International safeguards aspects of spent-fuel disposal in permanent geological repositories

Steps are being taken to develop safeguards approaches and policies

by A. Fattah and N. Khlebnikov

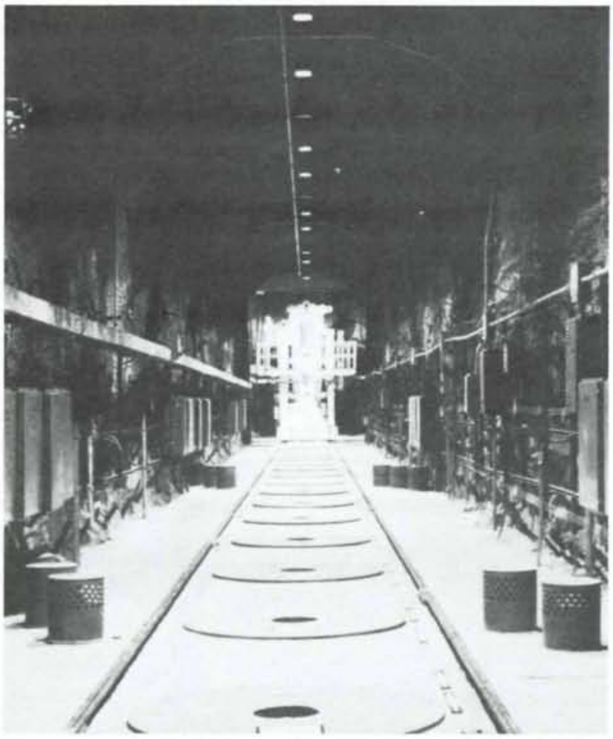
One important aspect of spent-fuel management is the practice of not reprocessing spent fuel to recover contained plutonium and other elements. States that follow this approach intend to condition the fuel and to dispose of it in a geological repository. Storage facilities at reactors and away-from-reactors (AFR) will be required to store and cool the fuel until suitable repositories are available.

In several States, spent-fuel reprocessing is neither envisaged nor considered to be economical. Recent developments make spent-fuel disposal in geological repositories more attractive than previously believed, thus introducing new challenges to safeguards. At the same time, the nuclear community has expressed concern about the pressing need to address issues of long-term safeguards for spent-fuel disposal in geological repositories.* It is thus necessary for the IAEA to develop safeguards requirements and methodology for geological disposal facilities for spent fuel and to formulate a safeguards policy before such facilities start operating.

Issue of safeguards termination

A fundamental consideration in the disposal of spent fuel is whether conditions can be met for termination of safeguards on the material or whether safeguards must be continued indefinitely.** Based on prescribed requirements, safeguards can be terminated once the Agency determines that the material has been consumed or diluted in such a way that it is no longer usable for any nuclear activities or has become practicably irrecoverable.

It has been suggested that there should be more precisely defined technical criteria based on the "consumed", "diluted" or "practicably irrecoverable" attributes which could accommodate spent fuel withdrawn from the nuclear fuel cycle. Spent fuel in AFR storage or in storage at reactor facilities does not meet the requirement of being "practicably irrecoverable".



No geological repositories for the disposal of spent fuel exist yet, but research has been done. In Nevada, USA, tests were conducted at the Climax research facility. (Credit USDOE)

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* "International Safeguards Concern of Spent Fuel Disposal Programme", by K.K.S. Pillay, INMM 29th Annual Meeting Proceedings, (June 1988), and "Final Disposal of Spent Fuel — Safeguards Aspects", by G. Stein, R. Weh, R. Randl, and R. Gerstler, *ESARDA Bulletin*, No. 12 (April 1987).

** The criteria for termination of safeguards are in paragraph 26(c) of Agency document INFCIRC/66/Rev.1 and in paragraph 11 of INFCIRC/153.

Spent fuel placed in any form of interim and retrievable storage remains accessible and, therefore, nuclear material therein is recoverable.

The situation is not so clear with permanent repositories, such as geological formations and engineered containment structures. The basic reason for a permanent repository is to dispose of the spent fuel in a way that isolates it from the biosphere and prevents human access.

An opinion does exist that spent fuel stored in geological formations becomes practicably irrecoverable because it cannot be accessed. Yet that may not strictly be the case. Various chemicals contained in spent fuel that has been stored for a long time become more easily recoverable because radioactivity decreases considerably after several decades; plutonium extraction thus becomes more feasible.

In the future, spent fuel could become a unique source of some chemical elements used in a number of everyday applications. Rhodium, for example, is alloyed with iron to produce a very corrosion-resistant steel. Geological repositories, therefore, would contain large quantities of such potentially valuable elements.

Changes in institutional and social systems may provide incentives for recovery of spent fuel for energy generation or as sources of other minerals. The possibility to recover nuclear material exists even following closure of a permanent geological repository, and any country which emplaces spent fuel could at any given time retrieve it. The same technology and skill are required for emplacement as well as retrieval. Should a State be intent on diverting material contained in fuel elements and deposited in a permanent facility, there is no conceivable way of making the material irrecoverable.

At this point, we are confronted with a very fundamental question, i.e., to what extent should safeguards on spent fuel be continued? One possibility is to continue safeguards even long after the final disposal facility is decommissioned. This view is not supported by others who maintain that it is impractical to suggest that safeguards be continued *ad infinitum.*

Defining a safeguards policy for spent fuel

In view of various technical, social, and political concerns, the IAEA has taken the initiative to develop an international consensus on the future policy of safeguards for spent fuel placed in permanent geological repositories. An advisory group meeting on safeguards related to final disposal of nuclear material in waste and spent fuel, held at IAEA headquarters in September 1988, was attended by 43 representatives from 17 Member States and Euratom.* Discussed at length was the basic issue of whether mere placement of spent fuel in a geological repository — or perhaps whether some added characteristic of the repository or degree and method of conditioning — would make the spent fuel practicably irrecoverable. Recommendations made during this meeting will be instrumental in formulating a safeguards policy for spent fuel placed in a geological repository. These recommendations are paraphrased below.

- Spent fuel does not qualify as being practicably irrecoverable at any point prior to, or following, placement in a geological repository, or even after closure of the repository, and the IAEA should not terminate safeguards on spent fuel.
- For the stages involving fuels in reactors, AFR stores, and up to the start of conditioning of the fuel, the material could be safeguarded using adaptations of existing safeguards measures.
- The process starting with conditioning of the fuel and ending with final placement in the repository raises new safeguards considerations. These arise from the possible dismantling and consolidation of the original fuel assemblies, placement in a disposal container, and placement of the container in the repository. This would require increased reliance upon containment and surveillance (C/S) and other monitoring systems. If the safeguards system fails to provide the assurance required, under most circumstances it will not be possible to re-establish the inventory by re-measurement. To provide a wide variety of C/S and monitoring systems, research and development should be started with high priority after the necessary systems study is done. To facilitate the application of C/S measures, early consultations should take place between the State/designer and the Agency.
- Spent fuel could be considered to be virtually inaccessible for physical verification when a particular area or drift in an operating repository is backfilled, and when all operations in the repository are completed and the repository is closed.
- There are technical and legal problems that have to be solved before implementing safeguards for a closed repository.

The Agency must develop a safeguards approach for such repositories while operational and after closure, and for associated conditioning facilities before they are commissioned.

Status of safeguards for spent fuel

The Agency's basic safeguards approach for reactor fuel assemblies is one of item accountancy. It is based on the principle that the integrity of the individual items can be assured, either because fuel assembly tampering would be so difficult that it can be considered unlikely, or because safeguards measures are implemented to verify or confirm their integrity. Nuclear material content is based on fabrication measurement data and it is adjusted based on the calculation of production and loss

* IAEA Advisory Group Meeting on Safeguards Related to Final Disposal of Nuclear Material in Waste and Spent Fuel, STR-243 (Rev.1), Vienna (1988).

during irradiation. Nuclear material content is assumed to be traceable as long as item integrity is maintained.

The success of item accountancy as a safeguards approach is critically dependent on the Agency being able to implement measures which provide an acceptable assurance of continued item integrity. Safeguards measures include the use of a combination of C/S devices that provide the required assurance of fuel integrity, and the monitoring of fuel shipments. The use of item accountancy has been further complicated by recent technological developments, namely, the increasing use of rod exchange and expansion of reactor storage pool capacities with high-density storage racks, consolidation of fuel rods, double stacking of fuel assemblies, and the use of special storage baskets or multi-element bottles to accommodate an increasing number of spent-fuel assemblies. Today's methods are not capable of verifying the loading of irradiated fuel shipping containers, fuel assembly dismantling and reconstitution, or the removal of individual spent-fuel rods.

These problems have raised questions about the adequacy of safeguards measures based on item accountancy. More recently the alternative of re-verifying integrity by non-destructive assay (NDA) measurement has been given increased attention. However, it is important to note that relying on C/S measures to confirm integrity or using NDA measures to re-verify integrity pose certain practical difficulties.

Similar safeguards problems have been encountered for AFR wet and dry storage facilities. The capacity of wet storage facilities, design features, and the extended time for storage create further problems because verification prospects are severely restricted. Even if NDA possibilities exist, the large number of spent-fuel elements make it prohibitively time-consuming.

Spent fuel stored in special storage baskets or multi-element bottles causes serious problems even for item counting and identification. The inaccessibility of the spent-fuel assemblies prevents direct periodic verification. Currently dry storage technology has been developed for storing spent fuel as an alternative to wet-type stores. Verification of the contents of each shipping container can be performed only during loading. Continuity of knowledge of the inaccessible fuel stored in such containers can be achieved only by C/S measures. Normally such dry storage has no provision for opening containers, so it is not possible to verify the inventory except at an unloading facility. Safeguards verification is based on item counting and identification of containers, application of seals, and containment and surveillance.

The problem to be recognized is that spent fuel will arrive at a preparation facility or a permanent repository with a presumption that the integrity has been preserved, but with an important question as to whether this is fact. If diversion has occurred and has not been detected at the time of disposal, then it may never be detected, because the Agency may never have another verification opportunity.

Safeguards for a geological repository

There are several stages through which irradiated fuel will pass before being placed in a permanent geologic repository. Each of these stages has its own unique safeguards problem to resolve in order to accomplish acceptable assurance of non-diversion of nuclear material.

Conditioning facility. Spent fuel can only be disposed of in accordance with criteria prescribed by the State. This involves immobilization or conditioning of the fuel assemblies either in conditioning plants located on the site or elsewhere.* These operations are generally carried out under dry conditions. After arrival at the conditioning facility, spent fuel is transferred to a hot cell where it is disassembled. The disassembled components are then put into containers which meet final disposal requirements. In some cases it may be necessary to cut the components into pieces. The important concern here is the need to provide assurance that the fuel assemblies have retained their integrity on arrival at the conditioning facility. The major impact on safeguards is the loss of identity of the fuel assembly as a discrete item for accountancy. The material handling operation which changes the content of spent fuel due to such operations should be followed by measures to verify the nuclear material content. Effective safeguards depend on the accounting practices to verify the content and composition of the material placed into final disposal.

Procedures must be developed to ensure that all irradiated fuel components are accounted for and that the content of all nuclear material placed into final disposal is accurately stated. Additional provisions must be developed to allow IAEA inspectors to verify that the nuclear material placed into final disposal is as declared by the operator. New measurement methods and surveillance techniques may be necessary.

Active repository. A geologic repository is expected to be similar to a mine and is expected to consist of access corridors and disposal caverns, excavated deep within the geologic formation.** Various supporting facilities are built on the surface of the repository. Shafts provide access to the disposal caverns (drifts). At least three separate types of shafts are envisaged to ensure optimum usage. These are: a canister transportation shaft, a personnel and ventilation intake shaft, and a ventilation exhaust shaft. The underground facilities at the

* "Final Disposal of Spent Fuel — Safeguards Aspects", by G. Stein, R. Weh, R. Randl, and R. Gerstler, *ESARDA Bulletin*, No.12 (April 1987).

** "Safeguards Problem and Possible Solution with Deep Underground Disposal of Used Nuclear Fuel and Fuel Cycle Waste", by R.H. Smith, and D.W. Jung, INMM 28th Annual Meeting Proceedings (1987). Also see, *Waste Management and Disposal*, INFCE Working Group 7, Final Report of the First Plenary Conference of the International Nuclear Fuel Cycle Evaluation (INFCE), Vienna 27–29 November 1978, IAEA STI/PUB/534, Vienna (1980).

repository may be designed to allow further excavation of new caverns, receipt and transport of spent fuel, emplacement, and backfilling of the disposal caverns. Mining operations may be performed on a continuous basis. Following excavation of the caverns, vertical access and emplacement shafts would be opened. Spent fuel would arrive at the repository from the conditioning plant in containers which are prepared for final disposal in surface facilities. The containers would be lowered through a shaft to the disposal level, transported to the disposal cavern, and placed in the emplacement shafts. All operations are expected to be remotely controlled. After the canister has been emplaced, the void space would be backfilled with low permeability material.

When the repository has been filled to design capacity and the room has been backfilled, final decommissioning would begin with the backfilling of all corridors and mine level openings. All shafts would be sealed to restore the formation integrity to a condition comparable to that which originally existed.

The considerations important to safeguards of a repository are: the identification of individual canisters that enter the repository, tracing the canisters to their final emplacement, and verification that they remain there until the drift is closed and the repository is sealed.

No permanent repository for spent-fuel disposal currently exists or is likely to be in operation soon. Some States are actively considering the construction of final repositories to be built early in the next century. In the meantime, extensive R&D work is being pursued by many countries for the final design. It is essential that international agreement be achieved at an early date regarding the safeguards measures to be applied at such repositories.

Closed repository. Continuation of safeguards following closure of a repository would likely be based on the use of C/S measures. Safeguards measures should be designed to confirm that the containment provided by the geological matrix of the repository has not been compromised. Periodic inspections may be required to verify the condition of the accessible tamper-indicating devices and of the detection equipment. Visual inspection of the area surrounding the repository site might also be necessary to verify that no tunnelling or mining activities have been conducted.

Repositories are expected to be located in areas which are not tectonically active. It is unlikely that any permanent disposal facility will be loaded to capacity, backfilled, and sealed before the middle of the next century. The nature of safeguards requirements at that time cannot be predicted.

Possible alternative safeguards approach

The objective of safeguards is the confirmation of the non-diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or for unknown purposes. Final disposal of spent fuel requires consideration of the safeguards measures which might be applied. Material accountancy, which is now a safeguards measure of fundamental importance, would simply not be possible. Since the spent fuel will be rendered inaccessible, physical inventory verifications could not be performed.

However, current safeguards inspections do not exclude the "use of other objective methods which have been demonstrated to be technically feasible" such as the use of containment and surveillance measures.* The application of these "objective methods" could contribute to the development of a safeguards approach for spent fuel placed in geological repositories.

Safeguards for difficult-to-access nuclear materials. The current safeguards methodology for long-term storage of irradiated fuel in a difficult-to-access area is based on a modified C/S system explicitly foreseen in INFCIRC/153.** This concept can be applied for fuel packed in discrete containers which are welded or which have an individual closure mechanism that cannot be easily opened for verification purposes, and/or when the average time needed to move items to the nearest convenient measurement location is greater than 4 hours using normal fuel-handling equipment and operating procedure. Before placing the fuel in difficult-to-access storage, the usual accountancy verification requirements to determine gross and partial defects must be applied.

The safeguards objective is achieved by maintaining continuity of knowledge by successful use of dual C/S devices operating in a redundant and independent mode and based on different physical principles. For each diversion path, at least two conclusive positive results, and no conclusive negative results, must be achieved. Once these conditions are met and the fuel is under successful C/S, inventory verification by accountancy measures is waived. However, reverification of design features at appropriate frequencies to confirm that the difficult-to-access conditions have not changed is essential.

The C/S system used in such difficult-to-access facilities must be extremely reliable, and there must be a high confidence level that the information provided is correct. Any alarm will require appropriate follow-up actions. In the event of C/S failure, even for spent fuel stored at a reactor, the requirement for reverification of nuclear material inventory can be costly in terms of effort for access and may be regarded as very intrusive by the operator. Resolving why alarms were generated would pose a major problem and reverification may or may not ultimately provide conclusive results on non-diversion.

* "The Structure and Content of Agreements between the Agency and the States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons", INFCIRC/153 (Corrected), Vienna (June 1972).

** "Safeguards Policy Series Number 11", *Safeguards Reference Material for Negotiations, Consultations and Discussions*, IAEA, Vienna (1988).

The important element of this approach's success depends on the design of reliable C/S systems which must produce conclusive positive results. The design specifications of a C/S system must conform with the principle formulated by the Standing Advisory Group on Safeguards Implementation (SAGSI), i.e. if C/S measures providing sufficient assurance against circumvention or defeat by any realistic means were available, remeasurement of material under such C/S would not be necessary.* Such a system should consist of devices operating in a redundant and independent mode based on different physical principles which have acceptably high standards of integrity and performance and which can be authenticated. Acceptable C/S means that a C/S system is accepted as a means of maintaining continuity of knowledge over a period of time at a confidence level comparable to that achieved during a previous material verification.

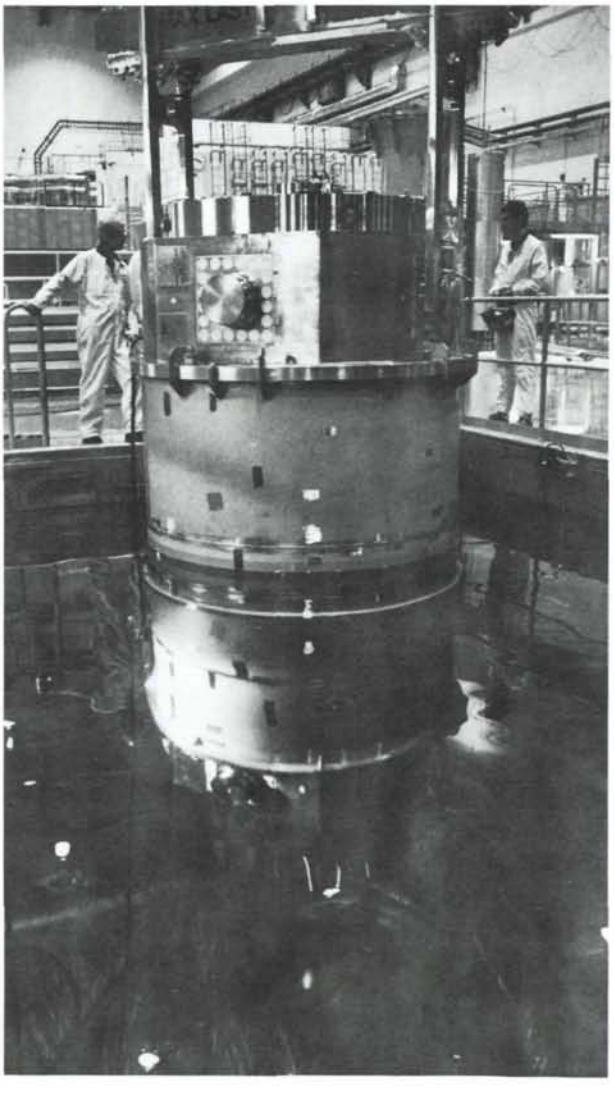
The development, evaluation, and selection of C/S safeguards equipment is expected to be an iterative process. Functional requirements such as quantitative and qualitative design specifications covering reliability, availability, tamper resistance and vulnerability, false alarm probability, detection probability, authentication, and other requirements must be fulfilled. Performance specifications, (i.e. a set of requirements with which a C/S system must comply) will be derived from these functional requirements. The Agency, national safeguards authorities, the developers of safeguards equipment, and nuclear facility operators must be involved in development, evaluation, and periodic review of functional requirements and performance specifications.

The underlying concept of difficult-to-access inventories can be extrapolated to include permanent geological repositories taking into consideration their design and physical characteristics. The aforementioned, together with properly designed multiple C/S systems and other measures, are expected to be of major importance in the implementation of safeguards at geological repositories for spent fuel.

Conclusion

In conclusion, the planned disposal of irradiated nuclear fuel in geologic repositories demands a fundamental systems analysis of alternative safeguards possibilities as a basis for defining required R&D programmes to explore specific safeguards measures and concepts. This analysis should include a review of safeguards-relevant design information for spent-fuel repositories. The review's objectives should be to identify and understand features which might contribute to safeguards; to explore alternative safeguards possibilities for feasibility, potential effectiveness, cost, intrusiveness, etc. in order to meet effectiveness; and to outline the R&D effort required for implementation. In addressing these requirements, the Agency has initiated discussions on the possibility of a multinational effort under Member State Safeguards Support Programmes.

Inside Sweden's CLAB facility for spent-fuel storage, a transport flask is lowered into the storage pool. (Credit: SKB)



* "Performance Specification for Containment and Surveillance", Department of Safeguards, IAEA, Vienna (unpublished), and "Report to the Director General on the 23rd Session of the Standing Advisory Group on Safeguards Implementation (SAGSI) Meeting, 15–17 May 1987 Vienna (August 1987).