LONG-TERM INTERIM STORAGE CONCEPTS FOR SPENT FUEL AND INTERMEDIATE-LEVEL WASTE: CURRENT STATUS OF R&D IN FRANCE

J.-P. Silvy, P. Jaecki, N. Moulin
CEA/DEN, CEA Valrhô, BP 17171, 30207 Bagnols-sur-Cèze Cedex, France

ABSTRACT

In the framework of the 1991 French nuclear waste management act, the CEA has undertaken an extensive R&D program on the long-term interim storage of high- and intermediate-level long-lived radioactive waste, and of spent fuel. This report focuses on concepts for interim storage of spent UOX fuel for up to a few centuries, either in surface buildings or in subsurface galleries. Spent fuel containers have been specifically developed for interim storage conditions. Intermediate-level waste storage is also mentioned.

The concept for long-term surface interim storage of spent fuel involves vault-type dry storage in heavily reinforced concrete modules, while the subsurface design consists of vertical shafts and access galleries excavated in the rock on a hillside. The container provides two leaktight barriers that supplement the fuel rod cladding, whose long-term integrity over periods exceeding a century may be difficult to demonstrate. A cast iron or low-alloy steel overpack encloses seven canisters. Special attention is given to sealing the canisters and overpacks, and to aging of the overpack materials. A demonstration program has been set up to validate the technology, feasibility and durability.

INTRODUCTION

The French government has mandated the CEA to set up and carry out a research program on long-term surface or subsurface interim storage of long-lived radioactive waste. The program objective is to provide evidence and data in support of a decision to be taken after 2006 concerning French radioactive waste management.

The waste in question includes high-level (vitrified) waste and intermediate-level waste (bituminized waste, technological waste, etc.) as well as spent fuel. This report describes the current status of research with regard to spent fuel, with a brief mention of the situation for long-lived intermediate-level waste.

LONG-TERM INTERIM STORAGE

A long-term interim storage facility is designed to accommodate and conserve waste packages for subsequent retrieval under safe and economically viable conditions on a secular time scale (100 to 300 years). The issue is thus to ensure that these functions will be maintained over the lifetime of the facility.

The design strategy has been to favor engineering solutions whenever possible that are simple, robust (relatively unaffected by changes in the technical and social environment), and intrinsically safe, allowing minimal operating constraints. This approach is based on the following properties:

- passivity: the design and operation rely on components that are as simple and passive as technically feasible;
- maximum inertia of the facility;
- allowance at the design stage for long-term aging processes and for the use of constituents whose degradation over time can be estimated;

- package integrity at the end of the interim storage period;
- allowance at the design stage for suitable maintenance and surveillance programs;
- traceability and archival of information concerning the packages.

LONG-TERM INTERIM STORAGE OF SPENT FUEL [1]

General design principles

Long-term interim storage is based on four constituents, each of which contributes to the overall function: the interim storage package, the ventilation system, the infrastructure, and the host site. No site has yet been designated for surface or subsurface long-term interim storage facilities. Our work is thus oriented towards generic sites, in particular for subsurface storage in a hard rock site.

The following design principles were adopted to meet these objectives:

- dry interim storage of double-wall metal overpacks cooled by natural air convection;
- overpack integrity ensured by dry corrosion conditions.

The overpacks are placed in heavily reinforced concrete surface bunkers arranged in modules, or in vertical subsurface shafts excavated in a rocky hillside.

The CEA studies cover not only the design of the facilities but also a performance demonstration with emphasis on durability. (From the standpoint of durability, only the overpack will be discussed here).

Interim storage concepts: Surface storage

The facility comprises three separate areas:

- an interface zone with entry provisions, hot cells for inspection and examination, utilities, and offices;
- a central transfer gallery leading from the interface zone to the interim storage areas;
- modular interim storage bunkers situated on either side of the transfer gallery.

Interim storage bunkers

Fig. 1, a cross sectional view of an interim storage bunker, shows the overpacks stacked vertically and secured at the top and bottom to prevent them from overturning accidentally.

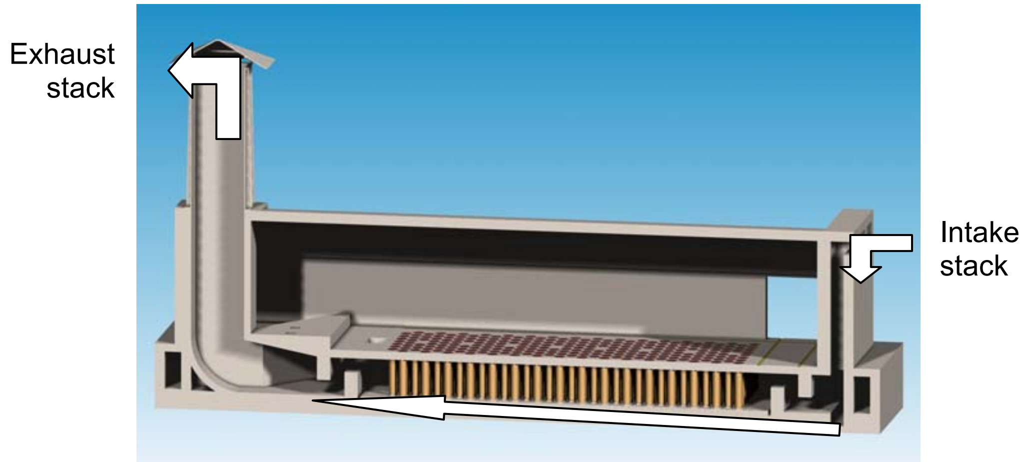

Fig. 1 Bunker cooling system principle

Ventilation system

Each bunker has a separate air cooling system based on natural convection: outside air is used as the heat sink, and is ducted through the array of containers. The bunkers are installed in pairs in a module, with twin ventilation stacks separated by a simple partition.

The system comprises a cool air intake stack and a hot air exhaust stack, and is separated from the handling room by the slab at ground level (0.0 m). The lower end of the air intake stack includes a pit for recovery of atmospheric particle matter.

In the event of failure of the exhaust stack, a mobile air exhaust system can be installed in the module handling rooms. The system is connected to bypass registers in the slab at the downstream end of the container array. Bypass registers are also provided at the upstream end of the slab in case of failure of the air intake stack (clogging of the intake grids). The registers can only be handled with heavy-duty lifting equipment.

Interim storage concepts: Subsurface storage

The subsurface concept is based on dry interim storage, with containers placed in vertical shafts excavated in the rock and cooled by natural convection. The facility includes:

- An interface zone similar to that of the surface concept;
- Two main air distribution galleries (cool air intake and hot air exhaust);
- Interim storage modules located parallel and at right angles to the two main galleries, and consisting of storage shafts accommodating the containers;
- Access galleries for shipping containers;
- A transfer gallery leading from the interface zone to the interim storage area.

Dry interim storage shafts

Each shaft can accommodate two overpacks positioned so cooling air flows in the annular gap between the container and the shaft wall.

The overpacks are placed on a concrete base resting on the lower gallery to prevent tensile or shear stress loading of the surrounding rock. They are centered in the shaft by devices that guide them during handling and limit their movement in the event of an earthquake.

A reinforced concrete liner in each shaft prevents small blocks from dropping into the annular gap between the overpack and the shaft to avoid any risk of the container jamming in the shaft. A layer of granular material (e.g. gravel) is added between the rock and the concrete to ensure drainage of any water seepage.

Each shaft is sealed by a plug throughout the interim storage period. The plug ensures radiological shielding but allows ventilation air to flow freely; it also prevents groundwater from trickling onto the overpacks. The plug is designed on the same principle as the transfer screws routinely used in hot cells. The central passage in the plugs can be used to insert tooling for in situ container inspection.

Interim storage module

An interim storage module comprises a group of 5 paired-tunnel systems arranged parallel to one another. Each tunnel system comprises an interim storage gallery with 150 shafts, leading to the air exhaust gallery, situated above a ventilation gallery that is connected to the air intake gallery.

Ventilation system

Each module has a separate ventilation system. The packages are cooled by natural air convection; air flows in the annular gap between the packages and the shaft walls as shown in Fig. 2.

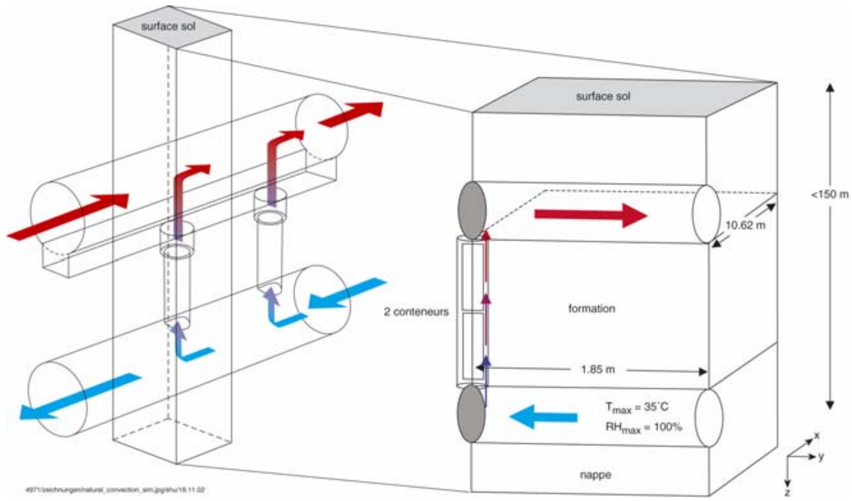

Fig. 2 Air cooling system principle

Cool air intake galleries supply air to the distribution gallery. An air distribution gallery at right angles to the air intake galleries supplies air to the lower ventilation galleries in each module, while an upper ventilation gallery with dimensions similar to those of the distribution gallery is constituted by the interim storage gallery itself, which collects and exhausts the hot air from the modules;

Several hot air exhaust stacks are provided, one for every two modules. The lower end of each stack is tunneled in the rock, and the above-ground portions are made of reinforced concrete.

R&D program

A development program has been pursued together with the design work, addressing mainly the following issues:

- the durability of the infrastructures, including their temperature behavior;
- high-temperature aeraulics;
- characterization of geological media and specification of the relate protocols.

SPENT FUEL OVERPACK [2]

As the spent fuel cladding integrity cannot be demonstrated over secular time periods, each fuel element is inserted in a leaktight canister and several canisters are placed inside a second leaktight interim storage overpack. The following discussion considers these points as they apply to UOX fuel.
The CEA's R&D program covers three aspects: design, feasibility demonstration and durability demonstration for both the canister and overpack.

Design
The relevant thermal, mechanical, criticality, transport and geometric optimization criteria are met by a cylindrical package made of spheroidal graphite 400-15 cast iron or unalloyed steel, enclosing seven 304L stainless steel canisters.

The overpack is about 40 mm thick and about 5400 mm high, with an outside diameter of about 1200 mm. The mechanical strength of the overpack is reinforced by heavy-duty bottom and cover plates 100 mm thick.

Canister
AISI 304L stainless steel was selected as the constituent material. This grade is widely used in nuclear applications because of its satisfactory mechanical properties, ease of forming, and controlled weldability. The canister will be sealed by TIG welding a few millimeters thick.

Overpack
Spheroidal graphite cast iron and unalloyed steel are considered the most suitable materials. Technological solutions are now being developed to overcome cast iron weldability problems.

The technological feasibility of a cast iron overpack was demonstrated by fabricating a full-scale prototype. No serious defects in the prototype were revealed by mechanical testing and microstructural examination of attached test coupons, geometric and dimensional checks, or by nondestructive ultrasonic inspection.

Fig. 3 Prototype canister and overpack

The nominal solution for sealing the overpack consists in welding the entire thickness of the container. Three full-thickness welding techniques have been developed and tested for long-term interim storage: TIG welding, YAG laser welding, and electron-beam welding.

Demonstration program: Package durability

The objective of this demonstration is to produce methods, rules and examples of technological solutions capable of ensuring that the packages are designed and manufactured in such a way that their long-term reliability can be ensured with a high level of confidence. The studies will focus on the two points with the greatest implications on long-term package behavior: leaktightness and integrity. This experimental work is expected to yield degradation or failure laws for the package constituents, and to validate the long-term performance of the selected options.

The experimental program set up to reach this objective includes aging tests on test coupons and mockups representative of the canister and overpack materials and of the closure and heat options considered.
The canister and overpack tests involve aging for 1, 3.5 and 10 years. The aging tests will initially be performed on small test coupons. The objective is to monitor variations in the mechanical properties, microstructure and chemical composition of the materials and the welded joints (TIG, laser, electron beam). Aging tests are now in progress on over 5000 representative test coupons. Mockup aging tests have also been initiated to corroborate and validate the models derived from aging tests on coupons, and to ensure that all possible degradation modes are taken into account. Similar destructive examinations are performed on the test coupons.

The ferrite content of the TIG weld seam on 304L stainless steel is monitored with particular attention to predict its aging behavior. The canister weld has an austenitic-ferritic microstructure. The presence of about 10% ferrite in the weld seams is necessary to prevent high-temperature cracking during the welding operation. However, ferrite is known to cause embrittlement in an austenitic-ferritic steel, even at low temperatures: the ferrite decomposes to form a fragile, chromium rich α' phase. One of the reasons for heat treatment after welding is to lower the ferrite concentration in the weld and thus minimize its embrittlement.
Variations in the ferrite concentration over time are followed to determine its decomposition rate. The ferrite content is measured at regular intervals at a specific position in the weld using a ferritescope.

LONG-TERM INTERIM STORAGE OF INTERMEDIATE-LEVEL LONG-LIVED WASTE PACKAGES

The waste packages in question include a range of contents, geometries and constituent materials.
The package interim storage facility is designed for up to 300 years of operation. The durability objective—a major technical issue—has been addressed by opting for a simple operating mode involving natural ventilation with uncontrolled atmosphere.

It was decided to group one or more primary packages inside an interim storage container made of cementitious binder on which the main long-term safety options are based.

Fig. 4 Example of a long-lived intermediate-level waste container

Five design guidelines were specified:

- Nondissemination of radioactive material: the container constitutes the containment system for radioelements in solid or aerosol form.
- Mechanical protection of the primary packages: in the event of an impact or drop, the container protects the primary packages to conserve their integrity and allow retrieval.
- Chemical protection of the primary packages: the container must prevent corrosion of the existing stainless steel primary packages by limiting or preventing any interactions with uncontrolled atmosphere.
- Contribution to the gas management strategy: various gaseous constituents can arise in the package, primarily hydrogen produced by radiolysis of organic compounds or water. The interim storage container must allow hydrogen to diffuse outward through the wall. Volatile radioelements may also be released together with hydrogen.

As for the spent fuel overpacks, the CEA R&D program seeks to demonstrate their technological feasibility and suitability with regard to the five long-term guidelines.

To optimize the compatibility with geological disposal, we have adapted the ongoing research programs to include, for example, the option of using rectangular containers.

For the interim storage facilities, in addition to component durability, the studies address the issues of radiolysis gas management and the feasibility of natural ventilation with nonthermal packages, which has been demonstrated for surface facilities but requires further site-related data for subsurface interim storage.

CONCLUSION

The CEA studies demonstrate the feasibility of long-term interim storage intermediate- and high-level long-lived waste and for spent fuel.

The durability demonstration is based on an experimental program currently in progress. The initial results have confirmed the predictive models.

Upcoming milestones include the fabrication of technological demonstrators for the end of 2004, leveraging the experience acquired with the initial prototypes, followed by durability experiments and design studies for interim storage facilities by late 2005.

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