CONCRETE CONTAINERS FOR LONG TERM STORAGE AND FINAL DISPOSAL OF TRU WASTE AND LONG LIVED ILW

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ABSTRACT

Transuranic (TRU) waste packaging development has been conducted since 1998 by the Radioactive Waste Management Funding and Research Centre (RWMC) to support the TRU waste disposal concept in Japan. In this paper, the overview of development status of the reinforced concrete package is introduced. This package has been developed in order to satisfy the Japanese TRU waste disposal concept based on current technology and to provide a low cost package. Since 1998, the basic design work (safety evaluation, manufacturing and handling procedure, economic evaluation, elemental tests etc.) have been carried out. As a result, the basic specification of the package was decided. This report presents the concept as well as the results of basic design, focused on safety analysis and handling procedure of the package. Two types of the packages exist:

- Package-**A:** for non-heat generating TRU waste from reprocessing in 200 l drums and
- Package-**B:** for heat generating TRU-waste from reprocessing.

INTRODUCTION

The RWMC has been involved in the research and development (R&D) of a TRU waste disposal concept in Japan with the objective to improve the safety of the packages with respect to handling, long-term interim storage and final disposal of TRU-waste.

In order to identify the optimal packages for TRU waste disposal, 22 package concepts have been evaluated by the RWMC, resulting in a selection of 5 concepts suitable for compliance with RWMC design requirements. The aims of the investigations were:

- to complement and improve the technical and economical performance of geological disposal system for TRU waste
- to rationalize the disposal specifications for repository facilities,
- to improve the handling efficiency of TRU waste packages.

This paper deals with the development status of the reinforced concrete packages for TRU waste in compliance with the Japanese TRU waste disposal concept.

DESIGN REQUIREMENTS

The mainframe for design goals of the TRU waste packages are summarized below (1):

Type of disposal facilities:
a) horseshoe-shaped cross-section tunnel, or silo (for crystalline rock)
b) circular cross-section tunnel (for sedimentary rock)

Depth for disposal: approximately 500 meters (m)

Volume of TRU-waste from reprocessing for disposal:
a) Group 1: waste silver-absorbent (including I-129) – 300 cubic meters (m^3)
b) Group 2: hulls and end-pieces (including C-14) - 4,900 m^3
c) Group 3: process concentrated liquid waste and bituminized waste - 7,000 m^3
d) Group 4: other low level wastes - 5,800 m^3

Condition of waste form:
a) 200 liter (L) drum (for group 1, 3, and 4)
  - Size : 0.6m (diameter), 0.9m (height), 1.6mm (wall-thickness)
  - Material: stainless steel or carbon steel
  - Weight : 0.25 ton (minimum), 1.6 ton (maximum)

b) Canister (for group 2)
  - Size : 0.43m (diameter), 1.335m (height), 5.0mm (wall-thickness)
  - Material: stainless steel
  - Weight: 0.7 ton
  - Heat generation: 4.5Watts/Canister (25 years after reprocessing)

Design requirements (main items):
a. Handling without difficulty
b. Pressure resistance (under disposal environment)
c. Resistance for drop accident
d. Physical confinement of radionuclides
e. Thermal resistance and thermal radiation capacity

According to this frame, the basic design targets of these packages are described below:

- Confinement of radionuclides until closure of repository taking into account
  - gas generation from waste during interim storage
  - accidental loads like drop accident (from 4.5 m height)
  - heat generation from waste (the temperature in the containers must not exceed 80 °C)
- Weight of filled containers are about 30-35 tons
- Safe remote handling and emplacement of containers with appropriate handling devices
- Integrity of containers and their holding devices even after a long-term interim storage of waste up to 100 years, which was set tentatively for this R&D project
- Compliance with Japanese Transport Regulations, which are principally based on IAEA transport regulations
- Low-cost packages to reduce overall costs of TRU waste management and disposal

In preliminary studies, the feasibility of different container concepts has been investigated based on the following evaluation criteria:

- Mechanical integrity and confinement of radioactivity in case of a drop accident during interim storage phase (ISP)
- Degradation of concrete due to carbonation or ground water access
- Confinement of radioactivity in the post closure phase (PCP)
- Performance in case of gas generation inside containers
- Available experience with container type and materials
- Costs
- The best overall performance of the investigated container concepts shows the closed container with a reinforced lid. Based on this concept, two types of waste packages have been designed (see Fig 1):
    - Package-**A:** Container for non-heat generating TRU waste in 200 l drums and
    - Package-**B:** Container for heat generating TRU wastes in canisters

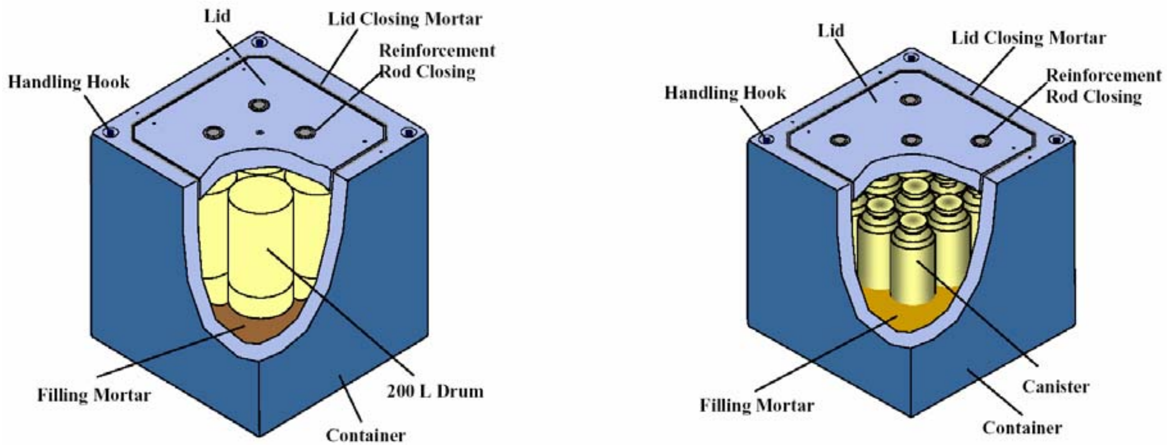

Fig. 1: TRU waste container types A (for 200 l drums) and B (for canisters)

MECHANICAL DESIGN OF THE CONTAINER

The mechanical design of the container type A (for 200 l drums) and type B are in compliance with the above described requirements. From the entire requirements, the following two have a particular influence on the safety of operation and disposal of the TRU waste containers.

- No radioactivity may release out of the container (confinement of radioactivity) within 100 years of ISP under consideration of normal operation conditions, gas pressure build-up and occasional accidents (e.g. drop accident).

- The integrity of the containers should be guaranteed for about 100 years including routine transportation requirements concerning size, weight and dose-rate limits according to the Japanese Transport Regulations

These above mentioned safety related requirements have influence on the design criteria which can be summarized as follows:

a) The integrity of the container should be guaranteed under operational and accident conditions so far that its contents do not scatter (i.e. no radioactivity release may arise). The integrity of the container should also be maintained against the internal gas pressure build-up.
b) Handling of the drums and canisters and filled containers should be safe and convenient by using remotely controlled crane and forklift attachments.
c) Layout of the shielding should be in compliance with Japanese Transport Regulations, if necessary, by using an overpack shielding, in case it is necessary to move the container from the storage place to another place.
d) The construction of the container (especially the lifting and gripping devices of the container) should also be in compliance with the integrity requirement during interim storage.
e) The content of canisters for type B packages should be limited by the thermal heat generation in the emplacement tunnels, taking into account the repository design.

Several container concepts have been investigated which are in compliance with above mentioned criteria to find the optimal solution for type A (drums) and type B (canisters) containers. The characteristic properties of these containers are summarized in Table 1.

Table 1: Characteristic properties of the TRU-Waste containers

Specification	Package-A for 18 drums (200 l)	Package-B for 16 canisters (*)
Dimensions (in m)	2.25 x 2.25 x 2.25	2.25 x 2.25 x 1.9 (h)
Wall thickness (mm)	200	250
Weights (tons)	35	30
Container material	Reinforced concrete	
Filling mortar	Portland cement: In compliance with Japanese industrial standard Water: Drinking water Sand: Non-metallic	

(*)- Canisters (Diameter: 0.43m, height: 1.335m, thickness: 5mm) for compressed hulls and end pieces (same as for vitrified HLW)

Reinforcement

The reinforcement of the container and fixing of the lid to the container bottom ensures the integrity of the container against operational and accidental loads (e.g. drop accident or earthquake).
For reinforcement it is foreseen to use welded steel material in the shape of a net. In addition, it will be necessary to use rods, bows and clamps as well. Since steel is very well protected in high quality concrete, normal steel for reinforcement is suggested. However, it is important to guarantee the distance of the steel mesh to the outer and inner surfaces of the container-shell during fabrication, which is subject to quality control.

The drop of a container on the top-edge from a 4.5 m height (the height of 3 containers stacked on top of each other) represents the most critical accident and covers all other potential accidental loads. As a result of the mechanical loads occurring in this case, the lid of the container has to be fixed by tie-rods to the bottom of the container (see Fig. 2).

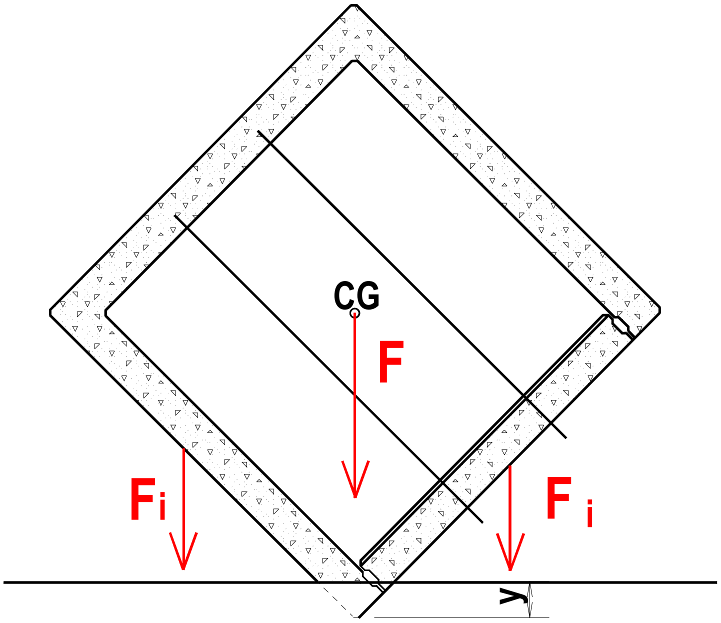

Fig. 2: Dynamic loads occurring in case of a worst-case drop accident

Additionally, the potential impact of the internal gas pressure build up due to corrosion of the metals and radiolysis in the container have been investigated. The result of the gas generation analysis clearly indicates that no damage of the containers is to be expected due to gas pressure. Even in the case where the internal gas pressure would exceed a certain limit, micro cracks develop in the closing-mortar, which fills the gap between the lid and the container walls (see Fig.1). The micro cracks act as a gas vent and reduce the internal pressure.

Handling of the container

The TRU waste container shall be handled fully remote controlled from filling the container with waste (drums and canisters) and mortar until emplacement into the repository. For eventual removal of the containers from the repository to another site, transport shall be in compliance with the Japanese Transport Regulations.

All of these operations may require different types of lifting and gripping devices. We suggested, therefore, having lifting and gripping possibilities for using cranes and forklifts as well. The design of the containers cope with the specific needs for the use of both lifting possibilities (see Fig. 3).

As shown in Figure 3, there are four lifting hooks installed on the top surface of the container shell – one in each corner- with a lifting capacity of 20 tons each. This specification is due to safety considerations. It allows rigging failures, since two lifting hooks are sufficient to withstand the container weight of 30-35 tons. This is important to comply with the integrity requirement taking into account unexpected performance impairment of hooks during a 100-year storage period. To maintain the lifting capacity, the hooks are made of stainless steel.

To provide redundancy, there are an additional four lifting hooks (stainless steel) installed on the bottom of the container, with a lifting capacity of 10 tons each. These lifting hooks can be used after a drop accident. The lifting hooks are anchored in the reinforcement of the container shell. The reinforcement design of the container considers the operational and accidental loads on the lifting devices.

All these lifting devices can be used by a crane or a forklift using a special remote controlled holding tool attached to the crane or the forklift.

As an alternative, it is possible to handle the lifting operations using gripping grooves on the container-shell. In this case, the forklift will be equipped with a special gripping device (see Fig. 3).

The forklift itself will either be a remote-controlled vehicle, or it shall have a shielded driver cabin. It can be equipped with either a holding device for the lifting hooks or a gripping device shown in Fig. 3, or both.

The forklift with a special design is optimized for the following purposes:

a) For routine handling, a gripping device is foreseen which fits to the gripping grooves, having the advantage of easy and convenient coupling by finding the target visually (eye or TV camera), (see Fig. 3).
b) In a case where there is no access to the gripping grooves, a forklift with remotely controlled claws which can be used from above could be useful.

The gripping grooves on the containers have also been designed under consideration of operational and accidental loads. In Fig. 3 the gripping grooves are shown on one side only corresponding to the present design. However, if desired, this system can be installed on two or even four sides with the same geometry. This would increase the flexibility under several operational and accidental conditions and consequently the costs.

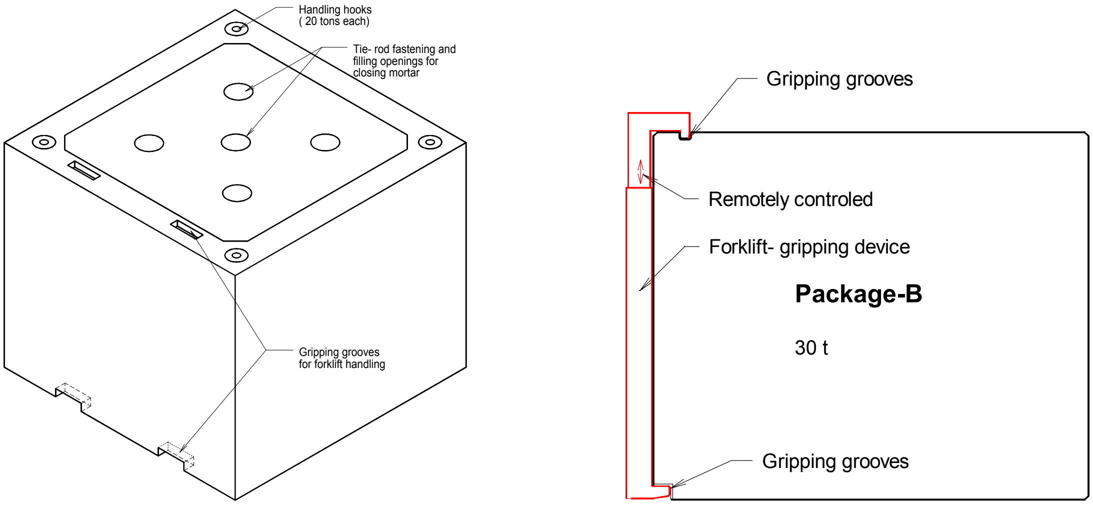

Fig. 3: left: The gripping grooves and the upper handling hooks, right: forklift adapter for gripping grooves

SHIELDING OF CONTAINERS

Package A: Container for 200 l drums.
Due to the low activity of the drums, the foreseen thickness of the concrete container-shell (200 mm) guarantees dose rates on the surface which are about two orders of magnitude below the Japanese Transport Regulations limits for safe transport (2 mSv/h).

Package B: Container for canisters.
Due to the higher activity inventory of the canisters, the dose rates on the surface are about two orders of magnitude higher than the Japanese Transport Regulations limits. Therefore, an external shielding is necessary if such containers should be removed from the repository for transport to another place. For the remote handled operations in the repository, such a shielding is not required.

THERMAL ANALYSIS

A detailed thermal analysis has been performed for Package-B due to heat generation of canisters. The following design items have been considered:

a) the temperature gradient in the package should be small to avoid thermal stresses and
b) the maximum temperature in the repository should stay below 80 °C.

Temperature gradients in a single package

A detailed thermal analysis of a single package-B containing 16 canisters (heat production of one canister is 4.5 Watt after 25 years of cooling time) has been performed to evaluate temperature gradients in the container package.
This temperature gradient is independent of the temperature level given by the isolation of the surroundings, however this ΔT is responsible for stresses inside the container.
For a conservative calculation, we defined the canisters to be cylinders consisting of concrete.
The following Heat Conductivity data (temperature level = 25 °C) were used:

Filling mortar:	1.2	W/(m .°K)	$\rho = 1.8$ g / cm^3
Concrete:	2.1	W/(m .°K)	$\rho = 2.5$ g / cm^3
Steel:	55	W/(m .°K)	$\rho = 7.86$ g / cm^3

The maximum temperature difference between the center and outer surface is calculated to be 3.2 °C, which is more than one order of magnitude below critical values (see Fig 4).

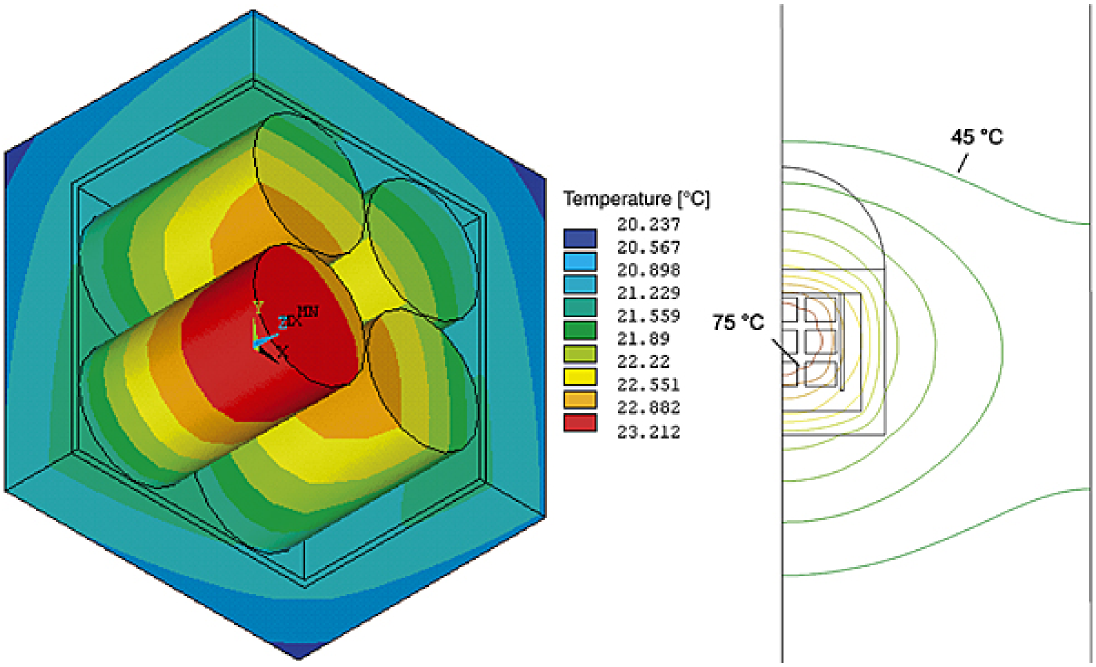

Fig. 4, Left: Temperature distribution in a $^{1}/_{8}$ part of the container
Right: Temperature distribution in a tunnel section at the time of maximum temperature

The above configuration is valid for a single container or for containers during intermediate storage with forced convection that assures a cooling to constant temperature at the container walls. In case of no cooling, the heat must be evacuated by the host rock and then the whole configuration of the repository tunnel must be considered.

Maximum temperature in the repository

The absolute temperature of the container is dependent on its wall temperature, which is potentially influenced by neighboring containers and cooling.

The container will be placed in a tunnel with 9 containers per section, and the tunnel will be backfilled (see Fig. 4, right). This will affect the heat distribution considerably.

Based on the following material parameters assuming a crystalline host rock (Tab. 3), the temperature distribution in around a repository tunnel has been calculated by using a 2-dimensional (2D) Finite Element Method (FEM) analysis with the code DIFFPACK (3).

Table 3: Material parameters

Material	**Density** [kg/m^3]	**Thermal Conductivity** [W/(m K)]	**Specific Heat** [J/(kg K)]
Host rock (Crystalline)	2670	2.80	1000
Structure	2500	2.56	1050
Bentonite	1600	1.04	730
Backfill	1600	1.69	770
Package	3195	7.63	481

Figure 4 shows the temperature distribution in a tunnel section at the time of maximum temperature. This analysis confirmed that the maximum temperature to be expected in the TRU waste repository using Package-B (with 16 canisters) is well below the limit design temperature of 80°C, even when accounting for conservatism in material parameters.

CONFINEMENT ANALYSIS

The confinement of radionuclides in the TRU waste container is one of the essential requirements to performance of the TRU waste container.

During the operation and interim storage phase, the confinement of radioactivity is guaranteed by the mechanical design of the container.

For the post closure phase, a detailed confinement analysis of the containers considering potential transport pathways of radionuclides due to diffusion and advection in groundwater has been performed by numerical simulation with the code TOUGH (3). The results clearly indicate that, in case of a defect of the canisters inside of the container, the mortar filling as well as the concrete container walls are effective barriers, which efficiently delays the release of radionuclides from the container. Furthermore, it has been shown that, in case of local cracks in the container (e.g., due to the gas vent), the confinement performance of the container is not significantly deteriorated. Even in the case of continuous cracks, the transport of radionuclides in the groundwater is significantly delayed by the sorption capacity of the concrete and mortar.

After closure of the repository, the long-term safety is provided by the multi-barrier system of the repository, consisting of physical and geological barriers, which must be considered by the long-term safety design of the repository. The contribution of the package to the long-term safety is of minor importance compared to the other barriers.

PERFORMANCE WITH RESPECT TO INTERNAL GAS GENERATION

In a waste repository, considerable amounts of gas may be generated, which may affect operational safety in the ISP by having deteriorating effects on the containers. In particular, it has to be assured that the gas development does not deteriorate the container performance in the ISP.

For the ISP, the gas production in a container due to anaerobic corrosion of steel is very unlikely, since the emplacement tunnels are ventilated and access of groundwater can be excluded.

In the post closure phase (PCP) anaerobic conditions may prevail. If, furthermore, the container becomes more or less saturated with water, gas generation may take place. Based on the materials used for the container, a gas generation rate leading to significant rise of pressure in the container and consequently to a mechanical loading cannot be excluded. It is therefore mandatory that the container is capable of releasing gas to limit the loading to a level that allows it to function within the specification limits, in particular with respect to mechanical integrity.

Both 2D and 3D FEM calculations show that gas production is not likely to be a critical issue for the container as designed, and there is no need for a special vent under the considered conditions. The natural vent of the closing mortar is sufficient to keep gas pressure and consequently mechanical stresses below critical values for the concrete structure. If micro cracks develop, they will develop in the vent due to the stress concentration there. The concrete will most likely stay unaltered, and the overall container performance is not expected to be deteriorated.

CONCLUSION

The reinforced concrete packages represent a technically safe and economically low-cost solution for treatment, handling, transport, long term storage and disposal of TRU waste. They can also be used for other long lived ILW (e.g., decommissioning waste).

These packages can easily and remotely be handled during storage and emplacement in the repository. They are designed against possible accidents and, for long-term storage; removal is therefore possible at any time before the final closure of the repository.

Some experimental tests are under investigation to verify and validate the above mentioned design characteristics of Packages A and B.

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