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Development of a transport container to transport High Level Waste and Spent Fuel to a Geological Disposal Facility in the UK

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Abstract

Radioactive Waste Management (RWM) is responsible for developing a Geological Disposal Facility (GDF) for UK's higher activity waste. RWM are developing concepts for a range of Disposal Containers for the geological disposal of high level waste and spent fuel. In support of this, International Nuclear Services Ltd (INS) is working with RWM to develop a concept for a transport container to transport the Disposal Containers to a GDF. This design of transport container is named the Disposal Container Transport Container (DCTC).

Initial studies carried out by INS optimised the container geometry and established the use of Multiple Water Barriers (MWB) as the preferred option to achieve criticality safety requirements for transport. Further development has focussed on detailed impact, thermal and shielding assessments and how this influenced the DCTC mass. These findings were presented at the 17th PATRAM conference, San Francisco in 2013. In particular that paper highlighted the challenge of designing a transport container where the contents were 45% of the total package mass limit.

As the DCTC design has been developed, so too have the external factors that define the requirements for it. Two factors that have a significant influence are: the developing technologies in the rail industry, resulting in increased payload capacities; and the triennial update of the UK derived inventory which defines the radioactive materials that could be transported to and disposed in a GDF. The 2013 inventory update has seen the introduction of additional materials with increased shielding, thermal and mass requirements, further challenging the overall mass limit.

This paper discusses how the DCTC has progressed to its current stage; how it is influenced by the associated rail wagon concept and sets out the opportunities that have been identified

jointly by INS and RWM to address the challenges presented by the expanded scope of the derived inventory. It also gives detail on how these opportunities can be incorporated in order for the DCTC design to meet the International Atomic Energy Agency (IAEA) regulatory requirements.

1 Abbreviations

ABWR	Advanced Boiling Water Reactor
AGR	Advanced Gas Cooled Reactor
AP-1000	Advanced Passive Pressurised Water Reactor
DC	Disposal Container
DCTC	Disposal Container Transport Container
DRS	Direct Rail Services
EPR	European Prototype Reactor
GDF	Geological Disposal Facility
HEU	Highly Enriched Uranium
HLW	High Level Waste
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
INS	International Nuclear Services
MOX	Mixed Oxide
MWB	Multiple Water Barrier
PFR	Prototype Fuel Reactor
PWR	Pressurised Water Reactor
RA	Route Availability
RWM	Radioactive Waste Management
SF	Spent Fuel

2 Introduction

RWM is responsible for the design and implementation of a GDF in the UK in which higher activity waste such as High Level Waste (HLW), Intermediate Level Waste (ILW), and Spent Fuel (SF), etc is to be disposed of. At present the location of the GDF has not been identified; however, RWM develops illustrative designs to demonstrate the feasibility of disposal, including transport to a GDF using a number of radioactive material package designs suited to each waste type. This helps ensure that current storage and treatment plans of legacy HLW or SF is suitable and supports the UK's Generic Design Assessment process for new nuclear build by providing confidence that the associated SF would also be disposable.

In support of RWM, INS has been developing a number of the package designs that are intended for transport of the radioactive waste to the GDF. One of which is the DCTC which is intended to carry Disposal Containers laden with HLW and SF. As this has been developed, the planned UK civil nuclear program has been taken account of. This has resulted in an evolution of the requirements for the DCTC, inclusive of an increase in the shielding requirements, which has a direct impact on the mass of the package.

The intended mode for transport of radioactive waste to the GDF is road and rail, with rail having the more limiting payload restrictions. In the early stages of the DCTC development, a maximum laden mass of 65t was specified as it is consistent with previous package types, and is compatible with the transport system requirements and the GDF handling systems. However, the expected mass of the DCTC has increased to a point whereby the original rail wagon concept is challenged. Therefore the wagon payload limit has been increased through reduction of tare mass and the use of higher rated bogies. This paper outlines; the current mass of the DCTC (considering all laden variations); assesses it against the UK's rail network limitations; and outlines approaches which can be adopted to address any shortfalls and any compromises that may be necessary as a result.

3 DCTC and Disposal Container Information

The DCTC is a cylindrical transport package intended for transporting HLW and SF to the UKs GDF (Figure 1). The original concept investigated the possibility of using two separate bolted lids, each with their own seal arrangement to form a MWB, thus permitting the transport of higher enriched fuels. However, it is highlighted in [1] that this approach gave rise to significant challenges in meeting the impact analysis criteria as it was found that some or all of the lid bolts were likely to fail. This was largely due to the forces generated by the relatively high percentage of contents mass (>45% of the laden DCTC mass).

Normally, it would be appropriate to mitigate the damage to the retaining bolts through modifications to the shock absorber design. However, the shock absorbers were already of a geometry that was very close to the limits imposed by the UK rail gauge, severely limiting the potential for significant improvements in the shock absorber performance. As a result it was decided to investigate a concept that utilised the Disposal Container as a water barrier in conjunction with a single sealed lid as the second water barrier, protected by a bayonet retention system, see Figure 1.

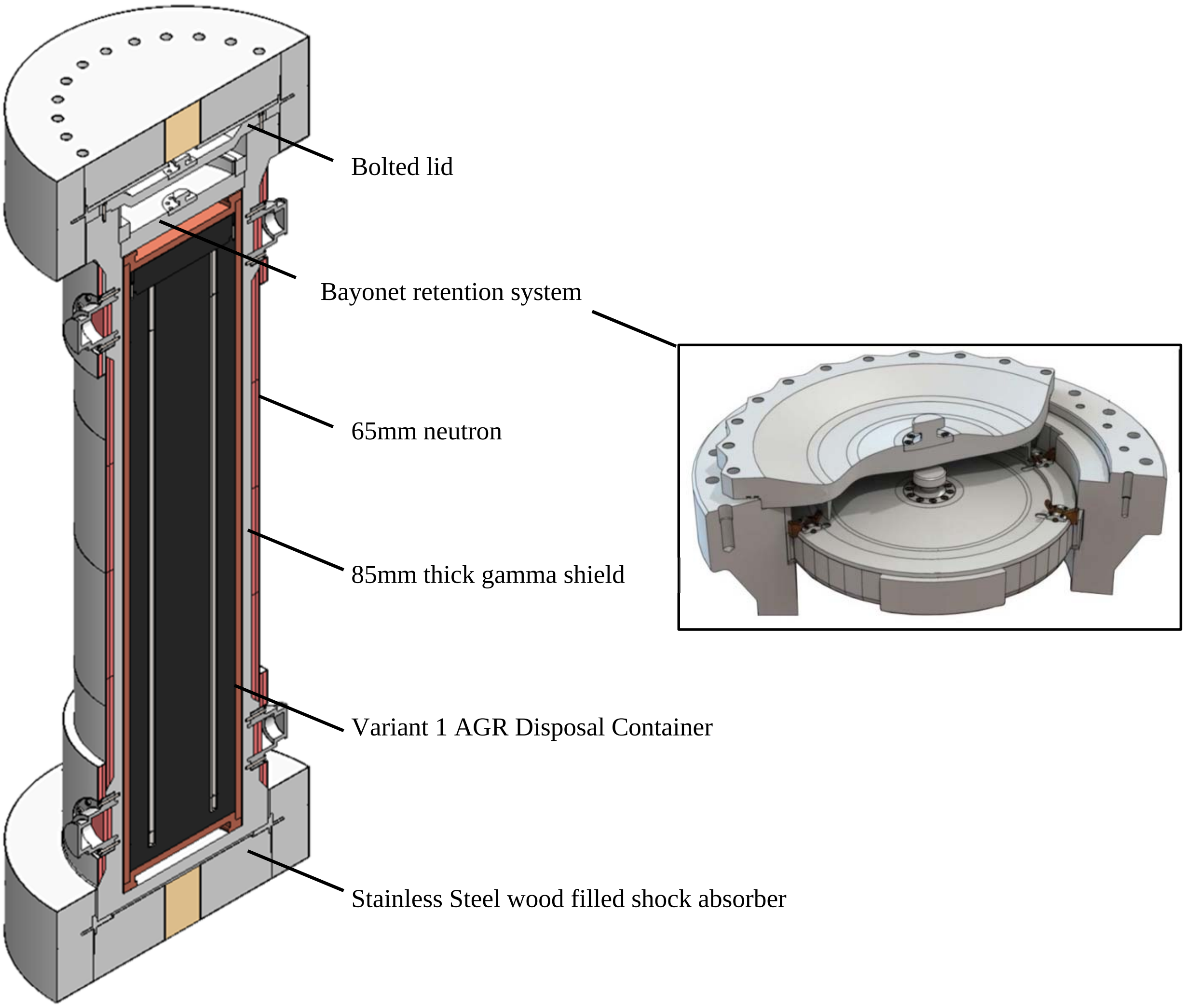

Figure 1 – DCTC package and bayonet retention system

Following incorporation of the bayonet retention system design, a focussed impact analysis of the worst case drop orientation was completed [2]. This showed that the bayonet retention system was effective in meeting the regulatory impact criteria. One of the compromises of incorporating this system is the required additional mass, the allowance for which is very limited due to the UK rail Route Availability (RA), which is a measure of the weight loading capacity of a rail route. However, given the difficulties in achieving an effective retention system it is considered to be a mass-efficient solution. In comparison, increasing the structural integrity of the original bolted double-lid arrangement would require a greater mass increase.

The current DCTC design weighs 31.43t unladen plus an estimated 6t for a transport frame that includes a weak-link mechanism as discussed in [3]. However, it has also been highlighted in [3] that, following the addition of new materials introduced in the 2013 Derived Inventory, the current DCTC design will require additional shielding; and will need to be lengthened to accommodate all the associated Disposal Containers. Therefore, estimates of the additional weight associated with alleviating these issues were made. The steel wall thickness was increased in 10mm increments from 85mm (current DCTC design) to 145mm to give an indication of implications of varying degrees of additional gamma shielding. For a wall thickness of 145mm, there is an increase of ~7.4t. A 1.14t increase in mass has been estimated for extending the cavity length sufficiently, giving a total additional mass of 8.54t. Therefore the mass of the unladen DCTC and transport frame is assumed in this report to be 45.97t.

To date, the DCTC has been developed for transport of two variants of Disposal Containers that have each been developed to meet the needs of a range of potential host rock environments that could accommodate the planned GDF. Each variant has concepts developed for three payload types: Pressurised Water Reactor (PWR); Advanced Gas Cooled Reactor (AGR); and Vitrified HLW. Variant 1 and 2 for each payload are shown in Figure 2 and Figure 3 respectively. In addition to these, illustrative Disposal Container designs have been produced by modifying the existing substantiated Disposal Container designs to accommodate the geometry of the new materials that have been added to the 2013 Derived Inventory [4], namely: Prototype Fast Reactor (PFR) SF, Highly Enriched Uranium / Plutonium (HEU/Pu) and Magnox SF; Mixed Oxide (MOX) SF, European Pressurised Reactor (EPR) SF[1] and Advanced Passive Pressurised Water Reactor (AP-1000) ; and Advanced Boiling Water Reactor

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[1] Also expected to accommodate transport of AP-1000 SF

(ABWR) SF[2] in [5], [6] and [7] respectively. These are similar in construction to those shown in Figure 2.

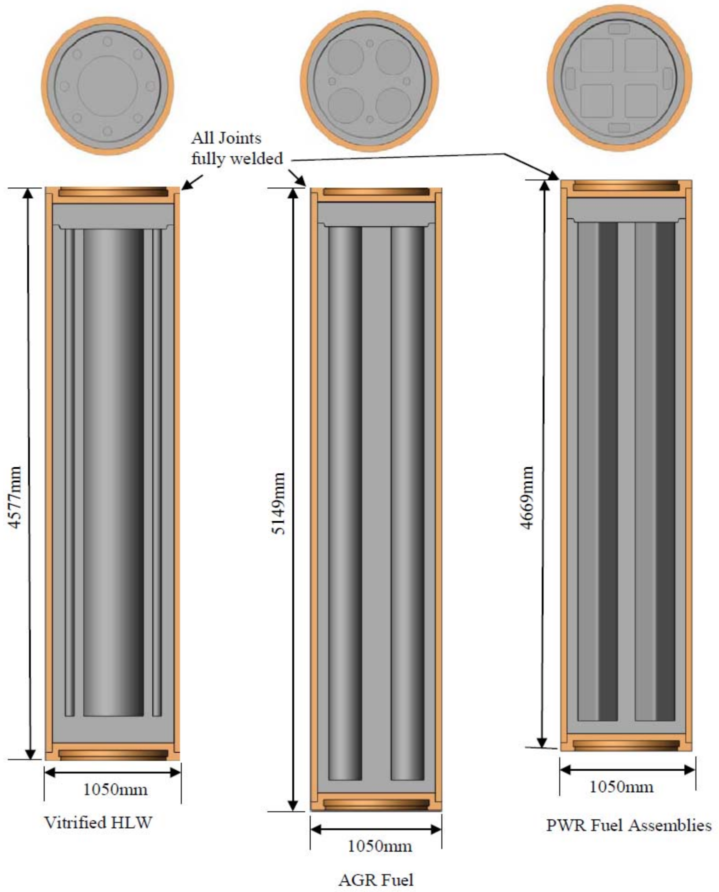

Figure 2 – Variant 1 Concept Disposal Container

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[2] Although ABWR has not been included in the 2013 Derived Inventory, it is being progressed through NDA's Generic Design Assessment process and is expected to be included in future derived inventories. It has therefore been included here to be comprehensive.

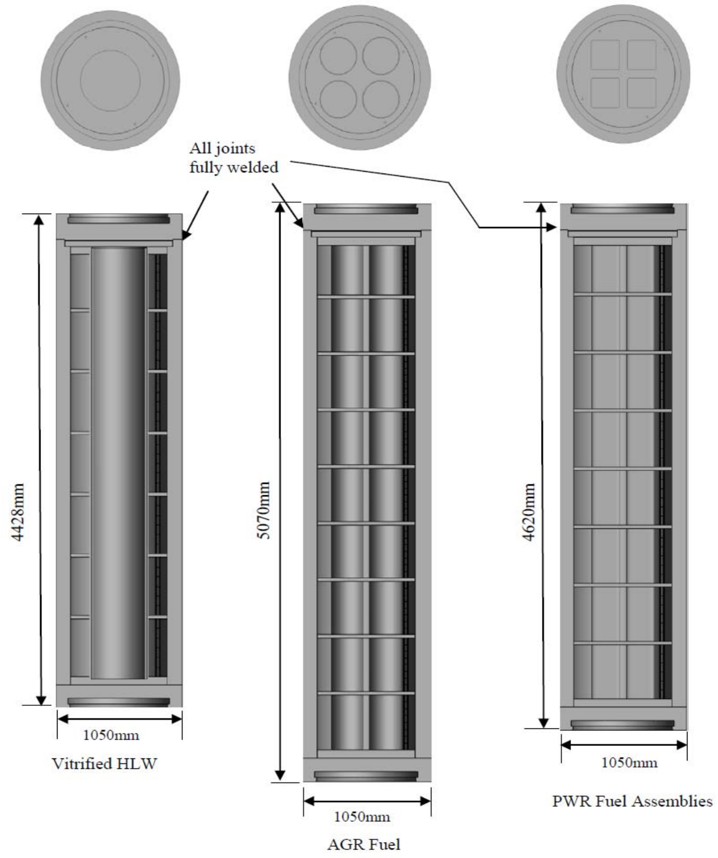

Figure 3 – Variant 2 Concept Disposal Container

The assumed masses of the DCTC (including the mass estimates for increased cavity length and gamma shielding) laden with each of the Disposal Containers and including the mass of the transport frame are given in Table 1. The masses for the illustrative Disposal Containers have been taken from [3] and the associated RA has been given for each when in-situ on a rail wagon (discussed in Section 5).

Table 1 – Disposal Containers and associated masses

	Fuel Type	Disposal Container Mass (kg)		Mass of Laden DCTC + Transport Frame (kg) [RA]	
		Variant 1	Variant 2	Variant 1	Variant 2
	AGR	27.73	20.4	73.70 [10]	66.37 [08]
	Vitrified HLW	25.88	16.59	71.85 [09]	62.56 [08]
	PWR	24.53	18.89	70.50 [09]	64.86 [08]
Illustrative DC	PFR SF	15.39	12.19	61.36 [08]	58.16 [07]
	HEU/Pu	17.27	12.31	63.24 [08]	58.28 [07]
	Magnox SF	21.74	15.43	67.71 [09]	61.40 [08]
	MOX SF	31.56	17.86	77.53 [10]	63.83 [08]
	EPR SF & AP1000	28.1	18.26	74.07 [10]	64.23 [08]
	ABWR SF	21.52	N/A	67.49 [09]	N/A

It can be seen from Table 1 that the maximum mass of the laden DCTC is 77.53t, which is close to the payload limit detailed in Table 2. However there is significant potential for enhancement of the MOX SF Disposal Container to reduce its mass and for the purposes of this study the EPR and AP-1000 SF Disposal Container is considered to be the bounding case at 74.071t. It is important to note that the mass estimate for the DCTC is for scoping intent and does not take into account varying thicknesses of neutron shielding (an order of magnitude less mass than gamma shielding). Furthermore, the resulting effects on the size and mass of the shock absorbers and transport frame were not considered. Therefore, although not significantly, it is expected that the DCTC mass will increase further. As an additional note, it can be seen that the Variant 2 Disposal Container has no RA > 8. This however is not advantageous given that, if Variant 1 were to be selected, significant weight savings could be achieved in the DCTC. This is discussed in Section 4.

4 Impact of Disposal Container Variant Selection

As mentioned in Section 3, there are 2 design variants of Disposal Container to be transported in the DCTC, one of which will be selected depending on the long-term safety case requirements of the GDF. Variant 1 has been designed to meet the requirements for a GDF in higher strength rock and is of a copper and cast iron construction. Variant 2 is designed to meet the requirements for a GDF in either lower strength sedimentary rock or evaporite rock and is of a steel construction. They are both designed to accommodate the same contents, but for each of the contents configurations, the Variant 1 Disposal Container can be assumed to be heavier than the equivalent Variant 2 of same contents.

The surface dose rates for the two variants of concept Disposal Containers are presented in [8]. The maximum (for primary gamma-ray) was calculated to be 0.04Gy/hr and 0.38Gy/hr for Variant 1 and Variant 2 respectively. This is reflected in the difference in mass that is presented in Table 1 and thus the greater degree of self-shielding for the Variant 1 concepts.

Each variant has specific design characteristics that make them the preferred option depending on the site of the GDF. However, as a result of the GDF site not yet being selected, the DCTC design currently has to accommodate the requirements for both variants. Therefore, when considering the feasibility of the DCTC whilst taking account of future developments, it is prudent to consider that;

1. If the Variant 1 Disposal Container is selected (with greater mass hence better shielding capability), the shielding requirements of the DCTC will be reduced hence the mass can be reduced.
2. It the Variant 2 Disposal container is selected (of lower mass and less shielding capability) the DCTC will require the same level of shielding as is currently defined, but will not have to accommodate the heavier contents i.e. the Variant 1 Disposal Container.

The differences in mass between the Variant 1 and Variant 2 concept Disposal Containers (Table 1) ranges from 3.2t to 13.7t, suggesting that the savings against mass could be of great significance following identification of the GDF location.

5 Rail Wagon Limits

A rail wagon concept for transporting the DCTC is presented in [9] with a number of bogie options, offering a 22.5t or 25.4t axle load. The subsequent differences are shown in Table 2. For each case, two bogies are required, each with two axles (4 axles in total).

Table 2 - Rail wagon details

	22.5t Axle Bogie	25.4t Axle Bogie
Gross Laden Weight (GLW)	90t	101.6t
Wagon Tare Mass	24t	24t
Max Payload	66t	77.6t
Route Availability	RA8	RA10
Length over buffers	14.0m	14.8m
Deck Height	1.255m	1.225m

The least restrictive RA (in terms of payload) is RA10. This is associated with a 25.4t axle bogie, but results in more restrictive routing options (in terms of number of routes that are rated at RA10). If a 22.5t axle bogie were selected, although reducing the maximum acceptable laden mass of the DCTC, it would allow for RA8. This is more restrictive in terms of payload, but less restrictive for routing options. RA9 is the intermediary categorisation that is applicable for the 25.4t axle bogie when carrying a payload between 66t and 72.5t.

Comparing Table 1 and Table 2 it can be seen that all laden configurations of DCTC have RA10 or less associated and are within the payload limit for the 25.4t rail wagon bogie. The 22.5t axle bogie has sufficient payload limit for 2 of the 9 contents types, therefore it will be assumed that the 25.4t bogie is the preferred option as suggested in [3], due to the less restrictive payload of 77.6t. It should be reiterated that the updated mass estimates for the DCTC are suggestive of further mass increases and that a number of the DCTC configurations are close to the payload limit. However, it is also of note that selection of the Disposal Container variant is expected to reduce the laden DCTC mass.

6 Assessment of the UK Rail Network’s Compatibility with the DCTC

The 2013 Derived Inventory identifies the materials that are to be transported to the GDF and their assumed storage location. Following this, a feasibility study of the UK’s rail network was completed by Direct Rail Services (DRS) to understand the RA or restrictions for each of the various storage locations [10]. The considered sites are shown in Figure 4. Details of the sites that have a RA < 10 for their nearest available railhead are presented in Table 3.

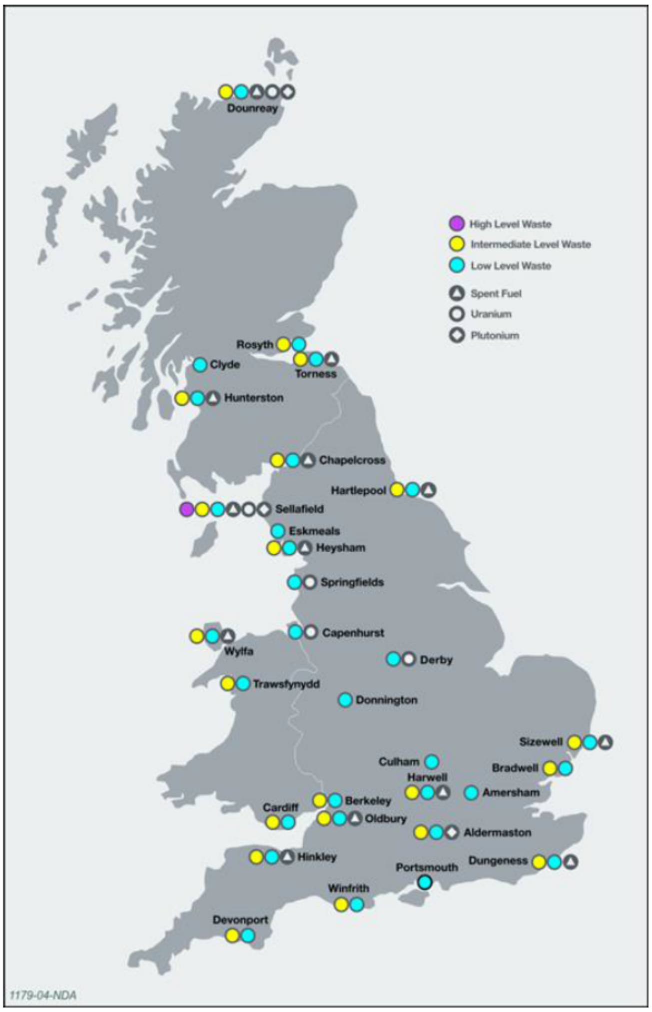

Figure 4 – Derived Inventory identified sites [10]

Table 3 – Derived Inventory identified sites with RA < 10 for their nearest available railhead

Location	RA	Requirement for DCTC on site?
Bradwell	RA9	NO[1]
Berkeley	RA9	NO[1]
Dounreay	RA5	NO[2]
Heysham	RA8	NO[2]
Rosyth	RA8	NO[1]
Sizewell	RA8	YES
Trawsfynydd	RA7	NO[1]

1 Site will not have any material that is included in the scope of transport using the DCTC

2 Material that is included in the DCTC scope will be moved to Sellafield Site prior to the GDF transport

Seven sites have been highlighted in Table 3 as having a RA < 10. Of these, 4 will not hold material that is intended for transport using the DCTC. Furthermore, the material located at Dounreay and Heysham is expected to be transported to Sellafield Site, which has RA10 access, prior to transportation to the GDF. Therefore, of all those presented in Table 3, Sizewell is the only site that will need to facilitate access for the DCTC, and has RA8.

Legacy PWR SF and new build EPR SF are the only radioactive waste materials to be produced at Sizewell that are included in the scope of the DCTC design. The mass for the Variant 1 PWR SF and EPR SF configurations of DCTC is 70.5t (RA9) and 74.07t (RA10) respectively.

Therefore, the DCTC laden with PWR SF and EPR SF Disposal Containers are the only configurations presented in Table 1 that give rise to questions of compatibility of the DCTC with the UK rail network limits.

7 Reducing the DCTC Mass

Table 4 shows the DCTC configurations that exceed the relevant RA and the minimum mass reduction that would be sufficient for their associated routes. It can be seen that EPR Variant 1 necessitates the largest mass reduction and will therefore be considered going forward.

Table 4 – Required mass reduction for compatibility on rail network

DCTC Config.	Mass (t)	Acceptable Mass (t)	Required Mass Reduction (t)
PWR Variant 1	70.5	67.2 [RA8]	3.3
PWR Variant 2	64.86	67.2 [RA8]	Not Applicable
EPR Variant 1	74.07	67.2 [RA8]	6.87
EPR Variant 2	64.23	67.2 [RA8]	Not Applicable

If Variant 1 Disposal Containers were to become the appropriate choice following identification of the GDF location, Variant 2 would no longer be required. As discussed in Section 4, the resulting shielding requirements of the DCTC would therefore be reduced, allowing for significant reductions in the mass of the unladen DCTC. Furthermore, locating shielding towards the centre of the laden cylindrical DCTC (i.e. in the Variant 1 Disposal Container as oppose to the outer wall of the DCTC) will decrease the volume and hence mass of required shielding material.

Shielding calculations have been done for all potential content configurations of the DCTC and are summarised in [3]. As a result of the scoping nature of these assessments, it is expected that future detailed development of the DCTC and enhancement of the input data representing the fuel types will allow for an optimised DCTC wall thicknesses to be determined. It is estimated that for every 10mm reduction in wall thickness of the steel body (i.e. gamma shield) of the DCTC, the overall mass is reduced by a minimum of 1.1t (Table 4, Ref [3]). It is also highlighted in [3] that the medial thickness of the inner lid (of ~1t mass) Figure 5 should be examined to identify if further reductions can be made.

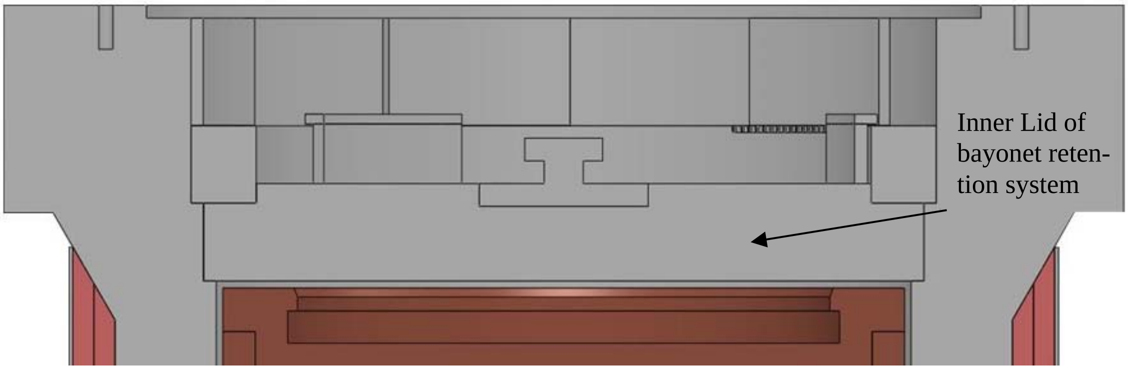

Figure 5 – Inner lid of DCTC

It is worth mentioning that Sizewell does not have an onsite railhead, resulting in the need for road transport to the nearest railhead, which has RA8 associated. Whilst the nearest railhead may be preferred to minimise the length of road transport, it may be practical to drive to a different railhead that does have RA10 capability. If the additional distance by road to the nearest RA10 was acceptable for such a transport, it would provide a viable alternative to reducing the laden mass of DCTC.

8 Conclusion

Following publication of the 2013 Derived Inventory and the associated increases in payload mass of the Disposal Containers to be transported in the DCTC, it was important to understand the resulting implications on the UK rail network’s ability to facilitate the newly bounding masses.

This report has identified that two configurations of laden DCTC (PWR SF and EPR SF), exceed the UK Rail RA for a specific site they are expected to be used at. It has been suggested that the DCTC may undergo mass increases in the future relating to the inclusion of additional neutron shielding and the improved structural integrity of the associated transport frame given high mass Disposal Containers. Nonetheless, there is confidence that when incorporating the efficiencies detailed in Section 7, the increases can be more than offset and that the laden DCTC can be developed into a solution with acceptable masses for all configurations at their relevant sites. However, it is understood that some of the mass savings cannot be fully quantified at this stage hence it is recommended that the conclusions be treated with appropriate caution. If it is found in the future that there are difficulties in achieving an acceptable mass for the PWR SF and EPR SF configurations, there may be additional contingencies that can be instigated such as investigation into; adaptation of sections of the railway network to increase access to Sizewell to RA10 and/or reduction of the tare mass of the rail wagon through further future development; or transporting the DCTC by road to a suitable railhead (i.e. of RA10) as opposed to the nearest railhead (i.e. RA8).

9 Acknowledgements

I would like to thank RWM and Mark Duffy (DRS) for their extensive supporting reference material.

10 References

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