ISSUES AT STAKE WHEN CONSIDERING LONG TERM STORAGE OF HLW A COMPREHENSIVE APPROACH TO DESIGNING THE FACILITY

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ABSTRACT

CEA has been conducting a comprehensive R&D program to identify and study key HLW storage design criteria to possibly meet the lifetime goal of a century and beyond. A novel approach is being used since such installations must be understood as a global system comprised of various materials and hardware components, canisters, concrete and steel structures and specific procedures covering engineering steps from construction to operation including monitoring, care and maintenance as well as licensing. The challenge set by such a lifetime design goal made the R&D people focus on issues at stake and relevant to long term HLW storage in particular heat management, the effect of time on materials and the sustainability of care and maintenance. This opened up the R&D field from fundamental research areas to more conventional and technical aspects. Two major guiding principles have been devised as key design goals for the storage concepts under consideration. One is the paramount function of *retrievability*, which must allow the safe retrieval of any HLW package from the facility at any given time. Next is the *passive containment philosophy* requiring that a *dual-barrier system* be considered. In the case of spent fuel, CEA's early assessment of the long-term behaviour of cladding shows that it may not qualify as a reliable barrier over a long period of time. Therefore, the overriding strategy of preventing corrosion and material degradation to achieve canister protection, and therefore containment of radioactive material throughout the time of period envisaged, is at the heart of the R&D program and several design alternatives are being studied to meet that objective. For instance available thermal power from SF is used to establish dry corrosion conditions within the storage facility. The paper reviews all of these different R&D and engineering aspects.

INTRODUCTION

The 1991 French law has organised the research work related to high level long lived radwaste management along three main themes:

- ways to minimise long lived radio-nuclides inventory,
- disposal of waste in deep geological formations,
- wait storage solutions to achieve the best possible safety level.

This paper illustrates how CEA is addressing the « wait storage solutions » component of that research program through its « long term storage » research initiative. The paper focuses on a particular area as an example, the spent fuel approach, although the research being carried out encompasses a much broader scope.

Long Term Challenge

Nuclear industry has developed a safe methodology to manage nuclear waste from the early days onward. There has been no ultimate disposal solution in operation as of yet in any country. Therefore, temporary storage facilities have been operating for several decades around the world. In France, for instance, about 10000 vitrified waste packages have been stored either at Marcoule or at La Hague. The Marcoule and La Hague facilities have been in use for more than thirty years and twenty years respectively. As a result, one way to cope with long term storage could be to rely on life extension and/or renewal of existing facilities while considering refurbishment and license extension. This approach does not require any additional research work. Since decision to construct a final repository may be significantly delayed, as has been the case so far, the long term storage option may prove quite useful, provided its safety is understood and well under control. Therefore, CEA was mandated to explore this alternative route which looks into the design of facilities which could stand long term operation from the start throughout centuries-long periods. Such time periods, far exceeding a few human generations, push researchers and engineers through challenging issues and also raise unique societal questions that Society would have to address.

Focusing on Spent Fuel as an Example

Spent fuel (SF) is not considered as a waste in France under the current regulation. It contains potentially valuable energy resources that it may be worth securing for future generations. SF is currently reprocessed at La Hague facility. However in the framework of the 1991 law the research also looks into how SF could be held secure in a long-term storage facility, should this need arise in the future. It appears to be a matter of paramount importance to store it in a way that can guarantee its retrievability and in a manner acceptable with regard to risk level and cost. In addition SF contains all the radionuclides produced during irradiation. As such, it is the most challenging nuclear material to deal with when addressing its long-term storage management. These two reasons have led the authors to focus this paper on SF.

GUIDING PRINCIPLES AND OBJECTIVES

Key aspects that are at stake and relevant with regard to essential storage functions must be identified for such a facility. The paper focuses on two principal ones.

Passive Containment Philosophy

The general design rule for waste package containment system is to consider two independent barriers. The waste form itself may be considered as a barrier (i.e. glass matrix). Decision to possibly consider the cladding itself as a long-term barrier has been discussed. To this effect, CEA has launched an ambitious comprehensive program dedicated to the SF long-term behaviour. One of the main outputs of the program shows that, for the time scale considered, the cladding may not qualify as a reliable barrier. However, this will be subject to a final review when all research results are obtained. Therefore the SF long term storage canister design must provide two barriers.

Retrievability Goal

Moreover, retrievability of SF packages at any time during the storage period is the paramount objective and becomes therefore a primary function of the long-term storage facility since packages cannot be safely stored indefinitely. Therefore, SF storage conditions must be controlled and monitored to maintain and achieve containment and therefore protect canister integrity and tightness over centuries. This is being addressed by choosing adequate materials, fabrication procedures and closing technology. In addition the demonstration of the effectiveness of the retrievability procedure for the entire storage lifetime must be provided. In that respect, a key characteristic of the storage facility relates to the atmosphere surrounding the SF canisters within the facility. More specifically, humidity-controlled atmosphere to prevent general corrosion best allows predictability of the long-term corrosion rate. This engineering approach must be implemented together with careful selection of materials for the containment system. Thus canister and storage facility designs must be looked at together as complementary features to meet pre-set engineering goals.

The undertaking to address these issues will combine engineering work together with research programs since some questions have not yet received appropriate answers as is the case for the delicate question of the long term behaviour of structural components affected by thermal stress. The paper introduces the main ideas at work in the design and associated research programs.

DESIGN FEATURES AND APPROACHES

The Storage Facility

Main functions may be listed as:

- protection of the SF canisters from external aggressions,
- management of thermal output,
- provision for a humidity controlled atmosphere as mentioned above.

Though a storage facility must be monitored during its entire lifetime passive systems are preferred. The first design step is to select the cooling mode. SF storage in pool has been operating for decades in many countries. Dry facilities are also used. An example is the CASCAD facility in France (CADARACHE) cooled by natural air convection. It was granted a license for forty years in 1990. The natural convection system option has been chosen for the long-term storage facility since it seems obvious that it qualifies as the most passive one. Thermal power output of SF canisters is tentatively used to engineer a naturally convective and humidity-controlled airflow. Figure 1 below shows the general layout of a surface long term dry storage facility.

Dealing with potential external events, subsurface facilities seem to provide more protection than concrete vaults built above ground. These two options are being explored and evaluated against criteria like safety, cost, and other technical aspects. First results will be available early in 2003.

Of paramount importance is to provide dry corrosion conditions in a passive way. In current air-cooled, dry facilities, SF packages are cooled by an axial cooling airflow. However transverse cooling airflow seems to be a promising technique to lower temperature gradients and therefore to prevent both condensation on cold areas and excess of heat on others. Nevertheless, the modelling of such a cooling mode is not yet sufficiently proven to insure that design goals can be met throughout the facility lifetime particularly after 100 years when canister temperature has dropped significantly. In that case temperatures range would have to be kept within a rather narrow gap limited on one hand by the long term behaviour of structural materials at high temperature (maximum of 80°C for concrete structure), and on the other hand by the obligation to meet the dry corrosion conditions (minimum of 40°C on the canister outer wall). Current thermo-aeraulic models together with existing data are not able to fit such conditions during more than 100 years. Therefore the controlled axial airflow along SF canister is the design option currently under consideration.

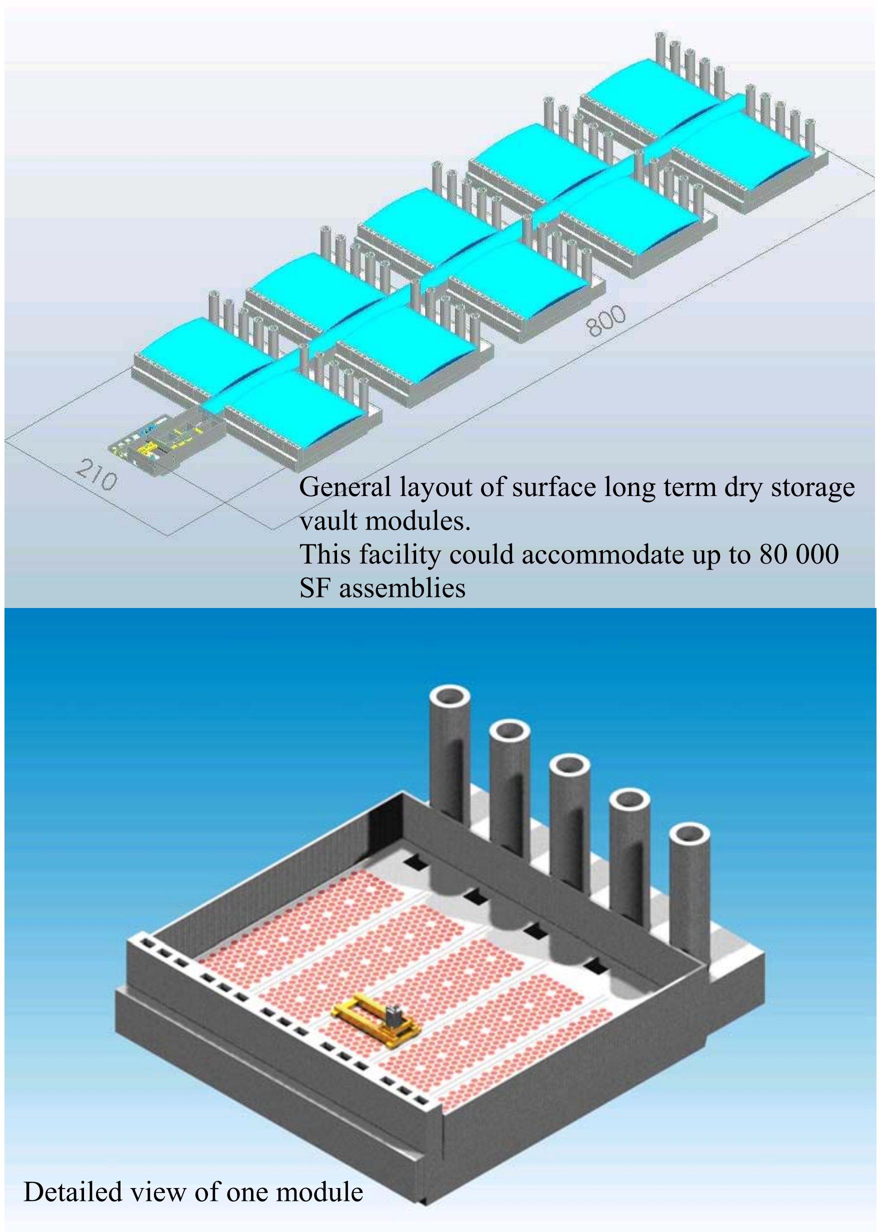

Figure 1 : General layout of surface long term dry storage vault modules.
The facility above could accommodate up to 80 000 SF assemblies

SF Canisters

SF canister design must meet containment and retrievability goals. A two-barrier system design is considered. First, each SF assembly is put inside an airtight steel case (first barrier), see Figure 2 below. Several cases fill one canister (second barrier). That second barrier must provide the best possible protection against corrosion. Materials chosen are cast iron or carbon steel since they are resistant to local corrosion and corrode in a generally predictive way. Wall thickness has to be adjusted according to the expected lifetime and the mechanical specifications (for instance for free drop). Calculations show that the prevailing parameter is mechanical which leads to a 50 mm thick wall. This can be decreased if "shocks absorbers" are introduced but they can be interpreted as a weak component since its safety function is not easy to ascertain over the long term. The steel case is made of stainless steel, protected against internal and external corrosion by inert gas (He) which fills up voids within the case and the canister.

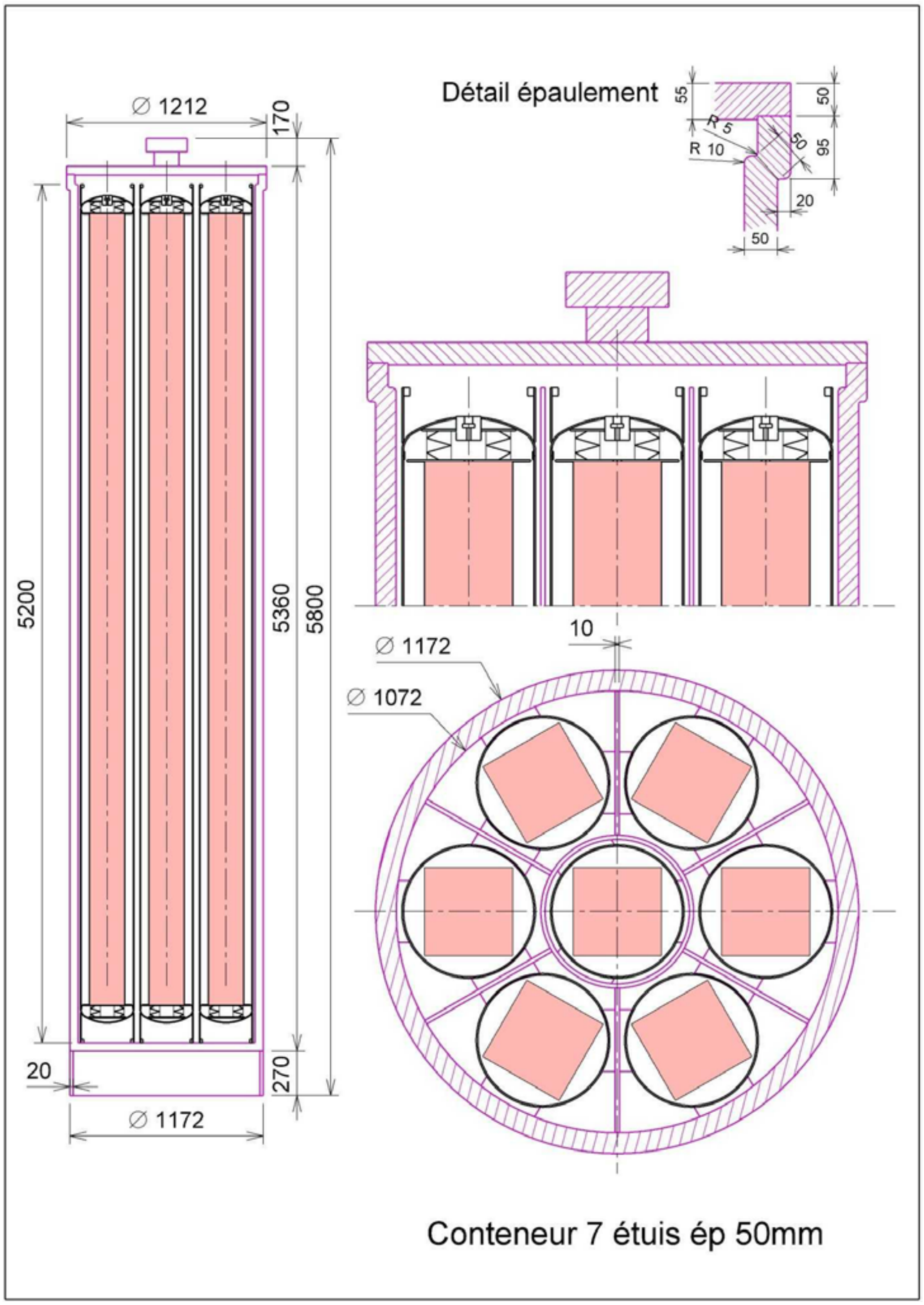

Figure 2 : Sketch of a SF canister

The choice of different metals to fabricate the case and the canister was also made to prevent potential common modes of failure. The case design remains compatible with the possible future SF reprocessing. It also allows the safe and contamination-free handling of each SF assembly. Nevertheless, a multiple-assembly case could also be used. The number of cases put inside a canister is primarily limited by thermal considerations. In the case of UOX SF assemblies, it may be limited to seven subject to burn-up levels. Cases and canister must be closed tight using welding techniques. Among those currently being investigated are electron beam, TIG or laser.

RESEARCH PROGRAMS

Demonstration of the Long Term Behaviour of Closures

Sixty mock-ups of welded components (case and canister) and 1600 samples are ageing under controlled temperature conditions. These experiments, combined with modelling, will help define the best technical choices for materials and welding techniques. It is generally considered that such experiment results can be extrapolated by 10 times as long as time is concerned. In other words, results from a ten-year experiment program can provide data to predict material behaviour under real conditions over a century. Figure 3 shows the test room for welds.

Figure 3 : Test room for welds

Thermo-Aeraulics

Controlling airflow and temperature profiles is necessary both to prevent the corrosion mechanisms and to manage the SF thermal power. Modelling alone cannot address these aspects.

Therefore, the SIGAL (Simulation Gallery) mock-up has been designed to study airflow balance within a subsurface gallery network. How air flows within the subsurface gallery grid is of interest in particular when the facility is only partly loaded with canisters.

Long Term Behaviour of Concrete Structures

The behaviour of concrete structures under thermal stress must be understood. In this respect specific large-scale mock-ups are operated at Saclay. These experiments combined with modelling will be used to produce data to eventually support the licensing process. On the other hand, the 80°C current maximum temperature criterion set for the concrete structure offers an engineering challenge for the cooling airflow system. The choice of a less severe criterion could be a valuable output from these studies with positive consequences on the general design. Figure 4 below shows the preparation of a lab-scale long term behaviour experiment on a concrete structure.

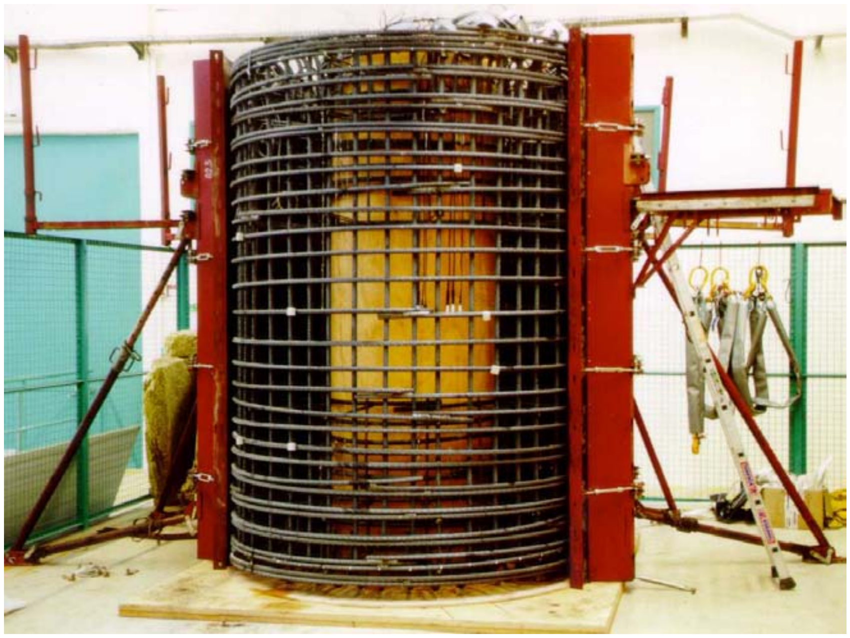

Figure 4 : Preparation of a concrete structure to test its long term behaviour under stress

CONCLUSION

The long-term storage study is considered as a global undertaking mixing engineering steps and research work. As such, it should help secure the future choices concerning nuclear waste management. It may turn out that, as a result, long term storage become a management option for decision-makers to consider. Beyond the technical issues that must be resolved to ascertain the feasibility of such a storage system there are associated societal aspects as well that also need proper answers.

The study schedule is built so that decision makers will have all the necessary inputs by 2005 to make informed decision. An important intermediate step was reached in 2002 with the conclusion of the so called "preliminary design" of both storage facilities and canisters. This step is currently feeding the scoping out of the detailed studies that come next and will be finished by 2004. At the end of the process, all relevant technical aspects as well as cost estimates will be available.