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Development of a Packaging to Transport the new Standardised range of Disposal Canisters to a Geological Disposal Facility in the UK

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Abstract

The UK's Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA) is developing concepts to demonstrate the viability of using a standardised range of Disposal Canister designs for geological disposal of High Level Waste (HLW) and spent fuel in the UK. The standardised Disposal Canisters (DC) are designed for disposal in a Geological Disposal Facility (GDF) with integrity requirements in the range 10000 to 100000years.
International Nuclear Services (INS), is also a subsidiary of the NDA, and working with RWMD to develop a design of packaging for transporting these Disposal Canisters which is called the Disposal Canister Transport Container (DCTC). Initial studies undertaken by INS focused on optimising payload and geometry for the canister designs. Subsequent studies focused on achieving Criticality Safety Requirements for transport which established the use of Multiple Water Barriers (MWBs) were required for higher enriched spent fuels. The results of this initial work were presented at the International Nuclear Engineering (INE) society conference at London in 2012.
Subsequently, RWMD commissioned INS to develop the design of DCTC to a level where it would be viable for licensing as a transport package with appropriate level of technical understanding. A specific requirement of RWMD was that the loaded DCTC should be capable of transportation on an existing design of four axle rail wagon, within a gross mass of 90 tonnes, this giving considerable logistic and overall cost benefits.
Recent development work has focused on detailed impact, thermal and shielding analysis and how these influence the DCTC transport mass and the position of that mass in relation to the four axle rail wagon, both of which influence its capability for the required transport. In terms of meeting mass limits, achieving the specified radiation shielding performance (Neutron and Gamma) for the spent fuel was found to be a major challenge. However, of equal challenge was to accommodate the high forces generated under impact accident conditions due to the high mass ratio of contents to container. In order to mitigate these forces, the shock absorber designs needed to be carefully judged because their dimensions were restricted by the rail wagon design. This paper describes the DCTC development work, how the design challenges were addressed and the conclusions reached.

Introduction

In 2011 International Nuclear Services (INS) were commissioned by the UK's Radioactive Waste Management Directorate (RWMD) to undertake studies to determine the optimum payload of a range of Disposal Canister (DC) designs for transport of radioactive materials in the public domain. Each DC would be transported in a package called a Disposal Canister Transport Container (DCTC) from a central loading facility to a Geological Disposal Facility (GDF). This study considered several options for the transport of irradiated fuel but concluded that to carry fuel of over 2.5%

initial enrichment, Multiple Water Barrier (MWB) features were required. The results from this initial study were given in a paper presented at the International Nuclear Engineering society conference in 2012 at London.

Subsequently, RWMD commissioned INS to develop the DCTC into a viable package design with MWB special features, for the transport of two distinct DC design variants. Each DC design variant was designed for the transport and subsequent disposal of the following payloads;-

1. High Level Vitrified Waste – stack of 3 HLW canisters
2. Irradiated AGR fuel – 108 fuel rods in each of 16 slotted cans these in 4 x 4 array
3. Irradiated PWR fuel assemblies – 4 complete assemblies in 4 separate lodgements

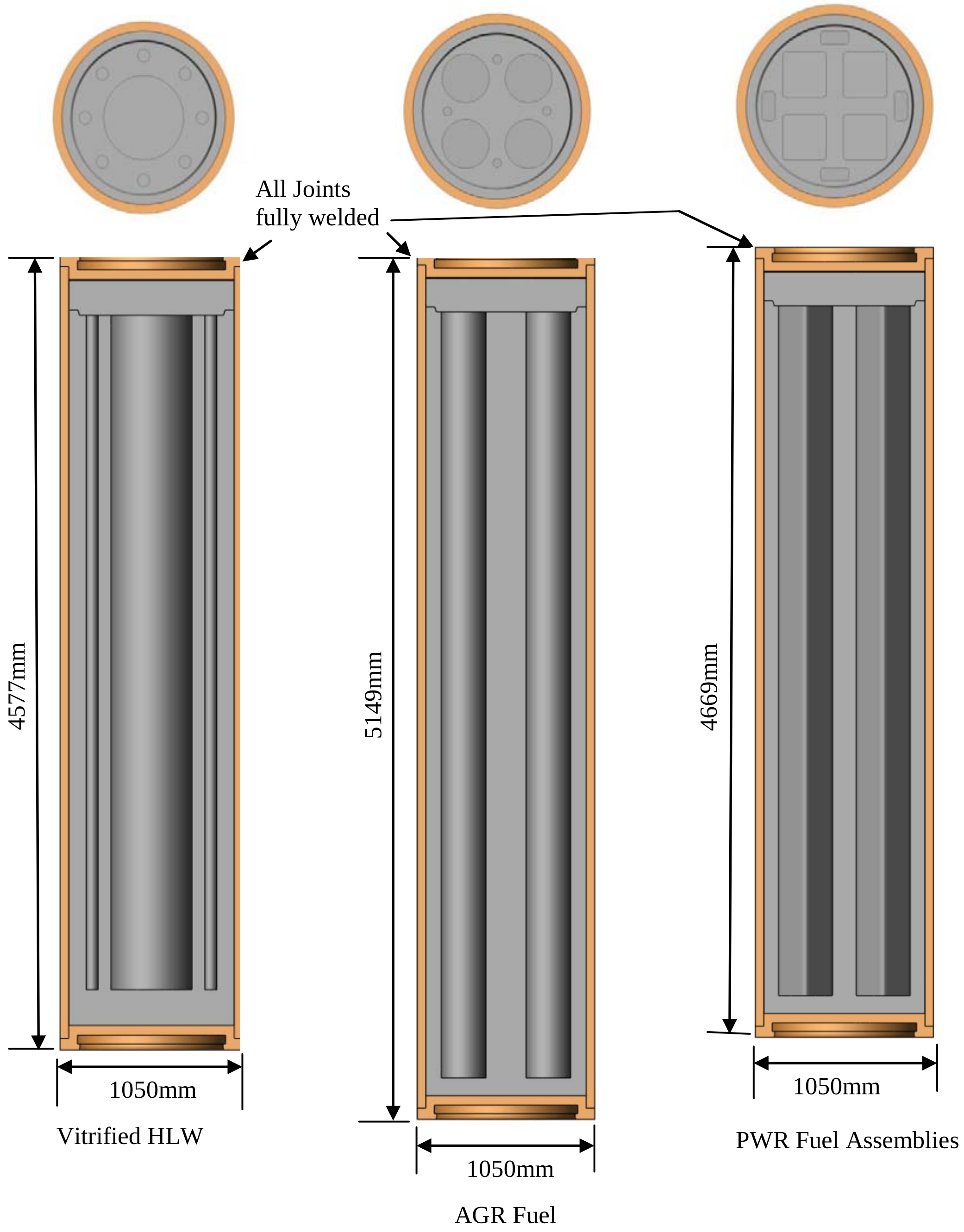
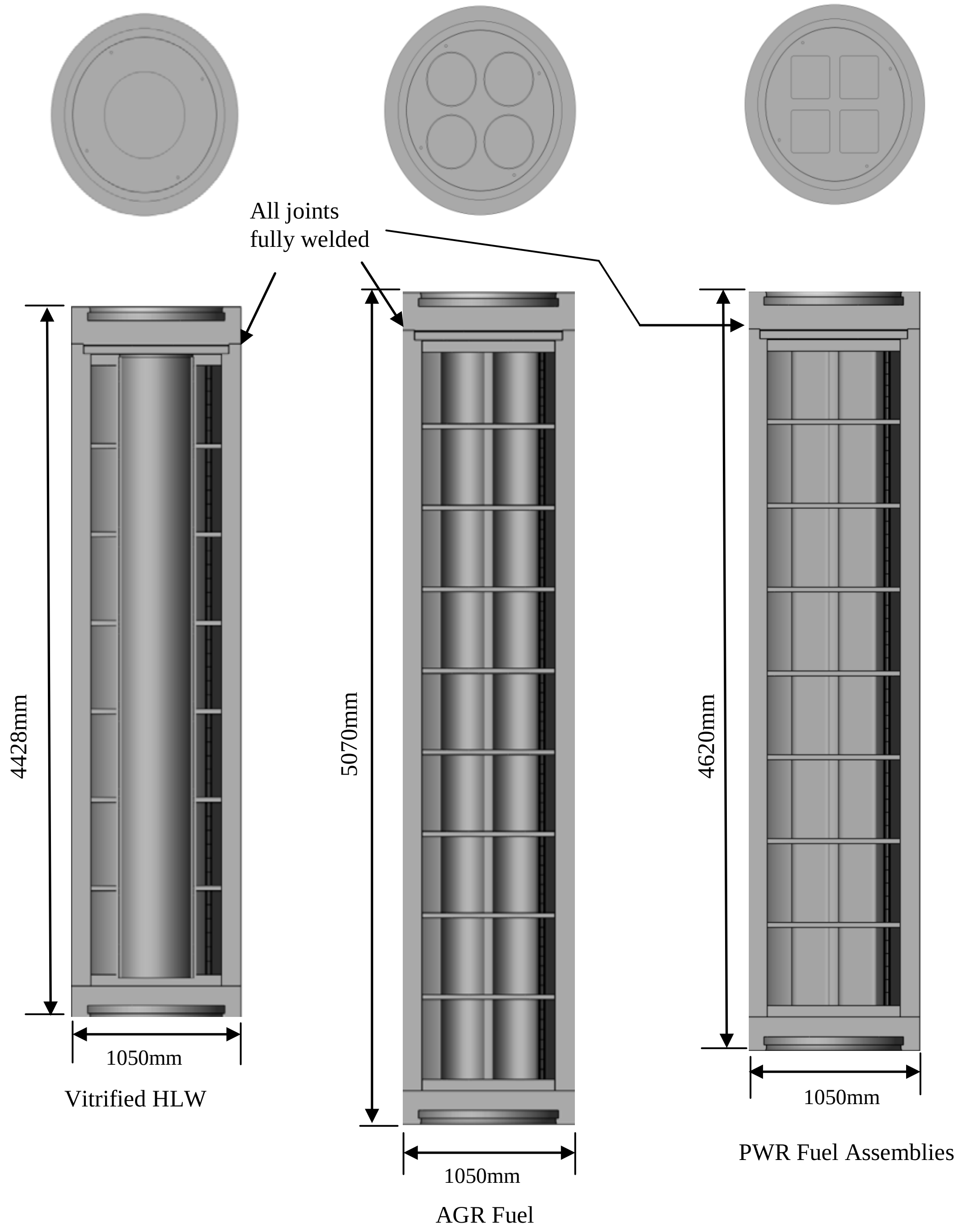


Figure 1 – Disposal Canister Variant 1 – Copper With Cast Iron Insert

The outside diameters of both DC variants are the same at 1050mm but their overall length varied according to the payload type.

The essential differences between the two DC designs were that Variant 1 comprised of a solid cast iron core with a copper outer shell, whilst Variant 2 comprised of an open design of internal support frame for the payload, within a thick walled steel outer shell, see Figures 1 and 2.



Vitrified HLW

AGR Fuel

PWR Fuel Assemblies

Figure 2 – Disposal Canister Variant 2 – Steel with Open Frame Design

Description of Disposal Canister Variants

Two variants of standardised disposal canister have been developed by RWMD, as shown in Figures 1 and 2. Variant 1 is the design for a long lived disposal canister (100000 + years) whilst the Variant 2 design is for a shorter term (10000 years) disposal canister.
The solid cast iron core of the Variant 1 DC provides the strength to resist forces generated by geological movements arising over long periods whilst the thick (50mm) copper shell provides full containment with corrosion resistance.
In the Variant 2 DC design, the thick steel outer shell has a dual purpose, providing both the strength against geological movements and full containment with corrosion resistance.
Both DC Variants will be manufactured to the highest Quality Assurance standards to ensure absolute containment integrity of each canister during both transport and long term disposal.

Variant 1 types are significantly heavier than Variant 2, whilst the masses of the payload types also vary, resulting in six different laden masses, see Table 1 below.

Table 1 – Mass Summary of Disposal Canister Variant with Payload

		Mass (tonnes)	
		Variant 1	**Variant 2**
HLW	Outer body	6.26	10.93
	Bottom	0.66	1.02
	Outer lid	0.66	1.24
	Inner lid	1.06	0.25
	Insert (Basket)	15.65	1.50
	Waste Contents	1.65	1.65
	Total laden mass	**25.94**	**16.59**
AGR SF	Outer body	7.06	12.76
	Bottom	0.66	1.02
	Outer lid	0.66	1.24
	Inner lid	1.06	0.25
	Insert (Basket)	17.10	2.31
	Waste Contents	2.82	2.82
	Total laden mass	**29.36**	**20.40**
PWR SF	Outer body	6.38	11.46
	Bottom	0.66	1.02
	Outer lid	0.66	1.24
	Inner lid	1.06	0.25
	Insert (Basket)	14.65	2.21
	Waste Contents	2.71	2.71
	Total laden mass	**26.12**	**18.89**

DCTC – Functional Design Specifications

RWMD had a number of major objectives for the DCTC package development, these are summarised below;-

- Compliance with the IAEA Transport Regulations

- Incorporation of Multiple Water Barriers to allow fuel enrichments up to 5%

- One DCTC design is to be capable of transporting both DC Variants and all payload types
- The maximum loaded weight including transport frame must not exceed 65 tonne
- Decay heat loads up to 1200W are to be carried

From assessment of the masses and lengths of each DC Variant (Table 1), INS soon realised that achieving a viable design within the above weight constraints was going to present a significant challenge. Nevertheless, a weight limit of 65 tonne including transport frame remained a key objective because it offered significant logistical and cost advantages by permitting the use of an existing design of four axle rail wagon. This wagon had considerable advantages over eight axle wagons because more packages can be transported by a single train together with the more efficient use of sidings and marshalling facilities.

DCTC Development Process - Radiation Shielding

Recognising that achieving a developed DCTC design within the weight constraints was a major challenge, attention was initially focused on developing the radiation shielding design.

All three payloads types emit both gamma and neutron radiation, hence the DCTC required both neutron and gamma shielding. For safety and operational reasons the allowable combined radiation dose limit was 0.1mSv/hr at 1m distance but there were no additional constraints on the neutron or gamma dose contributions to the total.
Typically, gamma shielding incurs the higher weight penalty whilst neutron radiation can be shielded by lighter materials, hence the design challenge was to achieve an acceptable combined radiation dose at 1m distance, but with the lowest resulting overall weight.

As shown in Table 1, Variant 1 Disposal Canisters have a significantly higher loaded mass and hence self shielding than the Variant 2 DC design. However, because the RWMD specification requires one DCTC design to be capable of transporting both DC Variants, the initial radiation shielding development had to be based on the Variant 1 DC. This was because the higher weight of the Variant 1 DC determines the maximum permissible weight of the DCTC.

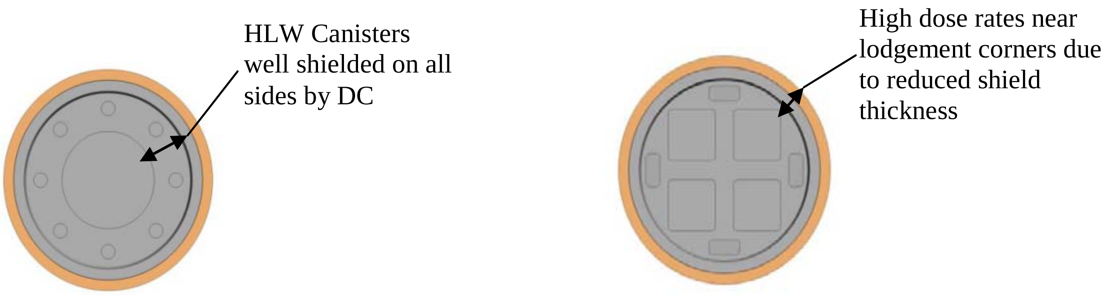


Figure 3 Radiation Shielding – Variant 1 Comparative Cases – HLW and PWR Fuel

One of the first steps in the radiation shielding development was to establish the most onerous or bounding radiation source. HLW was found to be a considerably higher radiation source than the AGR fuel and PWR fuel assemblies but was well shielded by the Variant 1 DC as a consequence of having a uniform thickness of cast iron all around. Conversely the corners of the PWR lodgements were relatively less well shielded and overall this proved to be the bounding case, see Figure 2.

Applying the Variant 1 DC loaded with four PWR fuel assemblies as the bounding source, scoping studies were undertaken to determine the optimum thicknesses of gamma and neutron shielding to meet specified dose limits and weight constraints.

To determine the potential implications of the shielding design on the loaded weight of a DCTC a conceptual model was drawn on SOLIDWORKS [1] which allowed weights to be rapidly calculated. Although the shielding design was developed for the PWR fuel payload, the SOLIDWORKS model for weight was based on the Variant 1 DC loaded with AGR fuel rods, this being the heaviest and longest DC to be transported in DCTC.

The maximum loaded weight of the DCTC and transport frame cannot exceed 65tonne whilst the maximum loaded weight of any DC Variant is 29.36 tonne, see Table 1. Studies of existing transport frames carrying packages of around 60 tonne indicate that a frame of approximately 4.5tonne would be required to comply with modal transport tie down constraints, this included a factor to cover the uncharacteristic support height required to fit the four axle wagon. On this basis, for the purpose of determining acceptable shielding parameters, the maximum allowable weight of an unloaded DCTC was set at 30.5 tonne, after allowing a small margin for calculation errors.

The shielding analysis considered a range of gamma and neutron shielding thickness parameters giving a combined dose rate below 0.1mSv/hr@1m distance and each was assessed for the resulting overall weight. This included estimates for the weight of components not yet designed, for example the weights attributed to the DCTC shock absorbers and trunnions were initially based on comparisons with existing packages types of similar weight.

Applying the weights calculated on SOLIDWORKS for each shielding arrangement against the limit of 30.5 tonne, potential shielding arrangements were assessed, see Table 2.

Table 2 – Generic Results For A Range Of Shielding Configurations That Meet Weight Limits

Four Irradiated PWR Fuel Assemblies In Variant 1 Disposal Canister	
Dose > 0.1mSv/hr@ 1m distance	Dose < 0.1mSv/hr@ 1m distance
55mm steel with 95mm thick neutron shield	85mm steel with 65mm thick neutron shield 75mm steel with 75mm thick neutron shield 65mm steel with 85mm thick neutron shield

Table 2 above presents four shielding configurations that were among several evaluated. These four all ensured the DCTC complied with the weight limits but the configuration comprising of a 55mm thick steel body with 95mm of external neutron shielding material resulted in the required dose limit being exceeded. The three viable shielding configurations were then evaluated against the following criteria:-

- Need to achieve the maximum structural strength, particularly under impact conditions, including punch impacts

- Need for the DCTC body design to incorporate the maximum provision for multiple lids or content restraining systems

- Need to have the maximum provision to include Multiple Water Barrier features.

Based on the above, the shielding configuration with the maximum steel thickness was selected, ie 85mm. This would give the most rigid DCTC body shell under impact conditions and be the most resistant to punch damage, although it was recognised even a steel thickness of 85mm required local strengthening around the trunnion attachment positions.

Table 3 – DCTC Side Doses (µSv/hr) – PWR Variant 1 Disposal Canister – 85mm Steel + 65mm Neutron Shielding Material

Position	Neutron	Gamma	Capture Gamma	Total
Contact	166	79	84	**330**
Side 1m	46	19	17	**82**
Side 2m	20	10	6.6	**37**

The calculated dose rates from the DCTC sides are presented in Table 3 above. Although not presented here, the end dose rates were well below 0.1mSv (100µSv)/hr at 1m distance, the highest lid and base end doses arising from the PWR fuel payload. Actually, the shielding analysis indicated potential to reduce the thickness of the DC end closures whilst still meeting dose criteria, thus potentially saving weight on the DC itself and also the DCTC by reducing its length slightly.

Variant 2 Disposal Canister

The Variant 2 DC is an open frame design, having lower self shielding than the Variant 1 DC, particularly for a HLW payload which now became the bounding case for radiation shielding analysis. Detailed analysis demonstrated the DCTC shielding parameters suitable for the transport of the Variant 1 DC bounding case were not acceptable for the Variant 2 DC bounding case. Results from this analysis are presented in Table 4, which shows the dose rate at 1m distance from the side is 5 times higher than the acceptance criteria. Further analysis has indicated the HLW canisters would require storage for another 60 years before they could be transported in the DCTC.

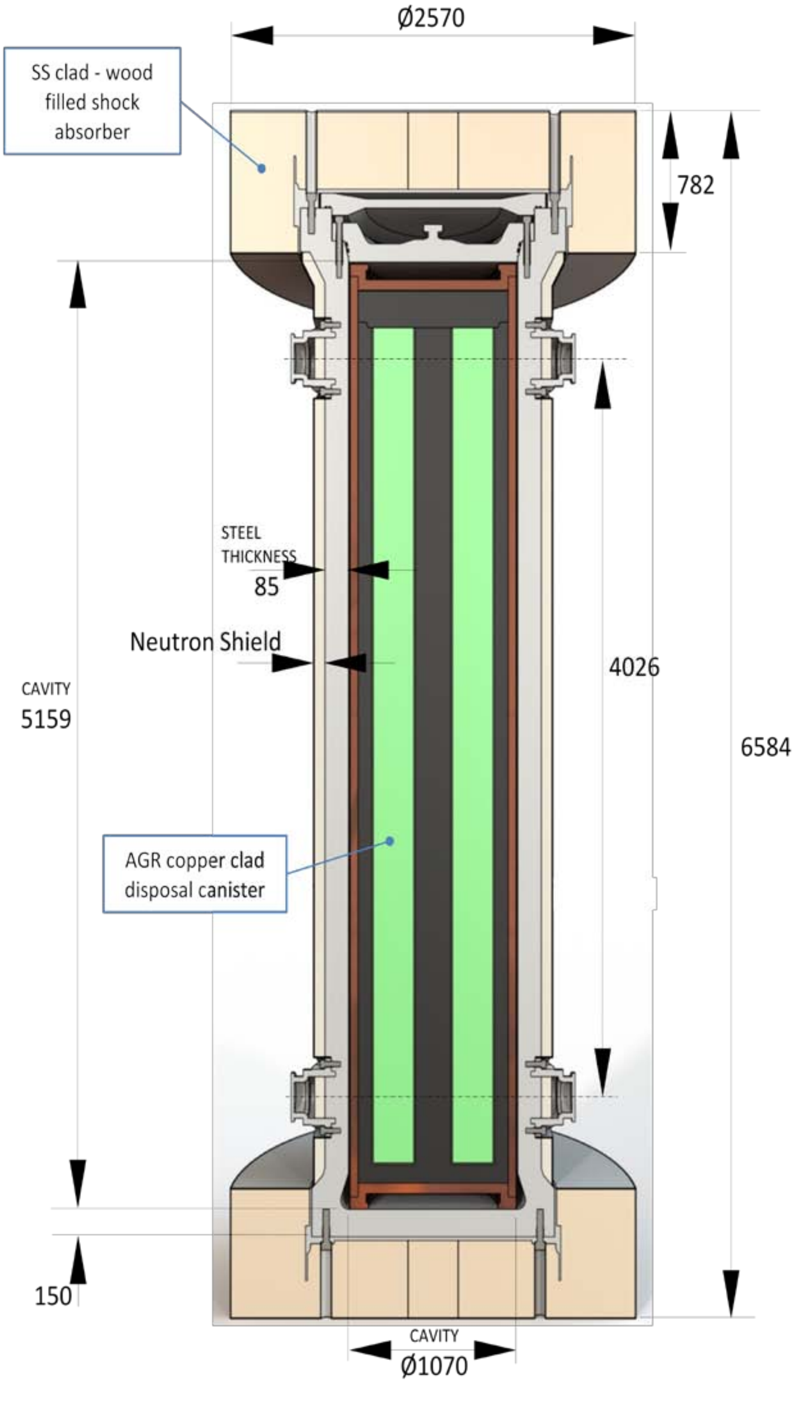
The requirement of this development specification was that one DCTC design must be capable of transporting both Variant 1 and Variant 2 DC types. The shielding analysis demonstrated this would only be feasible by extending the cooling period for payloads in the Variant 2 canisters. Another option, outside this development specification, could be a DCTC design just for the transport of the lighter Variant 2 Disposal Canisters. This would require that the weight difference between the two DC Variants of approximately 9 tonne would be used to increase the shielding on the DCTC, which would then make it too heavy to transport the Variant 1 DC within applicable weight restrictions.

Table 4 – DCTC Side Doses (µSv/hr) – HLW Variant 2 Disposal Canister – 85mm Steel + 65mm Neutron Shielding Material

Position	Neutron	Gamma	Capture Gamma	Total
Contact	298	1130	94	**1522**
Side 1m	100	382	24	**506**
Side 2m	53	202	11	**266**

DCTC Concept Design

A concept design of DCTC was developed around the selected shielding parameters, this becoming the basis for subsequent impact and thermal analysis, see Figure 4 below. The DCTC concept in Figure 4 shows the heaviest configuration, shorter Disposal Canisters may require the use of DC support stools to make up the length.



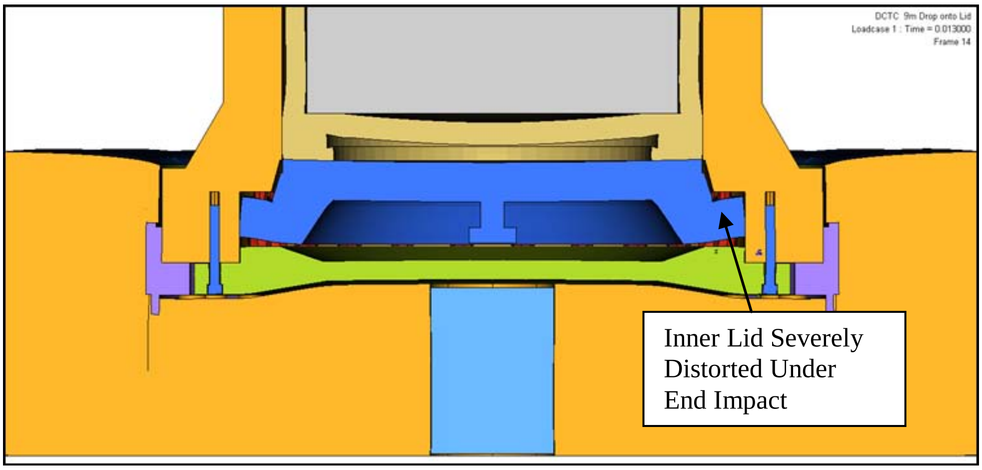
DCTC Analysis Model (85mm Steel & 65mm Neutron Shield)

Figure – 4 – Concept DCTC Carrying AGR Fuel Pins In Variant 1 DC (60 tonne)

Impact Analysis

An essential requirement of the DCTC was to incorporate Multiple Water Barrier (MWB) features to permit higher enriched fuels to be transported. It may prove feasible that the Disposal Canister itself could be one of the water barriers but another approach may be the use of two separate lids, as shown in Figure 4. Irrespective of the components classed as MWB features, the exceptionally high weight of the contents requires a restraint system to act under impact conditions. This restraint system could be a high strength inner sealing lid or a pure restraining feature with no seal function, the latter being appropriate should the DC itself act as a MWB feature.

The high weight of the contents presents a significant challenge to the impact design because the loaded DC represents over 45% of the total mass of the package, this being an unusually high percentage compared to a typical fuel transport package. Issues created by the high mass of the DC were demonstrated by the DCTC impact analysis which confirmed substantial distortions to the inner lid and bolting system under lid end and lid corner impacts, see Figure 5.



Inner Lid Severely Distorted Under End Impact

Figure 5 – FEA Impact Analysis Showing Severe Distortion Of Inner Lid Under End Impact

The extent of the calculated deformations and strains were so high it was probable that some or all of the inner lid retention bolts would fail with consequence to the outer lid. In terms of MWB features, this would be unacceptable as the design intent requires each feature to act independently, which clearly would not be the case here. The DCTC impact analysis also examined other drop orientations and concluded that side and base end impacts did not cause significant distortions to the inner lid.

In order to reduce the loadings on the inner lid, attention was given to improving the efficiency of the shock absorber design, particularly at the lid end. However, scope to do this was limited because any dimensional increase would challenge the limits of the UK rail loading gauge – see Figure 6. As evident in Figure 6, the DCTC has to be mounted high over the bed of the four axle wagon to clear the raised end platforms, meaning the shock absorbers are already virtually at their maximum permissible diameter within the UK rail loading gauge. Increasing the depth of the shock absorbers would still be possible, but this would add unwanted weight.

Irrespective of the practical restrictions on shock absorbers' modification, scoping calculations had indicated it would be virtually impossible to improve the shock absorber design sufficiently to mitigate the impact effects of the DC on the inner lid. Consequently a decision was taken to examine the feasibility of making the inner lid a contents retention device without sealing function and the DC itself as one of the MWB features. This proposal has been discussed with the UK Office of Nuclear Regulation (ONR) at a meeting in February 2013 without any fundamental objections being raised, although INS and RWMD were advised, ultimate acceptance would depend on justifications in the Package Design Safety Report (PDSR).

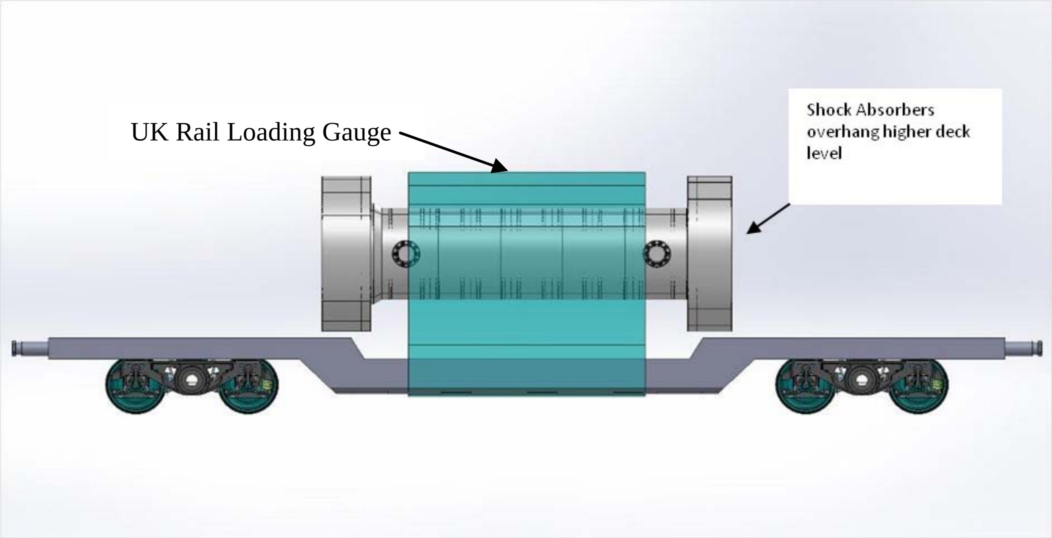
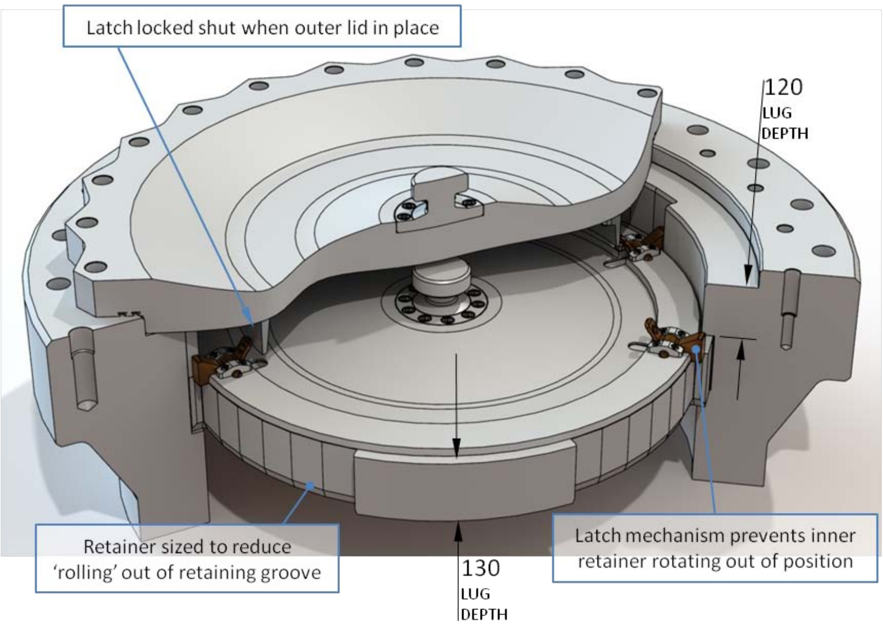


Figure 6 – DCTC Concept Fitted On Four Axle Wagon

Further Developments

The work described above highlighted a number of issues, particularly regarding weights and the retention of the contents under impact conditions. However, neither of these issues can be fully resolved until a viable design has been developed or proven to be unfeasible within the required criteria. To this end, further work has been commissioned to develop a bayonet fitting retention



Bayonet Concept Inner Retainer (Only Outer Lid Sealed)

Figure 7 – Concept Design For Bayonet Type Contents Retention Device

device of the type shown in Figure 7 and thereby determine the implications on weight and dimensions. This work is now underway for completion in March 2014.

Further work is being undertaken on the DC design to examine reducing the thickness of the end closures which will have the effect of reducing the weight of the DC itself and also the DCTC by reducing the length of the cavity it requires and hence its overall length.

Conclusions

The Variant 1 DC types have the highest self shielding performance but are also much heavier than the Variant 2 DC types. As one DCTC design is required to transport both DC Variants, the Variant 1 DC determines the thickness of the radiation shielding feature of the DCTC whilst remaining within the weight limit. A combination of gamma and neutron shielding materials has been shown to be viable for Variant 1 DC types and remain compliant with the dose target of 0.1mSv/hr at 1m.

A DCTC concept has been developed that has potential to transport the Variant 1 DC types but further development is needed to establish a contents retention system that operates effectively under impact conditions. The challenge will be to design a restraint system whilst remaining within the overall weight constraints, however this will be easier if some overall savings can be made by reducing the thickness of the DC end closures.

The Multiple Water Barrier (MWB) features on the DCTC will include the DCs themselves as weight constraints will prevent viable multi lid systems being applied.

The Variant 2 DC types cannot be transported within the DCTC because the external radiation dose rate is too high but here there are no consequent weight issues. Further work is noted to develop a DCTC version for the Variant 2 DC.

The four axle wagon design results in the DCTC sitting high above the wagon deck in order to clear the raised deck platforms at the ends. In consequence this leads to restrictions on the DCTC shock absorber dimensions when ensuring the UK rail loading gauge limits are not exceeded. A further consequence arising from the high mounting of the DCTC on the four axle wagon is the raised height will increase the weight of the transport frame required, although this is implicit in the estimated frame weight (4.5 tonne) applied is this study.

References

1. SolidWorks 3D Design Software 2012.