

Chapter 9

SAFETY OF ON-SITE WASTE STORAGE

1. Vitrified waste

1.1 *Technology and experience acquired*

Vitrified waste must be stored during the period between solidification and their disposal. This period can last up to several decades, mainly to enable the level of activity and the production of heat to decrease to suitable levels for disposal.

Several concepts have been developed for this interim storage, as described in the IAEA report [1]. They are air-cooled vaults, pools, and shielded sealed casks. In all three cases, the waste is conditioned in standard stainless steel containers. In the case of dry storage vaults, cooling can be by natural convection or forced circulation of air. In principle, natural convection is to be preferred because of its mechanical simplicity and its reliability. However, if the construction and size of the vault render natural convection difficult, or if extraction filters are to be used, then forced ventilation would have to be used.

Essentially, the choice between dry storage vaults and pools depends on the total heat extraction capacity and the thermal power of each HLW canister. Insofar as the cooling time between the unloading of the spent fuel and the vitrification of HLLW has steadily increased, air-cooled vaults are preferred; they are currently in operation notably in France, the United Kingdom, Japan, Belgium, and the Netherlands (Figure 9.1).

Figure 9.1. Vitrified waste interim storage room (Source: COGEMA – France)



The technique of shielded, sealed casks is intrinsically safe and only requires a minimum of monitoring as the heat generated by decay is dissipated by natural convection. It is used in Germany for vitrified waste.

1.2 Safety considerations

By definition, HLW generates heat. Vitrified waste typically has a heat output of the order of 10 to 20 kW/m³ of vitrified product. (This is only an approximate figure as heat output is dependent on the concentration of fission products in the waste, the initial fuel cooling time and the time taken for the various reprocessing stages through to vitrification). Reliable, continuous cooling is then important for the safe storage of vitrified waste, as it is for the storage of spent fuel and HLLW, but loss of cooling would have less serious consequences for vitrified waste because:

- the cooling time is longer;
- the waste is in a solid form which is chemically and thermally inert and thermally stable;
- the storage system displays considerable thermal inertia which enables natural convection to constitute the main mode of heat dissipation after prolonged loss of forced cooling, if any;
- the proportion of volatile products, notably certain fission products, is very low, as a direct consequence of the process used to solidify the waste.

The main consequences of failing to dissipate this heat would be:

- accelerated degradation of the structural materials used for shafts and extractor ducts when exposed to overheated air;
- a rise in temperature of the vitrified mass with the attendant potential for degradation as the kinetic mechanisms that can induce devitrification become significant at temperatures over 650°C.

The first point is not a short-term concern (there would be plenty of time to take mitigating measures), and the second point is a safety issue only for the geological disposal, not for the storage facility. The effect of devitrification is to increase the leach rate of fission products from the glass matrix in a process that will occur at best thousands of years after storing vitrified waste in a geological formation. Moreover, if such devitrification happened, it would be possible to anneal the glass by heating it – a probably costly operation, but possible.

Nevertheless, much attention is given to cooling systems reliability, particularly during the initial phase of operation when heat generation is at its highest.

As previously stated (Section 2-2.8.1 above), the storage building is systematically designed so that natural convection alone is sufficient to remove the heat output of waste, as well for direct cooling as for indirect cooling facilities. This ensures that operating temperatures will not be exceeded. However, it is common practice to install exhaust fans to provide forced draft ventilation in view of the advantages afforded by the additional investment:

- it may be difficult to remove heat during the initial phase of operation. Once the heat load has decreased sufficiently, the fans can be shut down in order to reduce operating costs;
- lower exhaust duct temperatures prolong the life of structural materials;

- fans can replace natural convection when the latter is precluded by adverse weather conditions;
- in direct cooling systems, exhaust air is generally passed through filters before being discharged via the stack (often a regulatory requirement for these systems). The filters will be by-passed in case of temporary forced ventilation shutdown, requiring a radiological monitoring of exhaust cooling air.

As stated above, a great deal of experience has been acquired in the field of air-cooled storage. In France, in first generation direct cooled facilities air-cooling is initially obtained by forced circulation of air and natural convection is used at a later stage. Indirectly cooled second generation facilities rely entirely on natural convection. The United Kingdom installation relies on natural convection from the outset, but ventilators are installed as a back-up, to deal with any significant reduction in natural convection caused by phenomena such as unfavourable weather conditions, or with the introduction of regulations requiring the addition of extraction filters. The maximum glass temperature is generally maintained below 600°C and the outlet temperature of the air is between 85 and 150°C depending on process characteristics. Insulation generally keeps temperature of structural materials below 60°C. Given temperatures of this order, the stability of the concrete or other structural materials can be ensured for the whole life of the store.

The second safety consideration relates to the possibility of a container being dropped as it is loaded into or unloaded from the shaft, following a handling system failure or operating error.

To reduce the consequences of this type of incident, shock absorbers are installed at the foot of each storage shaft. These are designed to absorb the impact energy and to prevent a loss of container integrity. In the event of such an incident, the container(s) must be removed from the shaft for inspection, repair and, if necessary, reconditioning.

Other safety issues, such as earthquakes, flooding, accidental plane crashes, etc., must be taken into account in the design. Their probabilities depend on the site. As these hazards are not specific to HLW, they are not addressed in this Section, but given the experience acquired in taking these constraints into account for the design of recent nuclear reactors and reprocessing plants, the design of vitrified waste stores should not present any difficulty.

The principal hazards to the operators reside in operations of filling or emptying the installation, connected with the handling (risk of dropping) of high radiation objects (risk of exposure) in the event of failure of the equipment or its control systems.

Regarding off-site impact, checks to ensure that the outer surfaces of the containers are not contaminated prior to storage, measures designed to ensure their integrity while in storage, either the containment of indirect cooling or the widespread practice of filtering cooling air with HEPA filters before venting it and radiation monitoring, all ensure that the quantities of radionuclides discharged to the environment are extremely low or nil.

The only secondary wastes generated by storage are either liquid effluent from container decontamination, where there is any, or extraction filters contaminated under abnormal conditions in directly cooled facilities.

2. Cladding waste

2.1 Introduction

Besides HLLW, waste streams include certain structural elements of fuel elements and solid residues. These wastes generally produce less decay heat than the vitrified waste mentioned in Section 9-1, and, in general, loss of cooling therefore presents no major safety problem. The characteristic shared by these wastes is their high level of radiation, caused mainly by products of activation, especially in the form of beta and gamma radiation. Contamination by actinides (from adhering undissolved fuel) may reach 1% in certain cases, which may increase levels of radiation (Modern plants have a much better record than this upper limit). The most important conditions to respect consist of installing adequate radiation protection shields and using remote handling techniques.

2.2 Magnox cladding swarf

Magnox cladding swarf can be pyrophoric in certain conditions [2]; it can also react with water to produce hydrogen. This reaction may accelerate to reach a point where it may lead to a dangerous instantaneous production of hydrogen.

The system chosen for Magnox swarf from the first nuclear programs, notably in the United Kingdom, was dry storage in concrete silos. Though no pyrophoric incident has been recorded in these silos, the dry storage silos in Sellafield, which date from the 1950s, have later been equipped with a rapid response argon inerting system, enabling the fire prevention system to be modernised.

A fire was recorded in a dry storage silo in the UP2-400 plant in La Hague in France. Two silos, each of a volume of 2 500 m³, had been installed for storing the graphite sleeves and magnesium end-pieces from GCR fuel elements. Slow combustion of part of the contents of one of the silos was detected by radiological monitoring. Nitrogen flushing, followed by the injection of large quantities of water, enabled the situation to be kept under control. The presence of fragments of uranium, combined with mechanical shocks during the last unloading of waste into the silo, is considered to be the possible cause of the fire. Subsequent to this incident, the equipment and the building have been refurbished and new precautionary measures have been taken to prevent a similar event from occurring in the future.

Most Magnox swarf from historic reprocessing operation, however, is stored under water in concrete silos. In principle, the production of hydrogen is slow, but the reaction also produces heat, and if heat transfer toward the outside of the silo is low it may generate a runaway thermal reaction with instantaneous production and release of hydrogen. The heat produced may result in structural damage to the concrete silo, and the concentration of hydrogen above the water level can reach 40 to 50% (within the detonation range). Cooling coils are often built into the silos, but the fragments themselves may limit convection phenomena, thus restricting cooling and possibly resulting in such an excursion. Many of the earliest underwater storage silos probably do not contain any more Magnox swarf, most of which has reacted with the water to form dense sludges. The silos are ventilated to prevent the build up of hydrogen. The more recent silos are equipped with argon or nitrogen inerting systems, activated by temperature or hydrogen sensors in the silos, which are intended to maintain the hydrogen concentration below the flammability limit in the event of an excursion.

Given the problems inherent in the dry or underwater storage of Magnox swarf in bulk in silos, this form of storage can best be seen as an intermediate stage while awaiting encapsulation or immobilisation of the swarf prior to disposal (see Section 8-4).

Newly arising Magnox swarf is encapsulated as soon as it is processed into a concrete matrix into stainless steel drums suitable for long term storage. Such waste is then held in ventilated and shielded stores.

2.3 *Stainless steel waste*

This waste may include stainless steel hulls from oxide-based fuel (FBR or first generation LWR fuel) or structural elements (end-pieces, grids, spacers, etc.) from fuel assemblies. It presents very few problems, apart from high levels of radiation, and is generally stored in silos. They are sometimes stored together with Zircaloy hulls, in which case the safety considerations concern the latter rather than the former. In any case, that is only an interim storage technique, and in France the steel components have been encapsulated in concrete with the Zircaloy hulls, with a view to disposal. Research and development work has been carried out in France into reducing the volume of hulls and end-pieces by melting or compaction [3]; only the latter process has been chosen for the La Hague plants, as described below.

2.4 *Zircaloy hulls and end-pieces*

In the UP2-400 plant in La Hague, end-pieces and Zircaloy hulls resulting from the shearing and dissolution of LWR fuel were transferred in bulk under water into a silo up until 1989. These hulls and end-pieces were transferred from the shearing cell to the silo in a hydraulically driven drum through a sloping pipe that ended in a cell above the silo. The drum was emptied into this cell and sent back to the shearing cell. The inside lining of the silo is in stainless steel. The pH of the water is maintained at a value of about 4. The silo plenum is continuously vented.

Although the operation of this silo had presented no safety problems, the French Nuclear Safety Authority requested that COGEMA plan more easily retrievable storage installations and prepare for the emptying of the silo. New organised storage was installed in the pools of the former GCR fuel decanning facility. Hulls and end-pieces are placed in separate drums. The drums are transferred from the shearing cell to the pool by a cask and stored under water. The pool water is subjected to the same treatment as fuel storage pools. Its level of activity is limited in operation to 185 MBq/m³.

In the UP3-A and UP2-800 plants, the hulls and end-pieces have been during a first period cemented in drums, around one drum per 2 tHM. Around 1 500 drums have been produced. In the second period, the hulls and end pieces are compacted and the resulting disks are placed into containers identical to vitrified waste containers. This operation takes place in the ACC facility described in Section 8-1. The hulls and end-pieces from UP2-400 stored in the silo and the organised storage will be also compacted in ACC.

The containers of hulls and end-pieces (either cemented or compacted) are transported in a cask by internal site road transport to be stored in a shielded and ventilated building (EDS or ECC respectively) in which they are handled by remote control.

2.5 Graphite waste

The head-end process applied to AGR fuel in the United Kingdom produces a waste stream of radioactive graphite resulting from the extraction and crushing of the sleeves of each fuel assembly. At present this is stored in steel containers in air-cooled storage facilities (of similar design to vitrified waste storage facilities). When it initially comes out of the process this waste is wet, and the release of hydrogen through radiolysis necessitates filtered venting of the steel containers. This waste is destined for future containerisation and disposal.

Similar waste exists in France, resulting from the operation of GCR. It is stored in silos, either on reactor site or on the site of the reprocessing plants, awaiting evacuation.

3. Insoluble residues

Dissolution fines consist mainly of insoluble noble metals, ruthenium, rhodium, palladium, and molybdenum together with Zircaloy or stainless steel fines produced during fuel shearing operations (see also Section 8-4). The typical quantity produced is 3 to 5 kg/tHM. These fines release a quantity of heat of about 300 W/kg, generated mainly by short-lived fission products (^{103}Ru and ^{106}Rh), and may contain small quantities of undissolved uranium and plutonium. They are recovered either at the bottom of the dissolver or in the clarification equipment down-line (centrifugal decanter or filter).

Safety can be improved by conserving these residues in a less dispersible form. Work carried out over the beginning of 90s has demonstrated that these residues can be incorporated into vitrified waste, the solution adopted in France and Japan. In the United Kingdom the residues and fines may be encapsulated in concrete after suitable cooling.

In the UP2-400 plant, the dissolution fines are stored in the silo of hulls and end-pieces. In the UP3-A and UP2-800 plants the dissolution fines are vitrified with the HLLW. Before this solidification, they are stored under water in tanks very similar to those used for HLLW. These tanks are equipped with reliable stirring and cooling systems to prevent accumulation or dehydration of the fines.

4. References

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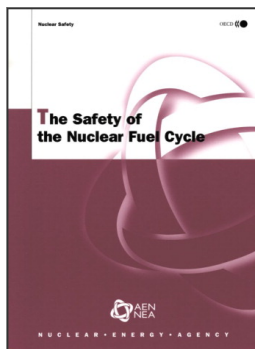
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