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TITLE INTERNATIONAL SAFEGUARDS RELEVANT TO GEOLOGIC DISPOSAL OF HIGH-LEVEL WASTES AND SPENT FUELS

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INTERNATIONAL SAFEGUARDS RELEVANT TO GEOLOGIC DISPOSAL OF HIGH-LEVEL WASTES AND SPENT FUELS

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ABSTRACT

Spent fuels from once-through fuel cycles placed in underground repositories have the potential to become attractive targets for diversion and/or theft because of their valuable material content and decreasing radioactivity. The first geologic repository in the U.S., as currently designed, will contain approximately 500 Mt of plutonium, 60 000 Mt of uranium and a host of other fissile and strategically important elements This paper identifies some of the international safeguards issues relevant to the various proposed scenarios for disposing of the spent fuel. In the context of the U.S program for geologic disposal of spent fuels, this paper highlights several issues that should be addressed in the near term by U.S. industries, the Department of Energy, and the Nuclear Regulatory Commission before the geologic repositories for spent fuels become a reality. Based on U.S. spent fuel discharges, an example is presented to illustrate the enormity of the problem of verifying spent fuel inventories. The geologic disposal scenario for high-level wastes originating from defense facilities produces a "practicably irrecoverable" waste form. Therefore, safeguards issues for geologic disposal of high-level waste now in the U.S. are less pressing.

I. INTRODUCTION

During the last two decades, the problems of nuclear fuel cycle wastes have become prominent political, environmental, and socio-economic issues, resulting in systematic efforts to develop strategies for the long-term storage/disposal of almost all forms of radioactive wastes. One strategy for long-term management of nuclear wastes adopted by the U.S. a decade ago involves direct disposal of spent nuclear fuels in geologic formations. All the present scenarios for the disposal of spent nuclear fuel pose unique safeguards problems that are not encountered in safeguards systems for bulk handling facilities or in item accounting facilities.

Presently, 28 nations have commercial nuclear power programs, and almost all of them still consider the recycling of fissile and fertile materials contained in spent nuclear fuels to be a method of extending valuable fuel resources. The U.S. and Sweden have changed their policies based on uranium market values and reprocessing costs to directly dispose of spent fuels in geologic repositories. Although the current U.S. policy allows the development of commercial reprocessing facilities in the private sector, the plutonium recycle possibilities in the commercial sector are paralyzed by the termination of commercial breeder reactor development and the lack of support for advanced fuel cycles using plutonium. In Sweden, the politically preferred option of a once-through fuel cycle is considered an interim option because it allows future alternatives.

Canada, probably because of its abundant uranium reserves, is presently leaning toward the geologic disposal of spent fuel, although a decision on the subject has been postponed, possibly until the next century. France, the U.K., the U.S.S.R., India, and Japan have proceeded with large-scale projects to commercially reprocess spent fuels and extend the plutonium fuel cycle to reuse the plutonium in both fast and thermal reactors. In addition, other countries, such as Argentina, Brazil, China, and Italy, are actively pursuing the reprocessing of spent fuels as part of the fuel cycle for generating nuclear power.[1,2] The Federal Republic of Germany (FRG) recently decided not to proceed with the construction of new reprocessing facilities but to use reprocessing the sources of France and the U.K. to continue plutonium reuse in their nuclear fuel cycle.

Although the present policy of the U.S. is to permanently emplace spent nuclear fuels from light-water reactors (LWRs) in geologic repositories, very

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few member States of the International Atomic Energy Agency (IAEA) have adopted this policy. A few states, such as the FRG, Finland, and Italy, that are considering geologic emplacement are considering it as an interim measure; they could possibly use the spent fuel in the future. In all these cases, it is important to safeguard the nuclear materials contained within the spent nuclear fuels to prevent nuclear proliferation and the diversion of nuclear materials to nonpeaceful purposes.

In civilian nuclear fuel cycles, the time from the removal of spent nuclear fuels from the reactors to the final stages of nuclear waste management spans several decades. Safeguarding nuclear materials contained in these spent fuels during this period varies with storage modes, methods of packaging and transporting the fuel, and treatment of spent fuel either to consolidate or recover fissile elements within it.

In the context of the U.S. program to manage spent fuel, it is important to consider immediately the requirements of safeguards, assuming that the spent fuels are to be placed in geologic repositories for an indefinite period. The United States, with the largest inventories of spent nuclear fuels in the world, has yet to give full attention to nuclear material safeguards as part of an overall program for waste disposal. Safeguards issues relevant to spent fuel disposal are quite different from those of conventional bulk handling facilities or item accounting facilities for the following reasons:

- the extremely large quantities of fissile materials involved,
- the attractiveness of the spent nuclear fuels, which increases with the age of the fuel,
- the requirement to maintain safeguards in perpetuity,
- the extreme difficulty and very large uncertainties in quantifying special nuclear materials (SNM) contents,
- the inability to verify quantities of SNM during various modes of surface and underwater storage, and
- the impossibility of direct verification after the spent nuclear fuels are emplaced in geologic repositories.

All spent fuel disposal scenarios presently examined pose a variety of safeguards problems; none are addressed adequately by any of the national programs or by the international safeguards community. The current design of the first geologic repository in the U.S. projects a capacity to accommodate wastes equivalent to 70 000 Mt of uranium from commercial and defense fuel cycles. Of this, approximately 62 000 Mt of uranium equivalent will be commercial spent fuel, containing over 500 Mt of plutonium. International safeguards commitments require us to address the safeguards issues of disposing of such large quantities of plutonium in a geologic repository, which has the potential to become a plutonium mine. This paper highlights several aspects of international safeguards relevant to the geologic disposal of spent nuclear fuels and highlights issues that should be addressed in the near term by the U.S. industries, the U.S. Department of Energy (DOE), and the Nuclear Regulatory Commission (NRC) well before the geologic repositories for spent fuels become a reality.

Although the most recent revisions of DOE's plans call for repository operation to commence in 2010 (see the *New York Times*, November 29, 1989), the DOE has already entered into contractual agreements with U.S. utilities to accept spent nuclear fuels beginning in 1998. Considering that the decision to change U.S. policies from reprocessing to the throwaway fuel cycle was made more than a decade ago, the time available for designing and insituting a reliable safeguards system for the spent nuclear fuel disposal program is rather short.

II. SAFEGUARDS AT THE BACK-END OF THE NUCLEAR FUEL CYCLE

The back-end of the nuclear fuel cycle offers considerable challenges to long-term management of a variety of waste forms. The last two decades saw an increased awareness of the problems of nuclear fuel cycle wastes as well as an increase in systematic efforts to develop strategies for the long-term storage/disposal of almost all forms of radioactive wastes. Among these strategies, the one involving the direct disposal of spent nuclear fuels poses one of the most difficult safeguards problems. Although spent fuels continue to be highly radioactive for many years after they are discharged from reactors, the radioactivity level decreases considerably after several decades,[3] and plutonium extraction from such aged fuel becomes relatively less hazardous (see Fig. 1). This characteristic of the spent fuel makes it a unique safeguards problem.

In the international arena, a broad spectrum of possible national, multinational, and international arrangements for spent fuel management has been discussed.[4-6] The international safeguards aspects of the long-term storage facilities for spent fuels range from benign international oversight of national facilities to arrangements for bilateral and regional cooperation, and even to the creation of entirely new international institutional mechanisms.[4,5] Because of the introduction of breeder reactors in some States and the indecision regarding reprocessing by others,

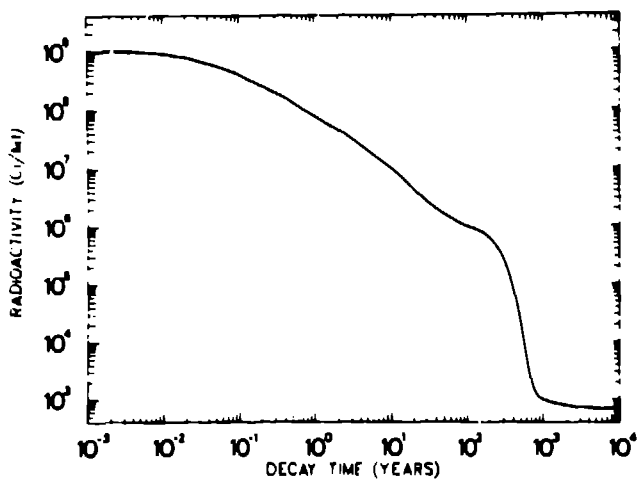

Fig. 1.
Decay of radioactivity in spent fuel discharged from a 34 000 MWd/Mt light-water reactor.[6]

spent fuel management is not one of the acute problems of the IAEA, and the concepts for safeguarding spent fuels have so far received only academic attention.

At the same time, reactor facilities are running out of interim storage space, creating serious problems for several facilities, including a large number of reactors in the U.S. Therefore, the focus has shifted from long-term disposal to short-term management of spent fuels and related safeguards issues.[7-15] Among the various storage modes proposed and studied, wet storage in pools,[6,7,10] and dry surface storage in air-cooled casks[8,10] and vaults[5] have become the most accepted methods. Also, none of the safeguards studies[11-15] associated with the spent fuel programs have so far addressed the issues of long-term geologic disposal of spent fuels. At the time of the International Fuel Cycle Evaluation studies (1977-80), the concept of permanent disposal of spent fuel was not selected by any of the member States of the IAEA.[5]

Recognizing the difficulty of arriving at an international consensus on long-term spent fuel management problems, several States, including the U.S., have embarked on a variety of domestic programs for the long-term management of high level wastes and spent nuclear fuels.[16,17] Presently, in the international arena, three scenarios are under consideration for geologic disposal of spent fuels. They are:

1. Geologic repositories within a State intended exclusively for disposing of spent fuels and wastes originating from its own nuclear fuel cycles. The United States, Canada, and Sweden have embarked on such a program for the disposal of spent fuel in igneous rocks or other suitable geologic formations.
2. A geologic repository within a State for the long-term storage of spent fuel from a State. The FRG has such a program involving a salt repository for nuclear wastes, including spent fuel, for possible participation by other Euratom members.
3. A commercial venture by a State to operate a geologic repository for permanent disposal of spent fuels from other States. The People's Republic of China has offered such a service, and some of the European nations expressed an interest in such a venture.

These spent fuel disposal scenarios pose a variety of safeguards problems, none of which are adequately addressed by the international safeguards community. The literature on safeguards-related technical issues of relevance to geologic disposal of high-level wastes and spent fuels is extremely limited. During the past 3 years, several papers have appeared in the open literature, expressing concerns and some new ideas for technology development.[18-36] Until very recently, the U.S. geologic waste repository program was moving forward without any discussion of long-term safeguards issues. The DOE's Office of Civilian Waste Management (OCRWM) has recently indicated that several interagency discussions have begun with the objective of formulating policies and programs.[33] Additionally, OCRWM is exploring with the Office of Safeguards and Security (DOE/OSS) to use their vast resources for systems and technology development to address the needs of international safeguards.[30,33]

III. INTERNATIONAL SAFEGUARDS FOR GEOLOGIC DISPOSAL OF HIGH-LEVEL WASTES

The term high-level wastes (HLWs) generally refers to sludges and composites of all liquid waste streams from spent fuel reprocessing and plutonium production or to waste forms derived from them. HLWs primarily contain non-volatile fission products and actinides that are not separated out during reprocessing. Of the present inventory of approximately 3 x 10^5 m^3 HLWs in the U.S., less than 1% was derived from civilian spent fuel reprocessing. It is only this small fraction of HLWs in the U.S. that may be subjected to international safeguards. The amounts of fissile materials in these wastes are too small for economical recovery. However, in the international safeguards arena, economics is a not an acceptable criterion for deciding whether to continue or to terminate safeguards. Therefore, "practicably irrecoverable" is the criterion used to determine safeguards termination.[37] Small amounts of fissile nuclear materials present in high-level liquid wastes containing large quantities of fission products from reprocessing are considered "practicably irrecoverable" when the liquid wastes are vitrified to form glass or ceramics or when they are conditioned and immobilized to form solid matrices for geologic isolation.

IV. INTERNATIONAL SAFEGUARDS

IAEA safeguards is a verification system within the framework of international nonproliferation policy applied to peaceful uses of nuclear energy. In the international safeguards arena, sovereign nations are considered potential diverters of nuclear materials. According to present guidelines for international safeguards, systems designed for safeguarding SNM should account for such materials, and the accounting must be independently verifiable by an agent of the IAEA. The desired result of effective application of IAEA safeguards is the assurance of non-diversion of nuclear materials by a State from peaceful applications to weapons. This goal is different from that of domestic safeguards, which relies on the State's own physical protection and materials accounting measures. The independent IAEA verification provides assurance that the States are complying with their commitments concerning peaceful uses of nuclear energy and therefore contributes to the increase of confidence among States.

Several important issues of long-term safeguards assurance for spent fuel disposal are not addressed in the IAEA's guidelines for international safeguards.[38,39] Although the 1987 edition of the IAEA Safeguards Glossary still lists plutonium contained in spent nuclear fuels as "direct use material," several important issues of long-term safeguards assurance for spent fuel disposal are not addressed in the IAEA's Guidelines for State's Systems of Accounting and Control of Nuclear Material. However, the desirability of spent fuels as a source of plutonium is well known, and the fate of spent fuels should be examined in the context of an extension of the Non-Proliferation Treaty (NPT) beyond 1995 and the possible termination of the NPT some time in the future.

IAEA safeguards are applied to U.S. facilities in response to an offer made by President Johnson in 1967 as an inducement to countries, especially West Germany and Japan, to sign the NPT.[40] The U.S./IAEA Safeguards Agreement[41] was endorsed by the U.S. Senate and entered into force on December 9, 1980. To prescribe policies and responsibilities, the DOE and the NRC have issued orders and regulations for compliance with this agreement.[42] Accordingly, there are nearly 200 nuclear facilities in the U.S. that have the potential to be under IAEA safeguards. These include all commercial reactors and fuel fabrication facilities, and almost all research reactors, critical assemblies, and test reactors in the U.S. However, because of the limited resources of the IAEA, only a few facilities in the U.S. are chosen for IAEA safeguards at any one time, and this list of facilities is changed periodically by the IAEA in consultation with the U.S. In applying safeguards at U.S. nuclear facilities, the IAEA employs the same scheme as for facilities located in non-nuclear-weapons States. Implementation of U.S./IAEA agreements on nuclear material safeguards is detailed in 10CFR75.

V. SAFEGUARDS AND THE U.S. SPENT FUEL DISPOSAL PROGRAM

In 1977, the United States adopted a national policy of indefinitely postponing reprocessing pending an evaluation of proliferation concerns. This policy was reversed in 1981 when the private sector was encouraged, once more, to develop this part of the fuel cycle. During this period, the U.S. nuclear development policy shifted away from demonstration of commercial fast breeder reactors and plutonium use in the commercial fuel cycle. In this context, there is no incentive for anyone to develop a closed fuel cycle including reprocessing and recycling plutonium in the commercial fuel cycle. Hence, the only viable option for the U.S. nuclear industry is to throw away spent nuclear fuels as a waste form.

In response to the 1982 Nuclear Waste Policy Act,[43] the U.S. government entered into contract with the industry to accept spent fuels and wastes from nuclear power plants in return for a fee in proportion to the amount of electricity generated. The collection of this fee since 1983 obligates the federal government to carry out the necessary research and development for interim and long-term management of high level wastes and spent nuclear fuels and to develop interim storage facilities and permanent geologic repositories.

These obligations and commitments by the federal government have shifted responsibilities away from the nuclear industry for long-term waste management. Furthermore, the U.S. nuclear industry is generally unaware of international safeguards commitments because very few facilities have been subjected to international inspections, and for only short durations. Therefore, there is a need for a concerted effort to promote awareness that the commitments of the U.S. to international safeguards would apply to the spent nuclear fuels discharged from commercial nuclear power plants.

The first geologic repository in the U.S. designed exclusively for the disposal of nuclear wastes from U.S. fuel cycles will accommodate nearly 62 000 Mt of uranium equivalent of commercial spent fuel, containing significant quantities of fissile and fertile materials along with a variety of other strategically important elements.[44] Assuming this design is typical of other facilities, it is possible to estimate the inventories of SNM and other valuable materials in such a repository as shown in Table I.[45,46] It is difficult to estimate the true value of all the materials contained in spent fuel. The 1985 market values of some of the rare elements of strategic importance are included in Table I.[46] There is no established market value for most of the other elements (uranium and transuranics) that could be readily recovered from spent fuel during reprocessing. In recent negotiations to reprocess spent fuels from the FRG to recover plutonium, the agreed upon reprocessing cost is approximately $100,000 per kilogram of contained plutonium.[47] It would seem that an overall strategy to recover and use all these valuable materials may be justified on economics alone. Disposing of such large quantities of fissile and fertile elements, as well as other strategically important elements such as palladium, ruthenium, rhodium, and technetium in geologic repositories, has the potential to create a mine for these materials in the future. International safeguards commitments require the U.S. to address safeguards issues of disposing of such large quantities of plutonium in geologic repositories.

Table I

Approximate Inventories of Valuable Materials in a Typical Spent Nuclear Fuel Geologic Repository

Material Type	Inventory (in Mt)	Value (10^6 $/Mt)
Spent Fuel	70000	NEMV*
^{238}U	66000	NEMV
^{235}U	800	NEMV
Plutonium	500	NEMV
Neptunium	30	NEMV
Americium	5	NEMV
Curium	2	NEMV
Rhodium	30	19.4**
Ruthenium	150	4.8**
Palladium	85	5.2**
Technetium	50	NEMV

*NEMV - no established market value.

** 1985 market value.

The Nuclear Waste Policy Act of 1982[43] and the Nuclear Waste Policy Act Amendments of 1987[48] are the Congressional mandates for all programs in the U.S. for the disposal of spent nuclear fuels and high-level wastes. Neither of these legislations have addressed the issues of long-term international safeguards for spent fuels in geologic repositories. However, prior commitments by the U.S.[40,41] to open all nuclear facilities, excluding only those with direct national security significance, for IAEA safeguards would require the geologic spent fuel repository in the U.S. to come under IAEA safeguards.

VI. SAFEGUARDS REQUIREMENTS OF THE SPENT FUEL DISPOSAL PROGRAM

The major elements of the U.S. program for the geologic disposal of radioactive wastes of relevance to long-term safeguards are shown in Fig. 2. Also identified in Fig. 2 are the two major waste forms--high-level wastes from reprocessing and spent nuclear fuels from commercial reactors--and various activities involved in the transfer of these waste forms to the same geologic repository.

Present plans for the spent fuels include various options for packaging and transporting them from reactors to the geologic repository. Almost all activities leading to the final disposal of spent fuels affect the long-term safeguards goals for them. Proper accounting for fissionable materials in various categories of spent-fuel-derived waste forms, such as intact spent fuel assemblies, canistered spent fuel assemblies, consolidated rods, and non-fuel-bearing materials, are required by the U.S. NRC to satisfy the needs of domestic safeguards. Present safeguards requirements by the IAEA would additionally require the States to allow periodic verification of the declared SNM values by direct measurements or by item accounting. The need for independent verification capability imposes additional requirements, which will be considerably more detailed and intrusive if rod consolidation is practiced.

Figure 2 identifies six measurement points where the SNM content of spent fuels or spent-fuel-derived waste forms could be accounted for through either direct measurements or by item accounting when prior measurements are usable. Depending upon volume reduction locations and monitored retrievable storage (MRS) facilities, the verification points can grow to a very large number. However, though proper system design during early stages, it is possible to limit the number of measurement points to a minimum.

One of the issues complicating safeguards implementation for spent fuels at commercial nuclear reactors in the U.S. is rod consolidation. According to an independent study by the Electric Power Research Institute,[13] "a substantial burden will be imposed on the utility if a requirement for independent verification of container contents (after rod consolidation) is forthcoming, as might be anticipated if the facility is selected for IAEA safeguards." A detailed site-specific study (for the Yucca Mountain

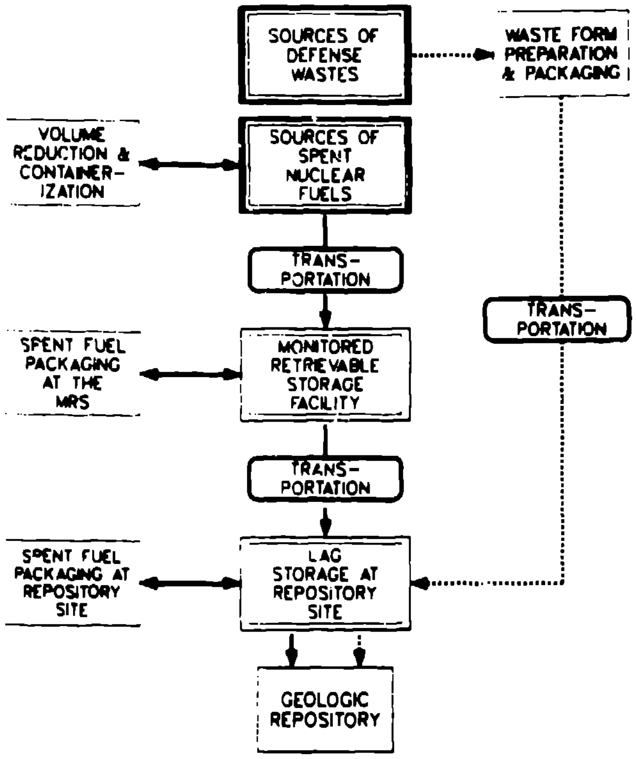

Fig. 2.
Major elements of the U.S. program for the geologic disposal of radioactive wastes.

Site repository) of the effects of consolidation on geologic disposal of spent fuels has demonstrated the undesirability of consolidation.[49]

However, as part of the research and development on spent fuel management, several Prototypical Rod Consolidation Demonstration Programs (PCDP) have been funded and a selected few have completed hot demonstrations. The next phase of this effort is to develop facilities and equipment for large throughput operations. These efforts to consolidate and store spent fuels will make the safeguards implementation efforts all the more complex and expensive. The pros and cons of rod consolidation were re-examined by the DOE. They concluded that the on-going consolidation efforts by utilities are not consistent with the waste management system requirements and that spent fuel preparation for disposal should be performed in the federal waste management system rather than at reactor sites. The DOE has, however, reserved the option to reevaluate the desirability of consolidation during the advanced conceptual design of the repository and the waste package.[50]

VII. AN EXAMPLE OF SPENT FUEL VERIFICATION

To design credible safeguards systems, it is necessary to analyze diversion scenarios and develop scientifically sound approaches to achieve thoroughness in safeguards implementation. Although some States may consider diversion scenarios as an affront to their commitments to international safeguards, it is important to recognize the relevance of the analysis of potential diversion strategies to the credibility of international safeguards.[51] In domestic and international safeguards, "timely detection" and "deterrence" aspects have become prominent and are even seen by some to be the overriding objectives of safeguards. However, the fundamental requirement of international safeguards is the "assurance" that they are effective by the ability to demonstrate the continued presence of nuclear materials within designated boundaries. This requires the establishment of a system of accounting for and controlling nuclear materials within spent fuels and thereby enables both the state and international regulatory agencies to verify the safeguards system.

Large quantities of plutonium are involved in spent fuel safeguards within a State. In principle, a State could divert material and conceal the diversion by data falsification--i.e., by accounting for material as if none had been diverted. To counter this possibility, the IAEA's mechanism is to verify the special nuclear material content (in this case plutonium) by making independent measurements of fuel assemblies and comparing those measurements with the declared (book) values of the facility. Such comparison allows for detection of anomalous activities, such as diversion or theft.

As with IAEA measurement of nuclear material in other forms, detection sensitivity is limited by two factors. The first factor is measurement coverage. Resource constraints lead to IAEA measurement coverage much less than 100%. Consequently, a large plutonium diversion could escape detection unless it were uncovered by containment/surveillance activities. Such activities, including use of optical devices to monitor stationary storage within spent fuel pools at reactor sites, are among presently accepted adjuncts to direct verification of the facility's accounting.

A second factor limiting detection sensitivity is the measurement uncertainties for the facility's and IAEA's measurements. This factor is important for potential diversions involving small amounts of plutonium (as fuel pins) removed from large number of assemblies.

To place these issues in a more concrete setting, consider the following idealized example based on spent fuel discharges from U.S. nuclear power plants. In early 1989, there were 111 operating reactors in the U. S.--74 PWRs and 37 BWRs. Assume for simplicity that each PWR discharges 30 spent fuel assemblies and each BWR discharges 74 assemblies every two years. With a burnup of approximately 30 000 megawatt-days per metric ton of heavy metal (MWD/MTHM), each PWR assembly contains approximately 3.0 kg of plutonium and each BWR assembly contains about 1.2 kg of plutonium. Again, for simplicity, assume that only half of the reactors (37 PWRs and 19 BWRs) discharge assemblies each year. The total amount of plutonium involved in these discharged fuel assemblies from 56 "active" reactors is nearly 5020 kg annually.

The facilities accounting for plutonium is based on burnup calculations,[52] assumed to correspond to a so-called systematic error of 0.5% (relative) applying to all assemblies State-wide and a so-called random uncertainty of 1% (relative). The IAEA's verification value of plutonium-content is assumed to be based on neutron measurements using a fork detector[53] and is assumed to have associated measurement uncertainties of 1% (relative) applying to measurements common to a single facility and a random measurement uncertainty of 3% (relative).

Ideally, all assemblies in all facilities could be inspected, thereby providing maximum sensitivity to detecting possible diversion. In practice, however, inspection resources are limited, as is a facility's tolerance of interrupted operations. For this illustration, we consider the case where 40 inspector-days per year are available for inspection. In the idealized U.S.-based example, we feel such an inspection effort allows for monitoring 10 of the 56 "active" facilities selected on a statistical sampling basis. Because the quantities of plutonium per facility are approximately the same in this example, a simple random selection determines the facilities to be monitored; if this were not the case, a stratified sample based on plutonium amounts might be more appropriate. Note that in this scenario, it is assumed that the spent fuel storage pools at these reactor facilities do not have any old inventories of spent fuels, the presence of which would make the verification exercise more complex.

At each of the selected facilities, the IAEA measures 13 of the 30 discharged assemblies (if PWR) and 33 of the 74 assemblies (if BWR). The rationale behind this choice is to allocate available resources so as to inspect roughly the same quantity of plutonium at each facility and to use all available resources for inspection during the year. Such an inspection plan is based on what is called, in the statistics literature, "two-stage" or "cluster" sampling. In the safeguards literature, the term "randomized inspection" is sometimes used.[54] By sampling in stages, it is possible to make more inspection measurements for a fixed amount of resources than for a simple random sample of all assemblies State-wide.

The IAEA's data analysis involves calculation of a D statistic. A "discrepancy" is computed for each facility by multiplying the average inspector-facility difference per assembly by the total number of assemblies for the facility. Then, the average discrepancy per facility is multiplied by the total number of facilities to estimate the State-wide discrepancy. The statistical question is to decide whether the State-wide discrepancy is larger than can reasonably be explained by measurement and sampling uncertainties. The mathematics underlying this type of calculation are addressed elsewhere[55,56] and need not be elaborated here.

In regard to detection sensitivity for this idealized example, the bottom line is that the D-statistic has a standard deviation of roughly 245 kg when there is no data falsification. Although this result is based on simplifying assumptions, a more detailed calculation involving the specifics for each facility would yield essentially the same conclusion: that falsification of plutonium equivalent to the content of several nuclear weapons (several "significant quantities") is unlikely to be detected unless by this inspection a gross falsification (i.e., a large falsification for an assembly that is inspected) is clearly revealed.

The major impediment to improved verification is the comparatively limited inspection coverage (over 80% of the facilities and 90% of the fuel assemblies are uninspected). Also, there is a large "systematic" uncertainty in burnup calculations (i.e., 0.5% of 5020 kg is approximately 25 kg of plutonium; a small falsification across all assemblies would be confounded with this uncertainty, even if there were 100% inspection and the IAEA was capable of error-free measurements). Importantly, any potential diverter could, following straightforward statistical principles, use such calculations as a guide in determining attractive diversion strategies. Obvious strategies, such as removing large amounts of plutonium from a number of assemblies in a facility and relying on the >80% chance of no inspection or removing small amounts of plutonium from many assemblies statewide and relying on this to be concealed by measurement uncertainties, offer an excellent chance of successfully evading detection.

Improving on this disconcerting situation is clearly possible. Problem areas, in approximate order of importance, are

(1) low inspection coverage (only 10 of 56 "active" facilities are inspected per year);

(2) the inspectorate's measurement uncertainties (although 1% and 3% relative uncertainty values are good in the context of relative errors, the large plutonium quantities involved lead to a large absolute uncertainty); and

(3) the 0.5% systematic uncertainty in the burn-up calculation.

The first problem can be addressed, obviously, by increasing available resources for inspection. Also, by making Cerenkov radiation measurements in storage pools, a method currently employed by the IAEA,[27] at many facilities not monitored as above, protection against large falsifications is provided. Advances in measurement technology[25] (should they come to fruition) and the related instrumentation if it is permanently installed on-site, could alleviate the first problem by allowing the inspectorate to measure all assemblies before being packaged and sealed. Finally, some benefit would accrue if it were possible to measure previously uninspected assemblies at the disposal site at later times, thereby continuing to hold facilities "at risk" beyond the time of initial disposal; however, this prospect appears unlikely based on the presently considered strategies for geologic disposal of spent nuclear fuels.

VIII. DESIRABLE ACTIONS

Because the international community values safeguards for fissile materials, it is important that all ongoing programs for the disposal of spent fuels begin discussions about the need to have international safeguards for the geologic repositories containing large quantities of plutonium and other fissile elements. It is recognized that the proliferation resistance of spent fuels decreases with storage time according to the total burnup and decay time. The IAEA should provide guidance to States on the requirements of safeguards for underground disposal sites. While the IAEA and the rest of the international community is developing a consensus, ongoing programs for spent fuel disposal should recognize that spent fuels will be a desirable source of plutonium in the future and proceed to incorporate program elements to address long-term safeguards.

Some of the issues that should be examined to address safeguards concerns expressed here are the following:

1. Domestic safeguards systems should consider, among other things, the following diversion scenarios: (a) removal of spent fuel elements from consignment after they leave the storage areas at reactor sites, (b) removal of fuel during its stay at monitored retrievable storage facilities and consolidation facilities for spent fuels, (c) removal of consolidated fuel elements from storage or shipment or both, (d) removal of fuel elements from interim storage at repository sites, (e) removal of fuel elements from an operating repository, and (f) removal of spent fuel from geologic repositories after the repository is closed. In the case of domestic safeguards, possible diversion may occur as a result of insider actions or collusion between insiders and outsiders or both and possibly by actions of outsiders alone.

2. International safeguards systems designs should consider (a) that a State might attempt to divert spent fuels; (b) that a State may not declare all the quantities of spent fuels or not declare all the facilities involved in spent fuel management; and (c) that secret agreements between States may result in diversion of spent fuels for clandestine use.

3. Because the IAEA has yet to offer guidelines to the States on the safeguards requirements of geologic disposal facilities for spent fuels, discussions with IAEA should be initiated to formulate long-term safeguards measures for underground disposal of spent nuclear fuels. The existing guidelines for safeguarding SNM in the rest of the fuel cycle have to be modified, recognizing the unique requirements of spent fuels placed in geologic repositories. Participation in international discussions to develop a consensus and a strategy to address issues of long-term safeguards for geologic disposal of spent fuels is a necessary near term undertaking.

4. The NPT will expire in 1995 unless it is renewed on a timely basis. Now is an opportune time to examine possible safeguards regimes assuming (i) that the NPT will be extended for an indefinite period, and (ii) that the NPT may be terminated some time in the future.

5. Consolidation of fuel rods destroys the integrity of the assemblies as an accountable item. Therefore, it becomes necessary to reestimate the fissile content of the consolidated packages through nondestructive assay techniques or by other methods. If consolidation is unavoidable, the activities of volume reduction and containerization of spent fuels should be limited to a few locations to address verification issues of international safeguards. It may be possible to carry out all volume reduction and containerization of spent fuels at centralized MRS facilities and transport all spent fuel to the repository as sealed items after proper accounting at the MRS.

6. If no major changes in the present system of international safeguards occur, it would be necessary for international inspectors to maintain continuous presence at the geologic repository during all transfers into and out of the repository.

7. When the time comes to permanently close the repository, it may be necessary to seal all entrances to it in a predetermined manner in the presence of international inspectors and establish appropriate containment/surveillance measures to assure safeguards.

8. To reduce the need for periodic IAEA inspection, it would be desirable to develop and install a remote monitoring system to detect any mining activities or intrusion in the vicinity of the geologic repository after the repository is sealed.

9. Although it is important to assure safeguards to the international community, now is the time to consider alternatives that would reduce the cost of safeguards measures for geologic repositories containing large quantities of plutonium and other fissile materials.

10. Although the present U.S. direction is to develop a geologic repository for the safe disposal of spent nuclear fuels, it is prudent to consider the safeguards requirements of alternative strategies should the nation change this stance in the future. Just as alternative strategies for long-term spent fuel management are numerous, so are the safeguards requirements for each of those strategies.

Accomplishing these safeguards objectives is not an easy task, especially under the present conditions in the U.S. where a variety of options are being considered for interim management of spent fuels and numerous options are being explored for fuel consolidation, packaging, storage, and disposal. For the spent fuel management program in the U.S., a comprehensive safeguards policy specifying stages of spent fuel management activities and safeguards requirements at each stage are essential to avoid an overwhelming problem for safeguards at some later time.

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