Appendix VIII. Description of Safeguards Technology and Procedures

First Draft by Science Applications, Inc.

Revised and Expanded by OTA Consultants

Appendix **VIII**

Description of Safeguards Technology and Procedures

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1. Introduction

This report supports OTA's ongoing assessment of nuclear proliferation and safeguards (1)* by providing a technical background on the systems and procedures which exist in the U.S. today and on the U.S. program to provide improved methods and procedures. Although the focus of the OTA study is on the international proliferation of nuclear weapons technology and nuclear weapons, domestic safeguards systems are relevant because each nation must protect its nuclear materials from non-national groups which might use such materials to threaten that nations society or threaten other nations. The U.S. safeguards programs are relevant insofar as they may contribute to the reliability of safeguards systems in other nations and provide direct or indirect support to the IAEA.

In the U.S., there are three major nuclear programs and three agencies having safeguards responsibilities. The three programs are: military, nuclear power, and nuclear research. The Department of Defense provides the safeguards for the nuclear weapons in its possession. The Energy Research and Development Administration (ERDA) operates production facilities for the nuclear military programs and conducts research on nuclear power and other non-military nuclear applications. The Nuclear Regulatory Commission (NRC) is responsible for applying safeguards to privately owned nuclear facilities and to a few ERDA-owned facilities (waste storage and power reactors feeding public electric power grids) . Major ERDA and NRC facilities are listed in Tables 1 and 2.

Some idea of the types and amounts of nuclear materials presently possessed by private organizations and under NRC safeguards may be derived from the following.

For uranium (2)*:

Dec. 31, 1975 Licensee Ending Inventory by Enrichment Range

Enrichment Range	# of Locations	Element Weight	Isotope Weight (U-235)
less than 5%	133	8,541,225 kg	166,282 kg
5% to 20%	72	2,168	226
20% to 80%	42	1,660	1,054
“over 80%	138	34,379	33,435

*(Ref. 1: See Reference List at end of Appendix VIII.)

*(Ref. 2: J. Inst. Nuc. Mat. Management, Special Report, Aug., 1976, p. 44)

Table 1.1

Major Government Owned, ERDA Facilities

Military Applications	Production	Research
Los Alamos Scientific Lab.	Union Carbide GDP, Oak Ridge	Oak Ridge National Lab., Tenn.
Lawrence Livermore Lab.	" " " , Paducah, Ky.	Argonne National Lab., Ill.
Sandia Laboratories	Goodyear GDP, Piketon, O.	Brookhaven National Lab., L.I.-N.Y
Rocky Flats, Colorado	Atlantic Richfield, Hanford, Wash.	Aerojet Nuclear, Idaho
Union Carbide, Y-12, Oak Ridge	Du Pont, Savannah River, S.C.	Hanford Engineering Development Lab., Wash.
Mason & Hanger, Tex.	Idaho Reprocessing Plant	
Monsanto Mound Lab., Ohio		
Nevada Test Site	GDP = gaseous diffusion plant to enrich uranium	
G.E. Knolls Lab., N.Y.		
Westinghouse Bettis Lab., Pa.		

Table 1.2

Major Privately Owned Nuclear Facilities Subject to NRC Regulations

Nuclear Power Plants

Built: 59

Being Built: 73

Planned 6/30/76): 79

Research Reactors

Total: 68

Containing more than 5 kg of high enriched uranium: 16

One megawatt or higher power: 23

Critical Assemblies

Containing more than 5 kg of high enriched uranium: 5

Misc. R&D

Licensed for more than 5 kg of high enriched uranium: 5

High Enriched Uranium Fuel Fabrication

Babcock and Wilcox, Apollo, Pa. (Naval Fuels)
Babcock and Wilcox, Lynchburg, Va. (Naval Fuels)
Nuclear Fuel Services, Erwin, Tenn. (Naval Fuels)
United Nuclear Co., Uncasville, CN. (Naval Fuels)
United Nuclear Co., Wood River Jct., R.I. (scrap rec.)
U.S. Nuclear, Oak Ridge, Tenn. (research fuels)
Texas Instruments, Attleboro, Mass. (research fuels)
Atomics International, Calif. (research fuels)
General Atomics, San Diego, Cal. (H.T.G.R.)

Low Enriched Uranium Fuel Fabrication

General Electric, Wilmington, N.C.
Westinghouse, Columbia, S.C.
Combustion Engineering, Windsor, Conn.
Babcock & Wilcox, Lynchberg, Va.
Exxon Nuclear, Richland, Wash.

Plutonium Fuel Fabrication

Babcock & Wilcox, Leechburg, Pa.(1)

General Electric, Pleasanton, Cal.(1)

Westinghouse, Cheswick, Pa.(2)

Exxon Nuclear, Richland, Wash.(2)

Nuclear Fuel Services, Erwin, Tenn.(2)

(1) ERDA fuels or R&D

(2) small or no operations

Fuel Reprocessing

None operable

Notes on Table 1.1:

LASL, LLL, Sandia, Rocky Flats, Y-12, Mason and Hanger have substantial amounts of HEU*, Pu or both.

Mound Lab. processes Pu-238.

The Nevada Test Site has weapons occasionally, for Tests. Knolls and Bettis have modest amounts of HEU for R&D.

The OR and Padukah GDP's produce only LEU.*

Goodyear GDP produces HEU for HTGR's, research reactors and military applications.

Atlantic Richfield, Hanford processes and stores Pu.

The Savannah River reactors produce Pu, Pu-238, etc.

The Idaho Chemical Processing Plant, reprocesses HEU fuels from research and naval reactors.

Argonne National Lab., West (Idaho) should be added to the list of research facilities. The SSNM at research facilities is primarily for or in reactors.

Note on Table 1.2:

As of 6/30/76, 59 power reactors had been built
57 power reactors were operable
73 power reactors were under construction
79 power reactors were planned

***HEU:** Highly-enriched uranium

***LEU:** Low enriched uranium

For uranium and plutonium[(3)*]:

"There are sixteen licensees in the private sector who are authorized to possess strategic quantities of plutonium and high-enriched uranium. These kinds of special nuclear material, if stolen in sufficient quantities, could be fashioned into a crude nuclear explosive, if the thieves had the requisite technical skill and equipment.

The greatest percentage of this high-enriched uranium is government-owned and is being processed in licensed facilities for national security programs. High-enriched uranium for commercial purposes (about six percent of the total quantity in the private sector) is mostly in storage vaults and is likely to stay there unless additional high temperature gas-cooled reactors are built and operated. A small amount of high-enriched uranium is being used to fabricate research reactor fuel.

About half of the plutonium in commercial plants is government-owned. Certain licensed facilities process plutonium for development programs related to the liquid metal fast breeder reactor. Otherwise, the material is being used in small quantities for R&D purposes or is in vault storage. Thus, the amount of special nuclear material, plutonium and high-enriched uranium, being used outside national security programs is very small and at this time is largely in vault storage."

*(Ref. 3: Kenneth R. Chapman, Director Nuclear Material Safety and Safeguards, NRC to Natural Resources Defense Council, Mar. 22, 1976.)

The total amount of plutonium in the private facilities is probably less than 1,000 kg at this time. There are between 1,000 and 1,500 shipments per year of significant amounts of high enriched uranium, plutonium or U-233. Less than 100 of these are shipments of privately owned nuclear materials.

In view of the several Government and private nuclear programs, it is useful to identify those which relate to national defense and those which pertain to civil applications. The former activities are classified in the interest of national security; the latter, generally, are not. The overall assessment of the benefits of a national military nuclear program relative to the safeguards risks of theft or diversion is different from such an assessment for non-military nuclear programs. From the point of view of proliferation, it is the nuclear power program and the R&D programs of both ERDA and NRC that are relevant.

The future course of nuclear power in the U.S. is being reviewed. The questions being publicly debated are whether or not to authorize private construction of uranium enrichment plants, private reprocessing plants, fabrication of mixed uranium-plutonium fuels for recycle in light water reactors and whether or not to proceed with the liquid metal cooled fast plutonium breeder program.

In view of this situation, the present safeguards systems described below are designed principally to protect Government owned nuclear materials. These systems have been significantly upgraded in recent years and are still in the process of review and improvement. The safeguards programs of ERDA and NRC are especially important for assessing the future safeguards risks which future nuclear energy choices might involve.

2. Domestic Safeguards in the Mid 1970's

2.1 Purposes and Objectives and their Application in the U.S.

In the international sense, "Safeguards" has heretofore implied the use of inspection and material accounting techniques to provide assurance that nuclear material has not been diverted to weapons programs; physical protection of the material is treated as a separate issue. In the domestic context "safeguards" are more broadly defined as "all measures designed to detect, deter, prevent, or respond to the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion; and sabotage of nuclear facilities." Hence domestic safeguards covers both physical protection and material control and accounting. Thus, the overall international and domestic 'safeguards" systems are concerned with comparable elements to attain similar but not identical objectives. A discussion of safeguards modes of operation and likely effectiveness is most usefully started with a consideration of purposes, implementation and regulation of safeguards in the U.S. In this chapter, we will be concerned with today's approach.

Note: IAEA safeguards pertain to 'control of and accounting for nuclear materials" supplemented by measures of containment and surveillance. Although the IAEA cannot assume responsibility for physical protection, it does recommend physical protection methods to member states.

The objectives of safeguards have been stated in several ways, for example:

"Safeguards measures are designed to deter, prevent, or respond to (1) the unauthorized possession or use of significant amounts of nuclear materials through theft or diversion; and (2) sabotage of nuclear facilities. The safeguards program has as its objective achieving a level of protection against such acts (as) to insure against significant increase in the overall risk of death, injury, or property damage to the public from other causes beyond the control of the individual-''(4)*

*(Ref. 4: Draft GESMO, WASH-1327, Aug. 1974, p. V-6)

An ERDA statement(5)* is:

'Specifically, the objectives of ERDA's integrated Safeguards and Security plan are to:

"1. Prevent successful malevolent acts involving nuclear materials or facilities, so as to protect the public against risk of death, injury, and property damage that could arise from such acts;

*(Ref. 5: See next page.)

"2. Protect classified information from authorized disclosure; and,

"3, Protect Government property from Theft or malevolence."

(Ref. 5: Master Plan , ERDA Div. of Safeguards and Security, ERDA-76/122 (Sept. '76], p.5)

Reference 6*, a report of a group of NRC consultants, expands on these generic statements and indicates how the safeguards system may be defined:

> "It is clear, at least within the context Of Civil order, that safeguards should be designed to prevent major disasters involving the use of nuclear materials and facilities. In addition, they should provide protection against serious incidents having adverse societal impacts. The requirements for safeguards become less clear at the lower levels of consequences, where misuse of nuclear material or facilities may constitute only a bothersome incident. Safeguards should protect the public from harm, but not necessarily prevent every conceivable incident. Lower thresholds of consequences, in terms of the significance of potential damage or the amounts and quantities of materials involved, can be used to identify one limit on the scope of safeguards."
>
> 'Limitations on the upper levels of threat, with which the safeguards system must cope, can be derived from the presumption of civil order. Within any given context of time, place and societal behavior, responsible police and intelligence organizations should be able to assist in defining the size and quality of threats that might emerge, with and without warning, to perpetrate malevolent acts involving nuclear materials and facilities. In the case of external threats, this definition might be of numbers of people and the quality of their arms and material and their training and tactics. In the case of internal threats, it might be of numbers of conspirators and their level of authority within the industry. Thus, the scope of both internal and external safeguards can be bounded-on the lower side in terms of the consequences of of the acts involved and on the upper side in terms of the credible threats that can be postulated within a context of civil order. This defines the breadth of the safeguards program. "

*(Ref. 6: A Report to the U.S. Nuclear Regulatory Commission on a "Conceptual Approach to Safeguards," 31 October 1975. Prepared by a group of NRC-sponsored consultants for the Division of Safeguards. U.S. NRC)

'Both physical protection and material accounting and control must be configured so that, at and above the consequence level at which disasters can occur, the combination of an active safeguards program (within the bounds of a credible threat) and contingency planning (extending beyond credible threats toward the realm of civil disorder) is sufficient to preclude any major disaster."

2.2 Elements of the U.S. Safeguards Systems

The sub-objectives of U.S. safeguards systems (of NRC, ERDA and the Dept. of Defense) are: (1) to deter hostile acts, (2) to prevent attempts to steal nuclear materials or to commit acts of nuclear sabotage, and (3) to minimize the consequences if the previous efforts should fail. The following discussion relates primarily to the second item, to the safeguards measures intended to block adversary attempts. An obviously strong preventive system will serve to deter most potential adversaries. Legal penalties for misuse of nuclear materials, also may serve as a deterrent. An example of a measure to minimize consequences would be the use of radiation detectors to detect the presence of plutonium, where it might be dispersed after having been stolen, so that people could be evacuated from a building or an area before they have inhaled damaging amounts.

Deter: Persuade potential adversaries that attempts to steal or to sabotage nuclear materials will not be successful or useful in achieving their ends. Deterrent activities include: (1) A system of safeguards in-depth that appears to offer little chance of success to the adversary, (2) condign punishment, if apprehended, (3) rewards for, information leading to conviction for attempted hostile acts. This offers a counter incentive to accepting bribes, and threatens to reveal conspiracies, (4) a public and government resolve to prevent development of a black market, so that individuals who might steal nuclear materials have no way to benefit from such acts.

Prevent: Ideally a safeguards system should absolutely prevent theft or sabotage. No system is perfect. But safeguards can and should be designed to <u>interrupt</u> any conceivable adversary action plan at a number of points so that the chance of completing his mission is vanishingly small. Since certain skills, knowledge and resources are required to steal nuclear materials, to fabricate a nuclear explosive, to disperse plutonium or to sabotage, e.g. a nuclear power plant, a properly designed safeguards system would aim to interrupt the sequence of adversary steps starting with the initial planning and going all of the way to minimizing the consequences, should the scenario proceed to the final stage. For analysis, it is useful to treat the recovery and response stages separate from those which are normally considered as preventive measures.

In as much as there are many conceivable action plans for outsider adversaries, insiders, and combinations thereof, the strategies for interrupting them should also be varied. In general, the earlier steps should aim at anticipating an adversary action. Intelligence agencies could be alert to discover nuclear conspiracies. Personnel reliability programs could aim to identify authorized personnel who may require special attention. Information which might reveal just where nuclear materials are accessible or the specifics of plant physical protection systems could be withheld from the public-at-large. The material control, material accounting and physical protection measures outlined in the Code of Federal Regulations are intended to place multiple barriers in the way of potential adversaries.

<u>Recover:</u> Even if nuclear materials should be stolen, it might still be possible to locate the thieves before they could make use of them. Experts do not agree on how long it might take to fabricate and to place a nuclear explosive, but it would take from days to

many weeks. ERDA and DOD have developed radiation detection instrumentation to make area and localized searches for stolen weapons and weapon materials (there is some more information in the Master Plan). If the theft were announced, one could count on the public to report suspicious activities for investigations. Plans could be made to search for inadvertent leaks of radioactivity or for deliberate dispersal.

Minimize consequences: This subject should be a part of national plans to respond to serious threats to the public health and safety. Equally serious threats could arise from natural causes, industrial accidents, or terrorist acts involving non-nuclear materials or facilities. It is a complicated subject because there are many conceivable emergencies. For example, in the case of the Legionnaires Disease, it was not clear whether the agent was a virus, a chemical, or whether it was a chance occurrance or a deliberate act. Credible hoaxes, nuclear or otherwise, present especially difficult problems. A panic reaction could cause as much death and destruction as the threatened event itself.

The general structure of national safeguards systems are described in two pamphlets which were written by experts from member nations for The International Atomic Energy Agency, These are: "States System for Physical Protection of Nuclear Materials" (INF/CIRC-225), and "States system for Control of and Accounting for Nuclear Materials" (IAEA-AG-26). The three basic elements are: physical protection, control of the nuclear materials and accounting procedures. "The general composition of each of these is as follows: (1) physical Protection comprises personnel reliability determinations and all of those measures related to access controls, physical barriers, penetration alarms and to armed protective response and recovery forces; (2) material control procedures are those which are provided to maintain continuous surveillance of the nuclear materials and of the personnel who have access to them; and (3) accountability procedures involve the measurement of materials received or shipped out of a facility and of materials transferred within a facility; the maintenance of books and records giving the location of nuclear materials and the amounts; and the taking of complete physical inventories at intervals in order to determine whether or not the book inventories are correct."*

*(Ref.: ERDA DSS Master Plan ERDA-76/122 (Sept. '76), p. 9)

The physical protection sub-system should prevent access to the materials in a plant or shipment by force, by stealth or false identity. It should prevent surreptitious-removal of nuclear materials and respond to internal attempts to divert or to sabotage equipment. The physical protection-sub-system overlaps the material control sub-system designed to detect any unauthorized or suspicious activity involving the nuclear materials. Present day accountability systems provide primarily for a determination, after some period of time, that the other two sub-systems have been effective or to provide information as to where and how they may have failed. Additionally, such information may detect continuing small diversions and-provide information useful for recovery operations. Highly automated semi-continuous measurement systems are under development which will provide prompt information that something may be missing.

The system, as a whole, should be an optimum combination of these facility sub-systems together with intelligence activities to help to anticipate adversary attempts and plans for a national response to hoaxes or to an actual theft or act of sabotage. The responsibility for intelligence gathering is assigned to the FBI and to other law enforcement agencies. NRC and ERDA have a primary role in assessing threats and hoaxes. Many Federal, state and local agencies would be involved in responding to credible nuclear threats.

2.3 Current US-Nuclear Regulatory Commission Safeguards

The basic documents defining the nature and extent of nuclear safeguards are in Title 10 of the Code of Federal Regulations (10 CFR). The first, Part 70 of 10 CFR, describes procedures and methods of material control for SNM. Similarly 10 CFR Part 73 covers the physical security requirements for protecting special nuclear material and related facilities and activities. Together, these two regulations form the regulatory framework for all safeguards.

Complementing these two regulations are a series of Regulatory Guides. Here the focus tends to be more specific with an emphasis on how regulations can and should be implemented.

The regulatory requirements are different for reactors, for facilities that process low enriched uranium, and for facilities that process high enriched uranium or plutonium. Material control and accounting requirements for reactors are minimal. Reactor management is required to submit a physical security plan for NRC approval which satisfies the requirements described-in Regulatory Guide 1.17 (on-site armed guards, alarms and redundant communications with local police). More extensive requirements for physical protection have been issued for comment, but not yet put into effect.

Both low enriched and high enriched uranium production facilities are required to meet the material control and accounting requirements discussed more fully below. No special physical protection requirements are placed on the low enriched uranium facilities. However, detailed physical protection requirements are given in 10CFR73 for shipments of strategically significant amounts of nuclear material and for production facilities having high enriched uranium and plutonium in more than threshold amounts.

The reasons for the difference in treatment are that low enriched uranium is not very radioactive nor can it be used as a nuclear explosive. Plutonium is produced in reactors but the hot spent fuel from reactors is extremely radioactive and hardly an attractive target for subnational subversives. It is important to maintain accountability of low enriched uranium in the interest of international control of nuclear materials and because quantitative measurement of the low-enriched fuel fed to a reactor provides one part of the data needed to determine how much plutonium is produced as the fuel is burned-up. Reactors need physical protection because they might be targets for sabotage. Facilities that process high-enriched uranium or plutonium obviously require both physical protection and material controls.

There are two papers on <u>material accounting for low-enriched uranium</u>: (1) A study that the Brookhaven Technical Support Organization made for NRC-MCSS and (2) A study by a special committee of the Institute of Nuclear Materials Management.*

U.S. industry maintains that the detailed material control and accounting requirements of 10CFR70 are unnecessarily burdensome for facilities with LEU, because LEU is not very radioactive (i.e., not a target for dispersal), and because it is not credible that U.S. terrorists would enrich LEU or use it to make Pu in a secret reactor. There are some crude estimates of the economic costs which could be saved by a relaxation of these requirements in Ref. 1.

Neither reference presents an adequate analysis of the international considerations. The IAEA is supposed to monitor all of the activities of a "state"" It starts with U_3O_8 prepared to enter the fuel cycle. IAEA will need reasonably good data on low-enriched fuel fabrication facilities in order to do an overall analysis of all of the nuclear materials flowing within a state. Accurate data on the uranium content and isotopic composition of the fresh fuel shipped to reactors is especially important to confirm the burnup-data from reactors and the amount of plutonium that should be recovered by reprocessing.

*(Ref. 1: "A Review of The Regulations Concerning The Control and Accounting of Nuclear Material" BNL-TSO, July 16, 1976)

*(Ref. 2: INMM - August 1976)

Actually, the conclusion of these references does not appear to be inconsistent with the needs of the IAEA.

The Brookhaven study concluded that MC&A requirements for facilities fabricating LEU fuel could be relaxed somewhat. It also concluded that MC&A for natural uranium should be increased.

The following discussion relates to the material control and accounting and the physical protection requirements now applied by NRC to the facilities that process high-enriched uranium or plutonium, i.e., spent fuel reprocessing plants and plants that manufacture fuels containing high-enriched uranium, plutonium, or U-233.

The regulations require that an organization establish a safeguards department which is independent of the production department, in order to obtain a license to possess and process special nuclear materials (enriched uranium, plutonium, etc.). The independent safeguards line organization is responsible for establishing material control and physical protection procedures and for enforcing them. NRC inspects the facilities to insure that the organizational structure and the procedures conducted comply with the requirements of the regulations and the specific safeguards conditions attached to each license.

Physical Protection at Fixed Sites

Regulation 10 CFR Part 73 treats physical protection in terms of 3 major groups of safeguards measures.

1. Barriers, intrusion alarms, portal controls, and surveillance to detect, and possible delay, (a) entry of unauthorized personnel and contraband and (b) unauthorized removal of SNM.

2. Alarm station, command post and communications to coordinate and direct the armed facility guard force and, when appropriate, to call for assistance from local law enforcement authorities.

3. Armed facility guard force to neutralize threats.

For example, fence, wall, floor and ceiling barriers are separately defined in terms of minimum dimensions and materials, guards are required to be uniformed and armed (guides recommend how they be trained) , the acceptable qualities of locks are specified as are materials for vaults.

Any facility is assumed divided into a hierarchy of **zones**, corresponding to the material, equipment or activities contained in each viz:

- Protected Areas: The overall plant region enclosed by barriers and having its access controlled.

- Vital Areas: Regions where equipment whose failure could endanger the public health (e.g., standby power supplies) is housed.

- Material Access Areas: Parts of a facility containing SNM.

Figure 2.1 shows in a schematic fashion the major components of a physical protection system for a fixed site.

The function of the fixed site physical protection elements described in the regulations are:

1. At least two physical barriers protect vital equipment and the special nuclear material (SNM) .

2* **Access** to the protected area is controlled by a system of coded badges. Access to the vital areas and material access area is by means of special authorization. Vehicles used primarily for the conveyance of personnel are not allowed in the protected area.

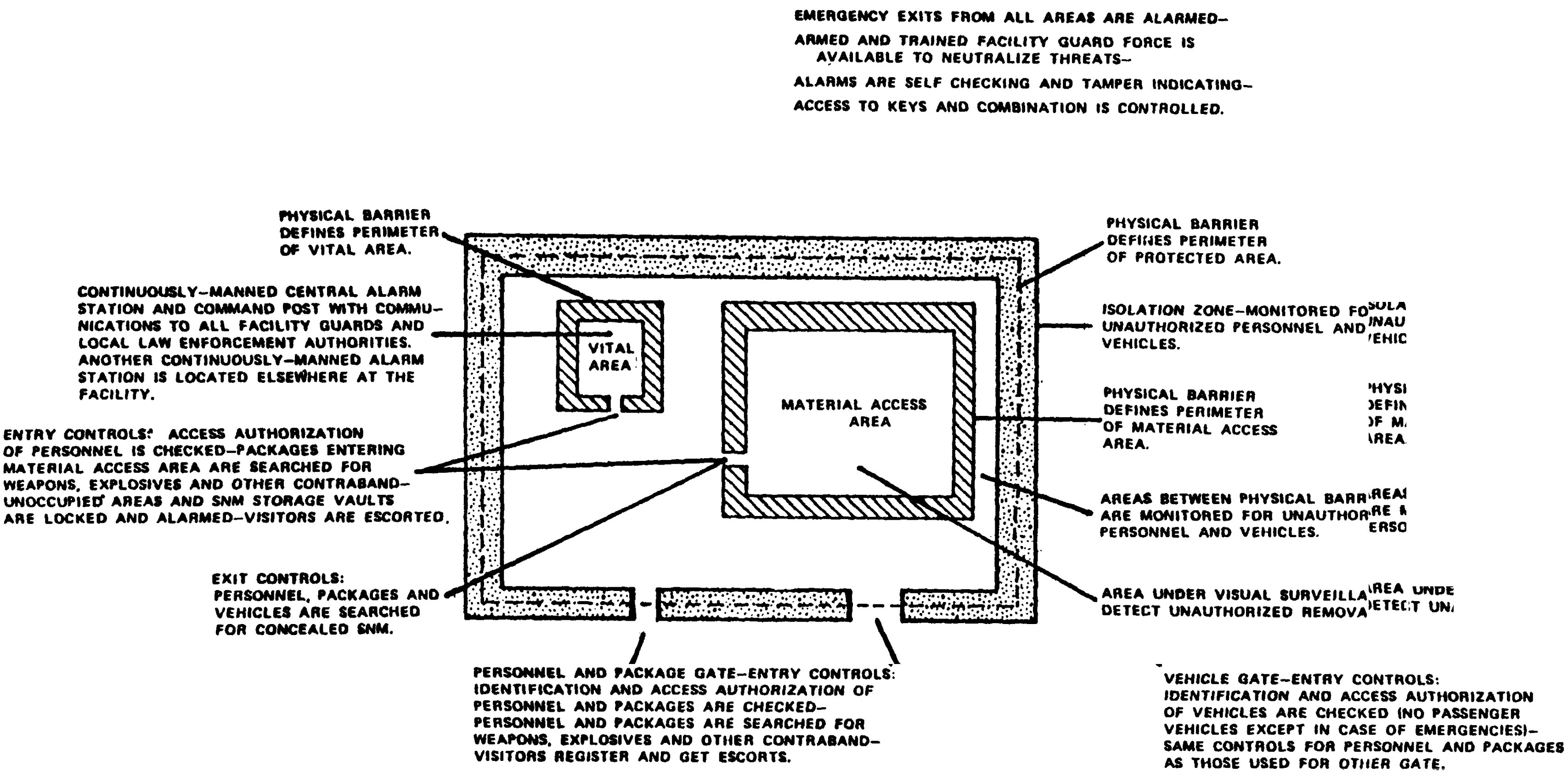

Figure 2.1 Physical Protection Requirements

3. At the protected area entrance, personnel and vehicles are searched for firearms, explosives or incendiary devices. All hand carried packages are searched. Other packages entering the protected area are searched at random.

4. Upon exiting a material access area, all personnel, Vehicles and packages are to be searched for concealed SNM.

5. Emergency exits of material access and vital areas are alarmed. Isolation zones and protected area barriers are monitored. All alarms annunciate in a continuously manned central alarm station within the protected area. A redundant continuously manned alarm station is also required.

6. Licensees must establish liaison with local law enforcement authorities, and be prepared to take immediate action to neutralize threats to this facility, either directly or by calling for local law enforcement authorities.

Material Control and Accounting

The physical protection systems, described above are designed to control the materials and the personnel entering or leaving the sensitive areas within nuclear facilities where vital equipment is located and where nuclear materials are stored or utilized. The material control and accounting systems are designed to detect diversion of SNM or sabotage attempts by personnel who have been authorized to enter the vital and material access areas. The ‘material control” subsystem is intended to detect attempted diversion or sabotage promptly, so that such attempts can be interrupted. up to this time, the material accounting operation has been employed primarily to determine, after the fact, whether or not all the materials which should be on hand are still there - the classical role of accounting. In the future it will be possible to measure material in vaults and material being processed on an essentially continuous basis, so that any theft or diversion should be detected in time to take remedial action. This highly automated, measurement and accounting system is described in Section 4.4 of this Appendix.

The material control subsystem is intended to prevent any single individual from diverting nuclear materials from storage or from processing by requiring that at least two individuals observe any transfer of SNM. Operations personnel will request that SNM be transferred from storage to a process, from one process to another and to storage. Each such internal transfer must be authorized by responsible management personnel and approved and witnessed by safeguards personnel. Every internal transfer is recorded on internal transfer documents, with copies for safeguards and for operations. These two independent sets of records should be compared frequently so as to insure that the records have not been compromised. A second level of control is applied at the perimeter of the material access areas by the physical protection system described above. Individuals entering or leaving must pass through radiation detectors (personnel monitors) which can detect small quantities of SNM; packages are searched and authorized SNM removals are to be certified by guards and health physicists, as well as by operating and MC&A personnel. The system is intended to prevent diversion from the facility by two "insiders" in collusion.

The material accounting system is presently similar to that employed for any type of highly valuable material. It is based on measurements of the amounts of material received, material shipped off-site and of all internal transfers (material may be sealed in containers, so that repeated measurements are not required unless a seal shows signs of tampering). All measured amounts are recorded in ledgers and on transfer documents (frequently the records system employs computers). At intervals, specified in the regulations, the plant is shut down, the processing equipment cleaned out, and a physical inventory is taken. The materials found on inventory are compared to the amounts expected to be on hand and any significant discrepancy is investigated.

The materials involved at a processing plant may be in many different forms: liquid solutions, powders, pellets, rods, contaminated liquids or powders, pellets rejected for not meeting specifications, and low-level disposable wastes, such as contaminated clothing, equipment or cleaning solutions. A variety of measurement techniques are employed. Unlike most other industries, it is necessary to measure the isotopic composition of the SNM as well as the amount of uranium or plutonium.

The licensee is required to determine by measurement, the nuclear material content of all receipts, shipments, discards, and material on inventory. A description of the various measurements and measurement uncertainties that are used in nuclear material control must be provided. Error models based on statistical methodology and techniques are required to demonstrate the licensee's capability to meet adequate material balance criteria.

This description of MC&A is based on a BNL-TSO paper* prepared for the NRC Special Safeguards Study.

It is probably an overstatement to say that "the system is intended to prevent diversion by two insiders." It would be more honest to say that the degree to which this system might prevent diversion by two or more authorized personnel is not presently clear. Although it would appear to have the potential to require collusion by three for diversion, its effectiveness depends on the interpretation of the regulations by NRC licensing and inspection and by facility operators. Until this system is submitted to rigorous assessment, e.g., by diversion path analysis, as operated at actual facilities, the effectiveness will remain unknown, as would suggestions for modifying it.

***REF:** Limitations on Personnel Access to SNM Records, NRC-Special Safeguards Study 'by Brookhaven National Lab. , Technical Support Organization. Nov. 10, 1975.

Adequacy criteria and frequency for material balances are established by regulation and specify that the uncertainty in the material unaccounted for (LEMUF)* does not generally** exceed the limits in Table 2.1 for the frequency given. The ability to detect diversion via a material balance cannot, however, be inferred directly from these criteria because of a dependence on plant flow or throughput and the statistical nature of the test. For example, the criteria in Table 2.1 means a material balance uncertainty of approximately 0.5 kilograms of plutonium for present day plutonium fabrication plants with a throughput of 600 kg per year but an uncertainty of 75 kilograms of plutonium for a large reprocessing plant with a throughput of 15,000 kg per year. More specifically, a material balance discrepancy is called when a larger quantity of material appears to be missing than can reasonably be expected when the measurement uncertainties are taken into account. Current procedures are to call a discrepancy in such a way that in the absence of any diversion or procedural error, the normal uncertainty in measurement will give rise to a false alarm in one occasion in 20. Some small fraction of the LEMUF could obviously be removed without a significant increase in the probability of calling a discrepancy and an analysis of this issue is given in Annex A. For fixing ideas on how large a theft might be feasible it is useful to think in terms of:

a. A theft of 25% of the LEMUF being hard to detect. The probability of a discrepancy being called is one chance in ten.

b, A theft of 50% of the LEMUF being an upper bound of the credible "theft within the LEMUF". There is (approximately) one chance in five of its being called.

In this light the diversion of only 0.12 to 0.25 kg of plutonium per accounting period is credible in the example 600 kg/yr fabrication plant, while 20 to 40 kg Pu could possibly be diverted without detection in the 15,000 kg/yr reprocessing

*The material unaccounted for (MUF) is the measure of a material balance and is equal to the (beginning inventory plus receipts] minus the (ending inventory plus shipments]. The uncertainty in MUF is given in terms of a quantity called the limit of error of MUF or LEMUF and in the U.S. is twice the standard deviation in the measured MUF.

**These limits may not apply to small facilities with LEMUF less than 200 grams of plutonium or 300 grams of high enriched uranium, nor to facilities that can demonstrate inability to meet these limits after reasonable efforts have been made.

Table 2.1

Material Type	LEMUF* on Any Total Plant Inprocess Material Balance (expressed as a percentage of additions to or removals from material in process, whichever is greater)	Frequency of Material Balance
Plutonium element or uranium-233 in a chemical reprocessing plant	1.0%	6 months
Uranium element and fissile isotope in a reprocessing plant	0.7%	6 months
Plutonium element, uranium-233, or high enriched uranium element and fissile isotope - all other	0.5%	2 months
Low enriched uranium element and fissile isotope - all other	0.5%	6 months

*LEMUF is the measurement uncertainty component used in constructing a 95% confidence interval associated with a quantity after any recognized bias has been eliminated or its effect accounted for. Assuming a normal error distribution the LEMUF corresponds to a two-sigma discrepancy in the material balance.

plant. * Thus, regulatory limits on material balance uncertainty and frequency may translate into a capability to detect a weapon quantity of material diversion for present day plants but a significant improvement will be required to achieve this same detection ability for future large facilities.

NRC & ERDA support R&D to improve this situation. In the meantime the primary safeguards measures to prevent or to detect diversion are those of physical protection and of material control. Although accounting may not be very useful for prompt detection at large throughput facilities, it serves the following important functions: (1) it can provide information on whether or not the material control and physical protection have been effective; (2) in case they have not, accounting by material balance area should indicate where weakness exists and controls should be improved; (3) if some materials should appear to be missing, the type, amount, location and responsible individuals could be identified, and (4) good material accounting procedures may be the best way to detect continuing, low-level diversion.

Material accounting is an essential element of the overall safeguards system which is of special interest to plant management and to NRC inspectors for monitoring safeguards performance, as well as for manufacturing process control and company financial purposes. The combination of material control, material accounting and internal and external physical protection must be considered in designing and evaluating safeguards for SNM at actual facilities.

2.4 Physical Protection for SNM in Transit

Presently NRC & ERDA require physical protection of shipments of "strategically" significant amounts of SNM, i.e., more than 5 kilograms (kg of high-enriched uranium, or 2 kg of plutonium or U-233. Until recently, ERDA-owned materials, as well as privately owned, were transported by private transport companies which met the then existing security requirements. In 1976, ERDA decided to provide a secure transportation system for its nuclear materials, including high enriched uranium fuels for Naval reactors and research and plutonium fuels for the test breeder program. In consequence, all ERDA shipments of such significant amounts of nuclear materials between its facilities, private contractors licensed by NRC, and ERDA and private facilities, are now protected by the ERDA system, while the relatively few shipments of such privately owned materials are subject to NRC regulations.

*Note, this discussion is only relative to material accounting and not to physical protection or material control.

The NRC regulations, published in 10CFR73, place responsibility for protection of shipments on the licensed facility which makes the shipment, whether in its own vehicles or by contract with commercial shippers. The regulations require that shipments by truck must be dedicated, in the sense that the shipment should be door-to-door with no intermediate stops to transfer other packages. The truck should have a driver and a guard and the truck must be accompanied by an escort vehicle with two armed guards or the truck must be especially designed to resist penetration, etc. The truck, and/or escort, must be equipped with radio telephones for frequent communications or the convoy must phone-in every 2 hours.

Shipments of this size are now no longer allowed on passenger aircraft. Shipments of plutonium in cargo aircraft are forbidden until NRC has determined that safe shipping containers have been developed and proven. Any transfer from one mode of transport to another must be monitored by an armed guard. There are similar provisions regarding shipment by rail or ship (the subject of export, import and of foreign shipments which cross U.S. territory, is under review at this time) .

The ERDA secure transportation system was developed several years ago to transport nuclear weapons and weapon materials. Its principal elements are secure vehicles (tractor-trailers and railroad cars) , escort guards and a nationwide communications system. The tractor cabs are securely built to provide protection to the drivers/guards. The trailer, which carries the nuclear materials is designed to delay penetration by sophisticated adversaries for an hour or more. The tractor-trailer can be immobilized so that hi-jackers can’t tow it away. The tractor and the escort vehicle maintain continuous communication by short range radio and one or both are connected to the ERDA Transportation communications network, based in Albuquerque. The Albuquerque station monitors all shipments on the road, advises the vehicles as to weather and other hazards, and has an up-to-date list of state and local law-enforcement agencies along the routes. Similar protection and communications are provided for ERDA shipments by rail.

2.5 DOMESTIC SAFEGUARDS OUTSIDE THE U . S ,

During the performance of the present work, literature on safeguards of other countries was reviewed, and informal contacts were made. The countries included Canada, West Germany, the UK, France, Sweden and the USSR. Very little specific information was obtainable from the published literature. informal contacts may be summarized as follows:

1. Material Accounting: All countries claim capabilities to meet at least IAEA accuracies; there are also several developments (W. Germany and France) on real time accounting.

2. Physical Protection: No details of any system are available (on security grounds?). There are verbal claims that local experience (e.g., in France during the Algerian war) has stimulated the development of highly effective systems.

3. INTERNATIONAL SAFEGUARDS AND PHYSICAL SECURITY IN THE CONTEXT OF U . S . EXPORTS

The basis for the licensing of exports of nuclear material and nuclear fuel facilities to any given country is normally a tripartite "Agreement of Co-operation" that has been negotiated by the State Department and ERDA, the country in question, and the IAEA. Such agreements have been written for terms ranging from 10 to 50 years and cover a broad span, including general conditions for co-operation, fuel trade framework where applicable, and safeguards conditions. These "Agreements for Co-operation" set the framework (5, 6, 7)* for the NRC to issue general export licenses for commercial organizations to trade in both "source material" (natural uranium and thorium and their ores) and in special nuclear material (plutonium, U-233 and uranium enrichment) .

The process of export trade in nuclear materials and facilities begins with an application from the commercial vendor to the NRC for a license to proceed with a proposed transaction. The NRC in turn asks the Executive Branch for "information to assist in a determination of whether issuance of the license in question is consistent with U.S. national security".

Quoting from Ref. 8*(GAO's 1976 report)

"The NRC then considers this information, together with data developed by its staff, in deciding whether to issue a license. NRC independently verifies some, but not all, of the information provided. For example, an NRC official told us that agreements for cooperation are examined to ensure that the export will be under appropriate safeguards and that on occasion additional information on physical security precautions had been requested.

"NRC believes that, although it must rely heavily on the information provided in the Executive branch position paper, this is a proper procedure since those involved agencies are able to make integrated policy evaluations concerning international relations and

*(See Reference List at the end of this Appendix.)

national defense. NRC officials believe it is impractical for them to develop an independent capability for collecting and validating similar information solely for nuclear exports."

According to ERDA's recent Statement on U.S. Nuclear Power Export Activities (ERDA 1542, Ref. 7,) minimum requirements set by the Executive branch are now:

1. That recipients apply IAEA safeguards on nuclear exports from the U.S. This includes facilities and certain equipment as well as special material.

2. Extract assurances from recipients not to use these exports to make nuclear explosives for any purpose.

3. Application by recipients of adequate physical security to exports to deter theft and sabotage, (which supplements existing policy requirements regarding significance of sensitive materials)

4. Assurances from recipients that they will also require the above conditions on any-retransfer of these exports of transfers of material or equipment derived from the original transfer.

3.1 MATERIAL CONTROL AND ACCOUNTING REQUIREMENTS APPLICABLE TO EXPORT LICENSING REVIEW

As noted in the above requirements, the application of IAEA safeguards standards is now mandatory, and according to ERDA 1542 has been called out in all agreements concluded since 1968. Hence much of the safeguards information reviewed by the NRC will be that of the agreement between the receiving nation and the IAEA; this information will normally conform to the guidelines set forth in IAEA publication INFCIRC153 [9]

The present IAEA system is summarized below:

1. Design Review - Nations supply the IAEA with design characteristics, specifically material flow and handling and material control and statistics. The IAEA reviews these characteristics. This information is submitted in a standard format prescribed by the IAEA.

2. Records - The plant operator maintains records to account for all transactions with nuclear material based on measurements. These records are open to review.

3. Reports- The nation reports to the IAEA the amount of nuclear material at each plant and transactions that have occurred since the last report. The IAEA maintains its own accounting records of national inventories.

4. Inspection - The IAEA performs on-site inspections based on independent measurements to verify that records and reports are correct.

The IAEA system is therefore based entirely on verification of plant material control and accounting systems. The IAEA is concerned with two questions regarding material control and accounting:

1. Is the material control and accounting system adequate?

2. Do the records and reports adequately represent the plant's material status?

The first of these questions are asked during the design review performed by the IAEA, where plant characteristics, material handling procedures, and the measurement and accounting system are checked for adequacy. The second question can only be addressed through site visits by IAEA inspectors. Here the inspectors first verify that all records and reports are correct or estimate proper corrections, and second evaluate the material control status, i.e., the material inventories and the material balance uncertainties.

The step-by-step approach used by the inspector is grouped as follows:

1. Verification of item identification (using records and reports supplied by the facility as a reference)

2. Semi-quantitative measurement to detect:

   a. a. Gross defects (complete removal from an item)
   b. b. Medium sized defects (partial removal from an item)

3. Accurate quantitative measurement to detect:

   a. Inflated random error variance
   b. Induced artificial bias

4. Statistical tests to evaluate material control:

   a. Operators MUF*
   b. MUF* adjusted for bias

Item identification consists of a 100% inspection effort to locate every item in the plant. included in "items" are the in-process bulk storage vessels that are not cleaned out for inventory. The qualitative and quantitative measurements are based on a random sampling plan which for each facility usually results in a measurement of 50 to 100% of the material in order to meet IAEA detection criteria. The major quantity of material to be verified is normally contained in items received or shipped and in storage vessels.

An indication of the quality of material control and accounting at facilities satisfying IAEA criteria for adequacy can be obtained by comparing material balance accuracy in these facilities with requirements in the U.S. Table 3.1 shows the IAEA expected accuracies of material balances relative to throughput.

TABLE 3.1. IAEA EXPECTED ACCURACY (STANDARD DEVIATION OF A MATERIAL BALANCE EXPRESSED AS PERCENT OF THROUGHPUT OR INVENTORY)

Facility Type	Expected Operators Accuracy
Uranium Isotope Enrichment	±0.2%
Uranium Fuel Fabrication	*0.3%
Plutonium Fuel Fabrication	±0.5%
Uranium in Power Reactors	*0.2%
Reprocessing, Uranium Line	±0.8%
Reprocessing, Plutonium Line"	±1.0%

*Material unaccounted for.

A comparison with the U.S. regulatory requirements on measurement accuracy (see Table 2.1) shows that U.S. standards are somewhat more demanding than those of the IAEA.

The IAEA, under INFCIRC/153, utilizes containment and surveillance measures to establish the material balance areas and define key measurement points used in the accounting verification. These safeguards measures are designed to guard against material being diverted into unmeasured flow or inventory and against tampering with the IAEA measurements or inventory procedure by the facility. This approach has been exercised in joint programs between the IAEA and the Brookhaven National Laboratory which included a three-month exercise by up to 16 inspectors at the Nuclear Fuel Services, West Valley, New York, reprocessing plant during 1969.(10) For the past five years, the IAEA has been developing automated instrumentation for containment and surveillance such as optical surveillance cameras,[11] gamma sensors or thermocouples to detect unauthorized transfers of material,[12] unattended radiation monitors for surveillance of personnel and packages at portals,(13) and nuclear detectors to monitor isotope concentrations and verify operators reports of flow.[13] The application of seals to discrete containers of SNM is now a conventional safeguards measure in routine use by the IAEA.[11] In addition, the Agency is investigating improved sealing devices such as random fibre optical finger-printing seals that are field readable.

3.2 PHYSICAL SECURITY REQUIREMENTS IN LICENSING REVIEW

In a presidential message dated May 1975,[6] it is stated that the U.S. has adopted a policy that no future license will be issued for the export or re-transfer of more than 5 kg of highly enriched uranium or of more than 2 kg of plutonium or

U-233 unless the government of the recipient country "has an established system of physical security measures acceptable to the United States." We are unaware of any detailed standards of acceptability beyond a statement that they should be "comparable to those imposed domestically." In any case, there may be reasons for classifying the details of methods and, indeed, we are unsure of whether absolute standards can be usefully applied.

The following ERDA statement, drawn from Ref. 7 (page 6-35) provides an account of the current position:

> "It is impossible to define in a concise recipe what physical standards are "adequate," due to the vast differences in the nuclear facilities of the various nations. What the U.S. does is review the foreign nation's physical-security standards in comparison to analogous U.S. standards and evaluate the purpose of each foreign regulation, relating it to its American counterpart. The determination of adequacy must consider such factors as the nature of the installation or facility, the differing levels of protection required, the technical sophistication of the nation involved, cost aspects, and manpower considerations. If the security measures, as enforced in the country, meet the goals of the American standards, then the foreign nation's standards are considered "adequate," because they are deemed to be "comparable." Various factors are thus considered in evaluating the viability of the standards of another nation. In some nations, for example, labor costs are minimal. Manpower is so abundant that primary reliance on human protection is both feasible and desirable from a monetary standpoint. Thus such compensating features as large numbers of trained guards or active and well-coordinated response forces are factors considered when making an overall assessment. In contrast, the U.S. , labor costs are extremely high and mixed security systems employing both manpower and high-technology systems incorporating detection devices, etc. , are in much wider use.
>
> "During visits to countries in question, U.S. experts review the nation's standards for physical security, the measures being employed, and the enforcement of the regulations and make suggestions on the upgrading and improvement of existing systems. The specific procedures followed in determining the adequacy of a nation's physical security measures are

1. Review of the nation’s established requirements for physical security.
2. Comparison of the nation’s physical security with current U.S. measures and guides, and any future modifications thereto, taking into account factors that may be peculiar to a particular nation.
3. When appropriate, a direct request of the recipient government for specific information on matters relevant to the entire area of physical-security.
4. When appropriate, visits to facilities involved with such material by a physical-security review team in order to ascertain that the procedures followed are adequate to the situation in that particular nation.

“In implementing this policy, U.S. physical-security review teams have visited 18 countries during the past year, and visits to some 21 additional nations are planned for 1976. By the end of the year, the U.S. will have made reviews of the physical-security measures of all the major recipients of strategic quantities of U.S. nuclear materials and intends to cover all nations with whom it has Agreements for Cooperation, as well as other nations that might receive trigger-quantities through the U.S.-IAEA Agreement.

“The national-security* policies of the foreign state prevent the U.S. from disclosing such information to the general public. Such unpermitted disclosure would result in an improper breach of confidence and would create at least a stress, if not a rupture, in the nations’ relations with the U.S.

“In addition, valid nondiplomatic reasons exist for not divulging information on the status of physical-security in a nation. Public disclosure would have the immediate effect of broadcasting to the world at large, including interested terrorist organizations, the details of the security system of the various nations. This could be extremely useful information on the hands of subnational groups or terrorists bent on taking advantage of such intelligence.

"Thus most foreign states continue to keep their specific physical-security measures classified and/or under proprietary restrictions. The results of the U.S. visits are therefore classified, at the request of the nations involved, and the U.S. cannot divulge results of the reviews.

Furthermore, the laws and regulations of the various recipient nations as well as the factors peculiar to each recipient nation make it difficult to present even general observations.

"However, foreign nations are actively committed to developing and maintaining adequate physical-security systems. All the countries visited by U.S. physical-security review teams were familiar with the IAEA guidelines on physical protection. Some nations actively participated in the development of the IAEA guidelines. All of these nations have generally accepted them as the basis for their own physical-security systems. However, in many cases, the visits by U.S. physical-security review teams apparently constituted a real impetus to prepare formal regulations and upgrade the physical-security systems, seemingly acting as a catalyst to subsequent security improvements.

"The U.S. physical-security review teams have been uniformly impressed with the positive attitudes of the authorities in each nation visited. Other countries recognize the importance of having a system of adequate physical-security measures and have a strong incentive of their own to assure protection of their own materials and facilities."

4. Safeguards Research and Future Safeguards

Both NRC and ERDA have safeguards R&D programs. ERDA has a responsibility to develop safeguards for the new energy systems that it develops and also to insure that the safeguards for its military and research programs will meet future safeguards goals. On the other hand, the Energy Reorganization Act of 1974 assigned NRC the responsibility for "confirmatory research." So far this has been interpreted to mean that ERDA would support the bulk of the 'hardware research," the technology development, and the demonstration and Testing of safeguards systems in actual facilities, while NRC has put emphasis on systems studies, on the development of analytical techniques, and on programs which should help it to: (1) define safeguards requirements for the facilities that it regulates, and (2) assess not only compliance of these licensees but also the effectiveness of its role in protecting and advancing the interests of the U.S. public. Before attempting to describe this R&D program, it might be useful to briefly review the past.

Safeguards, as such, began to attract official attention in 1957, when the UN voted to establish The International Atomic Energy Agency. Several R & D studies were funded by the Atomic Energy Commission in 1958 and 59, which were primarily addressed to international control or to certain arms control agreements then under consideration. An outstanding safeguards study, which is all but forgotten, was done by Westinghouse for the AEC for one million dollars in 1959. It outlined a system for us safeguards, explored the then available methods for measurement of nuclear materials, developed some new methods, and looked into techniques for physical protection including tamper-resistant recorders and communications. At that point, the AEC lost interest. It supported work on better chemical measurements of nuclear materials and some productive studies of material accounting for nuclear facilities at Battelle in Hanford, Washington. But it was not until 1967, after the big loss of high enriched uranium at Numec and after the US and USSR had agreed on the nuclear non-proliferation treaty, that the AEC finally set up a consistent program of R & D on safeguards.

Until recently, safeguards has not been a matter of high priority to the public or the Congress or the AEC. In the past several years, there has been a greatly renewed interest in the subject of safeguards, and funds to match. But the public and the Congress should not expect that a sudden renewal of interest and money will quickly make up for years of neglect.

The NRC program, as noted above, emphasizes systems studies and the development of methodology to assess safeguards systems and components. The ERDA research, test, and evaluation program will be summarized next. The most important subject for study, which both NRC and ERDA are emphasizing, is that of how to assess and evaluate safeguards systems and subsystems, of how to make cost-benefit analyses involving imagined threats, untested systems (no significant incidents so far) and consequences ranging from zero to very serious.

4.1 The ERDA Safeguards R&D Program

The ERDA R&D program is described in ERDA 76/122, referenced on p. 8 . The subject to be pursued and the estimated costs for fiscal years 1977 and 1978-81 are reproduced in Table 4-1. Items I-IV are relevant here (V relates to ERDA inspections, VII is an NRC-ERDA central computer data system, VIII is international safeguards support, IX is the ERDA/NRC analytical laboratory, and VI, missing from the Table, is the ERDA personnel clearance program) . The following is a summary of the program described in the ERDA Master Plan document:

Task I - Characterize Threat:

‘The product of this task will be the characterization of the capabilities of adversaries, an assessment of probable threats, and the development of a rational way for dealing with them, recognizing that potential human actions cannot be quantified to the same degree as for design failures (reactor safety or reliability). Furthermore, lacking a history of serious hostile acts involving nuclear materials, one has to extrapolate from other experiences of society.”

The task includes studies of adversary activities in other areas which may provide insight into possible nuclear threats; detailed analysis of the possible consequences of successful acts of diversion, theft, or sabotage to threaten or to cause dispersion of radioactivity or detonation of a nuclear explosive; assessment of the resources that an adversary group would need to undertake and to complete such adversary actions; and careful analysis of all of the conceivable ways that an adversary might pursue to gain her or his objectives.

This set of studies is intended to define design threats for the system designer and to identify all of the possible “adversary action sequences” which the safeguards systems should block. It is recognized that society and technology undergo changes with time that affect the nature of the threats. Consequently, the products of this task are to be reviewed periodically.

Task II - Conceptual Design, Development and Analysis:

"Conceptual design, the evaluation of cost and effectiveness of safeguards systems, and the development of new procedures for such evaluations is performed to assure that safeguards funds are allocated for maximum benefit and possible trade-off alternatives are examined. This task is divided into: (1) the development of effectiveness evaluation techniques and, (2) the development of generic concept definitions for fuel cycle facilities."

SAFEGUARDS AND SECURITY PROGRAM RESOURCE REQUIREMENTS

FOR FY-1977 AND FY 1978-81

(Outlays in Millions)

Table 4.1

TASK	FY-77 REQUEST	ESTIMATED RESOURCES FOR FY 78-81*
Operating		
I. Characterize Threat	$ 0,2	$ 005
II. Conceptual Design, Development and Analysis	2.8	4.0
111. Technology, Equipment, & Modular System Development & Test and Evaluation	9.7	33.0
IV. Integrated System Design (Plant Specific)/Installation & Test and Evaluation in Operating Environment	6.3	38.9
V. Assessments and Inspections	0.5	7.2
VII. Nuclear Materials Management and Safeguards System (NMMSS)	0.8	903
VIII. International Activities	0.7	3.8
IX. Safeguards Analytical Laboratory	1.3	5.3
Sub-Total	$ 22.3	102. (P**
Capital Equipment	2.5	14.5
Construction	2,5	2.4
Sub-Total	$ 27.3	118.9
VI. Personnel Clearance Program	10.0	40.0***
TOTAL**	$ 37.3	$ 158.9

*FY 1977 dollars - no escalation reflected in these figures.

**It is imPortant to note that these figures do not include safeguards implementation costs, i.e., the cost of implementing safeguards systems at operating facilities. Such costs are borne by the sponsoring ERDA divisions, and are reflected in their budgets.

***These totals represent the FY 1977 Presidential Budget Commitment Projection.

Taken from ERDA-76/122 (p. 32), **Safeguards** Master Plan

Effectiveness evaluation techniques are necessary in order to assess generic conceptual designs, specific safeguards system designs, and subsystems. Task II lists the following projects and schedules:

1. Effectiveness evaluation models for physical protection of facilities and shipments against overt or covert -threats. Preliminary computer based models have been developed by Brookhaven National Laboratory and the Sandia Laboratories for this purpose. They are being used to assess the effectiveness of physical protection facilities at ERDA facilities and to evaluate safeguards systems being developed by ERDA laboratories. The schedule calls for improvement of these analytical tools as experience is gained (references 1, 2)*.

2. During the last several years, a technique has been developed by a group at the National Bureau of Standards to asses the vulnerability of safeguard systems to adversary actions on the part of facility employees or others permitted access to nuclear facilities. It is known as "Diversion Path Analysis" (reference 3)*. This is a more difficult task for analysis than that described above. The method is being applied to a number of ERDA facilities in order to determine its utility and how it could be improved. The schedule calls for an effective analytical tool, in use, by 1978-80.

   NRC has supported studies of the vulnerability of nuclear power plants to sabotage, at Sandia, and is supporting the development of an effectiveness evaluation, computer-based, model at Sandia for protection of reactors (reference 4)*.

3. The generic safeguards systems designs, described in the Master Plan, are for future privately-owned, nuclear facilities which would process substantial amounts of special nuclear materials, e.g., reprocessing plants, plants to convert plutonium-nitrate to plutonium-oxide, mixed-oxide fuel fabrication facilities, breeder reactors, etc. Although identified as 'generic" designs, the designs are, in fact, quite plant specific and are generated with participation of the commercial plant designers in order to insure that the safeguards features are compatible with operations and to obtain realistic estimates of the costs. Specific facilities which are being or will be studied are: the Allied-General Reprocessing Plant at Barnwell, S.C., the Westinghouse mixed-oxide fuel fabrication plant intended to be located at Anderson, N.C., the "high-performance fuel laboratory" being constructed by ERDA contractors at Richland, Washington, to fabricate breeder-reactor fuel, and the Clinch River Breeder Reactor, proposed for Oak Ridge, Tennessee (reference 5)*.

*See next page for references 1-5.

References:

1. "Simulating Physical Protection Against Overt Attacks at Facilities Using, Processing, or Storing Nuclear Materials." W. Marcuse and J. P. Indusi, Journal of the Institute of Nuclear Materials Management, IV, No. III, 1975.

2. "Safeguards System Effectiveness Modeling," H. A. Bennett, et al. (Sandia), J. Inst. Nuc. Mat. Man. V, No. III, 239, 1976.

3. "Diversion Path Analysis Handbook" (2 vols.), by Nat. Bureau of Standards, Center for Radiation Research. Prepared for US-ERDA Div. of Safeguards and Security, October 1976.

4. "Safety and Security of Nuclear Power Reactors to Acts of Sabotage," D. J. McCloskey, Sandia Lab. report SAND-74-0069.

5. References 54, 55 and 56.* Unclassified papers on safeguards for a mixed-oxide fuel fabrication facility should be issued soon. The general concepts are described in: "Design of Integrated Systems for New Fuel Cycle Plants," J. M. de Montmollin and R. B. Walton, J. Inst. Nuc. Mat. Man., V, No. III, 317, 1976.

*See Reference List at end of this Appendix.

Task II also includes R & D on nuclear materials information systems and on inspection strategies.

Task III- Technology, Equipment and Modular Systems, Development, Test and Evaluation:

"The effort is directed toward the development and test and evaluation of. recommended improvements in technology, equipment, and/or modular subsystems for:

- physical protection;
- material control and accountability; and,
- detection and recovery.

These improvements, when tested and evaluated, are then applied in developing safeguards systems designs for specific types of facilities under Task IV (Figure 4.8, page 45). Specific equipment and subsystems being developed, tested, and evaluated are shown in Figure 4.7, page 44. A comprehensive research, development, test and evaluation implementation plan is contained in Appendix I."

This category includes the large number of safeguards projects concerned with hardware items and techniques. Some of these are relatively highly developed, due to past R & D programs, others will require substantially more research and testing. The general nature and scope of these activities is suggested in the following list of items: In support of physical protection: (1) intrusion detectors and entry control, computer security, effectiveness of barriers, guard equipment and training.

In support of material control and accountability: (1) improved measurement methods, on-line measurement technology, automated sampling and analysis, (2) better standards for analytical and nondestructive assay measurements, (3) improved techniques for measurement quality control, (4) development of measurement systems for advanced, large-scale nuclear facilities.

In support of detection and recovery: (1) mobile diagnostic equipment, and (2) high-resolution detection arrays.

Task IV - Integrated System Design, Installation, Test and Evaluation in Operating Environment:

'Concurrent with the development, test and evaluation discussed in Task III, effort is directed toward the concept definition, development, acquisition*, installation*, and evaluation* of integrated safeguards systems for selected generic classes of facilities. In an operating environment, conceptual systems are then modified to adapt to real work economic and operational constraints and then serve as working-model guidelines for the implementation of alternative systems."

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*in coordination with other ERDA program divisions

In addition to the whole-plant designs described above, ERDA is supporting the design, construction, and testing of a number of subsystems which will be components of such systems. These include: (1) development and implementation of automatic, on-line measurements equipment at the plutonium processing facility at Los Alamos. Items have been installed and tested in the existing, old facility. The new facility, to be operational in 1978, will have a complete system which should provide for material control and accounting on an essentially continuous basis so that material balances can be performed after each shift rather than once every two months, as is presently the case. (2) Design and demonstration of rugged physical protection and tight item control of containers of nuclear materials in vaults (Sandia and Los Alamos), and (3) installation and testing of physical protection techniques at the Sandia Laboratories research reactor.

4.2 Integrated Safeguards, a Summary

The integration of the previously separate safeguards functions of physical protection, and material control and accounting has received major attention during the past years (e.g., References 47, 48, 49)*; and a major ERDA program is now directed to the definition of a systems solution to the Safeguard problem. The program envisages a plantwide system having advanced physical protection mechanisms for deterring and defeating outside attack, comprehensive management of personnel entry and access to sensitive areas, explicit controls on plant procedures to provide the basis for techniques for detecting internal discrepancies, and the use of DYMAC-related accounting procedures. A description of the approach is excerpted from an ERDA paper (Ref. 55)* in the following paragraphs:

Current program objectives have been established as follows:

1. Develop, assess, and assure the availability of cost-effective safeguards systems for application of ERDA facilities and the commercial fuel cycles.

2* Assist the International Atomic Energy Agency (IAEA) in its safeguards role in guarding against the proliferation of nuclear explosive devices and defining effective safeguards internal control and physical protection systems, in conduction with efforts of foreign nations, for guarding against domestic threats to nuclear materials and facilities.

3. Develop, assess, and assure implementation of effective safeguards and information control systems for the protection of special nuclear material, classified information and property at ERDA, selected other US Government and privately-owned facilities.

*see Reference List at the end of this Appendix.

"ERDA's Division of Safeguards and Security (DSS), with the assistance of Sandia Laboratories, Los Alamos Scientific Laboratory (LASL), and Brookhaven National Laboratory (BNL) is developing design concepts for an integrated and balanced facility engineered safeguards system (ESS). The concepts are directed at application to LWR and LMFBR fuel cycle facilities and enrichment facilities. These safeguards systems would make use of the work being conducted under R & D programs to develop methodology, equipment, subsystems, and systems for better protection of SNM and facilities containing SNM.

"The objective of the ESS is cost-effective protection against a wide range of threats, both overt and covert, without causing an unreasonable impact of facility cost or operation. The ESS will interact closely with all aspects of plant operation. The system requires the computer to monitor and verify the integrity of the materials control and physical protection elements before operation can be initiated or to allow further processing to continue.

The ESS contains three interacting components, or centers:

- Personnel control system (PCS).
- Item operations control system (IOCS). .
- Material accountability system (MAS).

"The ESS works, conceptually, by plant or production management assigning a production task to the operations people. The specifics of the task - number of people, names of people, quantities of SNM, material access areas, time windows, etc., are included in the management-authorized work "order. The MAS then interacts with the other two centers and monitors production operations on the basis of the work order information. The MAS verifies location and status of the SNM. The PCS would verify the identity of the workers and permit entry into the work area. Closed-loop control insures all steps in the operation are followed in the authorized sequence and by approved personnel. If an off-normal or unauthorized condition takes place, an alarm is initiated or other appropriate response action is taken. The response is not arbitrary but is determined in advance. Integration with the facility - and the safeguards actions of the ESS - are established by plant management after consulting with the facility designer, processing people, the safeguards staff, and others."

Thus, in addition to providing for advanced management of physical protection and materials control, the system provides an automated management function which may have a major impact on the pervasive problem of detecting and determining thefts by insiders. For example, one main concern is to define in broad terms how the automatic system of safeguards shall handle prevention of theft during non-routine events such as fire, criticality incident, evacuation of injured employee, equipment breakdown, maintenance, etc. Another is the definition of means by which the broad class of administrative thefts by those in responsible positions in a plant can be protected against without substantial interference with plant procedures and without oppressive surveillance.

4.3 IMPROVED MATERIAL BALANCE ACCOUNTING FOR MONITORING COVERT DIVERSION

Improvements in material balance accounting for detecting covert diversion can be achieved in two ways: improving measurement system accuracy and reducing the amount of material in the balance by more frequent inventories. In the following discussion of these improvements the material balance is formed by periodically measuring SNM after it has been removed from the process. Section 4.4 discusses concepts for real-time material control in which the SNM is measured while it is in the process.

improved Measurement System Accuracy

Measurement system accuracy can be improved by more accurate measurements and by reducing the amount of material that is difficult to measure. These difficult-to-measure materials are scrap, waste, and residue remaining in equipment after most material has been removed from the process for inventory. In the late 1960's and early 1970's heavy emphasis was placed on the development of nondestructive assay (NDA) for scrap and waste measurement because in many existing facilities no accurate measurement techniques existed. ERDA support for development of improved NDA has continued at Los Alamos Laboratory (LASL), Lawrence Livermore Laboratory (LLL) and Mound Laboratory[15]* on scrap and waste assay and on the optimization of NDA's potential for prompt, on-line measurement in a real time accounting system. The result has been a significant improvement in ability to measure scrap and waste.[16, 17] This improvement combined with improved process design for higher yields means that scrap and waste measurements are not expected to contribute significantly to material balance uncertainty in future large commercial nuclear facilities.[18] The dominant uncertainties in material balance accounting in these facilities

See Reference List at the end of this Appendix will be the measurement of feed and product by laboratory analytical measurements and, for more frequent material balances, the measurement of equipment residue. This is the case even though laboratory analytical measurements are the most precise and accurate techniques available.*

ERDA is supporting the development of improved and automated analytical measurements at New Brunswick Laboratory (NBL), LLL, and LASL.[15] However, a recent survey[16] of measurement accuracy shows a significant difference in the accuracies achievable in production facilities compared to those achieved in research and development laboratories. Improvement of production accuracy to best R&D laboratory accuracy would reduce material balance uncertainty by approximately a factor of three to five, i.e., from 0.5% to 0.2% or 0.1% of flow for non-reprocessing plants and from 1% to 0.3% or 0.2% for reprocessing plants. To put these accuracies in perspective, the standard reference materials provided by the National Bureau of Standards and against which all measurements are ultimately calibrated have an uncertainty of approximately ±0.06%.[20] Thus, to achieve these improvements in production facilities would mean elimination of nearly all other sources of measurement error, such as errors arising from non-homogeneity of the sampled material, vessel volume uncertainties and actual sampling errors.

Improved analytical measurements would not be useful in reducing the uncertainty in frequent material balances unless a Parallel gain were made in measuring equipment residue. NRC has supported work at Argonne National Laboratory that resulted in guidance on equipment design to minimize this problem.[21,22]

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*These laboratory techniques such as gravimetry, electrochemistry, and mass spectrometry have one standard deviation accuracies from 0.05% to .5% whereas NDA of scrap and waste is only accurate to 1% to 5% and 5% to 15%, respectively. However, feed and product account for greater than 90% of the material in the balance whereas scrap and waste account for only 1% to 5% and 0.25% to 1%, respectively.

However, in large plutonium facilities approximately five kilograms of the material in a material balance may be residue remaining after clean-out for inventory. Recent NDA measurements of plutonium equipment residue (23, 24) made in accordance with NRC guides (25) have demonstrated uncertainties from 10% up to 50%. The best accuracy might reduce the residue contribution to the material balance uncertainty to approximately 0.5 kilograms for large facilities.

Increased Material Balance Frequency

The absolute uncertainty in a measured material balance is proportional to the amount of material measured and this, in turn, is proportional to the time interval between material balances. Thus, the more frequent the material balance, the lower the absolute uncertainty in each inventory period. In addition, reducing the time between material balances improves the timeliness of accounting and, in the limit of real-time accounting, means that information would be avail to detect diversion in time to permit more prompt remedial action. Calculations of frequent material balance uncertainties for future large commercial plutonium facilities were performed as part of the NRC Special Safeguards Studies. (26) The theoretical calculations indicated that considerable reduction in material balance uncertainty could be achieved for both fuel fabrication plants and reprocessing plants through taking frequent inventories. However, these material balances are based on inventories requiring the shut-down and clean-out of the process and therefore result in considerable lost production. In the fabrication plant, inventories conducted in a dynamic sequential manner (27) around batches of material would fit naturally in with normal operation. In the reprocessing plant approximately two weeks would be lost per inventory plus one or two weeks during which the process would not operate at peak efficiency due to shut-down and start-up. Dynamic inventory techniques for reprocessing plants based on introduction of a tracer isotope to separate the continuous stream into batches of material have been studied theoretically at Argonne National Laboratory. (28) This technique would not require shut-down of the process and could be used for material balances around batches of material that would naturally exist in a reprocessing facility. However, there has been no demonstration of such dynamic inventories of liquid processes.

Conclusions on improving the Accuracy Of Accounting

Improvements in material balance accounting can be achieved by improving the accuracy of laboratory analytical techniques and NDA of equipment residue (assuming waste and scrap generation are minimized). Further improvement will result from increased material balance frequency. However, frequent material balances could have an unacceptably severe impact on plant operation and plant economics. Computer based accounting systems that could process data in real-time for these frequent material balances have been studied. (29)

The necessary improvements in measurement accuracy and material balance frequency can only be determined once an absolute threshold for diversion detection has been established. NRC postulates that an accounting system having a LEMUF of 2 kg plutonium could give assurance that material for even a single weapon had not been diverted. The Appendix suggests that the risk of removing more than a kilogram at this LEMUF is significant. improved nuclear materials accounting systems could be configured to detect approximately two kilogram thefts of plutonium for large mixed oxide fuel fabrication plants. Equally effective accounting in large reprocessing plants such as the still unlicensed AGNS plant at Barnwell, S.C. appear infeasible, unless real-time material control can be achieved.

Material accountancy thus cannot be relied upon, now or in the future, as the sole safeguards measure, either in national or international safeguards. For IAEA safeguards, containment and surveillance must come to play more than a supplementary role (see Volume I, Chapter VIII, especially pages 206-207 and 209-211); for U.S. domestic safeguards, physical security and material control must continue to play vital roles.

4.4 REAL-TIME MATERIAL CONTROL

RETIMAC

In the preceding section on improved material balance accounting, material balances which might be performed monthly, biweekly or even weekly were discussed. These might be performed using on-line computers to acquire, process and store much of the measured data on material quantities. Real-time material control would include performing material balances even more rapidly (daily, end of shift, or nearly instantaneously), and it would involve even more extensive use of on-line computers. In addition, real-time material control offers the possibility of generating a variety of diversion indicators which are derived, not from material balances, but rather from data on the material processes.

To obtain material balances more rapidly, it is necessary to maintain running accounts of material transfers and to perform rapid inventories of materials in process* and in storage. These materials include the mainstream feed and product materials as well as the sidestreams of clean scrap, dirty scrap, solid waste, liquid waste and analytical sample materials. The accuracy of more timely determinations of material transfers and inventories varies considerably depending on the method and on the material. There are two general methods for obtaining such determinations: direct on-line assay measurements and the use of indirect on-line measurements together with process models to estimate material quantities.

The most general concept of real-time material control has evolved in a series of four papers (30) by T. E. Shea of NRC. Shea's concept, which in his first three papers is called RETIMAC (REal-TIme MAterial Control) has evolved to consist of the following four elements:

*Here in-process materials refer to all materials not in storage, and include residual holdup or heels, and materials in transit to, from and between processes.

- Material Isolation - use of barriers to limit operator contact with material to only non-routine operations which would be performed under intensified surveillance.

- Inventory Control - use of process control for unit processes to detect anomolous operations which may indicate diversions; use of storage control for vaults and buffer storages to restrict access to stored materials; and use of internal transfer control to protect materials being transferred between unit processes as well as into and out of storage.

- Inventory Characterization - use of on-line instrumentation to assay material flow streams into and out of unit processes; use of on-line instrumentation to monitor process parameters together with appropriate process models to estimate in-process inventories; and use of on-line instrumentation to perform in situ assay of residual holdup in process equipment after runout or cleanout.

- Inventory Containment Analysis - use of an appropriate hierarchy of computers and detailed models to perform real-time analysis of all data acquired to detect diversions as promptly and as credibly as possible.

As part of the NRC's Special Safeguards Study, Lawrence Livermore Laboratory[31] and Science Applications, Inc.[32] examined how the RETIMAC concept might be implemented in a future high-throughput mixed-oxide fuel fabrication plant like the one planned by Westinghouse for construction near Anderson, South Carolina. Based on these two studies, researchers concluded[30] that "timely, localized detection systems can be designed to substantially improve the detection sensitivity for covert theft over the systems currently required in U.S. licensed processing facilities. Further, this capability can be cost-effective and provide many corollary benefits to other plant operational systems."

Science Applications, Inc. later performed a similar, but less extensive, study for a high-throughput spent-fuel reprocessing plant similar to the one being built by Allied-General Nuclear Services near Barnwell, South Carolina. The results[33,34] of this study showed that the diversion detection sensitivity associated with rapid material accounting is less for the reprocessing plant than for the fabrication plant.

One of the key components of real-time material control as envisioned for RETIMAC is the use of process models together with certain limited measurements to estimate quantities of interest, such as in-process inventories. Related modeling work has been reported in a number of recent papers[35,36,37,38,39,40,41,42] Further development of the concepts is presently underway at Lawrence Livermore Laboratory.

Another real-time material control concept, called DYMAC (for DYnamic MAterials Control), is being developed and implemented at Los Alamos Scientific Laboratory[43] (LASL) . DYMAC is a system of in-plant nondestructive assay (NDA) instrumentation coupled with automated data processing equipment to provide essentially real-time accounting and material control on a unit process basis. DYMAC consists of four subsystems.

- NDA Instrumentation - on-line NDA instrumentation to assay a variety of materials, with design emphasis on automation to minimize operator action, built-in calibration capability, improved precision and accuracy, operational compatibility, reliability and maintainability.

- Data Acquisition - NDA instrumentation coupled directly or through minicomputers or microprocessors to a central computer; operator inputs to the central computer using a variety of terminals ranging from a few control buttons to a fully interactive video display with hard copy capability.

- Data Base Management - central computer hardware and software to organize incoming data into a file structure for retrieval in an efficient manner.

- Real-Tine Accountability - using the data base, performs unit process accounting for all material in plant by calculating current inventories for each area, MUF and LEMUF by unit process area and by material batch, and control limits; monitors for deviations outside control limits and for incomplete internal material transfers; maintains the standards and measurement control program; and generates printed reports.

DYMAC is being implemented at LASL in three phases. In phase 1, the present LASL plutonium facility at the DP site is being used as a test bed for component development and operator training. This work includes evaluation of on-line NDA instrument performance, upgrading of off-line NDA instruments and operation of a prototype four-terminal accountability system for one unit process accounting area. Phase 11 is the design and installation of a DYMAC system for the new plutonium processing facility (TA-55) which is presently under construction at LASL. This system, designated DYMAC/TA-55, tentatively consists of 15 unit process accounting areas with 20 to 30 terminals, 25 weighing devices and 20 to 30 NDA instruments. Installation of DYMAC/TA-55 is scheduled for June 1978. Phase 111 is a program to evaluate the performance of

DYMAC/TA- 55. Operation of DYMAC/TA-55 in the new LASL plutonium processing facility is intended to demonstrate:

- reliability and operational feasibility of on-line NDA instrumentation in a production environment,
- accurate and efficient data collection,
- common data base management,
- timely sensitivity to missing nuclear material, and
- capability for production control, quality assurance, and financial management.

In addition to the above work, the concept of real-time material control has been examined [44] in some detail by J. E. Lovett of IAEA. More recently, Lovett has discussed [45] the international safeguards aspects of real-time material control.

In summary, considerable development work and in-plant demonstration is required before the effectiveness **and costs** of real-time material control can be fully assessed.

4.5 HARDENED FACILITIES

Hardening the physical protection system of nuclear facilities against outsider attacks can be accomplished by making three general types of improvements.

- Use of more and/or better protective mechanisms,
- Better integration of the protective mechanisms,
- Upgrading quality assurance for the protective mechanisms and the integrated system.

The protective mechanisms referred to are the security force, security procedures, and security hardware and software. In addition, certain aspects of facility design such as the physical layout, the construction of walls, doors and roofs, the extent to which the facility is underground, and some facility procedures like emergency plans can have direct impact on the overall effectiveness of the physical protection system against outsider attack. The design and evaluation of such systems is addressed in a later section. Here, some of the recent developments in improved protective mechanisms for physical protection are summarized. Much of the information presented here is from four recent review papers by O.E. Jones [50,51] of Sandia Laboratories, H.J.C. Kouts [52] of NRC*, and J.J. Bastin and E.A. Conrads [53] of Westinghouse.

Development of advanced security devices and systems is sponsored by a number of federal agencies such as ERDA, Air Force, Army, Navy, Defense Nuclear Agency and Federal Aviation Administration. Probably the largest program with direct applicability

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* Now at Brookhaven National Laboratory.

to nuclear safeguards is at Sandia Laboratories under the primary sponsorship of ERDA. Some of this work was documented[54,55,56] recently for NRC's Special Safeguards Study.

Many of the protective mechanisms which have been under study are listed below by functional category.

- Portal Control (verification of personnel identity): devices based on unique human characteristics, including fingerprints, handwriting and voice prints–photograph retrieval from facility storage for comparison with appearance.

- Portal Control (search for SNM and explosives): detectors for SNM--search-dogs or other animals, and devices which examine individual absorption lines in the ultraviolet region for explosives search.

- Intrusion Alarms: CCTV with automatic motion detection alarm -- buried line sensors (magnetic, seismic, and pressure) -- free-standing sensors (infrared, microwave and radar) -- fence-mounted sensors (vibration and tilt) -- sensors in coincidence to reduce false alarm rate -- reduced vulnerability to tampering.

- Surveillance and Assessment: CCTV with alarm-actuated video tape recorder -- low-light level CCTV -- moving-target radar.

- Passive Barriers: explosion resistant doors -- vehicle barriers -- alarm-actuated closing and locking of doors.

- Active Barriers: dispersal of foam,smoke, tear gas or other such agents to delay attackers.

- Guards: motivation -- training -- deployment plans.

- Communication and Control Center: protected and supervised data lines -- message authentication -- hardened area -- computerized preprogrammed response to alarms, with manual override.

In addition to the above items, several systems, such as an advanced item control system for a SNM storage vault (51) and an integrated portal control system, (57) have been developed. Also recent studies were performed which focused on special topics, such as security forces (58) and psychological deterrents. (59)

4.6 TRANSPORTATION SAFEGUARDS

Most of the SSNM transported today (excluding shipments of nuclear weapons) involves government-owned materials moving between contractor/licensee plants. The majority of these shipments had been carried out by commercial transportation companies* operating under Interstate Commerce Commission authority and in accordance with the transportation requirements specified in 1OCFR73[60]. The present traffic level is of the order of hundreds of shipments per year. As the nuclear industry matures, this picture may change in the following ways:

- An order of magnitude increase in the traffic level could occur by the year 2000.[61]
- A significant fraction of the future traffic level could involve commercially owned SSNM for nuclear power applications.

In preparation for this possible expansion in transportation activity involving commercially owned SSNM, the Nuclear Regulatory Commission has supported efforts to assess the effectiveness of existing and future transportation safeguards. In addition, ERDA has an active development program underway at Sandia and other laboratories to develop new safeguards technologies for transportation links. NRC and ERDA are coordinating their research in this area; they are also monitoring efforts by agencies within the Department of Defense that are working on related problems.[62]

Efforts to improve the effectiveness of transportation safeguards include the following:[61,62,63]

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*A federally owned and operated transportation system for government-owned materials is scheduled to go into full operation by late 1976.

1. Immobilization system to bring cargo vehicles to a controlled stop and prevent further vehicle movement.

2. Cargo access denial measures to impede penetration of the vehicle and the possible use of devices which would affect an intruder's senses.

3. Driver protection during attack.

4. Effective communications between vehicle and control center during shipment.

5. Use denial techniques to despoil SNM and convert it to a form which requires additional processing for use as an explosive.

6. Develop evaluation methods to determine the nature and extent of the resources and tactics required to successfully defend against an attack on a shipment.

Research on transportation safeguards has already produced results, some of which are described in the technical literature. Much of it concerns hardened cargo vehicle design and improved communications. Portions of the work are classified. Some of the new technology will be introduced into the ERDA Safe-Secure Transportation System for tests under actual operating conditions.(51,64)

An obvious means of reducing the risk of diversion of SSNM during shipment is to minimize or eliminate transportation of SSNM by collocation plants. This concept has been studied by NRC. The results are published in the "Nuclear Energy Center Site Survey--1975 ."(65)

NRC's conclusions relating to transportation are summarized in the following statement:

> "Collocation, by eliminating some transportation links or shortening others, can thus have beneficial effects on safeguards. This is not to say, however, that collocation is necessary in order to achieve an adequate level of security. The analysis performed in the Special Safeguards Study shows that transportation of SSNM can be made secure with bearable costs." (65)

The following is taken directly from Reference 65:

1. "Collocation's principal consequence for safeguards is that it minimizes transportation. The question of whether collocation is desirable from the safeguards point of view initially becomes one of comparing the effectiveness and costs of fixed-site and in-transit safeguards."

2. "Fixed sites have the advantage of being able to utilize a sequence of barriers and detection systems. Also, a fixed site typically can depend on a local response force of known size and capability. A major disadvantage of fixed sites is that some personnel must be authorized to have access to both SSNM and vital areas. This compounds the security problem with respect to both the disaffected insider and the outside attacker (who may have inside cooperation) . The need to provide emergency exits to insure the safety of personnel again complicates security and adds to.. the cost of providing barrier integrity adequate against an outside attack."

3. "The primary advantage of an in-transit security system is that the adversary may not know where the shipment will be at any given time, Also, an in-transit system does not suffer from any requirement for personnel access to SSNM. The in-transit security system has the disadvantages that there are fewer opportunities for using multiple barriers or adversary detection systems and that the availability and characteristics of an immediate response force are less well defined. It should be noted, however, that technologies are being developed which will allow transporter systems to impose reasonable delay times on adversary force by applying sophisticated barrier and delay techniques to either or both the transporter and the SSNM container. The in-transit system has somewhat greater exposure to sabotage attempts."

4. "The element of a security system which offers the greatest degree of flexibility is the guard, or, in an in-transit "system, the escort force. The size and structure of this force can be altered to meet the needs of the security systems. The in-transit

security force can be structured to react to a threat in either of two ways: by calling for assistance and delaying the adversary forces until assistance arrives, or by attempting by itself to defeat the adversary. In the first case, the amount of delay required from the escorts must be equal to' or greater than the time required for a response force to arrive. If there is no planned response force, as in the latter case, then the escort force must be strengthened so it can win an engagement with the adversary group."

5. "It is concluded that collocation might have a beneficial effect on safeguards effectiveness; however, transportation safeguards considerations do not preclude dispersed siting."

6. "The cost of safeguards in SSNM transportation would be decreased by collocations."

   "A model for the year 1990 which compares collocated and dispersed facilities having total capacities corresponding to 342 MWe and 80% plutonium recycle projects a total (country-wide) annual cost saving from collocation of $1.7 million (in 1975 dollars). (Cf. total annual fuel cycle facility operating costs of $440 million.)"

7. "With respect to safeguards for the fixed facilities, no significant cost differences between dispersed and collocated models are estimated to exist."

The basis of the NRC's conclusions is not regarded as persuasive by many observers. These observers hold that a systematic study of the costs and benefits of collocating fuel cycle facilities has not yet been done.

4.7 REDUCING THE "ATTRACTIVENESS" OF NUCLEAR MATERIAL IN THE FUEL CYCLE

Since the beginning of the nuclear age, one of the more alluring ideas to safeguard nuclear material has been to denature it. Conceptually, the ideal denaturing agent renders the fissile material useless for nuclear weapons without significantly impairing its performance as a reactor fuel. This is practically achievable with uranium by keeping the U-235 (or U-233) concentration sufficiently low in mixtures with U-238. Weapons grade uranium can then only be attained by isotopic enrichment -- a non-trivial undertaking.

An analogous situation does not exist for the other possible weapon material constituent, plutonium-239. There are minor fraction concentrations of other isotopes of plutonium (Pu-240, Pu-242) naturally occuring in reactor produced plutonium. These isotopes do not however, prevent the use of the plutonium as a nuclear explosive. (See Volume 1, Chapter VI.)

plutonium (as well as highly enriched uranium) can, however, be made less attractive radioactively and/or chemically (66 ,67, 68) . The two generic possibilities are often termed:

1. Spiking - the plutonium bearing material is made more radioactive, possibly requiring remote handling and massive shielding.*

2. Blending - the plutonium concentration is lowered by mixing with uranium.

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*^{233}U typically has a natural spike with the inclusion o parts per million quantities of the highly radioactive ^{232}U and daughter products.

Either one of these possibilities are primarily deterrants against a subnational threat. A national entity could easily provide the necessary remote handling, shielding, and chemical separation that might be required.

There are a number of possible methods of making plutonium bearing material radioactively lethal or at least very dangerous. Four spiking techniques are listed in Table 4.3 along with a listing of some specific advantages and disadvantages for each.

Spiking has some additional general assets along with at least three major liabilities. The general assets (which may be negated by countermeasures) include:

- Facilitates detection of Pu in plant (by portal monitors, etc.)
- Assists in recovery operations if Pu is stolen

The liabilities are:

1. The additional costs and potential accident hazards for the required normal handling of spiked nuclear material.
2. The legal aspects associated with adding a potentially lethal substance to protect property.
3. The violation of the "as low as practical" radiation safety philosophy.
4. The increased risk associated with possible sabotage particularly for very high spiking levels.

Although definitive studies have not been performed to accurately pinpoint how much all the additional costs would be for each of the spiking techniques listed in Table 4.3 it is clear that in some cases they may be extensive, particularly if remote maintenance is required. Reference 68 concluded

TABLE 4.3

SPIKING OPTIONS

TECHNIQUE	ADVANTAGES	DISADVANTAGES
1. Partial Decontamination from Fission Products in the Reprocessing Plant.	Utilizes readily available radioactive sources. Intimate mix with Pu.	No fission product with sufficient radiation intensity for long enough period (2 years or more half life). The complexity of reprocessing increases. Possible impact on mixed-oxide fuel performance. Conflicts with "As Low As Practicable" (ALAP) radiation philosophy. Increased costs.
2. Intimate mix of high intensity radioactive source with Pu product.	Current reprocessing flow sheets unchanged. Source strength easily controlled. Intimate mix with Pu.	Costly. ALAP conflict.
3. Tamper-resistant self-contained gamma-ray source placed in product.	Reprocessing steps not affected. Lower cost than other techniques. Sources reuseable.	Protection reduced because activity not intimately mixed with product. Difficult to protect in process material.
4. Irradiate Pu product.	Intimate mix with Pu. Reprocessing steps not affected.	Costly. May not have sufficient radiation source available. ALAP conflict.

that a major cost increase (fabricating spiked fuel) might amount to as much as approximately 2% of the power cost for LWRs and nearly 4% of power costs for HTGRs. The AIF study ([66]) concluded that the spiking liabilities outweighed the possible safeguards gains.

Spiking does not appear to be cost-effective compared to massive containment and stringent physical security.

Blending alternatives to reduce material attractiveness have received more industrial support than the spiking option ([66,69]). Basically, the blending of uranium with plutonium accomplishes what eventually occurs within every fuel fabrication plant. The technique for blending, i.e. , wet blending, dry blending, and the degree of blending, are all possible variables. The net safeguard result is that a larger total quantity of material would have to be diverted to obtain a strategic quantity of plutonium. To utilize the strategic quantity of plutonium in a nuclear explosive would require a chemical separation of the plutonium from the uranium. This may be a substantial barrier for a subnational group. For a national entity with available resources, blended material might cause some delay in the construction of a weapon, but would not constitute a serious barrier.

Various degrees of blending, all accomplished at a reprocessing plant, have received consideration.

1. <u>Dilute Blend</u>

All light water reactor recycle fuel would contain from 0.2 to 0.6% plutonium: This could be accomplished by never separating the plutonium and uranium in the reprocessed spent fuel. An inherent advantage of this proposal is the most effective utilization of the plutonium. On the other hand, significant cost and safety liabilities accrue at the fuel fabrication plant, particularly if the plant were originally built to handle only uranium.

2. Custom Blend

In this case the blend contains from 2 to 5% plutonium that could in principle be directly utilized by the recycle fuel fabrication in the manufacture of the recycle fuel. A problem here is that the blended material would have to meet the individual fuel manufacturers specifications and quality assurance tests. This is not a practical option if custom blends have to be prepared for a number of recycle fuel manufacturers.

3. Master Blend

Here the blend might vary from 30% down to possibly as low as 7%[69] plutonium. The master blend would then be shipped to the fuel fabricator and further diluted and processed as the fabricator requires to suit his manufacturing process. A 20% to 30% master blend concept has received the endorsement of the AIF study group ([66]) as providing "the best balance between risk reduction and economics in these steps in the fuel cycle."

4.8 REDUCING THE RISK OF NATIONAL DIVERSION--MULTINATIONAL FUEL CENTERS

The concept of regional fuel cycle centers (RFCC) has been developed and advocated in the context of several world issues: how to provide the institutional structure for smaller nations to obtain the presumed benefits of fuel recycling, how to assure the security of sensitive nuclear material, and how to efficiently dispose of nuclear waste. The most recent and thorough review of the RFCC concept is being made by the IAEA. (70) Other literature dedicated to this subject has typically been directed to a policy level rather than enumerating the practical aspects of initiating a program. It is felt that the final IAEA report*will serve as the backbone of operational RFCC's, should they be implemented, largely because it relies on experience gained in previous international ventures such as EUROCHEMIC, URENCO and EURODIF for practical understanding,

The study says the RFCC concept envisages countries joining together for the purpose of constructing and operating facilities which are required for the following activities:

- Transport of spent fuel from reactor sites to the RFCC
- Storage of spent fuel
- Reprocessing of spent fuel
- Storage of resulting waste products and re-usable fissionable material
- Treatment of waste
- Conversion and fabrication of fissionable materials into new fuel elements
- Transport of new elements to reactor operators
- Long-term waste management.

The RFCC concept is not dependent on regional groupings in a narrow geographical sense. If the fuel enters or leaves the

*(Ref.: Regional Nuclear Fuel Cycle Centers, Vol. 1, Summary 1977 Report of the IAEA Study Project, International Atomic Energy Agency, Vienna, 1977, STI/PUB/445)

RFCC in a secure form, transport distance per se should not dictate service **only** to contiguous or nearby countries, Nor is the concept necessarily dependent on establishment of entirely new facilities; centers like Windscale (U.K.), La Hague (France) and Barnwell NFP (U.S.A.) could serve as the core of RFCC's. The processes listed above may be provided at an RFCC as demand arises.

The RFCC concept is one of concentrating facilities and does not imply the introduction of new processes. Typical basic criteria of an RFCC are shown in Table 4.4 and illustrated in Figure 4.1. The criteria are essentially comparable, from the standpoint of safeguards and security of the physical processes involved, to any other fuel cycle center. Therefore, implementation of RFCC's depends primarily on international acceptance of the need for reprocessing, international cooperation given a decision to reprocess, and the economies (and disadvantages) of scale.

The RFCC Study has identified these main topics for international discussions:

1. Legal status and structures
2. Governmental/non-governmental roles
3. Internal administrative structure
4. Commercial/service roles
5. Industrial arrangements
6. Technology (use, control, etc.)
7. Financial (basic policy considerations)
8. Privileges and guarantees
9. Membership, duration, etc.
10. International agreements

Assuming that institutional agreements can be successfully arrived at, there is good reason to expect RFCC's will reduce the risk of national misuse of fuel cycle centers. Clearly, the RFCC must work well enough for all concerned parties so that no recourse to national facilities is deemed necessary. Several other points for U.S. consideration are raised in this connection:

Table 4.4. Regional Nuclear Fuel Cycle Center
Basic Criteria--Phase 1 Study

CONSIDERATION		SIMPLIFYING ASSUMPTIONS
1.	Time Period	1985 to 2000
2.	Capacity of Reprocessing Plants	750 to 3000 Tonnes/yr
3.	Forecast of reactor capacity based on mixed oxide fuel	200 MWe to 1200 MWe
	Size of reactors	200 MWe to 1200 MWe
	No. of reactors	Determined by reprocessing plant capacity, and reactor size
4.	Types of Reactors	LWR--80 to 100% of total installed capacity HWR--0 to 20% of total installed capacity
5.	Fuel cycle Characteristics	Pu recycle to be considered. Also deferred fuel reprocessing.
6.	No. of Reprocessing Plants	1 to 3 per region initially
7.	Fuel Fabrication:	
	UO_2 fuel	outside of center as well as at the center
	- Mixed Oxide Fuel	only at center
	Manufacturing capacity	Determined by the installed electrical generating capacity.
8.	Fuel requirements:	
	- Uranium	Annual requirement Integrated total requirement
	- Enrichment plant	Capacity based on: Pu recycle Deferred reprocessing

Table 4.4. Regional Nuclear Fuel Cycle Center
Basic Criteria--Phase 1 Study (Contd.)

CONSIDERATION	SIMPLIFYING ASSUMPTIONS
9. Spent Fuel Storage	
- At reactor site	1 to 10 years
- At the center	1 to 10 years Adequate to satisfy optimal fuel reprocessing plant capacity. Alternately, when breeder requirement for Pu demands reprocessing of spent fuel, say 1995 (i. e. , 10 years storage)
10. Pu Storage	Up to 1995 if no Pu recycle occurs. Thereafter additional Pu storage capacity not neces-sary because of its use in breeders.
11. Radioactive waste management	
- From reprocessing plant	Waste solidification at center
- From fuel refabrication plant	Waste solidification at center
- From power reactors	Processing at reactor site, hence not to be considered.
12. Waste storage or disposal	Retrievable storage at center or elsewhere after solidification for long term For short term up to 10 years, most economical method Ultimate disposal at center or at remote location
13. Transport	
- For spent fuel	In casks according to regu-lations recommended by IAEA. By road, rail and sea.
- For radioactive waste and H.L.	According to regulations recommended by IAEA By road, rail and sea.
14. Discount rate	10%

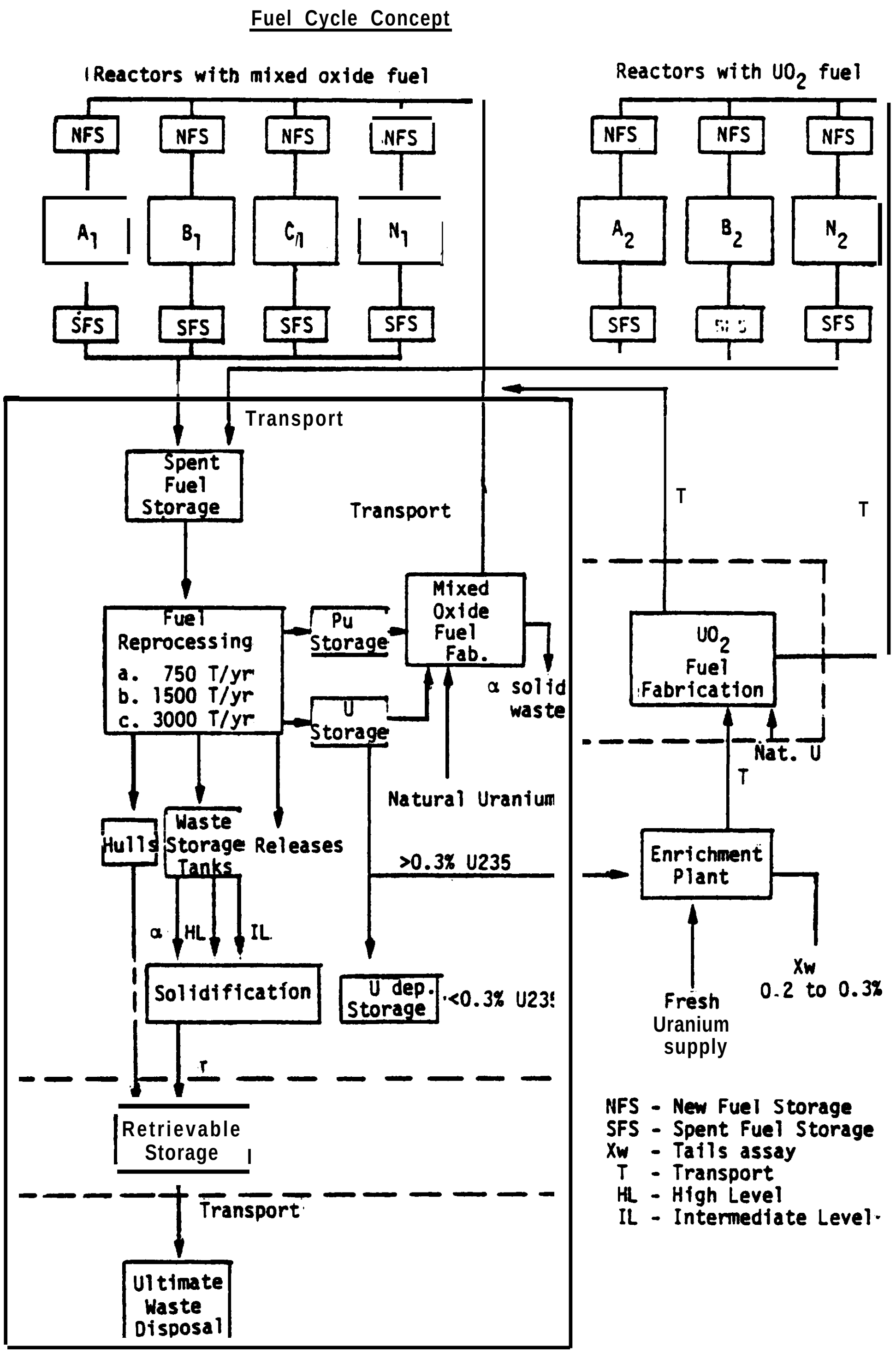
Fuel Cycle Concept
Reactors with mixed oxide fuel
Reactors with UO2 fuel
NFS
A1
B1
C1
N1
A2
B2
N2
SFS
Transport
Spent Fuel Storage
Transport
T
T
Mixed Oxide Fuel Fab.
Fuel Reprocessing
a. 750 T/yr
b. 1500 T/yr
c. 3000 T/yr
Pu Storage
U Storage
α solid waste
UO2 Fuel Fabrication
Nat. U
T
Natural Uranium
Hulls
Waste Storage Tanks
Releases
>0.3% U235
Enrichment Plant
α
HL
IL
Solidification
U dep. Storage
Xw
0.2 to 0.3%
Fresh Uranium supply
Retrievable Storage
Transport
Ultimate Waste Disposal
NFS - New Fuel Storage
SFS - Spent Fuel Storage
Xw - Tails assay
T - Transport
HL - High Level
IL - Intermediate Level

Figure 4.1

- Sponsors should proceed on the premise that the nature of the RFCC operations will require a substantial degree of governmental involvement. Definite matters of government discretion are (a) the nature of services available to non-partners, (b) the extent to which partners shall fund an RFCC and (c) the disposal of radioactive waste.
- Who shall construct and maintain the plant(s)? Are standardized components an issue?
- Suppliers and/or partners may wish to have technical information remain proprietary or classified.

Thus, the potential benefits of the RFCC concept are that it is a rational use of scarce (and sometimes insufficient) technological and financial resources, that collocation and multi-party interest in the plant could provide a new dimension of safeguards and physical protection of materials wit-h the interest of all partner States in mind, and that the RFCC provides an avenue for effective and safe management of radioactive waste.

There remains much work to be done before these benefits can be weighed against the counterbalancing concerns. A partial list of the latter would include the procedures for management and control among a group of users with common but not identical interests, the acceptability of the waste and effluent liabilities by potential host countries, and (implicit in the whole concept), the need to formulate the institutions in such a way that it would be apparent to the partners that future fuel supplies are assured.

4.9 THE COSTS OF SAFEGUARDS

The costs of safeguards have been estimated by several organizations during the past two years (Refs. (71, 72, 51). The primary breakdown is in: (a) the incremental capital costs of industrial facilities above those for the case where plants are built to normal unsafeguarded standards, and (b) the additional operating costs (e.g., guards) associated with safeguards implementation.

As a general thesis, since the cost of the primary fuel is only a small fraction of the cost of delivered electricity and since safeguards should not increase fuel costs by more than a fraction, we should expect that safeguards will increase the overall cost of electricity by only a small margin. The three studies referenced above all indicate that given a mature nuclear industry, the fractional increase in the cost of delivered electricity due to safeguards is of the order of 1%. However, the absolute annual cost of safeguards is estimated in the range of hundreds of millions to more than a billion dollars. Furthermore, there is a considerable spread in the estimates of the cost of safeguards given by the three referenced sources. As an example of physical protection costs alone, we reproduce results from Ref. 51 in Table 4.5.

These results were developed by Sandia Laboratories for NRC: a mathematical interpolation (based on assuming the industry works at 60% load factor] leads to the conclusion that in 1990 a little over $1 billion out of a $70 billion electrical utility income could be spent on safeguards.

The report of Ref. 71 by E.R. Johnson Associates develops a somewhat lower figure for costs. Given a 500 GWe nuclear power component (at that time projected for the early 1990's, according to Table 4.5.1)* they estimate an annual safeguards

*present projections are lower. See Volume I, Chapter X.

Table 4.5. Projected Costs* of Physical Protection Safeguards for U.S. Nuclear Fuel Cycle Utilizing 80% Pu Recycle

(in 1975 Dollars)

Year	Total Electric Power, GW_e †	Percent Nuclear †	Total Protection Personnel ‡	Safeguards Costs, Mil/KWH Facilities	Safeguards Costs, Mil/KWH Transportation §	Percent of Base Cost Facilities	Percent of Base Cost Transportation §
1980	655	13	7,200	0.49	—	3.8	—
1985	800	29	10,800	0.27	0.005	2.1	0.04
1990	1040	39	15,200	0.21	0.004	1.6	0.03
2000	1575	54	25,800	0.17	0.002	1.3	0.02

*Includes all amortized capital, personnel, and Maintenance costs, and assumes a base electricity cost of 13 mils/kwh.

†Based on Case A projections of Nuclear Power for Growth 1974-2000. WASH-1139(74), USERDA, Office of Planning and Analysis, February 1974. Present projections are considerably lower. See Volume I Chapter X.

‡ Compares to 1975 local law enforcement agency total of 505,011.

§ Transportation cost represent an upper bound due to inclusion of HTGR HEU shipments.

cost of $580 million for a plutonium recycle LWR system or an approximately 1% increment on the total cost of all electricity in this time-frame. The same report estimates that in the absence of plutonium recycle, annual costs would be 25% less at $430 million.

Thus, there is no evidence that economic impact of safeguards on the consumer will be substantial. However, the impact on selected portions of the nuclear industry, such as reprocessing plants and recycle fuel fabrication plants, may reconsiderable. The accuracy of an estimate of this impact is fraught with uncertainties such as the specific process employed and the specific safeguards techniques deployed in protecting the SSNM.

4.10 DESIGN AND EVALUATION

Safeguards system designs in the U.S. are presently developed to meet the NRC regulations that are published in Title 10 of the U.S. Code of Federal Regulations. The implementation of these regulations for specific facilities is assisted by the use of U.S. NRC Regulatory Guides. The licensee or applicant submits a plan for compliance with the regulations which is then evaluated by the NRC staff. Except in those cases in which the applicant or licensee proposes an alternative method, the NRC staff utilizes the methods described in the guides in evaluating an applicant's or licensee's capability for and performance in complying with specified portions of the Commission's regulations. The Regulatory Guides are not, however, substitutes for regulations and a literal compliance with them is not required. Judgment by the NRC staff is the basis for resolving detailed licensing issues.

The future nuclear regulatory base in the U.S. is expected to be oriented toward a performance objective approach rather than a set of procedural requirements[4,74]. Consequently, a licensee will be judged not on the narrow basis of strict compliance with written regulations but on a demonstrable ability to control materials and protect his facility. This new approach to Safeguards of "performance requirements plus demonstrable capabilities equals adequacy" has received the support of industry . Regulation by performance objectives allows a facility operator the freedom of specifying the methods and approaches that will be applied to his possibly unique situation. On the other hand, the licensee must prove that his material is safeguarded and not just behind an 8 ft.

high fence with three strands of barbed wire, etc. Thus, on-site performance as rated by analysis, operational (black hat) evaluations, and on-site review will most likely be the key to operating licenses[4]. The performance objectives of (1) preventing with high confidence a civil disaster; (2) providing substantial protection against serious civil damage; and (3) providing timely and accurate information on the status of nuclear material and facilities must be shown to have been achieved in the operational sense.

Design of Integrated Systems

Recent studies on up-graded material accounting in model high-throughput fuel-cycle facilities (i.e. , reprocessing plant and mixed-oxide fuel fabrications plants) have shown that material accounting alone is not likely to meet all safeguards performance objectives at all areas of the model plants[26]. In a similar vein, a fortress concept of physical protection is not totally adequate since the amounts and locations of the material inside the facility would not be known. Thus fuel cycle facilities handling a high throughput of strategic special nuclear material will most likely require an integrated safeguards system design to meet performance objectives. The term "integrated" implies that overlaps, gaps, and interfaces between customary subdivisions of safeguards control and responsibility (accounting, access control, containment, physical protection, etc.) would be taken into account. Consequently, an effective prevention, deterrence, or detection of the total spectrum of threats involving the malevolent use of nuclear materials employs all aspects of safeguards systems.

A design concept for an integrated safeguards system can be summarized by the following procedures: identify all the perceived threats leading to theft and sabotage; identify the necessary protective measures to counter these threats in accordance with system performance criteria; organize these protective measures into major subsystems for effective management and operation[75]. Information and data resources required to accomplish the design include system performance criteria, available protective measures and plant design features. The perceived threat, however, is the major driving force in developing an integrated safeguards systems design.

The threat, since it is central to determine the adequacy of safeguards, has received considerable attention at NRC[76]. No simple, fixed, single answer appears to be appropriate for the question "What is the Threat?" A response that changes with time and accommodates the inherent uncertainty associated with the threat appears to be the only defendable response for the definition of this complex multi-dimensional parameter. The safeguards system design must behave well in the range of this uncertainty and not degrade catastrophically against larger and larger threats.

<u>Evaluation</u>

A necessary attribute of a regulatory operation based wholly or partly on performance objectives is a capability of consistently evaluating a safeguards system effectiveness. A recent ERDA report[77] has developed a general framework for evaluating safeguard system effectiveness in terms of the societal risk.* There are problems in quantifying all aspects of the societal risk, Particularly in determining the expected frequency of attempts[78] of deliberate destructive acts on nuclear facilities, however, the general structure and definition of terms has placed a clearer perspective and delineation of the over-all safeguards problem. The thrust of the developing evaluation methods is to place less reliance on an individual expert review to a more systematic/engineering approach.

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*Societal risk is a concept that evolves from a generalization of reliability theory which has frequently been used in nuclear power safety studies. Societal risk describes the risk in terms of the frequency of attempts, times the probability of events occurring, times the consequences if they do occur.

The development of safeguards effectiveness methodology[79] has logically separated into two rather distinct phases:

1. **Techniques for identifying and enumerating potential adversary action sequences for the access and acquisition of SSNM[79,80,81].**
2. Quantification techniques to evaluate the probability of success of the identified adversary action sequences[79,80,82].

A successful development of these methodologies will aid the safeguards system designer in developing a truly effective safeguards system, will assist the facility operator in the conduct of trade-off studies such as

- costs versus security level
- guards versus hardware
- security versus operating flexibility

and would assist the regulatory agency in the evaluation of the adequacy of a proposed safeguards system.

NRC is supporting several research programs that "involves, mainly, the development of the methods, models and data necessary for assessing the effectiveness of existing and potential systems of safeguards." "The research to develop these methods of evaluating effectiveness involves definitions of objectives and of the related performance parameters -- for the safeguards system as a whole and for the various subsystems of which it is comprised."[52]

4.11 IAEA SAFEGUARDS RESEARCH

Until very recently, the Department of Safeguards and Inspections (DSI) of the IAEA consisted of an Operations Division and a Division of Development at which time a Division of Information Treatment was formed. The present Division of Development has a staff of approximately twenty-five people divided into the following three sections: System Studies; Methods and Techniques; Field Operations. In addition to staff salaries, the Division's actual 1975 obligations included approximately $144,000 in scientific and technical contracts, a relatively modest level of support that had remained almost constant for a number of years. Approximately $400,000 was committed for the purchase of scientific supplies and equipment, a significant portion of these funds being used in commissioning the Safeguards Analytical Laboratory at Sibersdorf, near Vienna.

For 1976 the adjusted budget for the Division of Development includes for scientific and technical contracts, $490,000 and for scientific supplies and equipment, $510,000. For 1977 the estimated budget for these items are $486,000 and $578,000 respectively. The substantial increase in funds available for contract research in safeguards reflects an effort to remedy both the low level of expenditures available in the past and an effort to place the IAEA in a stronger position in the critical years ahead.

Since its founding in 1957, the IAEA has benefited from technical experts from states with active nuclear power or research programs. These experts have assisted both the operations and development staff of DSI through meetings and advisory groups in the formulation of its own safeguards procedures and research projects and in the identification of new problems and areas for safeguards research and development. At these Technical Working Group and committee meetings the Agency has addressed the procedures, instruments and techniques that it might use in safeguarding reactors, reprocessing plants, fuel fabrication plants and enrichment plants. In December of 1975, the first meeting of the Standing Advisory Group on Safeguards Implementation (SAGSI) was held. The group was formed to provide IAEA with technical advice on safeguards and is composed of one senior scientist from the UK, FRG, Canada, India, Japan, the USSR, and the U.S.

In an effort to implement the preambulatory paragraph of the NPT, "Expressing their support for research, development and other efforts to further the application of the IAEA Safeguards System .. by use of instruments and other techniques at certain strategic points", the United States and the Federal Republic of Germany, in particular, undertook safeguards research programs related to international safeguards. In the United States, the AEC/ERDA made available the technical spin-off from its domestic safeguards research and development program and provided the Agency with technical expertise. In support of the IAEA, the U.S. Arms Control and Disarmament Agency initiated in 1967 a safeguards research program that rose to an average funding level of approximately $500,000 per year. Initially, the funding for the German safeguards program was substantial but unfortunately it was severely reduced in 1971, apparently in response to criticism from German industry. Finally, in 1975 Canada undertook a major effort with the IAEA to improve the safeguards Instrumentation for the on-power refueled CANDU reactor.

With the growing public awareness of the dangers of nuclear weapons proliferation, Congressional support for improvements in IAEA safeguards has rapidly increased. This very substantial additional U.S. financial support as Gifts-in-Kind is now coordinated in the

International Safeguards Project Office, Brookhaven National Laboratory. The Program Plan for Technical Assistance to IAEA Safeguards reflects many of the urgent needs of the Agency and the direction which safeguards research will take in the next five years. The major task areas outlined in the January 26, 1977, draft report include:

1. Measurement technology
2. Training
3. System Studies
4. Information processing
5. Surveillance and containment
6. Support for field operations

For many of these tasks, funding has been approved and a schedule for completion of the work set. These programs will commit a total of over $2,000,000 for both FY 76 and FY 77.

It is reported that for FY 78 Congress is considering appropriations of approximately $10,000,000 to support and to strengthen IAEA safeguards. The need for strong support for the Agency's international inspection effort is almost universally acknowledged. However, this very large increase in funds on top of the large increases in funds authorized in FY 76 and FY 77 will place an especially heavy burden on ERDA's International Safeguards Project Office to make certain that these new monies will be wisely spent. This level of support will make possible the use of advanced technologies in attacking such problems as "timely detection" when timely may mean hours rather than weeks or months; the use of dynamic methods of inventory and control and the development of highly portable, versatile, non-destructive assay instrumentation for the precise measurement of uranium and plutonium in the field. These and equally difficult problems in the area of surveillance and containment can be attacked on a scale not considered possible until now. As has been noted, money is essential, but outstanding technical competence and the highest levels of organizational skills will be required to ensure that this kind of support is effective. It is particularly important that the U.S. make every effort to convince all of the remaining nuclear supplier states that there is both a need and a role for their contributions.

ANNEX A

HOW LARGE A THEFT IS POSSIBLE WITHIN THE LEMUF?

The statistical notion of material accounting implies that when a theft is perpetrated, there is never an absolute certainty that it will be detected. The procedures used in the nuclear industry to generate a material balance involve an accounting based on measurements where the statistical variations in the measurement error are frequently comparable with the small discrepancies that it is desired to detect. Thus, when an operator or inspector "calls" that a material discrepancy exists, he is saying implicitly only that there is a chance that material has been removed, and is admitting that there is a finite expectation of a false alarm.

In order to estimate how large a theft might be perpetrated without significant chance of detection it is necessary to review the current formalism for calling accounting discrepancies. Given perfect procedures and measurements, and assuming no diversion, the material balance:

Inventory (BI) at beginning of period + Additions (A)

- removals (R) - Inventory (EI) at the end of period

is zero. In practice, because there are instrumental (and sometimes human) error in measuring BI, A, R and EI, the balance departs from zero, and this deviation is designated "MUF" or "material unaccounted for". Current NRC control procedures require that a discrepancy be called when the MUF exceeds a threshold of twice the expected standard deviation (2σ) of the

MUF. This threshold is called the LEMUF (limit of error of the MUF) and is computed using statistical techniques to combine the individual measurement errors to form the total error in MUF. If measurement errors are distributed normally with zero mean, the probability of a MUF being greater than this LEMUF threshold when no material is missing is approximately 5%*. The currently acceptable value of LEMUF (for the domestic case) or the overall standard deviation (for IAEA) are given in Tables 2.1 and 3.1 of the main text.

insight into how large a theft relative to the LEMUF is possible without substantial risk of detection can be obtained by again making the (not-unreasonable) approximation that the uncertainty in the MUF is distributed according to a "normal" error distribution as in the top illustration of Figure Al. In the absence of thefts** the expected value of MUF will be zero. Given a theft the expected MUF will be biased, so that the probability of the theft leading to a discrepancy call is increased. The lower graph of Figure Al shows how this probability increases with the magnitude of the theft (normalized to the standard deviation or LEMUF) for different decision criteria. Curve A shows the call probability based on application of the current NRC criteria (a discrepancy being noted when the MUF exceeds the LEMUF, which implies a .025 probability of a false call when no loss exists). Curves B and C show how the chance of detection might be increased by accepting higher (.05 and 0.1) probabilities of falsely calling a discrepancy in the absence of a theft. We should note that while more sophisticated data processing is in the exploratory phase, there are also more sophisticated ways of removing material. Nevertheless it seems that the risk of detection following the diversion of 0.25 of the LEMUF in a

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*Half of the time the MUF will be positive, indicating a loss of material, and the other half of the time it will be negative, indicating a gain. Thus, the probability of falsely calling a loss discrepancy is only one-half of 5% or 2.5%.

**This discussion assumes the absence of unmeasured losses or gains.

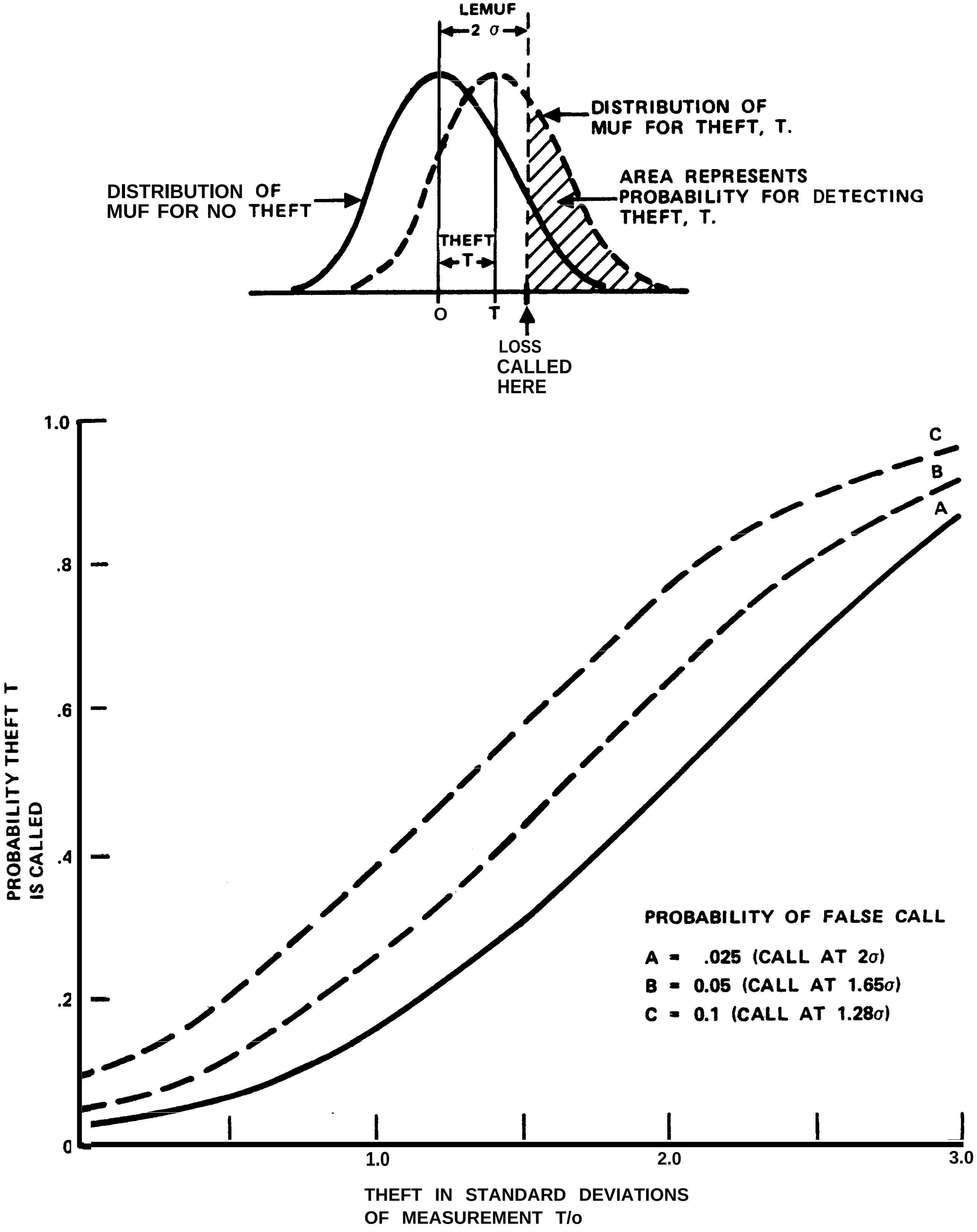

Figure A1. Capability of Accounting System for Detecting Theft at Various Levels of Confidence single accounting period is small enough so that no authority would have confidence in making an accusation of theft based on accounting alone. A theft of one half the LEMUF stands a chance of one in four or five of detection; enough to give pause to the diverter who plans a long series of thefts, but probably insufficient to deter the one-time-only thief.

The above discussion has not taken account of efforts to resolve a discrepancy prior to “calling” a material discrepancy. Because the “calling” would undoubtedly entail added cost and inconvenience to the operator, there would likely be an effort to resolve the discrepancy. This raises the possibility of introducing an unsuspected bias. The varying degree of scrutiny applied to favorable and unfavorable numbers can introduce significant bias.

REFERENCES

1. Preliminary Working Paper: "iNuclear Proliferation and Safeguards". Office of Technology Assessment August 17, 1976.

References 2 and 3 have been deleted.

4. Kenneth R. Chapman "NRC Perspectives on Fuel Cycle ana Safeguards". Journal of the institute of Nuclear Materials and Management (INMM) Vol. V No. 111 Fall 1976.

5. Victor Gilinski (NRC Commissioner). Testimony Before the House Subcommittee on Energy and the Environment. July 22, 1975.

6. Message from the President of the United States transmitting a report on the adequacy of domestic and International Safeguards, etc. House Document 94-131 May 6, 1975.

7. ERDA 1542: "Final Environmental Statement on U.S. Nuclear Power Export Activities", April 1976. U.S. Energy Research and Development Agency.

8. "Assessment of U.S. and International Controls for the Peaceful uses of Nuclear Energy", Report to the Congress by the Comptroller General of the United States, Sept. 14, 1976.

9. IAEA INFCIRC/153. The structure and content of agreements between the Agency and States required in connection with the NPT.

10. Sylvester C. Suda, "Evaluation of IAEA Safeguards Inspection at Nuclear Fuel Services, West Valley, N.Y.". Brookhaven National Laboratory Report BNL 50228, March 1970.

REFERENCES (cent)

11. E. Lopez-Menchero and A.J. Waligura, "The IAEA Programme for the Development of Safeguards Techniques and Instrumentation", IAEA-SM-201/101, presented at the international Symposium on Safeguarding Nuclear Materials, Vienna, October 1975.

12. T. Dragnev, et al., "Some IAEA Contributions to the Development and Use of instrumental Techniques in Safeguards", IAEA-SM-201/96, presented at the international Symposium on Safeguarding Nuclear Materials, Vienna, October 1975.

13. Glenn Hammond and Lorin Stieff, "Development of a Safeguards System for Containment and Surveillance at Uranium Enrichment Plants", IAEA-SM-201/11, presented at the international Symposium on Safeguarding Nuclear Materials, Vienna, October 1975.

14. Warren H. Donnelly "indications of Congressional interest and Concern Over Proliferation of the Ability to Make Nuclear Weapons". Paper presented at AIF Conference on Nuclear Safeguards Orlando, Florida, April 11-14, 1976.

15. H. E. Lyon, "The Role of Material Control and Development in ERDA's Safeguards Program", 17th Annual Meeting of institute of Nuclear Materials Management, INMM Journal Vol. V, #3, Fall 1976.

16. L. A. Kull, "Catalogue of Nuclear Materials Safeguards Instruments", Brookhaven National Laboratory Report (unnumbered) , August 1972.

17. Progress Reports of the Los Alamos Laboratory Nuclear Safeguards Research Group, R-1 (formerly A-1) and Proceedings of the Annual Meetings of the institute of Nuclear Materials Management.

18. U.S.N.R.C. Special Safeguards Study Reports:

    "Evaluation of the Real-Time Material Control Concept for Safeguards in Highly Enriched Uranium Fuel Cycles", Aerojet INEL, September 1975.

    "Improved Material Accounting for Plutonium Recycle Facilities and a 235U - HTGR Fuel Fabrication Facility", Battelle Pacific Northwest Laboratories Report, October 1975.

REFERENCES (cont)

"An Evaluation of Real-Time Material Control and Accountability on a Model Mixed-Oxide Fuel Plant", Science Applications, Inc. , SAI-75-648-LJ, September 1975.

"Material Control and Accounting for Plutonium Recycle Facilities", Science Applications, inc. , SAI-76-539-LJ, March 1976.

19. D. Rundquist, et al., "Material Control for a Reprocessing Plant", Science Applications, inc. Report SAI-76-747-LJ, August 1976.

20. Certificate of Analysis - Plutonium and Uranium Standard Reference Materials, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C.

21. U.S.N.R.C. Regulatory Guide 5.8, "Design Considerations for Minimizing Residual Hold-up of Special Nuclear Material in Drying and Fluidized Bed Operations".

22. U.S.N.R.C. Regulatory Guide 5.25, "Minimization of Residual Hold-up in Wet Process Operations".

23. "Measurement of Plutonium in Processing Equipment at Ken-McGee Plutonium Fuels Fabrication Facility", A draft report to the Director of inspection and Enforcement of of the U.S.N.R.C. by the Division of Safeguards and Security of the U.S. ERDA, June 1976.

24. A.R. Anderson, et al. , "Hidden inventory and Safety Considerations", and J.W. Tape, et al., "Total Room Hold-up of Plutonium Measured with a ~-Area Neutron Detector", 17th Annual Meeting of the institute of Nuclear Materials Management, INMM Journal Vol. V, #3, Fall 1976.

25. U.S. N. R.C. Regulatory Guide 5.23, "In Situ Assay of Plutonium Residual Hold-up".

26. G. Dan Smith, "U.S.N.R.C. Special Safeguards Study on Nuclear Material Control and Accounting", 17th Annual Meeting of the Institute of Nuclear Material Management, INMM Journal Vol. V, #3, Fall 1976.

REFERENCES (cont)

27. U. S. N. R.C. Regulatory Guide 5.13, "Conduct of Nuclear Material Physical Inventories" and W.B. Seefeldt "Some Considerations Enabling Dynamic Inventory in Fuel Cycle Facilities", 14th Annual Meeting of the Institute of Nuclear Material Management, INMM Journal Vol. 11, #3, Fall 1973.

28. S.M. Zivi and W.B. Seefeldt, "Temporal Response Methods for Dynamic Measurement of In-Process Inventory of Dissolved Nuclear Materials", Journal of institute of Nuclear Materials Management, Vol. V, #1, Spring 1976.

29. J. P. Sarich, "Real-Tim Plutonium Accountability and inventory Control System", and H. Akutsu, et al., "A Real-Time Accounting and Control System at Plutonium Fuel Facility of PNC", and M. Batson and T.C. Bishop, "The Application of Real-Time Data Processing to Mound Laboratory's SS Accountability System", papers presented at the 16th Annual Meeting of institute of Nuclear Materials Management, INMM Journal Vol. IV, #3, Fall 1975.

30• T. E. Shea, "instrumentation for Real-Time Materials Control", IEEE Trans. on Nuclear Science, NS-22, 752 (1975).

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

T.E. Shea, "RETIMAC - A Real-Time Material Control Concept for Strategic Special Nuclear Material", Nuclear Material Management, 4, No. 3, 376 (1975) .

T.E. Shea, "A Real-Time Material Control Concept for Safeguarding Special Nuclear Material in U.S. Licensed Processing Facilities", Proceedings of the IAEA international Symposium on the Safeguarding of Nuclear Materials, Vienna Austria, October 1975.

31. C.L. Pomernacki, et al. , "Technical Appendix for the Special Safeguards Study on Material Control and Accounting Systems"; Unnumbered Report, Lawrence Livermore Laboratory (1975) ,

32. E.E. Bain, Jr. , et al., "An Evaluation of Real-Time Material Control and Accountability in a Model Mixed-Oxide Plant", SAI-75-648-LJ., Science Applications, Inc. (1975).

REFERENCES (cont)

33. G.R. Bray, et al., "Material Control and Accounting for Plutonium Recycle Facilities," SAI-76-539-LJ, Science Applications, Inc. (1976).

34. L. Harris, Jr., et al., "Material Balance Accounting and Nondestructive Assay Systems for Plutonium Recycle Facilities," Nuclear Materials Management, 5, No. 3, 501 (1976).

35. D.W. Wilson, "Dynamic Inventory: Dream or Necessity?," Nuclear Materials Management, 2, No. 3, 30 (1972).

36. C.L. Pomemacki, et al., "Modeling, Simulation, and Estimation for Real-Time Materials Control," Nuclear Materials Management, 3, No. 3, 308 (1974).

37. K.E. Sanders, "Physical Protection, Accountability, and Process Modeling," Nuclear Materials Management, 4, No. 3, 256 (1975).

38. K.E. Sanders, "Simulation of Nuclear Fuel Manufacture= as a Safeguard Tool," Proceedings of the 1975 Summer Computer Simulation Conference, San Francisco, California, July 1975.

39. E.B. McCutcheon, "Simulation and Control Synthesis for a Pulse Column Separation System for Plutonium-Uranium Recovery," Doctoral Dissertation, Iowa State University (1975).

40. R.B. Hollstien and C.L. Pomernacki, "MHSS-A Material Handling System Simulator," Proceedings of the 1976 Summer Computer Simulation Conference, Washington, D.C., July 1976.

41. R.H. Sanborn, "MD200: A Model for Evaluating Safeguards through Material Accountability for 2 200 Tonne per Year Mixed-Oxide Fuel-Rod Fabrication Plant," Proceedings of the 1976 Summer Computer Simulation Conference, Washington, D.C., July 1976.

42. D.L. Alspach and T.L. Greenlee, "Dynamic Safeguards Accounting and Material Control via Modern Estimation Methods, "Proceedings of the 1976 Summer Computer Simulation Conference, Washington, D.C., July 1976.

REFERENCES (cont)

43. G. R. Keepin and W. J. Maraman, "Nondestructive Assay Technology and In-Plant Dynamic Materials Control - DYMAC," Proceedings of the IAEA international Symposium on the Safeguarding of Nuclear Materials, Vienna, Austria, October 1975.

R.H. Auguston, "Development of in-Plant Real-Time Materials Control: The DYMAC Program," Nuclear Materials Management, S_, No. 3, 302 (1976).

44. J.E. Lovett, "Concepts of Real-Time and Semi-Real Time Material Control," Nuclear Materials Management, 3, No. 4, 24 (1975).

45. J.E. Lovett, "In-Plant Dynamic Material Controls--An international Perspective," Nuclear Materials Management, 5, No. 3, 342 (1976).

46. R. F. Lumb, "Nuclear Material Accounting," Proceedings of the Atomic industrial Forum, Conference on Nuclear Safeguards, Orlando, Florida, April 1976.

47. J.M. de Montmollin, R.B. Walton, "The Design of Integrated Safeguards Systems for Nuclear Facilities," institute of Nuclear Materials Management, inc., Vol. V, No. 111, Seattle, Washington, Fall 1976.

48. LeonD. Chapman, et al., "Development of an Engineered Safeguards System Concept for a Mixed-Oxide Fuel Fabrication Facility," Sandia Laboratories, August 1976.

49. L.M. Brenner and S.C.T. McDowell: "ERDA's Integrated Safeguards System Program." institute of Nuclear Materials Management Vol. V, No. 111, Fall 1976.

50. O.E. Jones, "Advanced Physical Protection Systems for Nuclear Materials, "Proceedings of the IAEA international Symposium on the Safeguarding of Nuclear Materials, Vienna, Austria, October 1975.

51. O.E. Jones, "Advanced Physical Protection Systems for Facilities and Transportation," Nuclear Materials Management, 5, No. 3, 211 (1976).

52. Herbert J.C. Kouts, "NRC Safeguards Research Program", paper given at the AIF Conference on Nuclear Safeguards, Orlando, Florida, April 11-14, 1976.

REFERENCES (cont)

53. J.J. Bastin and E.A. Conrads, "Advances in Physical Protection," Proceedings of the Atomic Industrial Forum Conference on Nuclear Safeguards, Orlando, Florida, April 1976.

54. "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle - Volume I - Executive Summary," SAND 75-0457, Sandia Laboratories (1976).

55. F.H. Bennett, et al., "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle - Volume II - Fixed-Site Physical Protection, Systems (U)," SAND 75-0457, Sandia Laboratories (1976). Confidential

56. B. Sewell, et al., "Physical Protection of Special Nuclear Material in the Commercial Fuel Cycle - Volume 111 - Elements of Physical Protection for Fixed Sites (U)," SAND 75-0457, Sandia Laboratories (1976). Secret

57. H. Miller, "Nuclear Security Enclosure," Nuclear Materials Management, 5, No. 3, 274 (1976).

58. "Security Agency Study," NUREG-0015 and NUREG-0015, ES (Executive Summary), U.S. Nuclear Regulatory Commission (1976).

59. P.G. Meguire and J.J. Kramer, "Psychological Deterrents to Nuclear Theft: A Preliminary Literature Review and Bibliography," NBSIR 76-1007, National Bureau of Standards (1976).

60. J. Edlow and D. Rudolph, "Physical Security During Transportation--1976," INMM Proceedings, Vol. 5, No. 3 (1976) p 258.

61. J. deMontmollin and T. Sellers, "A System for Communication with Commercial Special Nuclear Material Shipments," Nuclear'Technology, Vol. 23 (1974) p 117.

62. H. Kouts, "Remarks on Nuclear Regulatory Research," Program Report--AIF Conference in Nuclear Safeguards, Orlando, Florida, Vol. 3, No. 5.

63. R. Reed, "Design Concepts Study of a Special Nuclear Material Cargo Vehicle," Nuclear Technology, Vol. 23 (1974) p. 112.

REFERENCES (cont)

64. D. Dickason, "The ERDA Transportation Safeguards Communications System, " Program Report --AIF Conference on Nuclear Safeguards, Orlando, Florida, Vol. 3, No. 5.

65. U.S. Nuclear Regulatory Commission, Nuclear Energy Center Site Survey--1975, NECSS-75 (1976) .

66. "Technical Options for Plutonium Safeguards", a report of the Atomic industrial Forum Study Group on Fuel Cycle Safeguards, Fall 1975.

67. Bruce A. Hutchins, et al., "Denatured Plutonium -- A Study of Deterrent Action", report prepared for the Electric Power Research Institute, EPRI 310, July 1975.

68. E.V. Weinstock, Study Coordinator, "The Spiking of Special Nuclear Materials as a Safeguards Measure", report prepared by the Technical Support Organization of the Brookhaven National Laboratory for the Nuclear Regulatory Commission, September 19, 1975.

69. R.L. Dickeman, "Safeguards Perspectives -- An Expression of industry's Responsibilities and Views", paper presented at the AIF Conference on Nuclear Safeguards, Orlando, Florida, April 11-14, 1976.

70. "Regional Nuclear Fuei Cycle Centre Study: institutional Legal Framework Aspect." IAEA-RFCC/ 2. Vienna, Austria. July 1976.

71. E.R. Johnson Associates, "Costs for Extended Safeguards", Study sponsored by the Atomic Industrial Forum July 1975 and Paper presented by Russell P. Wischow AIF Conference on Nuclear Safeguards, Orlando, Florida, April 11-14, 1976.

"72 . "Draft Generic Environmental Statement on Mixed Oxide Fuel". U.S. Atomic Energy Commission WASH 1327, August 1974.

73. R.G. Page, "Features and Requirements of the U.S. Nuclear Material Control System", paper given at the International Symposium on the Safeguarding of Nuclear Materials, IAEA-SM-20V52, Vienna, October 20-24, 1975.

74. Kenneth R. Chapman, "NRC Approach to Safeguards". Paper given at the AIF Nuclear Fuel Cycle Conference, Phoenix, Arizona, March 21-24, 1976.

REFERENCES (cont)

75. L.A. Kull and W.P. Melling, "The Design of Integrated Safeguards Systems for New Fuel Cycle Plants", INMM Proceedings 18th Annual Meeting, Seattle, Washington, June 22.24, 1976, pp. 333-341.

76. Carl H. Builder, "Safeguards Perspectives: The Threat". Paper delivered at the AIF Conference on Nuclear Safeguards, Orlando, Florida, April 12, 1976.

77. Carl A. Bennett, William M. Murphey, Theodore S. Sherr, "Societal Risk Approach to Safeguards Design and Evaluation", ERDA- 7, June 1975.

78. Norman C. Rasmussen, "Probabilistic Risk Analysis - Its Possible Use in Safeguards Problems", 18th Annual Meeting INMM, Seattle, Washington, June 22-24, 1976, pp .66-88.

79. H. Kendrick, E. Lofgren, D. Rundquist, R. Fullwood, "An Approach to the Evaluation of Safeguards Systems Effectiveness", 18th Annual INMM meeting, Seattle, Washington, June 22-24, 1976, pp. 226-238.

80. W.M. Murphey, J.C. Schleter, "Practicality of Diversion Path Analysis", Nuclear Material Management 3, 3 (1974) 236.

81. H.A. Bennett, D.D. Boozer, L.D. Chapman, S.L. Daniel, D. Engi, B.L. Hulme, and G.B. Varnado, "Safeguards System Effectiveness Modeling", 18th Annual INMM meeting proceedings, Seattle, Washington, June 22-24, 1976, pp. 239-247.

82. William Marcusi and Joseph P. Indusi, "Simulating Physical Protection Against Overt Attacks at Facilities Using Processing or Storing Nuclear Materials", Nuclear Material Management Vol. IV, No. 3, Fall 1975.