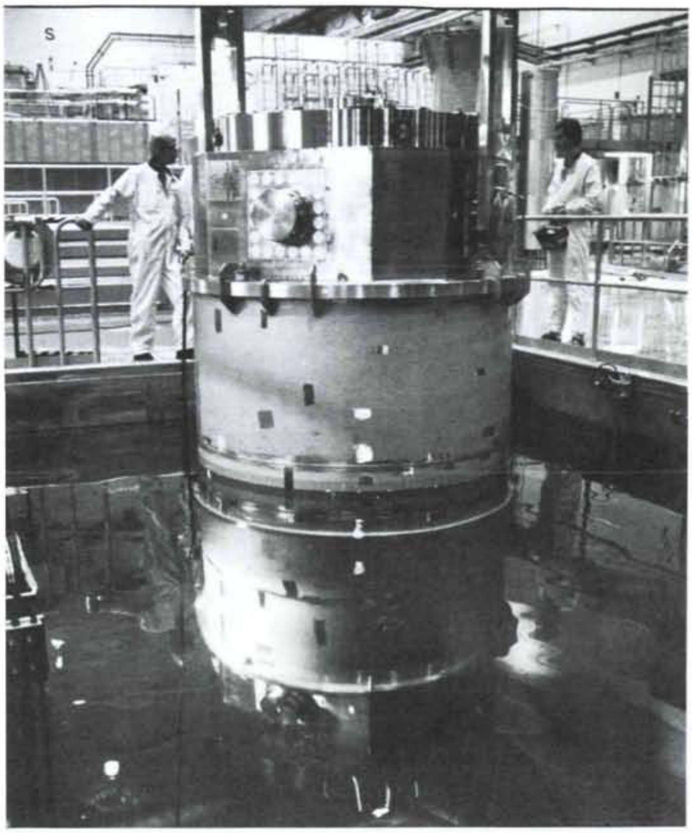
International safeguards aspects of spent-fuel storage

Techniques and approaches are evolving to meet future challenges

by V. Pushkarjov and E. Tkharev



Spent-fuel storage is an important independent element within the nuclear fuel cycle. Because of the delay in taking decisions regarding the ultimate disposition of spent-fuel assemblies in some countries, an ever increasing amount of spent fuel is accumulating in storage. Storage must be provided either at-the-reactor (AR) or away-from-the-reactor (AFR), regardless of the management option chosen.

The first power plants were constructed with normal reactor spent-fuel pools capable of storing from two-thirds to one-and-two-thirds of a core. It was expected that after an initial cooling time of 2 to 3 years, the spent fuel would be moved to a reprocessing plant. When the original programmes for reprocessing were delayed, plans on spent-fuel storage were modified to increase existing storage capacity at the same location.

On the other hand, it appears there may be possibilities for alternative storage of spent fuel. These technologies involve the use of long-term, separate spent-fuel storages of two types, wet and dry. These are foreseen as large, centralized facilities capable of accepting spent fuel from a number of reactors. At present, separate spent-fuel storages are becoming increasingly important facilities in the nuclear fuel cycle because most spent fuel will be stored there for an extended period of time before reprocessing or final disposal.

Wet storage of spent fuel is still the predominant storage method, with long and positive experience available. In some European countries, different designs of wet storages have been developed and these facilities either have already been constructed or will be constructed (in France, the German Democratic Republic, Sweden, the United Kingdom, and the USSR, among others).

Dry storage of spent fuel currently is being evaluated as an alternative option to water-cooled pools, and as a method of final spent-fuel disposal. Dry storage programmes are under way and are being investigated in countries including Canada, the Federal Republic of Germany, Spain, Switzerland, the United Kingdom, and the United States.

Safeguarding stored spent fuel

Safeguarding spent fuel is one essential element of the international safeguards system implemented at nuclear fuel cycle facilities. The IAEA has always paid due attention to the development of safeguards procedures for irradiated-fuel storage but, at present, this problem is becoming one of particular importance due to the situation described earlier.

A few years ago, the IAEA Secretariat began a study on the development of safeguards approaches for separate spent-fuel storages. Related to this, tasks are being developed under support programmes for IAEA safe-

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Photo: Inside Sweden's CLAB facility for AFR spent-fuel storage, a transport flask is being lowered into the pool. (Credit: SKB) guards of the FRG, USA, and USSR. In 1983, a meeting took place in the USSR on safeguards problems for a particular design of wet storage planned for construction in a number of countries of the Council for Mutual Economic Assistance (CMEA). In 1984, the IAEA organized a consultants' meeting on problems related to safeguarding AFR storages and future trends in this area.

All this strongly emphasizes the importance of problems concerning safeguards of spent fuel and its practical implementation.

Safeguards procedures for stored spent fuel

In classifying nuclear fuel cycle facilities with respect to material accountancy, spent-fuel storage is considered as an item facility. This means that all nuclear material is contained in identifiable items (e.g., fuel assemblies, sealed canisters, or casks of spent-fuel assemblies) during its residence at the facility. The quantity of nuclear material contained in each item should be known from measurement or estimate. Furthermore, the nuclear material content is assumed to be constant (or to change only in known ways, e.g., due to radioactive decay) so long as the integrity of the items is preserved. (See the accompanying box for a review of basic safeguards concepts.)

In such cases, IAEA safeguards are based on item accounting procedures, which include item counting and identification, examination of the continued integrity of the item, and non-destructive measurements. Containment and surveillance (C/S) measures supplementing nuclear material accountancy have particular significance in safeguarding spent fuel. In international control practice, the Agency seeks to use the nuclear facility's containment or physical barriers (e.g., walls, transport containers, storage casks, etc.) to restrict or control the movement of, or access to, nuclear material. Through surveillance, such as TV or film cameras, the

Basic safeguards concepts

Safeguards for spent-fuel storage are being implemented in accordance with the IAEA Statute and two fundamental agreements (INFCIRC/66/Rev. 2 and INFCIRC/153 [corrected]).

The objective of safeguards as stated in INFCIRC/153 is "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown and the deterrence of such diversion by the risk of early detection". In safeguards agreements concluded under the non-NPT system (INFCIRC/66 Rev. 2), there is no specific definition of objective, but in current practice essentially the same concepts apply.

In the practical implementation of international safeguards, the Agency is guided by the technical objectives based on three fundamental parameters ("detection goals"):

- The significant quantity of nuclear material
- The detection time (the maximum time that may elapse between diversion and its detection by the IAEA)
- The detection probability, which determines the required reliability of IAEA safeguards measures.

In designing a safeguards approach for spent-fuel storage facilities and evaluating results obtained, the IAEA assigns the following quantitative values to the detection goals relating to spent fuel:

- *Significant quantity:* eight kilograms of plutonium (all isotopes); 25 kilograms of uranium-235 contained in highly-enriched (greater than or equal to 20%) uranium; 75 kilograms of uranium-235 contained in low-enriched (less than 20%) or natural uranium
- *Detection time:* 1 to 3 months for plutonium and highly-enriched uranium in spent fuel; order of 1 year for uranium-235 in low-enriched uranium;
- *Detection probability:* 90 to 95%.

Using the detection goals as guidelines, the Agency draws up for every facility the inspection goals, taking into account actual operational conditions, the provisions of the safeguards agreement, and the current technical possibilities for applying safeguards measures.

The fundamental concept of IAEA safeguards is verification that nuclear material subject to safeguards under the agreement is not diverted from peaceful nuclear activities. In practice, this verification is performed by means of regular inspections with a frequency defined by the detection time. IAEA verification is based on nuclear material accountancy as a safeguards measure of fundamental importance, with containment and surveillance (C/S) as important complementary measures. It includes examination of the operator's records and reports regarding the amounts of nuclear material present and its use, as well as independent measurements and observations conducted by the Agency.

As a first step for developing a safeguards scheme, a safeguards approach is designed for a specific facility type. The safeguards approach is a system of nuclear material accountancy and C/S measures to attain the verification goals, taking into consideration the capabilities of these measurement systems, facility design features, and facility practice.

To simplify verification of spent fuel, an Ion-1 detector (shown here during safeguards training) involving gross gamma-ray and neutron measurements was developed.

Agency collects information using devices and/or inspector observation to detect any undeclared movement of nuclear material, tampering with containment, falsification of information related to locations and quantities of nuclear materials, or tampering with IAEA safeguards devices.

This combination of C/S as complementary measures to nuclear material accountancy can provide for continuous knowledge of the verified nuclear material, on the integrity of items, and on movements of nuclear material. The most desirable combination of these measures is the one that permits the safeguards objectives to be achieved at acceptable costs and with minimum intrusion into routine plant operations.

IAEA experience safeguarding spent fuel

It must be understood that basic safeguards concepts with regard to spent fuel may serve only as guidelines within the scheme of practical implementation of international safeguards at a specific facility. At first, spent fuel appears at the reactor after irradiation of fresh fuel, then it is placed in reactor storage for some time. Then, following a chosen policy, it is transferred to a reprocessing plant, or to either interim or long-term storage for future reprocessing or final disposal. It is obvious that at each stage practical safeguards measures may differ significantly depending on facility type, its design features and regime, and length of spent-fuel storage. If spent fuel is transferred from one nuclear facility to another, this interrelationship between corresponding facilities should be taken into account in the design of a safeguards application scheme at each of the facilities involved.

For a long time in the practice of IAEA safeguards, the only locations at which irradiated reactor fuel was kept under international control were in storage sites at the reactor. In the late 1970s when reprocessing facilities came under Agency safeguards, the IAEA started to gain experience in the control of irradiated reactor fuel in the buffer storages of such facilities. Since then the Agency has accumulated experience and developed safeguards approaches and procedures for such types of storages. Recently, the first long-term, AFR storages have been constructed in a number of countries and now are subject to safeguards.

In the following sections, possible ways of safeguards application, and IAEA experience regarding spent fuel at different nuclear facilities, are briefly described.

Storage at power reactors

In the majority of reactors, irradiated reactor fuel is stored in pools filled with water to provide cooling and proper shielding. At present there are about 100 such storages at reactor sites under IAEA safeguards.

Accountancy measures such as item counting, identification, and non-destructive assay (NDA) measurements can, in principle, be performed at all reactor pool storages if they are provided with appropriate instruments and equipment. Different C/S measures, using TV and film cameras and seals, may be applied in the storage area as complementary measures. NDA measurements provide the ability to re-verify the inventory of spent fuel in the event of failure of C/S measures.

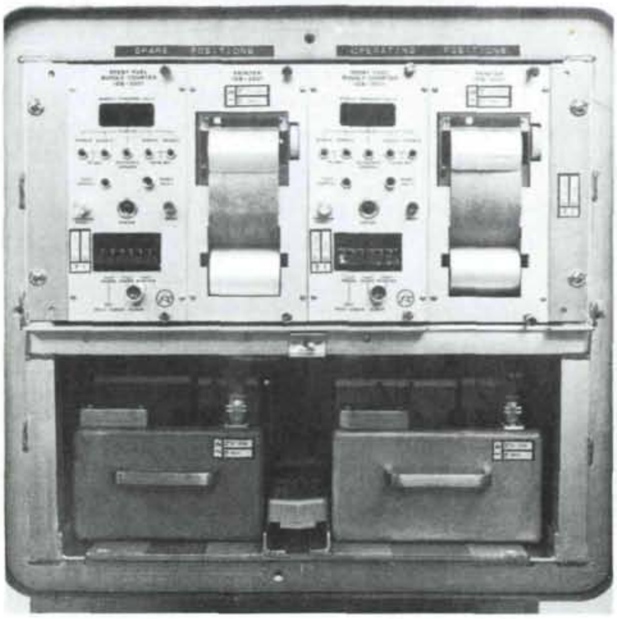
A few specific safeguards features relevant to the different design concepts of power reactors are presented below:

- *Light-water reactors (LWRs).* Spent-fuel storages at LWRs are foreseen as short-term ones. Spent fuel discharged from a reactor is stored underwater, usually in "baskets" that hold the assemblies in a vertical position providing favourable conditions for counting and identification. The minimum storage time before shipment is variously quoted as 90 to 180 days, but more fuel currently is stored for longer times (years) due to lack of reprocessing capabilities. Most reactor storage facilities were designed with a capacity of perhaps two to four complete reactor cores.

All LWR fuel assemblies are manufactured with a serial identification number on the top. In theory, this serial number is readable after irradiation under typical spent-fuel storage conditions. In actual practice, the storage conditions are such that readability is sometimes questionable. The core reloading at LWRs normally occurs at 12 to 18 month intervals, during which spent fuel is transferred from the core to the storage ponds, where it is verified by the inspector. At times other than reactor reloading, the flow of spent fuel occurs only during shipment, either to reprocessing or to long-term storage.

- *Heavy-water reactors (HWRs) – CANDU type.* The CANDU reactor was not designed on the assumption that reprocessing will occur, and due to this fact long-term storage of irradiated fuel is foreseen. Capacities at spent-fuel storage bays vary with reactor type, but in all cases capacity is expandable by adding secondary storage facilities. Storage capacity of approximately 1 year is usually provided in the primary storage bay at multi-unit CANDU power stations. Bundles are stored horizontally in containers (trays or baskets or modules) suitable for stacking. After this period, the stored fuel will be transferred via an underwater canal to the secondary storage bay having a storage capacity of 30 operating years.

The safeguards approach developed for CANDU uses unique instruments and techniques because of particular design features (namely, continuous on-load refuelling, large inventory, and difficulties of access for routine inventory measurements). Item accountancy for inventory and flow verification forms the foundation of the safeguards approach, although for routine purposes the CANDU approach uses flow-verification methods in combination with C/S to verify irradiated-fuel inventory. Use of seals in the secondary bay will provide a significant decrease of inspection effort required for inventory verification.



A spent fuel bundle counter was developed for Candu reactors that are refuelled on line. (Credit: AECL)

• *Gas-cooled reactors (GCRs).* The IAEA has only limited experience in safeguarding nuclear reactors with gas-cooled storages of irradiated reactor fuel. There are only three such storages at GCRs, and one demonstration facility for experimental storage of irradiated reactor fuel in concrete canisters. Due to the delay in reprocessing irradiated fuel, there has been considerable effort recently to increase the capacities of existing storages and those under construction at reactor sites. Among proposed technical solutions, which may create additional difficulties for verification and influence practical inspection activities, are storage compaction, addition of a second level of storage racks, and consolidation of spent-fuel rods by placing them into special containers. These modifications have to be taken into account in the design scheme of safeguards implementation and, in some cases, the development of new safeguards methods and techniques is required.

Storage at reprocessing plants

Storage pools at spent-fuel reprocessing plants were generally designed on the assumption that received spent fuel would soon be reprocessed. Sufficient space was provided for fuel storage covering 3 to 4 months of operating capacity for a reprocessing plant. Some later designs of large-scale reprocessing plants exist where it is foreseen to increase the storage time of spent fuel in buffer storage up to several years (4 to 5) before reprocessing.

Fuel assemblies are received at reprocessing facilities in shielded casks typically weighing 20 to 100 metric tonnes and holding in the range of 10 to 20 assemblies. In the storage ponds, spent-fuel assemblies may be stored either in simple racks designed to support the assemblies in a vertical position and to maintain the spacing required for nuclear safety, or the assemblies may be kept in various types of baskets or containers for ease of handling or for other reasons. These special containers often are of safeguards interest because they result in covering the top of the assemblies, preventing visual observation of serial numbers, observation of Cerenkov radiation, or even simple physical presence of assemblies.

If spent-fuel assemblies are accessible for direct verification in storage ponds, the inspection procedures are, in principle, similar to those performed at spent-fuel storages at the reactor site, though they may require considerable efforts. In other cases, when fuel assemblies stored in special closed containers are inaccessible for examination, these storage containers are defined as basic items of material accountancy. It is assumed that their content is verified by inspectors either at the reactor immediately before shipment, and then sealed, or at the reprocessing plant upon receipt, and then sealed.

Taking into consideration the operation regime of the reprocessing plant, item accountancy and bulk material accountancy are combined for verification of spent-fuel flow from storage to the process area.

Long-term spent-fuel storage

The Agency has gained some experience in safeguards implementation of wet storages at reactors and reprocessing plants, and it seems that safeguards procedures at long-term, separate wet storages will be similar in many respects. Meanwhile, the extended time period of storing spent fuel, the capacity of long-term, separate storages, and their design features raise new questions on safeguards application at such facilities.

Verification procedures based on accountancy measures are limited at a number of wet-type storage facilities because of the design features and the limited technical possibilities of performance of NDA measurements. In addition, it appears that these measurements (where they are feasible) are likely to be very time-consuming because of the large number of spent-fuel assemblies (up to several thousand) stored in these facilities. In some cases, when spent-fuel assemblies are stored in special storage baskets or multi-element "bottles", even item counting and identification of assemblies may cause serious difficulties.

This situation is even more complicated for dry storages where spent fuel cannot be verified in practice by accountancy measures because it is physically inaccessible. Based on these facts, the role of C/S measures is becoming extremely important for safeguards implementation at long-term, separate spent-fuel storages for both wet and dry types.

Fortunately, favourable conditions for application of C/S measures at these facilities are provided in so far as spent-fuel assemblies remain in a static position for long periods of time. Diversity of C/S measures applied at storage should be such that corresponding

C/S devices do not possess a common mode of failure and provide a high level of technical performance and redundancy.

For the same reasons, the establishment of an initial inventory of irradiated fuel loaded at the reactor is a task of high priority. It is particularly important for dry storages where transport/storage containers cannot be re-opened for verification upon their arrival at the storage facility. Reliable sealing systems are to be applied to transport containers to preserve integrity and continuity of knowledge on nuclear material transferred from reactor to storage.

It is clear that operating procedures related to transfer of spent fuel from the reactor to long-term storage will considerably influence the safeguards inspection scheme. For designing a safeguards approach, this interrelationship between shipping (reactor) and receiving (storage) facilities should be taken into consideration for the optimization of inspection efforts and effective safeguards implementation.

It appears that the regular presence of an inspector during shipment of spent fuel from the reactor and its receipt at storage will demand considerable inspector resources. The development of advanced C/S techniques may solve this problem and provide potential benefits to reduce the demand for inspection resources. As an example of these new techniques, two particular devices are currently being developed under support programmes for Agency safeguards. These are the spent-fuel assembly counter and the electronic sealing system, which are capable of storing all opening and closing times of seals attached to transport casks. Information collected through these instruments and supported by surveillance cameras at both facilities may allow continuity of knowledge on spent-fuel shipments from the reactor to storage without an inspector's presence at either facility.

The described devices have conceptual safeguards meanings and form the basis of new ideas for safeguards implementation relevant to the storage of spent fuel. The practical use of these devices should, under realistic conditions, be properly analysed on the basis of future tests of this instrumentation, relevant to technical performance, reliability, and tamper resistance. The feasibility of applying this technique to particular facilities also will depend on the specific design features of these facilities.

Design guidelines

All nuclear facilities are subject to many economic, technical, legal, security, safety, environmental, and other design constraints, and it is the function of the facility design team to find solutions that are in some sense optimal. For nuclear facilities, the ability to facilitate safeguards implementation is an additional concern that should be taken into account to the greatest extent possible at the design stage. This is particularly true for spent-fuel storage, where C/S measures play a very important role. This problem has been thoroughly discussed at a number of meetings held by the Agency. Member States have expressed their understanding of this problem's significance and are taking into account corresponding guidelines and recommendations in the early design stages of spent-fuel storages.

Satisfactory application

In this article, some general aspects of safeguarding spent fuel have been described. Of course, they do not reflect all details and peculiarities relevant to the international safeguards system regarding spent fuel. With respect to storage at the reactor and buffer storage at reprocessing plants, the IAEA has a proven scheme of safeguards implementation. Current safeguards techniques may be satisfactorily applied at long-term spent-fuel storages to achieve the safeguards objectives, in spite of a number of unique features at these nuclear facilities.