 10, occurs in the corridor between the control room and the workroom. In addition, equipment, tools, and other small items are routinely moved through this exit. Detection

of SNM diversion at this exit is accomplished through the use of a personnel portal monitor which contains a passive SNM and metal detection system and by a material pass-through portal which utilizes a neutron-activation SNM detection scheme. The movement of small quantities of uranium and plutonium foils in and out of the MAA (which is not a daily operation) requires the presence of an IAEA inspector. An alternative method for handling the foils is a separate pass-through at this exit. Since the foils are very small in size, an optical or mechanical method of scanning the foil holders would eliminate the need for inspector participation.

Both the personnel portal and the material pass-through have two doors interconnected to provide an alarm if both doors are open at the same time. This prevents material from being thrown through the portal. To assure an acceptably low false rejection rate, all personnel and material passing through the portals may be interrogated several times. An alarm will occur only if there is SNM detection on all interrogations together with an exit from the portal. The IAEA instrumentation must be tamper-safe to protect both equipment and information from unauthorized access.

Corridor to Material Storage Area -- All large items that enter or leave the MAA pass through this exit. In addition, hundreds of tons of nonfissile reactor materials (depleted uranium, graphite, sodium, steel, etc.), which are normally stored outside the MAA when not in use, will be transported through this corridor. Also, shipment and receipt of large amounts of reactor fuel takes place occasionally. SNM detection at this point is accomplished by two portal monitors, one for personnel and the other (a material pass-through) to allow drawers containing nonfissile material to pass both ways. When any other items are being removed from the facility, the presence of an inspector is required. When not in use, the doors are secured with IAEA-approved seals.

The personnel portal has the same features as the portal that is located in the corridor to the control room. The drawer pass-through

portal consists of a neutron-activation SNM detector and a conveyor for transporting the drawers between the MAA and the storage area. Both portals require tamper-safing features.

An alternative to the drawer pass-through exists at the reference facility. A storage area could be included inside the MAA to store the nonfissile reactor material. The final selection would depend upon cost, operational impact, safeguards effectiveness, and physical layout of an actual facility.

Escape Exit -- The basic scheme for detecting possible diversion of SNM through this exit is based on applying procedural restrictions to the flow of traffic through the tunnel and then monitoring to determine if the established rules are violated. Any time a violation is detected a special inventory verification would be required.

The preferred method of safeguarding the escape exit is to apply a seal to one or more of the doors and to verify seal integrity on a routine basis. When inspection or maintenance of the exit is necessary, the inspector would have to be present to monitor these activities.

An alternative method for safeguarding this exit which could reduce inspector participation is monitoring the direction of traffic. Routine exit from the facility is not allowed. Limited movement is permitted from outside to inside for the inspection and maintenance of the emergency doors. A violation of these procedures would be detected by the monitors and a special inventory could be required.

Abnormal Exits -- A possibility exists that SNM may be diverted through abnormal paths. These include openings made in the reactor containment, the walls and ceiling of the structure, tunnels made through the floor, or existing openings through pipes, ducts, vents, and conduit. Detection of these openings or of unauthorized modifications to the structure is achieved by visual inspection of both

the interior and exterior of the structure and/or by review of the unattended CCTV surveillance records. Other low-cost containment and/or surveillance techniques to complement the inspection may be used.

Procedural Restrictions

Certain operations at fast critical facilities require the establishment of administrative procedures to assure containment of SNM. Details of these restrictions must be negotiated with each particular facility. For the reference facility, the following activities are among those assumed to require monitored procedural restrictions:

1. The movement of large items and SNM through all uninstrumented portals is restricted. Seals are applied to these portals to detect use of these doors during inspector absence.
2. Emergency exits are not to be used routinely. They are to be monitored and/or sealed. Any unauthorized or emergency use of these exits constitutes an alarm and could cause a special inventory.
3. Deliberate facility exit through instrumented portals following SNM detection comprises a procedural violation and generates an alarm.

SNM Detection

The conceptual containment system for the reference facility consists of SNM detection at two personnel portals, a material pass-through for small items, and a conveyor system for moving drawers containing nonfissile material into and out of the MAA. The personnel portals use passive SNM detection in conjunction with metal detection so that both shielded and unshielded SNM can be detected. The other portals use neutron-activation which is capable of detecting both shielded and unshielded SNM. This method is particularly effective in detecting ^{235}U which does not emit neutrons and is relatively easy to shield from passive gamma detection.

For SNM and metal detection, the principal trade-off is between sensitivity and false alarm rate. High sensitivity minimizes the amount of material that can be removed on a single try and makes protracted diversion difficult. However, the false alarm rate must be acceptably low to minimize interference with facility operation. Consequently, it is proposed that multiple measurements be made each time personnel or material pass through a portal. The measurement must indicate the presence of SNM or metal on each try before SNM or metal detection is indicated. However, no alarm is generated if the person (or material) returns to the MAA rather than continuing to exit from the facility.

This multiple-try capability allows the adversary to make repeated attempts to divert material and increases the chances for successful diversion. To account for this, statistics on each of the measurements can be recorded. The inspector will review these records periodically to determine if there has been a change in the measurement statistics and number of attempted passages, both of which could indicate protracted diversion attempts.

Since practical limits exist for SNM and metal detection, it is necessary to consider their capabilities in the context of a complete safeguards system. Current technology permits high-confidence, timely detection of the single diversion of a significant amount of SNM. Small quantities are detected with less confidence on each try but the risk of detection increases with the number of attempts. In addition, protracted diversion would be detected by routine inventory procedures, although possibly not in a timely manner.

It should be noted that ^{233}U , in comparison to plutonium, is more difficult to detect, is easier to shield and, consequently, may be easier to divert. However, this is partially offset by the fact that approximately three times as much must be diverted to achieve a significant quantity. Although ^{233}U has not been

considered in this study, it does not present a difficult detection problem because of its high gamma activity and the ^{233}U daughters that are present.

Special Inventory and Inspection

The overall success of the monitoring, alarm, and subsequent special inventory verification to a large extent depends on the ability to verify inventory rapidly and in a timely manner. A report is currently being prepared by LASL which describes procedures and techniques which will be applicable to the special inventory verification task.⁶ The results of this study will be published in a separate report and no attempt is being made herein to evaluate the effectiveness of the material accountancy scheme. However, one possible technique and sampling plan was investigated as part of the conceptual design effort to gain insight into the time that might be required to perform a meaningful special inventory verification. This verification procedure uses autoradiograph techniques to rapidly count plutonium fuel elements.⁸ Photographic film placed near the fuel is exposed by the 60-keV gamma radiation from the ^{241}Am in the plutonium fuel elements. A piece count can then be made from the developed film.

The greater part of the plutonium fuel element inventory at the reference facility is assumed to be in the reactor core. Typically, hundreds of kilograms could be in the reactor, with the balance of the inventory stored in containers in the vault. A representative reactor loading and vault inventory was assumed and is shown in Table VII.

Also shown in Table VII are the inspection activities assumed for this hypothetical special inventory verification. Using this inventory makeup, an estimate was made of the time necessary to perform an inspection by using autoradiography. No allowance was

made for preparation, assay measurements, book inventory review, or delays caused by radiological exposure problems. The results of these estimates are shown in Figure 11.

Table VII INSPECTION ACTIVITY FOR A TYPICAL REACTOR LOADING AND SNM INVENTORY	
ASSUMED SNM INVENTORY	INSPECTION ACTIVITY
<u>In Reactor Core</u> 1500 Drawers Containing Pu Fuel (=8000 Fuel Elements)	Verify on Sample Basis Using Autoradiography
<u>In Vault Storage</u> 150 Unsealed Containers Containing Pu Fuel (=1300 Fuel Elements)	
----- 300 Sealed Containers Containing Pu or ^{235}U Fuel (=10,000 Fuel Elements)	Verify Seal Integrity on Approximately 50 Seals
4 Sealed Containers Containing ^{235}U and Pu Diagnostic Foils	

With reference to Figure 11, the following observations are made:

1. If an alarm (indication of a possible diversion) is generated which causes a special inventory verification to be performed, the amount of time required to detect diversion of relatively large amounts of SNM (for example, 50 kilograms of plutonium) is relatively small. Thus, there is a high probability of detecting diversion of large quantities in relatively short periods of time.
2. When the SNM amount diverted is small (for example, 8 kilograms of plutonium), long inspection time periods are required to obtain a reasonably high detection probability.

* Estimate based on actual autoradiographic procedures used at an existing fast critical facility. No allowance is made for preparation, assay measurements, book inventory review or radiological exposure.

Figure 11. Estimated Inspection Capability
at Model Reference Facility

VI. CONCLUSION

It was concluded that practical routine inventory verification techniques can be effective in detecting protracted diversion but will not meet the seven-day timeliness criteria either for protracted or large one-time diversions. An effective international safeguards system requires a method of continuously monitoring facility activities either with instrumentation, inspectors, or a combination thereof. It was also concluded that a resident inspector is required at this type of facility because of the many nonroutine operations. However, a single inspector cannot adequately monitor all activities to assure that no diversion is taking place. The use of existing structural features and unattended monitoring at portals as well as surveillance by a resident inspector can provide an effective detection capability. A rapid special inventory verification is required following detection to verify any suspected diversion.

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APPENDIX A

SURVEY OF FAST CRITICAL FACILITIES

In general, fast critical facilities are of two types. The first type provides a copious source of fast neutrons for general experimental purposes and is frequently referred to as a fast source reactor. It usually contains a few tens of kilograms of fissile material in several separate parts. The second type of facility is used to create a mockup of the cores of fast power reactors for physics studies. These assemblies, frequently called zero power fast reactors, are near full scale and often require from hundreds to thousands of kilograms of fissile material distributed through the core in many thousands of individual pieces. They can use enriched uranium and/or plutonium as fuel.

Fast source reactors are fairly common throughout the world and are relatively easy to safeguard because they have only a limited number of items that must be accounted for. Zero power fast reactors are limited in number but present unique safeguards problems because of the large number of individual fuel items. The problems encountered in safeguarding these zero power fast reactors are the subject of this study.

A survey of zero power fast critical facilities located in countries outside of the Soviet bloc was made to determine whether there are generic solutions to the safeguards problem. A summary of these facilities, along with some pertinent safeguards information, is contained in Table A.I.

In general, these facilities have the following features in common:

1. Because the reactor operates at very low power, negligible fuel burnup occurs. Consequently, the fissile material remains relatively uncontaminated and can be handled safely.

Table A.1
Summary of Fast Critical Reactors

Location	Name	Reactor Type	Fuel	Element Size	Fuel Assembly	Fuel Inventory	Structure-Containment	Number of Safeguards Portals*	Fuel Handling
Argonne, Illinois	ZPR-6	Split table with horizontal matrix tubes	Pu alloy PuO ₂ HEU metal	Plates: 31 mm high up to 6.5 mm thick up to 203 mm long Pin: 9.5 mm Dia. 152 cm long	51- x 51- x 915-mm unsealed drum	100's of kg	Reactor cell: Reinforced concrete shell Vault: Reinforced concrete	2	Manual fuel element loading; manual transfer; manual assembly loading
Argonne, Illinois	ZPR-9	Split table with horizontal matrix tubes	Pu alloy PuO ₂ HEU metal	Same as above	Same as above	100's of kg	Reactor cell: Reinforced concrete shell Vault: Reinforced concrete	2	Same as above
Idaho Falls, Idaho	ZPR	Split table with horizontal matrix tubes	Pu alloy PuO ₂ -UG HEU metal	Same as above	Same as above	1000's of kg	Reinforced concrete with earth overburden	3	Same as above
Tokai-Mura, Japan	JCM	Split table with horizontal matrix tubes	Pu alloy PuO ₂ -UG HEU metal	Plates: 51 mm high up to 6.5 mm thick up to 31 cm long	51- x 51- x 915-mm unsealed drum	100's of kg	Reactor cell: Double shell of reinforced concrete	2	Manual fuel element loading; two fuel assembly transfer trolleys; manual core loading
Earlville, IAC	SNEX	Fixed vertical assembly type	HEU metal PuO ₂ -UG	Plates: 31 mm square up to 6.25 mm thick	34-mm square by 116-mm long fuel rods	100's of kg	Reactor cell: Double shell steel with concrete shielding	1	Isolated fuel element; manual transfer; fuel assembly loading machine
Cadarache, France	MUSICA	Vertical lattice	Pu alloy HEU metal	Rods: 12.7 mm square 10 cm long	104-mm square by 1200-mm long fuel rods	100's of kg	Reactor cell: steel shell	1	Automated fuel element loading; fuel assembly transport trolley; fuel assembly loading machine
Winfrith, UK	LENA	Fixed vertical assembly type	HEU metal Pu alloy PuO ₂ -UG	Plates: 51 mm square up to 6.25 mm thick	34-mm square by 293-mm long fuel rods	100's of kg	Reactor cell: steel cylinder containment with concrete shield		Automated fuel element loading; transfer trolley; fuel assembly loading machine
Aldermaston, UK	VERA	Split table vertical matrix	HEU metal Pu alloy	Plates: 43.2 mm square thickness variable	46-mm square by 1170-mm long fuel rods	100's of kg	Reactor cell: concrete shell		

* Number of portals requiring safeguards (monitors, seals, etc.)

2. Typically, fissile fuel material at fast critical facilities consists of metal alloys and oxides of plutonium and uranium. In some cases, the fuel can be used directly to fabricate a nuclear device, while in others some processing might first be required.
3. The fuel elements are relatively small and therefore can be easily concealed and transported. Because they are small, the number in the inventory may be quite large.
4. The quantity of fissile material available at one of these facilities is sufficient to fabricate anywhere from tens to hundreds of weapons.
5. The SNM inventory is generally static with only limited shipping and receiving activities.
6. The isotopic content of the fuel is well-known.
7. A broad spectrum of activities occurs at these research and development facilities.
8. Because of safety considerations and the nature of the work, both the number of access points and the number of people having access to reactor fuel are limited.

Based on this survey, the following conclusions concerning safeguards for fast critical facilities were reached:

1. The type and degree of material control (containment/surveillance) required would not vary significantly from facility to facility. However, the implementation of a safeguards system may require different amounts and types of structural modifications at each of these facilities.
2. The greatest difference between these facilities is in the fuel assembly configuration, which might have an impact on the type of inventory verification technique employed. For example, at some facilities the fuel assembly is an unsealed drawer approximately 1 metre in length which contains a small number of fuel plates. At some of the other facilities, the fuel assembly is a sealed fuel rod approximately 3 metres in length which contains many small fuel pieces. Verifying the

SNM content of this fuel rod might be considerably more difficult and time-consuming than verifying it in the drawer configuration. Consequently, different techniques for material accountancy might be required in order to minimize interference with facility operation.

3. The general approach and system concepts developed by using the reference facility are transferable to other critical facilities.

APPENDIX B
MODEL REFERENCE FACILITY

The model reference facility consists of a control room, a material storage area for nonfissile material, and the MAA, as shown in Figure B.1. The control room is in a concrete block structure, while the material storage area is in a sheet metal building. A reinforced concrete structure houses the MAA, reactor cell, SNM vault, and workroom. Blast and seal doors are located in the corridor between the reactor cell and the workroom and also in the escape exit which provides an emergency route from the reactor cell. Heavy seal doors are also located between the control room and workroom and between the material storage area and workroom.

Figure B.1. Plot Plan of Model Reference Facility

The SNM inventory at the model facility is presumed to be large and includes both plutonium and enriched uranium. The fissile material is in the form of thin flat metal-clad plates which are nominally 50 mm wide and vary in length from 25 to 200 mm. There are many thousands of these fuel plates in the assumed inventory and plutonium fissile content per item ranges from about 5 to 300 grams. When not being used, this material is stored in aluminum containers which are located in special borated-concrete bins in the vault. Figure B.2 shows such a container.

Figure B.2. Fuel Storage Container

The vault also contains several kilograms each of small plutonium and uranium foils (0.2 to 0.25 gram per piece) which are routinely used for neutron diagnostics.

Frequent personnel and material movements within the reference facility are necessary due to the experimental nature of the work. Fuel is moved through the workroom to either the reactor or vault, depending on the ongoing operation. Nonfissile material and equipment also move through the workroom enroute to either the reactor or the material storage area outside the MAA. Except for small amounts of plutonium and uranium in the form of foils and for shipment and receipt of SNM, movement of SNM across the MAA boundaries normally is prohibited. Figure B.3 illustrates how these movements occur.

Figure B.3. Material Flow in the MAA

In a typical fuel loading, fuel elements are taken from the vault to the workroom where fuel drawers (Figure B.4) preloaded with various non-SNM material, are loaded. The nominal dimensions of a fuel drawer are 50 mm square by 900 mm deep. These fuel drawers are then moved to the reactor cell for loading in the reactor core. When the reactor is in operation, much of the SNM inventory may be in the reactor.

During a core change, the loaded fuel drawers are taken to the workroom, the fuel elements are removed and returned to the vault, and the drawers with the remaining material (depleted uranium, sodium, etc.) in place are taken to the material storage building outside the MAA. Several hundred tonnes of drawers filled with material other than fuel are also moved between the reactor cell and the material storage building.

Figure B.4. Fuel Drawer

Small amounts (up to 50 grams) of SNM in the form of plutonium or uranium foils are routinely used for core flux measurement. These foils are taken from the vault to a counting room outside the MAA for loading into the proper fixture and then moved to the reactor cell for loading into drawers. After exposure in the core, the foils are returned to the counting room for activity measurements before they are taken back to the vault.

The assumed state system of accounting and control (SSAC) includes a complete physical inventory of all accountable SNM every 2 years; in this inventory all items are identified on a piece-by-piece basis. Nondestructive assay is also performed on randomly selected samples to verify material composition. In addition, book audits are performed to verify that the location of all accountable material is known.

APPENDIX C

DIVERSION ANALYSIS

Identification and analysis of all possible scenarios for diversion of significant amounts of SNM from a high-inventory fast critical facility represent an unbounded problem, due primarily to the human aspects of the safeguards problem. This is particularly true for international safeguards, where the resources of a state may be used to counter the safeguards system. Event/fault tree techniques have been developed and used extensively in physical security studies to identify detailed scenarios which could lead to a high probability of adversary success. These scenarios are formed by the combination of scenario elements which can be considered fundamental to any attempt to divert SNM. Event/fault tree techniques have not been applied to the more general international safeguards problem, but the scenario elements have been identified. The diversion analysis employed in this study is based on the premise that a successful safeguards system will be able to effectively counter each scenario element which could contribute to a successful diversion. This approach makes it unnecessary to undertake a detailed analysis of many diversion scenarios, while still retaining completeness by considering those adversary actions which would make up the diversion scenarios.

Potential Diversion Goals

In international safeguards, it is necessary, at least to a limited extent, to explore possible goals which might motivate a state to attempt to divert SNM. Table C.1 outlines several possible considerations. Three levels of nuclear explosives capability are identified to demonstrate their impact on safeguards. A single device capability, though of major political concern, would have relatively limited military usefulness. However, presuming the technical capability to fabricate an explosive device exists within the country

Table C.1	
POTENTIAL DIVERSION GOALS	
Nuclear Explosives Capability	Degree of Secrecy Desired
--- Single Device	--- None
- Political	- Open Diversion
- Military Application Unlikely	- Announced Treaty Abrogation
--- One-Time Military	--- Interim Secrecy Until
- Single Diversion	- Announced Capability
- 10 to 100 weapons	- Open Testing
--- Ongoing Military Program	- Use
- 10 weapons/year	--- Long Term
- 100 weapons/year	- No Announcement
	- No Demonstration

acquiring the SNM, this goal would be relatively easy to accomplish because of the small amount of fissile material needed. The desire for a single device would more reasonably be associated with an underdeveloped country, which would be expected to have limited technical capability. Thus, diversion with intent to fabricate a single device, though probably the most difficult to detect, would be expected to have the least effect on international security.

A second level of capability desired by a state might be a military capability based on a single diversion of fissile material, either in a single try or in multiple attempts over a short period of time. The goal might be to produce 10 to 100 devices in military configuration with delivery capability. This unquestionably could be a major threat to international security but would require hundreds to thousands of kilograms of fissile material. Without an ongoing weapons program, this one-time capability would probably be accomplished by diversion of near-weapons-grade material from existing facilities such as high-inventory fast critical reactors. These types of facilities are typical of advanced technology countries which would also have the capability to support a nuclear weapons program.

An ongoing military program would be the upper bound on a national goal of becoming a nuclear weapons state. Here a production rate of 10 to 100 weapons per year might be considered reasonable. Since an annual supply of hundreds to thousands of kilograms of weapons-grade fissile material would be needed, it would be reasonable to expect a state to routinely divert SNM from an existing nuclear power cycle or establish a separate program to produce weapons-grade material. Advanced technology would be required not only to obtain the weapons-grade material but also to militarize the device and provide delivery capability.

Table C.I also lists the degree of secrecy desired by the diverting state as the diversion goal. A policy of open diversion and announced treaty abrogation is one possible choice available to the state. Such a choice amounts to detection of diversion by the international community in a timely fashion. An alternate goal for the state might be to maintain secrecy until the nuclear device has been fabricated and openly tested and/or used for nonpeaceful purposes. This is probably the most realistic secrecy goal for a nation because it is difficult to test nuclear devices without detection. Long-term secrecy with no announcement or demonstration is also a possibility, but this is more likely to be associated with military secrecy rather than with the existence of a nuclear weapons capability.

A graphic presentation of the goals just discussed and their interrelationship is shown in Figure C.1. The levels of technology required to achieve the various goals of nuclear explosives capability and secrecy are indicated by the zones within the plot, with higher capability and secrecy requiring higher technology. As shown, the level of international concern directly follows nuclear capability qualitatively. For example, a state intent on obtaining a one-time military capability while maintaining an interim degree of secrecy would probably require a mid-to-high level of technology to succeed in this goal. This potentially would be a cause of high international

concern. Ideally, a high-confidence international safeguards system would have an equal likelihood of detecting diversion for all levels of capability and secrecy; however, a realistic system may provide a graded detection capability which increases in confidence as the threat and international concern increase.

Figure C.1. Diversion Goals

Diversion Strategies and Scenario Elements

Four basic strategies for diversion are considered in this analysis. They are concealment, substitution, record falsification, and actual/staged abnormalities.

The scenario elements assumed as generic to a concealment strategy for diverting SNM at a fast critical facility are shown in Table C.II. This strategy presumes that there is some level of international safeguards that would at least deter direct open removal of SNM from the facility. Path details for material removal, such as through doors, walls, pipes, etc., are site specific and will be discussed later. Concealment for immediate or future removal requires a method of secreting the material out of the facility. This may be accomplished immediately after the beginning of the diversion attempt, or material may be aggregated within the facility to await an opportune time for removal. A third concealment element is the potential use of shielding to mask the passive characteristics of SNM or to hide the material from active sensing instruments such as metal detectors.

Table C.II	
SCENARIO ELEMENTS FOR CONCEALMENT	
Concealment For Immediate Removal <ul style="list-style-type: none"> --- Hand Carry --- Within Equipment <ul style="list-style-type: none"> - Instruments - Handling Equipment - Experiments --- With Normal Materials Flow <ul style="list-style-type: none"> - Diluent Materials - Tools - Waste 	Concealment For Future Removal <ul style="list-style-type: none"> --- Accumulate SNM --- Await Opportune Time for Removal Shielding For Concealment <ul style="list-style-type: none"> --- Mask Passive Characteristics <ul style="list-style-type: none"> - Visual - Radiation (γ, n, thermal) - Chemical --- Block Active Interrogation <ul style="list-style-type: none"> - EM Field (Metal Detector) - n-Activation - X-Ray

Table C.III lists the scenario elements for substitution that might be used to mislead an international inspector into thinking that the declared SNM is present both in the correct quantity and assay. Since substitution requires replacement and subsequent removal of material from the facility, it is reasonable to assume the elements of concealment will be involved in a substitution scenario. It is also noteworthy that the substitution scenario involves one or more replacement items that must be introduced into the facility and hence may be detectable.

Table C.III	
SCENARIO ELEMENTS FOR SUBSTITUTION	
SNM Item Substitution By Matching	
---	Appearances
---	Geometry
---	Weight
---	γ/α Characteristics (Surface, Distributed)
---	Identification Marks
---	Partial Substitution of Fissile Materials
Substitution In Critical Assembly By	
---	Replacement with Nonfissile Materials
---	Mask with Core Changes
Reactor Drawer/ Vault Container Substitution By	
---	Replication of Drawer/ Container
---	Matching γ/α Characteristics
---	Reproducing Identification/ Seals
Shipping and Receiving Operations Substitution By	
---	Complete Container Replacement
---	Partial Substitution of SNM

Scenario elements for record falsification are listed in Table C.IV. Overstating of contained SNM per item on the amount of material shipped could allow direct diversion of the difference. Likewise, understatement on receipt, biasing NDA measurements, or deletion of items from book inventory could be used to mask diversion. The experimental nature of operations at critical facilities could also be used by the state to deliberately mislead inspectors. For example,

the contained fissile material in the core could be reduced while overall reactivity is maintained as constant by alteration of the core geometry. Unreported exchange of physical inventory between the reactor and SNM storage during international inspection could also lead to undetected diversion.

Table C. IV SCENARIO ELEMENTS FOR RECORD FALSIFICATION	
Overstatements --- Contained SNM per Item --- Amount of SNM Shipped	Bias in NDA Measurements Misrepresentation of Experimental Operations --- Core Configuration Changes --- Modification of Reactor Instrumentation
Understatements --- Amount of SNM Received --- Item Removal from Book Inventory	Inventory Exchange

The elements of the diversion scenario involving an actual or a staged abnormality at the facility are presented in Table C.V. Routine drills or an actual or falsified emergency would provide a unique opportunity for SNM removal since safety dictates that

Table C. V SCENARIO ELEMENTS FOR ACTUAL/ STAGED ABNORMALITIES
Emergency Evacuations (Radiation Release, Criticality Incident, etc.) --- Routine Drill --- Actual/ Staged Condition - Within Facility - At Adjacent Locations
Major Accident (Fire, Explosion, etc.) --- Physical Inventory Unavailable For Verification --- SNM Declared Lost --- Possible Long Term Effects

personnel egress be unrestricted. A simulated major accident could also be used by the state as a reason for preventing facility inspection, thus permitting easy removal of fissile material. This could be particularly attractive to the potential diverter because of the seemingly legitimate lengthy delay in obtaining access to the physical inventory.

Path Specifics

In addition to these generic international safeguards diversion scenarios, a set of path variables which are site specific is given in Table C.VI for the model reference facility. Included are "normal" exits as well as "abnormal" paths that could be prepared to allow removal of fissile material. The structure of the reference facility limits the normal paths to the following: the escape exit, the corridor to the reactor control room, and the corridor to the material storage area. The abnormal paths have been identified as a hole through the floor or an existing opening caused by plumbing, heating, wiring, or air conditioning equipment.

Table C.VI PATH SPECIFIC VARIABLES	
Potential Points of Diversion	
--- Vault	
--- Cell	
--- Workroom	
Physical Paths for Removal	
--- Normal Exits	
- Control Room	
- Materials Storage Area	
- Escape Exit	
--- Other	
- Pipes, Vents, Conduits, etc.	
- Walls, Floor, Ceiling	
- Reactor Containment	
Mode of Diversion	
--- By Items	
--- By Canister	
--- By Drawer	
Equipment Required to Divert SNM	

Figure C.2 illustrates the generic sequence of actions that is required for a successful diversion. Path specifics are associated with obtaining and removing material while the diversion strategies are primarily related to maintaining secrecy. An effective safeguards system has the capability to interrupt this sequence at no less than one and preferably at more than one point. Evaluation of safeguards options for effectiveness involves assessing the ability of the system to counter the strategy elements and path specifics associated with the diversion sequence.

Figure C.2. Diversion Sequence

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