Development of a Multi-Purpose Container System for the Storage, Transport and Disposal of PWR Spent Fuel in the UK – 15466

Mark Johnson *, Chi-Fung Tso **, Neil Carr *, Conrad Izatt **, Ryoji Asano ***, Chris Fry ****, George Wright ****
* Radioactive Waste Management Limited
** Arup
*** Hitachi Zosen Corporation
**** AMEC

ABSTRACT

Radioactive Waste Management Limited (RWM) is a wholly owned subsidiary of UK's Nuclear Decommissioning Authority, and is responsible for implementing UK Government policy on geological disposal of higher activity radioactive waste. An aspect of the generic work programme that underpins the current generic disposal concepts includes the development of the associated disposal containers. To date RWM has focused on the development of a range of disposal container designs that fulfil the requirements for transport and disposal in a Geological Disposal Facility (GDF) for legacy high heat generating wastes, one of which includes legacy Pressurised Water Reactor (PWR) spent nuclear fuel (SF). In line with a number of European countries exploring deep geological disposal, the conceptual disposal container solution developed for this waste type has a capacity of 4 PWR fuel assemblies.

Since 2013, the feasibility of developing an alternative higher capacity disposal container design based around the Multi-Purpose Container (MPC) concept has been explored. In general terms, MPCs are containers that are designed to meet requirements for safe containment of radioactive waste during storage, transport and disposal. The fundamental design philosophy of the MPC is that once the waste is packaged in an MPC, it would not need to be handled again. That is, after a period of initial cooling in a fuel pond, the SF could be packaged for long term dry storage and would not require direct handling for its eventual transport to, and disposal in, a GDF. The novel feature of the MPC system design considered is the inclusion of an additional overpack specifically for the final deep geological disposal phase.

The conceptual MPC and its associated storage, transfer, transport and thick walled carbon steel disposal overpack have been developed to a conceptual level of design detail to demonstrate concept feasibility, with the final design solution confirming a MPC system with a capacity of 12 PWR SF assembles. This represents the highest capacity PWR MPC system that complies with the mass and rail gauge limits of the UK W6a rail gauge. Such a capacity realises a contents loading three times that of the standard PWR disposal container and presented technical challenges from both a structural performance and thermal perspective; necessitating the need for the inclusion of features to enhance heat transfer from the central fuel assemblies within the MPC and novel lid features on the transport container overpack to maintain structural integrity and containment during the hypothetical accident conditions of transport tests.

In developing the MPC system conceptual design it is recognised that, depending upon the safety functions of the MPC disposal overpack, the choice of carbon steel material may not be suitable for all geological environments. Consequently, the MPC system design and its materials of construction will require further evaluation once detailed knowledge of the disposal concept to be implemented, its safety functions and geological environment are known.

INTRODUCTION

Radioactive Waste Management Limited (RWM), a fully owned subsidiary of the Nuclear Decommissioning Authority (NDA), is responsible for the implementation of geological disposal in the UK. As part of this remit RWM has developed illustrative concepts to demonstrate the viability of geological disposal in the UK of long-lived Low Level Waste (LLW), Intermediate Level Waste (ILW), High Level Waste (HLW) and Spent Fuel (SF).

In 2010, the Nuclear Industry Association (NIA) and existing and prospective UK nuclear power plant operators commissioned RWM to conduct a feasibility study exploring options for storage, transport and disposal of spent fuel [1]. The study identified a number of viable options for optimising the management of legacy SF and SF from new nuclear power stations and recommended further work to demonstrate feasibility of a Multi-Purpose Container (MPC) that meet requirements for safe containment of radioactive waste during interim storage, transport and disposal.

In general terms, MPCs are containers that are designed to meet the requirements for safe containment of radioactive waste during storage, transport and disposal. The fundamental design philosophy of the MPC is that once the waste is packaged in an MPC, the waste would not need to be handled again. After a period of cooling in a fuel pond, spent fuel could be packaged into MPCs for long term dry storage and would not require direct handling for its eventual transport to, and disposal in, a geological disposal facility (GDF).

There are two broad types of MPC systems that have been developed in the industry, container based systems and cask-based systems

- In container-based systems, the SF would be packaged into an MPC which would in turn be packaged into different overpacks for storage, transport and disposal, as well as for transfer between these stages.

- In cask-based systems, the SF would be packaged into a cask, for interim storage, transport and disposal.

In the former, containment, shielding, criticality, structural and thermal performance are provided by the combination of the MPC and its overpacks, whereas in the latter all functions are provided by the cask. A study carried out by RWM in 2012 [2] recommended proceeding with the container-based system as it offers the greatest flexibility at the current stage of the UK geological disposal programme and has potential cost, handling and emplacement, and programme acceleration benefits.

A project to develop a conceptual design of an MPC and its overpack system for packaging PWR SF was instigated by RWM and was carried out in 2013-2014 by a team consisting of Arup (overall lead), Hitachi Zosen Corporation and AMEC.

OPERATING SYSTEM FOR THE MPC

In an MPC container based system, containment, shielding, criticality, structural and thermal function of the package are provided by a combination of the MPC and its overpacks, with the overpack addressing the specific requirement of each specific environment as the system progresses in its operating life from packaging of the SF assemblies into the MPC at the spent fuel pond, to disposal at a GDF.

Broadly, there are four main stages of the System:

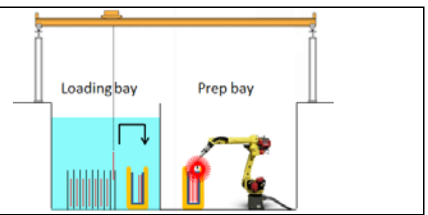
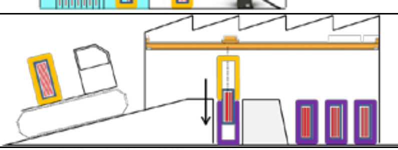
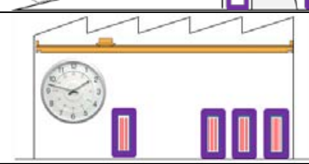
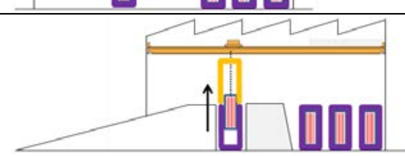
1. Packaging of SF into MPCs at the Nuclear Power Plant (NPP)
2. Storage at the Interim Storage Facility (ISF)
3. Transport to a GDF
4. Disposal at a GDF

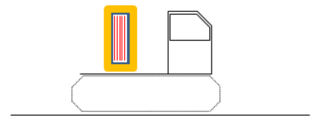
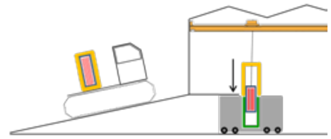
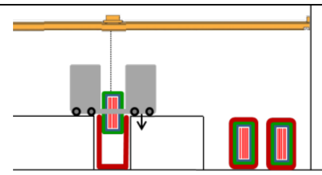
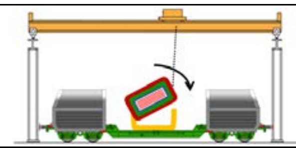
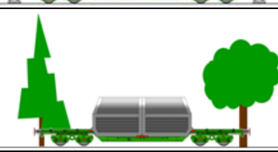
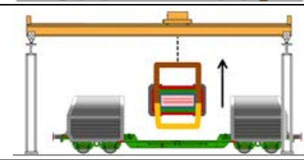
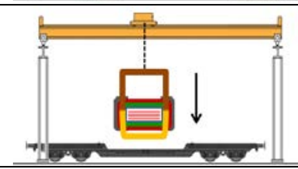
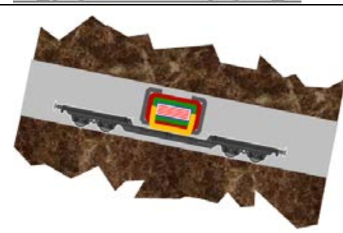
In the whole operating life of an MPC after the SF has been packaged into it, it is enclosed within an overpack - Storage Overpack, Transfer Overpack, Transport Overpack and Disposal Overpack.

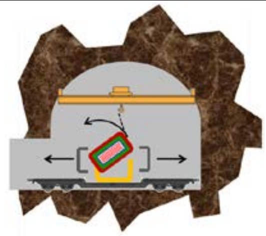
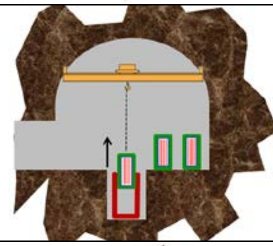
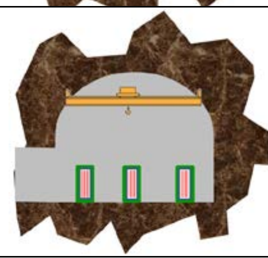
- Transfer Overpack holds the MPC during packaging operations at the NPP and provides temporarily enclosure for the MPC when it is transferred from one Overpack to another.
- Storage Overpack contains the MPC during the storage stage at the Interim Storage Facility.
- Transport Overpack encloses the MPC during transport to a GDF or centralised store.
- Disposal Overpack contains the MPC for disposal.

The design of each Overpack is determined by the specific requirements and constraints of each stage of the operating system.

A number of alternatives operating systems corresponding to different assumption regarding of the location of the plant for packaging MPCs into Disposal Overpacks and different assumptions regarding the function of the Disposal Overpack were identified and evaluated. While not precluding alternative arrangements in the future, the option that was taken forward for the current work can be illustrated as follows:

Packaging of SF into MPC at NPP	Loading of the MPC in SF pond and canister closing	
Storage at ISF adjacent to NPP	Transfer of the MPC to the ISF and mating with the Storage Overpack	
	Storage in the Storage Overpack	
	Transfer of the MPC from the Storage Overpack to the Transfer Overpack	

	Transit of the MPC + Transfer Overpack to the packaging plant adjacent to the NPP	
Packaging of MPC into Disposal Overpack	Transfer of the MPC from the Transfer Overpack into the Disposal Overpack	
	Closing of the Disposal Overpack	
	Loading of the MPC + Disposal Overpack into the Transport Overpack and closing of the Transport Package	
Transport to GDF	Loading of the Transport Package onto the transport vehicle	
	Transport to the GDF	
Disposal at the GDF	Unloading of the Transport Package from the transport vehicle	
	Loading of the Transport Package onto the GDF drift wagon	
	Transport of the Transport Package to the disposal vault	

	Unloading of the Transport Package from the GDF drift wagon	
	Unloading of the Disposal Package from the Transport Overpack	
	Disposal of the Disposal Package	

SCOPING STUDY

A scoping study was carried out to establish the number of PWR SF assemblies that can be accommodated in the MPC and to establish the overall dimensions, mass and material thicknesses of the MPC and Overpacks, which would be the starting point for conceptual design of the MPC and Overpacks. At commencement, the scoping study recognised that the most constraining features dictating the number of PWR SF assemblies that could be packaged into an MPC were compliance with the dimensional and mass limits for transport on the UK rail network.

Preliminary thermal, shielding and structural/impact calculations were carried out to evaluate the largest number of PWR SF assemblies that could be carried in the MPC, while satisfying the dimensional, thermal, shielding and structural design criteria.

Design assumptions concerning the layout and structure of the MPC and Overpacks as the basis of the scoping study are as follows:

- The MPC uses a basket-type arrangement to hold the PWR SF assemblies, with additional copper plates for heat transfer and allowances for neutron absorber material.
- The thin walled MPC shell is made from stainless steel and fully seal welded.
- For disposal, the Disposal Overpack will be manufactured from carbon steel and suitable allowance will need to be made for long term corrosion performance.
- Neutron Shielding would be placed around the exterior surface of the Transport Overpack.
- Impact Limiters would be placed around the ends of the Transport Package.

- Rail transport (both on the UK rail network and within a GDF) would be assumed to be via an 8-axle rail wagon, with a tare mass of 56 tonnes and a total gross mass limit of 180 tonnes (22.5 tonnes per axle).
- The Transport Package would be attached to the 8-axle rail wagon using a transport frame, which was assumed to have a mass of 6 tonnes.

The following key design constraints for transport operations were adopted in the scoping study:

- Width limit = 2.82m – based on the UK W6a gauge for rail transport.
- Length limit = 6.1m – based on the current GDF package length limit.
- Mass limit for GDF transport = 150 tonnes (including drift wagon, etc.) – based on indicative payload limits for inclined drift operating on 1:6 gradient and vertical shaft winding.
- Dose-rate limits – IAEA Transport Limits.

Applying these assumptions and design constraints, preliminary calculations using empirical methods were used to estimate the required material thicknesses necessary to meet the shielding and structural requirements for the MPC and its associated overpacks. Calculations were performed or a given number and layout of PWR SF assemblies, and corresponding the size and masses of the MPC, Disposal Overpack and Transport Overpack estimated. Noting that there are simplifications and assumptions in the scoping calculations, a 5% contingency was added to the mass and dimension values of the calculations.

The results of the scoping study indicated the following:

- With 9 PWR SF assemblies, the Transport Package satisfies both the W6a rail gauge width dimension limit and also the UK rail network and GDF mass limits.
- With 12 PWR SF assemblies, the Transport Package also satisfies the W6a rail gauge width dimension limit, but slightly exceeds the GDF mass limit (162t against 150t), although it is within the UK rail network mass limit of 180t.
- With 16 PWR SF assemblies, the Transport Package exceeds the W6a rail gauge width dimensional limit and also exceeds both the GDF mass limit and the UK rail network mass limit.

Although the 12 PWR SF configuration exceeded the GDF mass limit, it was noted that the drift wagon could be enhanced to reduce the weight used in the scoping study calculations and that it may also be possible to increase the GDF mass limit by uprating the handling systems. Predicated on the assumption that the GDF mass limit could be increased, the scoping study concluded that the 12 PWR SF configuration was the optimum number of PWR SF assemblies which satisfied the design constraints of the scoping study. Consequently, an MPC configuration with 12 PWR SF assemblies was taken forward into conceptual design.

OUTLINE OF THE DESIGN BASIS

The design requirements and constraints on the MPC and the MPC in its overpacks have been derived with reference to the safety functions of a waste package during interim storage, transport, the operational period and the post-closure period of a GDF. In all stages of the waste management, for normal conditions and hypothetical accident conditions, the complete package (i.e. MPC plus Overpack) has to provide a passively safe system which:

- Provides shielding to protect workers, the public and the environment against the effects of radiation

- Provides criticality safety
- Prevents damage caused by heat
- Provides protection against unacceptable dispersion of the radioactive contents.

In order to design an MPC and its associated Overpacks the external constraints, in terms of operational processes, at all stages of the waste management process, including storage, transport and disposal, and any pre-stages (e.g. fuel loading and container sealing) need to be defined. In addition, at each of the intermediate stages e.g. at point of transfer between one stage to another stage, the system constraints (in terms of the contents heat load, dimensions, radioactivity, etc.) also need to be defined. Finally, for each step of the operation route for the MPC, the operational requirements (e.g. lifting features, dimensional envelope) and the performance requirements (e.g. structural, thermal, criticality safety, shielding and containment performance in both normal and accident conditions) need to be defined. From these, a "bounding set" of operation requirements and performance requirements can be distilled.

A design specification which sets out all the requirements for the design of the MPC and the Overpacks was developed. Design criteria are defined under the following areas: shape, general arrangement, external dimensions, clearances, contents, mass limit, design life, materials, integrity, lifting features, identification, decontamination, inspection/monitoring, containment, criticality, shield and dose rate, thermal performance, structural performance and impact performance.

The key references for the design requirements are included as references [3] to [8] at the end of this paper.

CONCEPTUAL DESIGN OF THE MPC

The MPC is the primary container for the PWR SF. Although it is enclosed within various overpacks throughout its life and a number of safety functions of the overall MPC + overpack combination is provided by the overpack. The MPC is required to provide the first line of containment, maintain the geometry of the PWR SF, provide heat transfer for the decay heat of the PWR SF and provide structural integrity and structural features for handling.

Based on current MPC system operations for loading of the PWR SF into the MPC, it is envisaged that the MPC will be located within the Transfer Overpack. After the PWR SF assemblies have been loaded, the lid of the MPC will be fitted and fully seal welded. The MPC is not required to provide a shielding function (this is provided by the overpacks), although shielding is provided at the top of the MPC to protect personnel during the set up operations for welding and inspection of the MPC lid to the body weld.

Once the MPC Lid is welded on, the water will be drained (through a port incorporated in the MPC lid) and the inside of the MPC then vacuum dried and backfilled with inert gas.

The MPC and internal basket arrangement is shown in Figures 1 and 2.

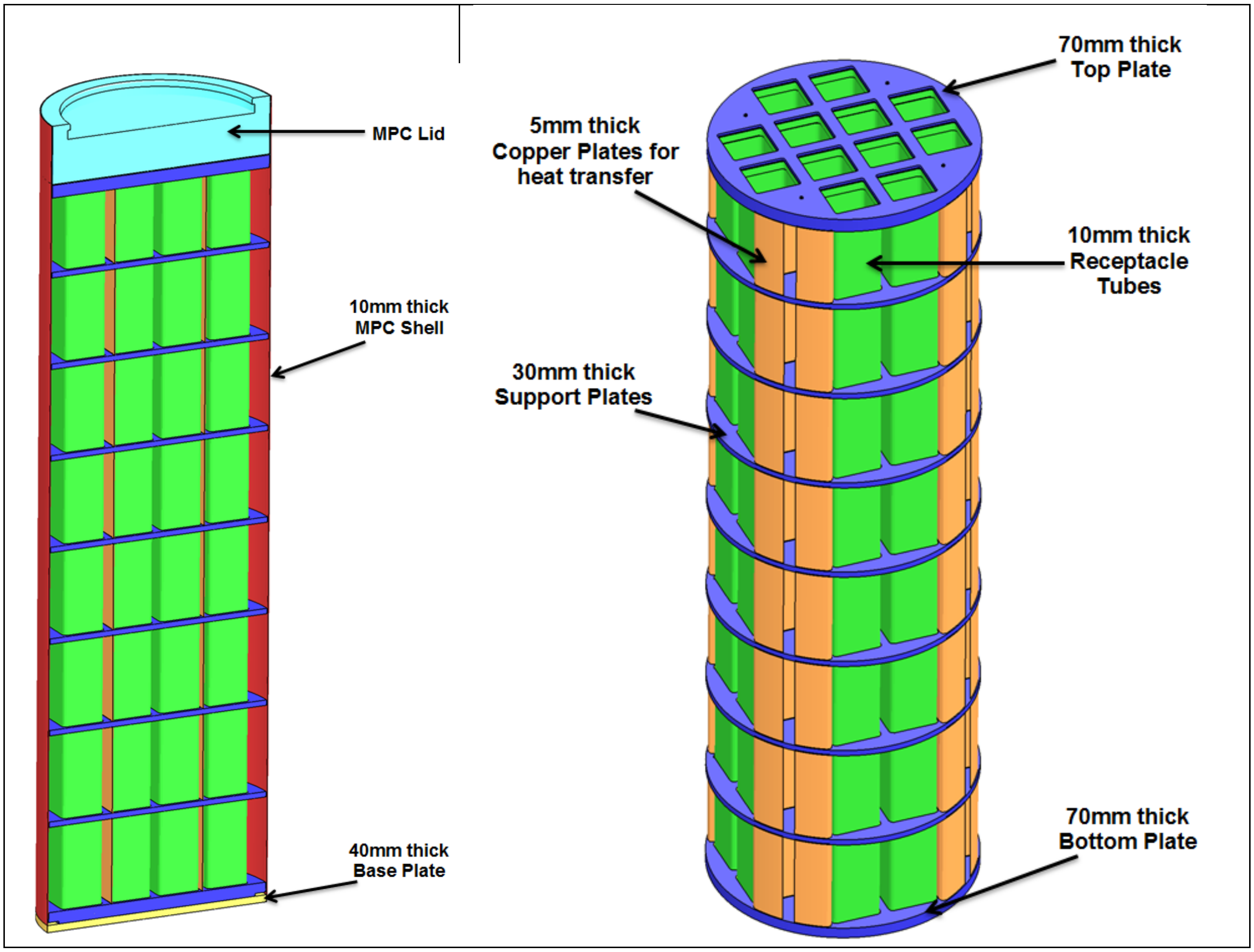


Figure 1 Vertical section through the MPC (left) and the basket of the MPC (right)

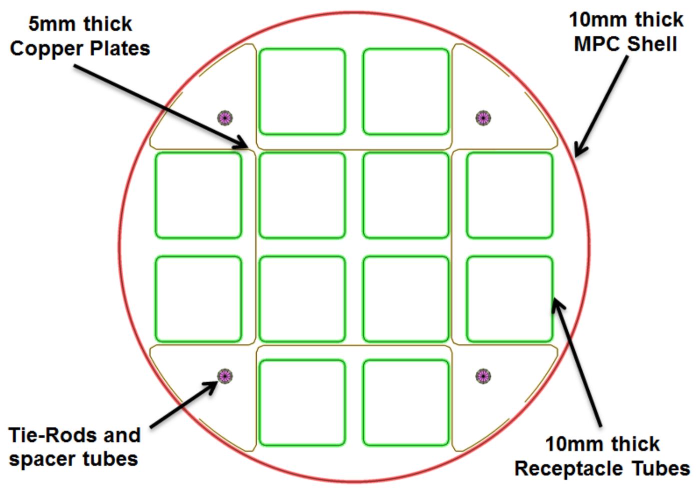


Figure 2 Horizontal section through the MPC

The MPC consists of a lid and body with an internal basket arrangement on the inside for holding the PWR SF assemblies. The construction is similar to that adopted in the generic conceptual disposal container design developed previously by RWM [9].

The basket employs a "tube and disc" type of arrangement. PWR SF assemblies will be accommodated in twelve receptacle tubes. The spacing between these tubes is maintained by a top plate, a bottom plate and seven support plates evenly spaced over the height. The spacing between the plates is maintained in turn by a tie rod system. All these components are to be made from 316L stainless steel. In order to facilitate the transfer of decay heat from the PWR SF to the body of the MPC and beyond, four sets of zig-zag shaped copper plates interweave the receptacle tubes between each pair of adjacent support plates. They sit within grooves in the support plates and top and bottom plates.

The body of the MPC consists of a 10mm thick 316L stainless steel cylindrical wall with 40mm thick 316L stainless steel base. It has four lifting lugs located near the top on the inside of the cylindrical wall for handling of the empty body and to locate the lid before it is welded to the body.

The lid is 240mm thick and also made from 316L stainless steel and is connected to the MPC body by welding along the top edge. It has an integral lifting feature for lifting of the lid itself and for lifting of the completed MPC.

CONCEPTUAL DESIGN OF THE TRANSFER OVERPACK

The Transfer Overpack supports the MPC during loading of the SF into the MPC and during welding of the MPC lid to the MPC body. Thereafter, it encapsulates the MPC during transfer from the NPP to the storage facility (assumed located at the NPP site), and during transfer from the storage facility to the plant for packaging the MPC into the Disposal Overpack.

It provides the necessary interfaces for the MPC with the various overpacks, and it provides the facility for lifting and lowering the MPC in these transfer operations. It provides shielding for the workers during these transfer movements, protects the MPC against insolation and fire accidents, and protects the MPC during impact accidents. For the transfer operations, the MPC is considered to be the containment barrier. The cavity in the Transfer Overpack in which the MPC is accommodated is not considered the containment barrier and does not need to be sealed.

The design of the Transfer Overpack is shown across a vertical section and across a horizontal section in Figure 3.

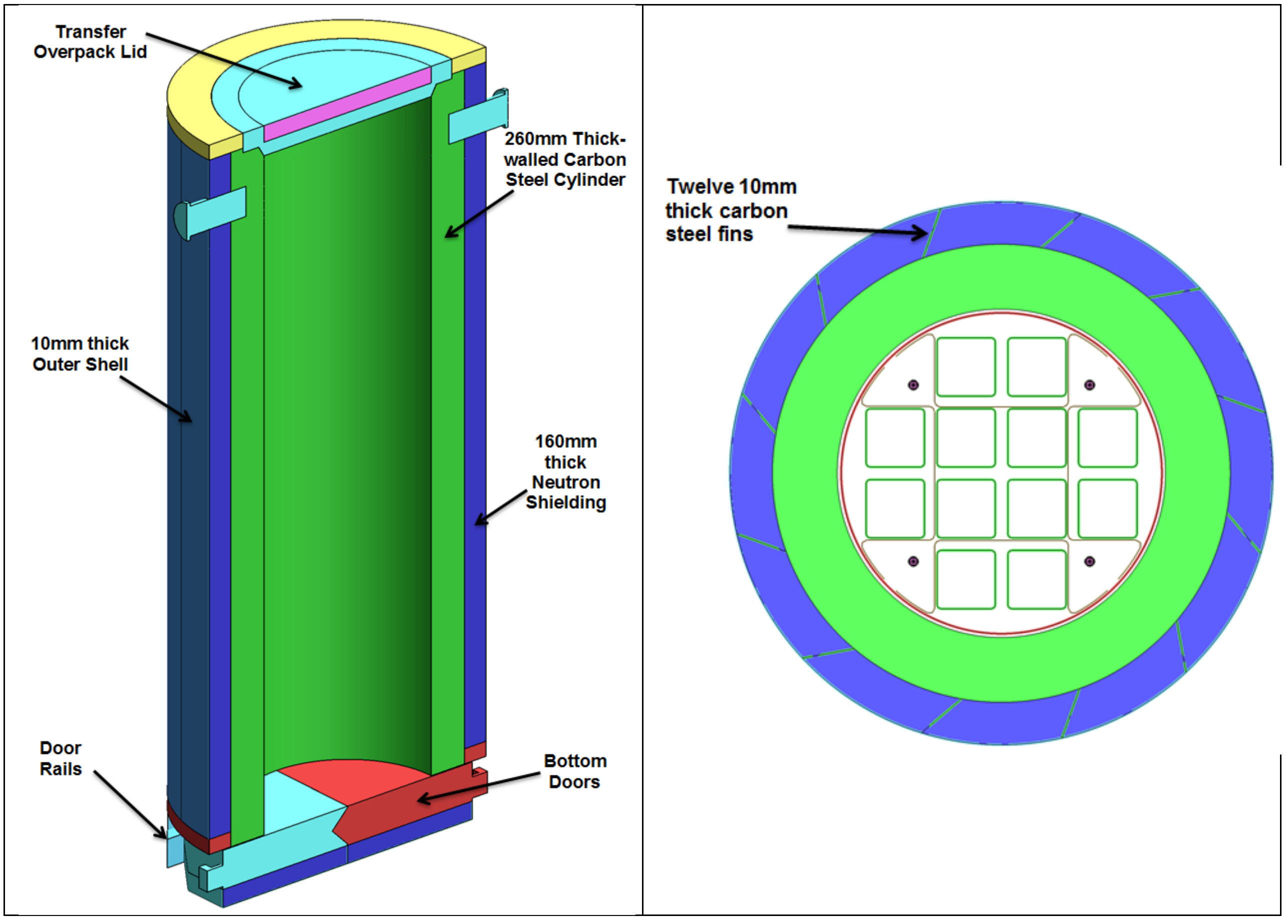


Figure 3 Vertical (left) and horizontal (right) section through the Transfer Overpack

The Transfer Overpack consists of a cylindrical body, a circular lid at the top, and a set of doors at the bottom.

The body of the Transfer Overpack consists of, from the inside to the outside, a 260mm thick carbon steel cylinder, a 160mm thick layer of neutron shielding and a 10mm thick carbon steel outer shell. Twelve 10mm carbon steel fins pass from the cylinder to the outer shell through the neutron shielding to facilitate heat transfer, but are angled to maintain cause shielding performance.

The lid of the Transfer Overpack is connected at its perimeter to the top of the body of the Transfer Overpack by sixteen M30 carbon steel bolts. Away from the perimeter, the lid consists of an 80mm thick carbon steel disc, a 110mm thick neutron shielding layer and a 10mm thick carbon steel outer shell.

Gamma gate shield doors are located at the bottom of the Transfer Overpack allowing the MPC to be lowered into or withdrawn from another Overpack positioned underneath the Transfer Overpack, using a lifting device operated through the lid aperture at the top of the Transfer Overpack. The two halves of the gamma gate shield door meet in a “chevron” shape to prevent shielding weakness at the interface between the two halves of the door.

The Transfer Overpack is fitted with four carbon steel trunnions for handling.

CONCEPTUAL DESIGN OF THE STORAGE OVERPACK

The Storage Overpack encapsulates the MPC during interim storage. It provides the necessary shielding and containment to the MPC during the interim storage period. It provides structural and thermal protection to the MPC in all normal and accident conditions, including earthquake, flood, wind, variation in external pressure, extremes in temperature variation and in fire accidents, so as to maintain the required level of shielding and containment. It provides the necessary facilities to conduct decay heat from the SF to the environment. It is also designed to maintain its function over an extended period of storage.

The design of the Storage Overpack is shown across a vertical section and across a horizontal section in Figure 4.

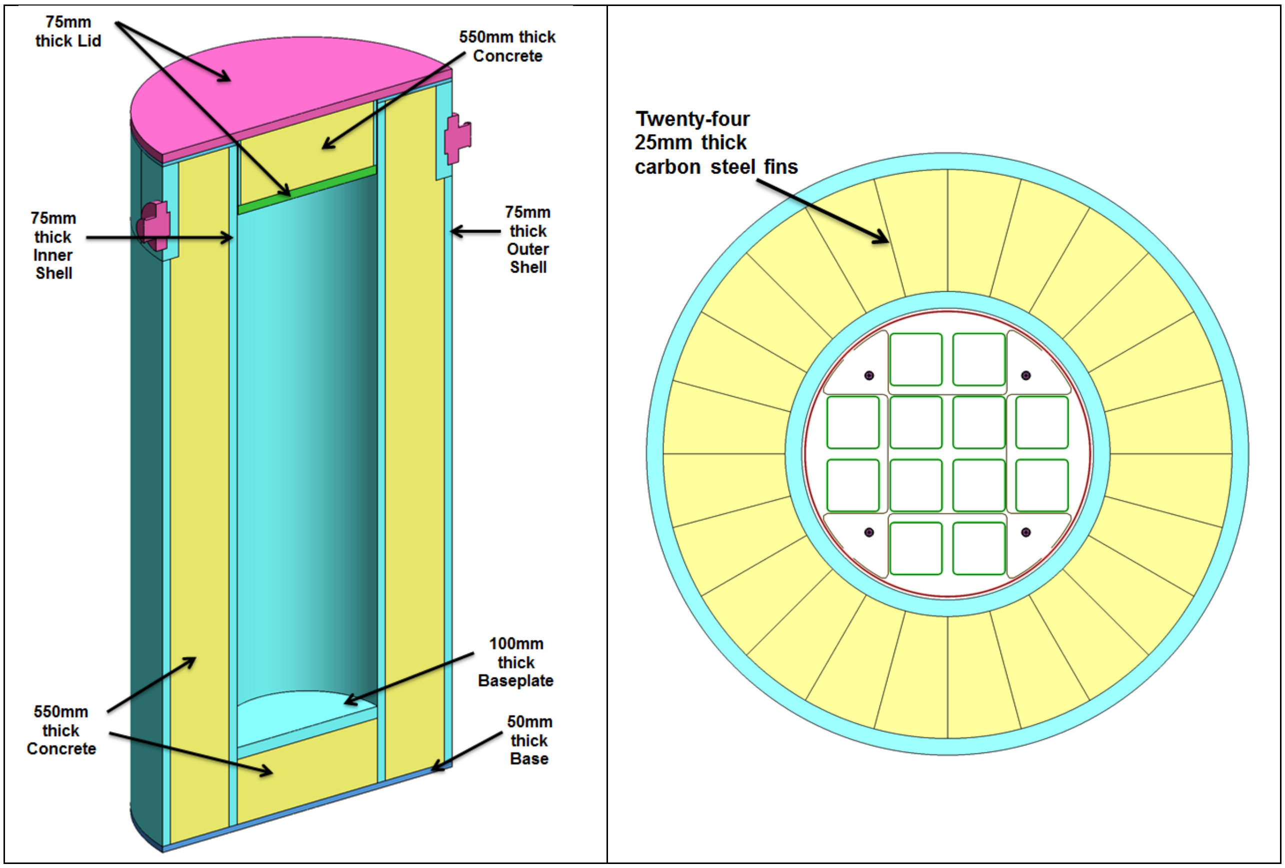


Figure 4 Vertical (left) and horizontal (right) section through the Storage Overpack

The Storage Overpack consists of a body and a lid.

The body employs a steel-concrete-steel sandwich construction, with 75mm thick carbon steel inner liner, 550mm thick concrete and 75mm thick carbon steel outer liner which thickens to 150mm towards the top to provide good structural anchorage for the trunnions.

There are twenty four 25mm thick carbon steel fins connecting the inner liner and the outer liner to aid heat transfer from the MPC to the environment.

The lid of the Storage Overpack consists of a 75mm thick lid plate with a 550mm thick concrete plug in the middle. It is bolted to the body by twenty four M56 carbon steel bolts and a metal gasket is located inboard of the lid bolts for sealing at the lid-body interface. Although the MPC is the containment barrier, the Storage Overpack is nominally sealed using a gasket to prevent ingress of water and contaminants build-up inside the Storage Overpack. These features prevent chloride deposition onto the MPC which alleviates the potential for stress-corrosion cracking of the stainless steel MPC.

In order to avoid iron contamination of the MPC from contact with the carbon steel surfaces of the Storage Overpack, and to ensure heat transfer across the cavity of the Storage Overpack, the surfaces of the cavity of the Storage Overpack will be coated with stainless steel or a suitable paint that is compatible with stainless steel.

CONCEPTUAL DESIGN OF THE TRANSPORT OVERPACK

The Transport Overpack encapsulates the Disposal Package for public domain transport and transport at the GDF to the disposal vault. The Transport Overpack, with a pair of impact limiters, and with its Disposal Package content, constitutes the Transport Package which is a Type B transport package which complies with the IAEA Transport Regulations [6] including all the structural, thermal, shielding, containment and criticality safety requirements.

Although the Transport Overpack is considered the containment boundary for the Transport Package, in reality, both the Disposal Overpack and the MPC would both be sealed and would provide added barriers for containment.

A vertical section and a horizontal section through the complete Transport Package are shown in Figure 6.

The Transport Overpack consists of a body, an inner lid and an outer lid.

The body consists of a 120mm thick carbon steel cylindrical wall, a 80mm thick base, a 110mm thick layer of neutron shielding and a 10mm thick carbon steel outer shell.

The inner lid is a 110mm thick carbon steel disc and is fitted to the body by a “bayonet” type arrangement. It does not form part of the containment boundary and its main purpose is to carry the impact loading from the Disposal Package contents in lid downward impacts in hypothetical accident impact conditions, so that the loading does not need to be carried by the outer lid which is part of the containment boundary.

The outer lid consists of an 80mm thick carbon steel disc, with a 110mm thick neutron shielding and a 30mm thick carbon steel outer shell. It is connected to the body by 32 M36 carbon steel bolts. A set of double O-Ring elastomeric seals are located at the lid-body interface inboard of the lid bolts for sealing.

The impact limiters consist of energy absorbing foam enclosed in a carbon steel housing. The energy absorbing foam is a LAST-A-FOAM® FR-3700 series of close-cell polyurethane. Two different densities/strengths of foam are employed for the core and perimeter areas of the impact limiters. Each of the impact limiters are connected to the Transport Overpack by sixteen M36 carbon steel bolts.

The mass and dimensions of the Transport Package satisfies the mass and dimension limits imposed on it by the transport system, both in public domain transport and at the GDF.

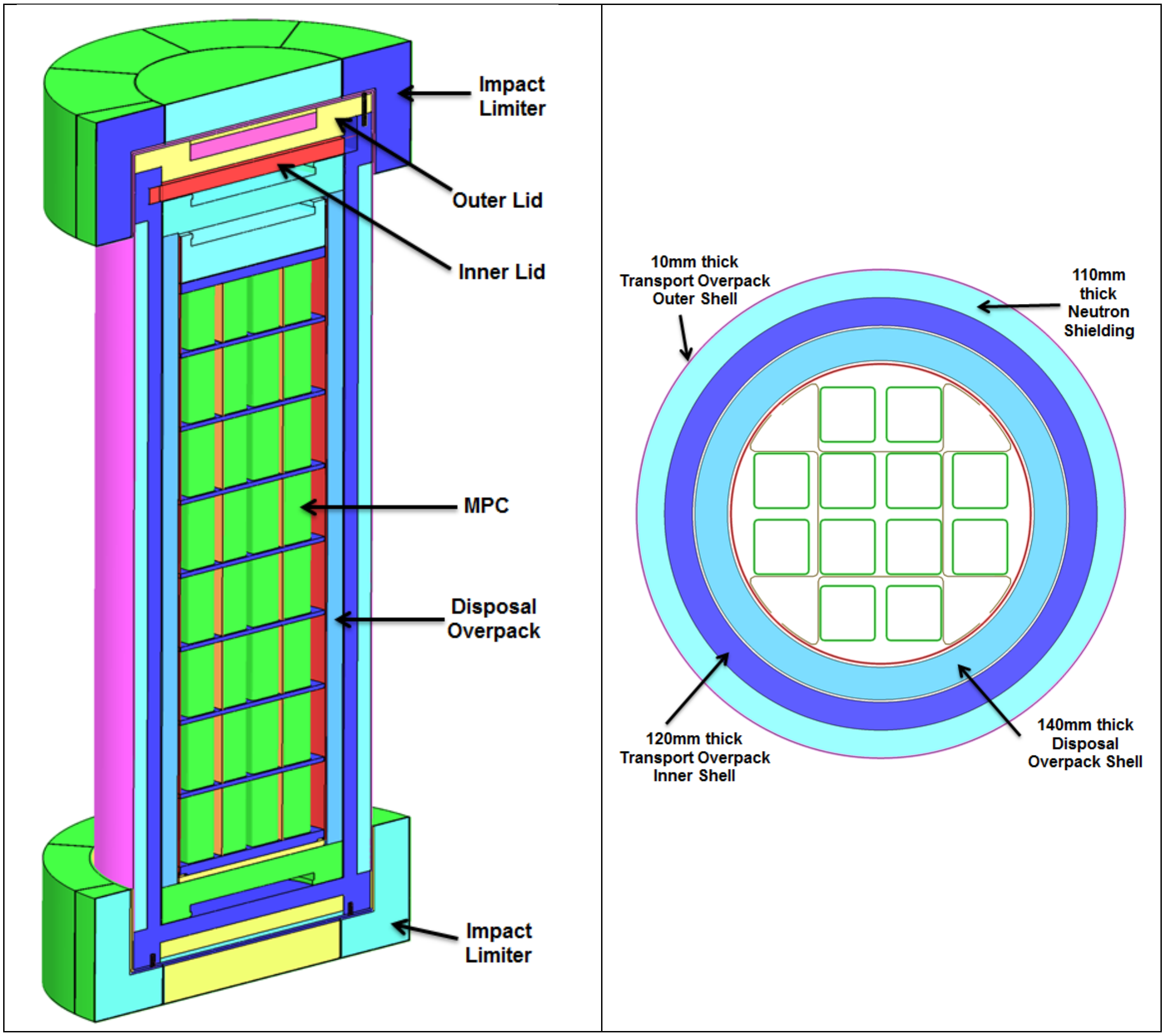


Figure 6 Vertical (left) and horizontal (right) section through the Transport Package

CONCEPTUAL DESIGN OF THE DISPOSAL OVERPACK

The Disposal Overpack encapsulates the MPC for disposal. The Disposal Overpack, with the MPC and its PWR SF content constitutes the Disposal Package. The Disposal Overpack protects the MPC from the repository loading over the timescale required for disposal and it provides the containment for the MPC and the PWR SF contents.

A section through the Disposal Package is shown in Figure 5.

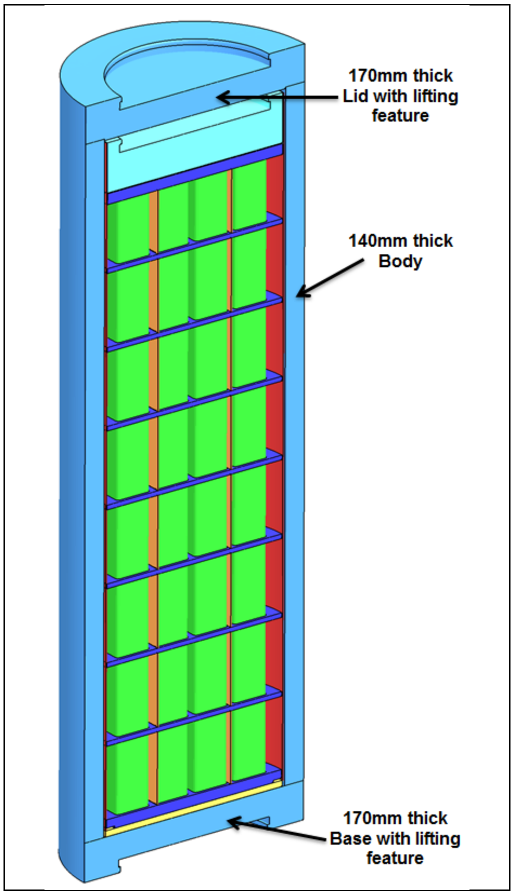


Figure 5 Vertical section through the Disposal Package

The Disposal Overpack consists of a carbon steel body and a carbon steel lid. The body consists of a 140mm thick cylinder shell and a 170mm thick base. The lid is 170mm thick. The base will be welded to the bottom of the cylinder shell during the fabrication process while the lid will be welded to the cylindrical shell after the MPC has been loading.

Once the MPC is packaged inside the Disposal Overpack, the Disposal Overpack will be considered to be the containment barrier. However, in reality, both the Disposal Overpack and the MPC will provide containment.

The assumed design life of the Disposal Overpack is 10,000 years. The total degradation due to corrosion of the carbon steel over a period of 10,000 years is estimated to be 20mm. In the analyses to assess its performance in the long term pressurisation load cases, this amount of reduction of the thickness of the carbon steel was taken into account.

CONCLUSIONS

A conceptual design of an MPC system for the storage, transport and disposal of PWR SF, including the MPC and its associated Transfer Overpack, Storage Overpack, Disposal Overpack and Transport Overpack, has been developed.

The work has demonstrated feasibility of the concept, confirming that employing the MPC system with a higher capacity than the existing disposal containers is feasible. With a capacity of 12 PWR SF assembles, the MPC system represents a contents loading three times that of the standard PWR disposal container. The paper has presented the operating system for the MPC, the design criteria, and the design of the MPC and its associated overpacks. It has discussed various technical challenges from both a structural performance and thermal perspective, necessitating the need for the development of innovative features to enhance heat transfer from the central PWR SF assemblies within the MPC and novel lid design on the Transport Overpack to maintain structural integrity and containment during the hypothetical accident conditions of transport tests.

It is recognised that, depending upon the safety functions required of the MPC system, the choice of carbon steel material for the disposal overpack may not be suitable in all geological environments. These aspects would require further evaluation once detailed knowledge of the disposal concept to be implemented and its safety functions and geological environment are known.

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