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ISM

# SUBMARINE DISMANTLING PROJECT

# Reactor Pressure Vessel Transport Feasibility Report



Issue 2.0 – Aug 2011

SUBMARINES

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## Distribution

# Abbreviations

| | |
|---|---|
| CA | Competent Authority |
| DDLP | De-fuel, De-equip and Lay-up Preparation |
| DfT | Department for Transport |
| DNSR | Defence Nuclear Safety Regulator |
| ILW | Intermediate Level Waste |
| ISOLUS | Interim Storage Of Laid Up Submarines |
| LLW | Low Level Waste |
| LSA | Low Specific Activity |
| MOD | Ministry of Defence |
| NDT | Non-destructive Testing |
| PST | Primary Shield Tank |
| PWR | Pressurised Water Reactor |
| RC | Reactor Compartment |
| RPV | Reactor Pressure Vessel |
| SCO | Surface Contaminated Object |
| DUU | Used Fuel Flask |

# Executive Summary

Once a nuclear-powered submarine has been defuelled most of the remaining activity is the result of neutron activation of the Reactor Pressure Vessel (RPV) and the Core Barrel. When these have been removed the remaining activated components are relatively low activity and can be dealt with using conventional nuclear decommissioning techniques. The submarine can then be sent to a suitable recycling facility.

Intermediate Level Waste (ILW) is found, almost entirely, within the RPV that is located in the Reactor Compartment (RC) of each submarine.

It is assumed that the RPV must be cut up into smaller pieces and placed in packages before it can be disposed in the proposed Geological Disposal Facility (GDF). Based on this assumption, the main difference between the three initial dismantling options is the timing for when the RPV is cut up and how and where the ILW is stored whilst awaiting a disposal solution. The three options being considered by the Submarine Dismantling Project are:

- Separate and store the **whole Reactor Compartment**: In this option the whole RC (with the RPV within it) is separated from the rest of the submarine, as a slice, and stored whole. When a final disposal solution is available for the radioactive waste, the RPV would be removed from the RC, cut into smaller pieces and packaged for disposal.

- ***Remove and store the Reactor Pressure Vessel***: In this option the RPV and other radioactive waste is removed from the submarine whilst leaving the submarine intact. The RPV would then be stored whole until a final disposal solution is available. It would then be cut into smaller pieces and packaged for disposal.

- ***Remove the Reactor Pressure Vessel and cut it into smaller pieces to be stored as packaged waste*** In this option the RPV and other radioactive waste is removed from the submarine whilst leaving the submarine intact. The RPV is then cut into smaller pieces and stored as packaged waste. Once a final disposal solution is available the packaged waste can be disposed of without any further processing.

To help inform the analysis of the technical options the feasibility of transporting a whole RPV in the public domain has to be assessed. Therefore this report looks at some of the practical aspects of transporting an RPV. In this respect it utilises and builds on previous work carried out by BNFL (**Reference 1**) and Babcock (**Reference 2**). It summarises the regulations governing the transport of radioactive materials and considers the design aspects of how the RPVs would be packaged. Simple scoping calculations are provided. Issues around road, rail and sea transport are discussed. Budget costs and a high-level programme are included. Finally, to provide a context for developing this approach to decommissioning, some examples where RPVs have already been transported are given: these are mainly from the US.

It is concluded that transporting a submarine RPV is a practicable proposition. All three modes of transport (Road, rail and sea) are valid, therefore this aspect of the decommissioning process is not limiting. Most of the discussion is based on the PWR1. Little information is currently available on PWR2, though similar arguments apply. However the size and weight of a PWR2 package make it less suitable for rail transport since it may exceed the most restrictive loading gauge and therefore impose limits on where it can be

used. However, road and sea transportation of a PWR 2 are still considered to be as feasible as for PWR 1.

# Table of Contents

# 1. INTRODUCTION

MOD policy for decommissioned nuclear submarines is to undertake De-fuel, De-equip and Lay-up Preparation (DDLP), and then to store the vessels afloat. At some suitable time the radioactive components will be removed and transferred to an interim storage facility. Ultimately it will be consigned to the national repository, which is not expected to be ready to accept waste until at least 2040. The remaining non-radioactive parts of the vessels will be broken up at a conventional recycling faciltiy.

Once the fuel has been removed, the significant radioactive inventory lies with the Reactor Pressure Vessel (RPV) and its contents (notably, the Core Barrel). The inventory comprises the nuclides within the RPV that have been created by neutron activation together with an unknown quantity of crud and some residual water. Other radioactive components within the Reactor Compartment (RC) are readily handled and processed for subsequent disposal.

One option is to remove the RPV and its contents and to transport it as a single unit to the interim storage site, which is what this report addresses. No new information has become available since **Reference 1** and **Reference 2** were written, so their conclusions remain valid. Consequently, this report builds on the previous work to consider what issues are involved with the transportation aspects and develops outline cost and programme estimates.

# 2. REGULATORY LIMITATIONS

## 2.1. Requirements for radioactive materials transport packages

**Reference 1** contains a thorough treatment of the regulations covering the transport of radioactive materials by road, rail, sea and air. For the purposes of this report a brief summary is included below.

The main types of radioactive materials package are as follows:

| Type | Typical contents |
|---|---|
| Excepted | Small samples, swabs, radiopharmaceuticals for medical use. |
| Industrial Package (IP) | Bulk materials: contaminated clothing, rubble, contaminated/activated metals, liquid effluent, ores containing naturally occurring radionuclides. |
| Type A | Sources for NDT, borehole logging, medical diagnosis, teletherapy. |
| Type B | Irradiated fuel, powerful sources, highly-active components. |
| Type C | For transporting more highly radioactive material by air. |

In the case of Excepted, IP and Type A packages safety is assured through limitations placed on the quantity or form of the contents. Therefore the packagings need only demonstrate resistance to Normal Conditions of transport. In an accident it is assumed that the contents may escape but that the consequences are limited. The contents of Type B and Type C packages are effectively unlimited. Therefore safety needs to be built into the packaging and as a result it must resist Accident Conditions of transport.

One can say straight away that the RPV will require either an IP or Type B packaging. Both **Reference 1** and **Reference 2** discuss this at some length and conclude that provided a decay period is allowed, then an IP packaging will suffice.

Industrial packages are used to transport two types of material:

- Material having low activity per unit mass (known as Low Specific Activity or LSA material). Items classified as LSA material include hospital waste;
- Non-radioactive objects having low levels of surface contamination (known as Surface Contaminated Objects or SCO). Fuel cycle machinery or parts of nuclear reactors, whose surfaces have been contaminated by coolant or process water, are considered as SCO.

Both types of material are inherently safe, either because the contained activity is very low, or because the material is not in a form easily dispersible.

(LSA is limited by the concentration of radionuclides and by the dose from the unshielded material. There are three classifications LSA-I, -II and –III. LSA-I is relatively innocuous and can be ignored for the purposes of this report. **Reference 3** defines a value for each nuclide (its $A_2$ value) that marks the threshold between

Type A and Type B. The $A_2$ value varies widely depending on the hazard presented by each nuclide.

**Reference 3** para 409 contains the following definitions:

> LSA-II: Material in which the activity is distributed throughout and the estimated average specific activity does not exceed $10^{-4} A_2$/g for solids and gases, and $10^{-5} A_2$/g for liquids.
>
> LSA-III: Solids (e.g. consolidated wastes, activated materials), excluding powders, meeting the requirements of para. 601, in which:
>
> i. The radioactive material is distributed throughout a solid or a collection of solid objects, or is essentially uniformly distributed in a solid compact binding agent (such as concrete, bitumen, ceramic, etc.);
> ii. The radioactive material is relatively insoluble, or it is intrinsically contained in a relatively insoluble matrix, so that, even under loss of packaging, the loss of radioactive material per package by leaching when placed in water for seven days would not exceed $0.1A_2$; and
> iii. The estimated average specific activity of the solid, excluding any shielding material, does not exceed $2 \times 10^{-3} A_2$/g.

IP packagings are sub-divided into three categories designated as IP-1, IP-2 and IP-3. In addition **Reference 3** para 516 states that:

> The quantity of LSA material or SCO in a single Type IP-1, Type IP-2, Type IP-3 package, or object or collection of objects, whichever is appropriate, shall be so restricted that the external radiation level at 3 m from the unshielded material or object or collection of objects does not exceed 10 mSv/h.

IP packagings differ in the degree to which they are required to withstand routine and normal conditions of transport (see Table 1). The required tests simulate normal transport conditions such as a fall from a vehicle, exposure to rain, or being struck by a sharp object, or having other cargo stacked on top.

**Table 1 Industrial Package requirements**

| Criteria | IP-1 | IP-2 | IP-3 |
|---|---|---|---|
| Design requirements | • General requirements for all packages<br>• Additional pressure and temperature requirements if transported by air | • General requirements for all packages<br>• Additional pressure and temperature requirements if transported by air | • General requirements for all packages<br>• Additional pressure and temperature requirements if transported by air<br>• Type A additional requirements |

| Criteria | IP-1 | IP-2 | IP-3 |
|---|---|---|---|
| Test requirements – normal transport conditions | | • Free drop (from 0.3 to 1.2m, depending on the mass of the package)<br>• Stacking or compression | Each of the following tests must be preceded by a water spray test:<br>• Free drop (from 0.3 to 1.2m, depending on the mass of the package)<br>• Stacking or compression<br>• Penetration (6kg bar dropped from 1m) |

Both **Reference 1** and **Reference 2** conclude that the RPV is LSA-11 Material, and consequently can be transported in an IP-2 packaging. Both note that the issue of crud needs to be fully resolved. The radionuclides in LSA-11 material need to be reasonably well distributed through the wasteform. So when more information is available on the quantity and activity of the crud an argument will need to be developed to show that this is substantially the case. The specific activity of the Core Barrel is also likely to be notably higher than the RPV itself and this will need to be argued too. The reason for the requirement for the nuclides to be distributed is to avoid a high-activity component being "diluted" in the middle of a mass of, say, barely active rubble. In the event of an accident the source could be exposed, breaking the principle of an inherently low-hazard wasteform. However, in this case this would hardly apply since the higher activity material is safely encased in a massively thick steel shell.

Type B packages are required for the transport of highly radioactive material. These packages must withstand the same normal transport conditions as Type A packages, but because their contents exceed the Type A limits, it is necessary to specify additional resistance to release of radiation or radioactive material due to accidental damage. The concept is that this type of package must be capable of withstanding expected accident conditions, without breach of its containment or an increase in radiation to a level which would endanger the general public and those involved in rescue or clean-up operations. The adequacy of the package to this requirement is demonstrated by stringent accident conditions testing (see Table 2).

**Table 2 Type B Package Requirements**

| Criteria | Requirements |
|---|---|
| Design requirements | • General requirements for all packages<br>• Additional pressure and temperature requirements if transported by air<br>• Type A additional requirements<br>• Type B additional requirements (internal heat generation and maximum surface temperature) |
| Test requirements - normal transport conditions | Each of the following tests must be preceded by a water spray test:<br>• Free drop (from 0.3 to 1.2m, depending on the mass of the package)<br>• Stacking or compression<br>• Penetration 6kg bar dropped from 1m |

| Criteria | Requirements |
|---|---|
| Test requirements - accidental transport conditions | Cumulative effects of:<br>• Free drop from 9m or dynamic crush test (drop of a 500kg mass from 9m onto a specimen)<br>• Puncture test<br>• Thermal test (fire of 800°C intensity for 30 minutes)<br>• Immersion (15m for 8 hours)<br><br>Enhanced immersion test for packages carrying a large amount of radioactive material:<br>• 200m for 1 hour |

## 2.2. Aspects of regulatory limitations related to mode of transport

Refer to **Reference 1** for a detailed review of regulations covering the different modes of transport. The Department for Transport (DfT) has devolved responsibility for package design approval to the Defence Nuclear Safety Regulator (DNSR). It would, however, make sense to keep DfT abreast of any proposals and approved packages that result from this programme.

It is suggested in Appendix A that the movement of the WAGR Heat Exchangers from Windscale to Drigg in 1995 resembles the proposed RPV transportation. This is the case in that it is a large item of solid waste (in the case of WAGR, transported as SCO). At 190 te the Heat Exchangers were certainly a heavy load, but by no means excessively so. Of course, much larger loads are not uncommon on UK roads; for instance, a power station transformer typically exceeds 200 te. In physical terms the RPVs resemble the Used Fuel Flask (UFF) which is 4.09 m long, 2.41 m in diameter and weighs 74 te. (The UFF design number is GB/3337A/B(M)F.) This is qualified as a Type B(M)F package and is transported by road and rail. So for the practical details of shipping an RPV it is instructive to consider the UFF, though the potential hazard associated with the latter is of course much greater. In fact the radiological hazard inherent in a packaged RPV is minimal and there should be no fundamental problems with transporting it by whichever mode of transport is deemed to be most suitable (except, of course, air).

As noted above, the packaged RPV will not be excessively heavy for road transport. Figure 1 shows an example of a comparable non-radioactive load being moved by road. In the case of a lengthy journey, say from Rosyth to Devonport, some tactical decisions would need to be made, e.g. whether to overnight in a secure site or whether to do complete the journey in one go. (A non-stop trip from Rosyth to Devonport would take 18-20 hours.)

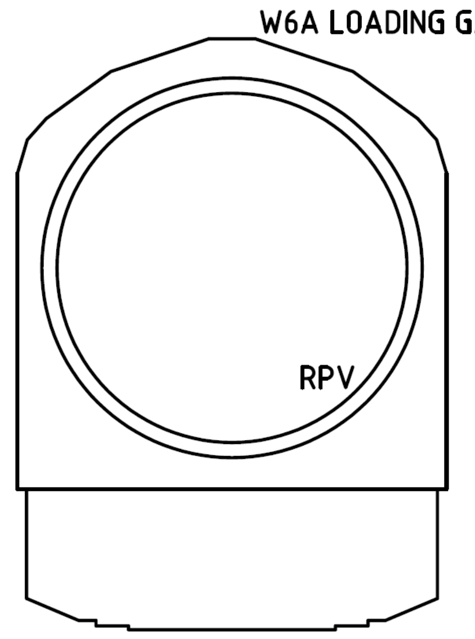
[redacted]



**Figure 1 Typical road transport arrangements for 55 te and 80 te loads**


The packaged RPV should be able to fit within the most limiting rail gauge (W6a), though this still needs to be confirmed. See Figure 2. This is not surprising since, as noted above, the RPV is physically similar to the UFF and that package is designed to be moved by rail.

**Figure 2 PWR1 package outer diameter superimposed on the W6A loading gauge**



Sea transport has been discussed with S&MO staff and Henry Abrams & Sons. No issues have been identified with transport by sea. In maritime terms the load is small and would require only a correspondingly small vessel. It would be sensible to plan the journey to coincide with the time of the year when the weather is known to be good.

It should be noted that where the main mode of transport is by rail or by sea, depending on the route taken by the package, there is likely to be road transport involved at some point. This might be, say, transportation to the nearest rail head or movement within a dockyard.

# 3. RPV PACKAGE DESIGN

## 3.1. IP-2

Both **Reference 1** and **Reference 2** conclude that, given a reasonable decay period, the RPV can be shipped as an IP-2. This agrees with a number of similar movements performed outside the UK. Appendix A presents a selection for illustration – it is not intended to be exhaustive. **Reference 1** and **Reference 2** both speculate that the RPVs will be loaded into a steel container and grouted prior to transport. Again, this approach has been used elsewhere and is illustrated in Appendix A. Rheinsburg, La Crosse and Connecticut Yankee all used a steel overpack. Yankee Rowe used a steel overpack and also grouted the RPV in place.

The activation in the RPV Head is known to be low, allowing the Head to be sent to a melter for recycling. **Reference 2** therefore assumes that is it replaced with a flat closure plate, giving the new weight of the RPV as ≈ 50 te. The cylindrical container is 2500 mm in diameter and 4000 mm high which with a 50 mm wall gives a weight of ≈ 16 te. The shielding will be augmented by the grout, notionally also 50 mm thick, weighing 7 te. Hence allowing for some additional supports the gross weight is ≈ 76 te.

The overall shielding is therefore similar to the 75 mm of steel used for the Connecticut Yankee RPV, though significantly less than the maximum of 120 mm used for the Rheinsburg RPV. There is of course a significant variation in the dose rates from the submarine RPVs due to the range of decay times and the fact that there is a factor of ≈ 2 in the degree of irradiation. The dose rate also varies along the RPV, being higher around the centre. The container wall thickness will also be affected by what happens to the RPV after it has been delivered to the receipt facility. If it is to be size-reduced then it will probably not be grouted into the container, with the consequence that the container wall will need to be correspondingly thicker.

The subsequent actions on the RPV could also influence the nature of the closure. **Reference 2** suggests that the lid closure is by welding. But again, if the RPV is to be size-reduced a bolted closure would be easier to deal with.

Testing the packaging involves a stacking test and a drop test. A stacking test involves placing a load five times that of the package on top of it for 24 hours. In fact, experience shows that for steel packagings this generally has negligible effect. In this case, the compressive load in the container would only be:

$$\sigma_c = \frac{76{,}000 \times 9.81 \times 5}{\frac{\pi \times (2500^2 - 2400^2)}{4}} = 10\,MPa$$

This offers a factor of safety of ≈ 20 and we can reasonably assume that this will not cause any difficulty.

The drop test will be from a height of 0.3 m and to be successful there must be no loss or dispersal of the radioactive material from the package, and the radiation dose rate must not increase by more than 20% at any point.

[redacted]



**Reference 4** Section 6, Appendix A provides a simple approach to scoping the deceleration experienced by a container during a drop test. The volume of material needed to deform and absorb the impact is given by:

$$V = \frac{E}{\sigma_t} = \frac{76{,}000 \times 9.81 \times 0.3}{250 \times 10^6} = 895 \times 10^{-6}\, m^3$$

Where *V* is the volume, *E* is the kinetic energy on impact in Joules and $\sigma_f$ is the flow stress of the material in N/m$^2$.

It is very common for the orientation of impact to be with the package centre of gravity over the lid edge. Under this condition the angle θ between the underside of the package and the ground is:

$$\theta = \tan^{-1}\frac{2500}{4000} = 0.559\, rad$$

**Reference 4** then requires the following equation to be solved iteratively or graphically:

$$\sin\theta - \theta.\cos\theta.\frac{\sin^3\theta}{3} = \frac{V}{R^3.\tan\phi}$$

Where *R* is the radius of the package in metres and *Φ* is half the angle subtended from the centre to the extent of deformation.

*Φ* can be deduced to be ≈ 0.065 rad. So the area at the extent of deformation is:

$$A_m = R^2.\frac{\theta - \sin\theta.\cos\theta}{\cos\phi} = 1.25^2 \times \frac{0.559 - \sin 0.559 \times \cos 0.559}{\cos 0.065} = 0.171 m^2$$

The deceleration is:

$$d = \frac{A_m.\sigma_f}{m} = \frac{0.171 \times 250 \times 10^6}{76{,}000} = 563 m/s^2 = 57g$$

The extent of deformation, or “knockback”, is:

$$k = R.\sin\phi.(1 - \cos\theta) = 1.25 \times \sin 0.065 \times (1 - \cos 0.559) = 0.012 m$$

These figures are not particularly severe and should be able to be accommodated within the design. If fact, if the package is not grouted into the packaging it would be possible to fit internal impact limiters to reduce the loads further.

There is a requirement for “no loss or dispersal” of the contents during testing. If, prior to loading into the packaging, the RPV is fully sealed by bolting the new closure and welding over the nozzle holes then the RPV itself could be defined as the containment boundary since it is sufficiently robust to withstand the drop test loads. This would leave the container as providing shielding only. In this respect it would be similar to the Rheinsberg movement where the container was actually open-ended. It is unlikely that the container will be damaged in the drop test to the extent that the shielding will be affected.

One possible problem with using the RPV as an active part of the package could be demonstrating the material properties; specifically, the degree to which the material has become embrittled. But given the relatively low stresses applied to the vessel it is likely that a worst-case could be used without affecting the safety assessment.

## 3.2. Type B

The current assumptions are that the RPV will be shipped in an IP-2 package, and that the probability of requiring a Type B package is low. However, for completeness a brief discussion of the form a Type B packaging that could resist the drop and fire tests might take is provided below.

The loads generated in a drop test from 9 m will be much more severe so the question of material embrittlement will become more prominent. Finite element modelling would need to be carried out to analyse possible packaging options and generate a suitable design solution. The RPV will probably need to be protected from most of the impact loading and this implies a thicker container, probably with an impact limiter at each end. In terms of its size and weight the RPV resembles a typical fuel flask and one can anticipate a similar sized impact limiter.

The fire test would probably pose less of a threat. Previous work on the SWTC-150, carried out for UK Nirex, indicated that where no thermal insulation was fitted a maximum internal temperature of 200°C occurred. Provided the lid-end impact limiter remains in place the temperature rise around the RPV lid seal would probably only rise to maybe 125°C, which a seal made from EPDM would be able to withstand.

## 3.3. Lifting the RPV

Minimal design work has been carried out so far on how to lift the RPV. It is possible that the skirt could be used as a lifting feature. But the most obvious approach is to utilise the bolts that retain the Head. Since the Head is to be replaced with what is in effect a flat plate, this new Replacement Head could be designed with a lifting feature – simplistically, a large lifting eye. This would follow previous practice, examples of which are included in the Appendix.

Details of the Head bolting arrangement were not available for this report. However, **Reference 2** contains a weight calculation that gives the bolt diameter as 85 mm. So the following scoping calculation has been carried out to provide assurance that having the load path through the bolts will give a conservative design.

Taking a pessimistic case that the container is being lifted too gives the dead load as 76 te. Assume a worst-case snatch load of 100%, i.e. an imposed load of 152 te. Assume the bolt material is only equivalent to grade 4.6, i.e. it has a 0.2% proof stress of 240 MPa. If the largest standard thread pitch for an M85 of 6 mm is assumed then the bolt core diameter is 77 mm (**Reference 5**).

[redacted]



This gives the tensile stress area as:

$$A_{bolt} = \frac{\pi}{4} \times \left(85^2 - 77^2\right) = 1018\,mm^2$$

If the allowable tensile stress in a bolt is 0.4 × $\sigma_{0.2}$ (**Reference 6**, para 6.2.1.2.2) then the minimum stress area is:

$$A_T = \frac{150{,}000 \times 9.81}{240 \times 0.4} = 15{,}330\,mm^2$$

This implies a need for the minimum number of bolts to be:

$$\frac{A_T}{A_{bolt}} = \frac{15{,}330}{1018} = 15$$

There are 40 bolts securing the Head, so there is a satisfactory level of redundancy.

Appendix A of **Reference 7** provides formulae for the stripping area for a Unified threadform as follows. Subsequent calculation makes the assumption that the load is taken on the length of thread engagement equivalent to 0.6 × nominal diameter (**Reference 7** para 6.2). The bolts are M85 × 6 - 6H 6g.

External thread:

$$AS_s = \pi.n.L_e.K_{n,\max} \cdot \left(\frac{1}{2n} + 0.577.\left(E_{s,\min} - K_{n,\max}\right)\right)$$

Internal thread:

$$AS_n = \pi.n.L_e.D_{s,\min} \cdot \left(\frac{1}{2n} + 0.577.\left(D_{s,\min} - E_{n,\max}\right)\right)$$

where:

n = threads / mm = 0.167

$L_e$ = length of engagement = 0.6 × 85 = 51 mm

$K_{n,max}$ = Maximum minor diameter of internal thread = 79.305mm

$E_{s,min}$ = Minimum effective (pitch) diameter of external thread = 80.743 mm

$D_{s, min}$ = Minimum major diameter of external thread = 84.320 mm

$E_{n,max}$ = Maximum effective (pitch) diameter of internal thread = 81.478 mm

Hence:

- external thread, $AS_s$ = 8114 mm$^2$.
- internal thread, $AS_n$ = 10,455 mm$^2$.

For shear loading, a factor of 0.37 from **Reference 6** para 5.1.5.1 is applied. Assuming the RPV material has similar properties to the bolts, then the maximum load that can be applied to each bolt is:

Bolt: $240 \times 0.37 \times 8114 = 721$ kN

Tapped hole: $240 \times 0.37 \times 10{,}455 = 928$ kN

The applied load is:

$150{,}000 \times 9.81 = 1.47$ MN

Therefore this load can be taken by the following number of bolts:

$$\frac{1470}{721} = 2$$

This implies a high degree of redundancy and that bolts will fail in tension rather than by thread stripping, which is correct.

The means of lifting the package will depend on the facilities available at the dispatch and receipt facilities. Precedents for using large mobile cranes in similar situations have been established, and that is the assumption made in the estimate. No calculations have been carried out, but for costing purposes a 1000 te crane has been assumed.

# 4. PWR2 RPV

Similar remarks and analysis apply to PWR2 RPVs. Clearly the main differences are:

- Unless a comparable decay period (a likely minimum of 10 years) is allowed the specific activity and, consequently, the dose rate will be higher and could well require a Type B packaging.

- PWR2 RPVs are significantly larger and heavier: **Reference 2** estimates a 90 te package.

Designing such a large packaging to meet Type B requirements would be challenging and probably impracticable. The essential requirements of a radioactive materials transport container are to maintain shielding and containment. In the case of a Type B this needs to be achieved under accident conditions of transport; represented chiefly by the 9 m drop test and 30 minute fire test. This could be difficult if safety were to be provided solely by the packaging. It might, however, be possible to define the PWR2 as containment boundary which would make things easier. A design study would be needed to scope the problem.

Of course, if the material is allowed to decay to LSA-II then an IP-2 package is appropriate. The likely outside diameter of the container to hold a PWR2 (around 3.3 m) exceeds the W6a gauge. W6a approximates to a worst case, so the possibility remains that PWR2 might be transportable on certain specific routes. These routes would need to be defined and carefully analysed.

The weight of the PWR2 vessel plus container is likely to be around 96 te. Figure 3 shows a 127 te capacity wagon made in 2009 by WH Davis. The overall length is 25 m. Note that the use of double-bogies is likely to exacerbate the gauge problem since it overhangs on the bends.

**Figure 3 Rail wagon, 127 te capacity**

# 5. COSTING AND PLANNING

## 5.1. Cost Estimate

An order of magnitude cost estimate has been developed, and is included in Appendix 2.

The estimate includes

- Design and licensing of the RPV container and associated equipment, including the Replacement RPV Head.
- Manufacture of the containers and ancillary equipment, including the Replacement RPV Head.
- The operational cost to remove the RPV, load it into the container and ship it to another site by each of three modes of transport.

The estimate is intended to address transportation of the RPV so it does not include:

- Whatever preliminary design or assessment work, or stakeholder liaison is needed to reach the point where engineering design begins.
- Site costs such as transferring the submarine to dry dock and the cost of occupying it.
- The preparatory work in the RC (cutting open the hull, cutting off and blanking the nozzles, machining the RPV from the PST, fitting the replacement Head, etc.).
- The capital and operating cost of any facility for inspecting the RPV prior to packaging it for transport.
- The capital and operating cost of the facility for carrying out size-reduction and packaging for disposal.

The following sub-contractors have been approached for budget prices:

[redacted]

[redacted]

[redacted]

[redacted]

Manufacturing costs have been estimated on the basis of typical £/te figures for fabrications and adjusted according to the perceived degree of complexity or size.

Design and other staff costs have been estimated from experience with similar projects.

No contingency has been added. It is likely that the accuracy is approximately -0% to +30%.

A summary of the estimates is given below. The detailed cost sheets are included in Appendix B.

[redacted]

In the event that a Type B container is required then an increase in design cost of at least [redacted] should be allowed for.

## 5.2. Planning

A high-level Gantt chart of the RPV transport programme has been developed, and is included in Appendix C. As with the estimate, the programme starts with the commencement of engineering design, i.e. the pre-design and data gathering and analysis is not included. Durations have been estimated from experience with similar projects and are believed to be realistic.

# 6. REFERENCES

Reference 1 Sunman CRJ, et al. *Options for transportation of decommissioned submarine reactors.* March 2004. BNFL Environmental Services.

Reference 2 *Reactor pressure vessel - transport and disposal technical feasibility.* 000019419. June 2010. Devonport Royal Dockyard Ltd. RESTRICTED.

Reference 3 *Regulations for the Safe Transport of Radioactive Material*. TS-R-1, 2009 edition. International Atomic Energy Agency.

Reference 4 *Design of Transport Packaging for Radioactive Material*. TCSC 1042, December 2002. Transport Container Standardisation Committee.

Reference 5 *ISO metric screw threads - Part 2: Specification for selected limits of size*. BS 3643-2:2007. British Standards Institution.

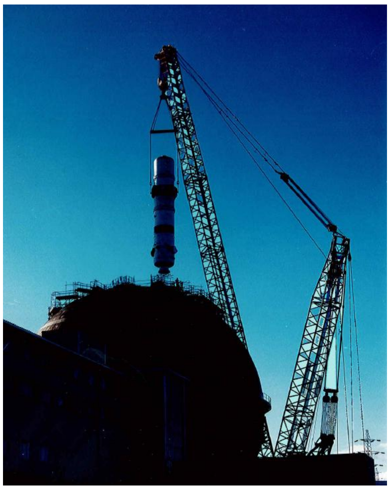
Reference 6 *Rules for the design of cranes – Part 1*. BS 2573:1983. British Standards Institution.

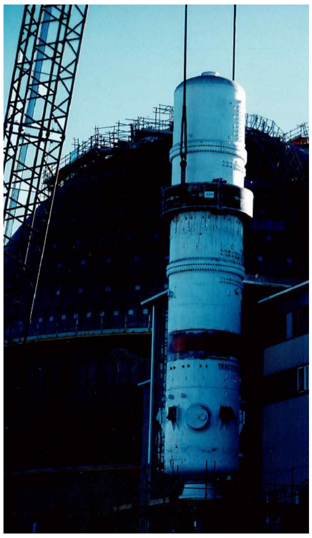
Reference 7 *Guide to design considerations on the strength of screw threads*. BS 3580:1964, confirmed 1985. British Standards Institution.

# A Annex A: EXAMPLES OF RPV TRANSPORT OPERATIONS

## A.1 WAGR Heat Exchangers

In terms of loading and potential hazard, probably the most similar operation to RPV removal carried out in the UK is when the WAGR Heat Exchangers were removed. The Heat Exchangers were 21 m long, 3.4 m diameter, and each weighed 190 te. The operation was carried out towards the end of 1995. Prior to removal, the Heat Exchangers had been lifted from their original positions and holes cut in the outer containment sphere. Other preparatory work included the protection of kerbs and grass verges along the route, many covered with hardcore, compacted and plated and some signposts and lamp standards were also removed and later replaced. Using two of the largest cranes in Europe in a tandem lift, each heat exchanger was lifted clear of the reactor hall and placed on a special road transporter. Each Heat Exchanger was taken 2-3 miles through a number of villages to the Low-Level Waste Repository at Drigg.





## A.2 Rheinsberg

Rheinsburg was a PWR type WWER-70 constructed in what used to be East Germany. The reactor was shut down, and a key decommissioning milestone achieved in 2007 when the RPV was removed and transported to the Interim Storage North (ISN) store at Greifswald NPP.

The reactor was rated at 70 MW(e) and 265 MW(t). The RPV is 11.162 m long with a maximum diameter of 3.275 m. For transport it was placed inside engineered shielding which enclosed the sides and base of the vessel. The weights are: RPV, 109 te; shielding 60 te; gross weight 169 te. The shielding thickness of up to 120 mm limited the maximum dose rate to 24 μSv/h at 2 m.

The vessel was lifted from its operating position and laid on its side: the photographs seem to imply that some sort of bogie on rails was used for this. The shielding was slid into position and the assembly loaded onto a road vehicle for transport to the rail-head. The journey to the ISN was completed by rail, with another short road trip to the vault.

[redacted]




[redacted]



### A.3 La Crosse Boiling Water Reactor – LACBWR

La Crosse, Wisconsin was a 50 MW(e) Boiling Water Reactor (LACBWR). It was built in 1967 and shutdown in 1987 because the small size of the plant made it no longer economically viable.

A key decommissioning activity occurred in 2007 when the plant operator, Dairyland, contracted with Energy Solutions to facilitate the removal and disposal of LACBWR's RPV and other low-level, non-fuel waste to Chem-Nuclear's low-level waste disposal facility at Barnwell in South Carolina.

It is clear that the RPV was shipped in a shielding jacket and required both road and rail transport; though unlike Reinsburg the jacket enclosed the entire vessel. The shipment weighed approximately 285 te and required a specially designed rail car.

The following photographs give a good appreciation of the removal and shipment processes.


Removal of the Reactor Pressure Vessel (RPV) from the reactor building

Set down of the RPV in the lower half of transportation canister


Placement of the upper half of transportation canister

[redacted]




Downending of RPV transportation package for transfer

Transfer of the RPV transportation package to the rail siding


Transfer of RPV transportation package from the heavy hauler to the rail cars


RPV transportation package in-transit

Final placement of RPV transportation package in disposal trench

## A.4 Connecticut Yankee

Located in Haddam Neck, Connecticut the 590 MW(e) Connecticut Yankee began commercial operation in 1968 and ran for 28 years. The decision to close it was taken in 1996. After two years of planning and preparation, actual decommissioning began in 1998 and was completed in 2007.

The RPV was removed, loaded into a containment vessel and shipped to Barnwell, South Carolina by road and barge.

## A.5 Yankee Rowe

Yankee Rowe, Massachusetts was a 167 MW(e) PWR that was shut down in 1991 after 30 years service.

The RPV was removed from containment in November 1996 and placed in a specially designed, NRC-approved shipping container. The reactor vessel was stored in the container on-site until April 1997 when it was shipped to a low-level waste disposal facility in Barnwell, South Carolina for burial.

The RPV weighs 150 te and is approximately 8.235 m long and 3.66 m maximum diameter and with 200 mm wall thickness. The steel container weighs 82 te and is 8.54 m long and 3.965 m in diameter; its wall thickness is 75 mm.

Prior to the removal, the container was moved into an upright position underneath the containment sphere. The opening of the shipping container was matched to the opening of the equipment hatch on the underside of the containment sphere. About 73 te of concrete was injected into the RPV and the spaces between the vessel and its shipping container: the container lid was then permanently welded in position. The package, which weighed 330 tons including 18 te of wire rope tie-down equipment, was the last large component removed from the plant as part of decommissioning.

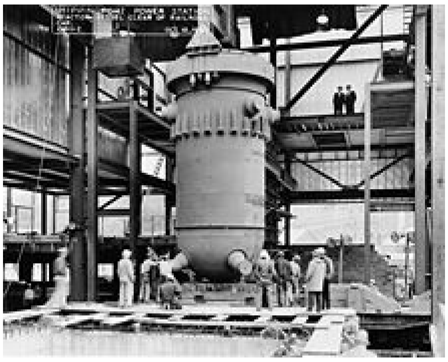
The 1100 mile journey to Barnwell was carried out by road and rail. The rail wagon, leased from TransAlta Utilities Corporation of Alberta, Canada, was chosen because it was designed to transport large, heavy loads and has the ability to shift the load from side to side to clear obstacles.

[redacted]



## A.6 Shippingport NPP

The Shippingport NPP in western Pennsylvania is the first nuclear power station to be decommissioned with the goal of restoring the site to a radiologically clean condition that is acceptable for unrestricted use. It was an experimental, light water moderated thermal breeder reactor notable for its ability to transmute $^{232}Th$ to $^{233}U$. The reactor had an output of 60 MW(e) and operated from 1957 until 1982.



In 1988 the 870 te RPV/NST assembly was lifted out of the containment building and loaded onto road transport equipment for subsequent removal from the site and shipment to a burial facility in Washington State. (Note: the accompanying photograph was taken during construction.)

# B Annex B: COSTING SHEETS

| | | Man-days | £/day | £ |
|---|---|---|---|---|
| **1.000** | **DESIGN + LICENSING** | | | |
| 1.100 | **PACKAGING** | | | |
| 1.101 | ***Engineering drawings***: Design layouts showing main features plus key dimensions | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.102 | ***Hand calculations***: For scoping lifting assessments, tie-downs etc., includes checking. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.103 | ***Shielding calculations***: Uses the predicted/measured values of Bq/cm2 to determine the dose rate 3 m from the unshielded RPV and then to determine the wall thickness of the packaging and predict the external dose rate. Assume the use of Monte-Carlo analysis by an external contractor. | | | |
| | Contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.104 | ***FE modelling***: To demonstrate drop-test survivability and confirm the worst-case impact orientation. Cost is based on previous experience modelling a relatively simple package and assumes the use of a specialist contractor. The engineer prepares the spec for the work and monitors its execution. | | | |
| | Contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.105 | ***FE modelling***: For other structural members, to support hand calculations, e.g. for package lifting points and tie-downs. | | | |
| | Contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.106 | ***Engineering drawings***: Manufacturing drawings. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.107 | ***Engineering drawings***: Operations and tie-down system. Drawings show the conditions of the package during loading and closure, including the orientations as it is rotated from vertical to horizontal. Also the way the package is secured for transport, specifying the tie-down system. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.108 | ***Engineering drawings***: Scale model for drop-testing, assume 1/3 scale. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |

| | | Man-days | £/day | £ |
|---|---|---|---|---|
| **1.000** | **DESIGN + LICENSING** | | | |
| 1.109 | ***Drop test***: Budget price obtained from Vinci Construction UK Technology Centre. Engineer writes test procedure and witnesses it. | | | |
| | Contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.110 | ***Documentation***: Design Safety Report - this is the document that forms the basis for the application for IP-2 approval. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.111 | ***Documentation***: Documentation supporting the DSR - operating and handling instructions, maintenance instructions, model scaling justification, calculation package, assembling FE reports, test reports. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.112 | ***Management***: Overall project management, but including correspondence and meetings with regulatory bodies and other stakeholders. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for Package Design and Licensing** | | | [redacted] |
| | | | | |
| 1.200 | **RPV LIFTING EQUIPMENT** | | | |
| 1.201 | ***Engineering drawings***: Design layouts showing main features plus key dimensions. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.202 | ***Hand calculations***: Scopes the design enabling the load-path to be sized. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.203 | ***FE modelling***: Confirms the approach developed from hand-calculation. | | | |
| | Contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.204 | ***Engineering drawings***: Manufacturing drawings of the lifting system. Includes associated proprietary attachments and proof test arrangements. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.205 | ***Engineering drawings***: Drawings show the lifting arrangement throughout the stages of operations. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.206 | ***Management***: Allowance for project management. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for RPV Lifting Equipment** | | | [redacted] |
| | | | | |
| 1.300 | **PACKAGE TURNING + LIFTING EQUIPMENT** | | | |

| | **1.000 DESIGN + LICENSING** | **Man-days** | **£/day** | **£** |
|---|---|---|---|---|
| 1.301 | ***Engineering drawings***: Design layouts showing the approach to turning and lifting the package. | | | |
| | Engineer | xxxxxx | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.302 | ***Hand calculations***: Scopes the design for the turning frame and lifting equipment. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.303 | ***FE modelling***: Confirms the approach developed from hand-calculation. | | | |
| | Contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.304 | ***Engineering drawings***: Manufacturing drawings of the lifting system. Includes associated proprietary attachments and proof test arrangements. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.305 | ***Engineering drawings***: Drawings show the lifting arrangement throughout the stages of operations. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.306 | ***Management***: Allowance for project management. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for Package Turning + Lifting Equipment** | | | [redacted] |
| 1.400 | **REPLACEMENT HEAD** | | | |
| 1.401 | ***Engineering drawings***: Design layout showing the design intent. Assumed that the Replacement Head will also provide the attachment point for lifting the RPV. Includes an allowance for the engineer to obtain information on the likely strength/brittleness of the RPV structure. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.402 | ***Hand calculations***: Includes an assessment of the likely RPV strength, the behaviour of the Head under combined internal pressure (from temperature changes) and lifting. Pressure vessel code used to confirm high margin of safety. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.403 | ***FE modelling***: Confirms the approach developed from hand-calculation. Analyses the stresses around the Head bolts. | | | |
| | Contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 1.404 | ***Engineering drawings***: Manufacturing drawings. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |

| | | Man-days | £/day | £ |
|---|---|---|---|---|
| **1.000** | **DESIGN + LICENSING** | | | |
| | Designer | [redacted] | [redacted] | [redacted] |
| 1.405 | ***Management***: Allowance for project management. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for Replacement Head** | | | [redacted] |
| | **TOTAL FOR DESIGN + LICENSING** | | | [redacted] |

| | | Man-days | £/day | £ |
|---|---|---|---|---|
| **2.000** | **MANUFACTURE** | | | |
| 2.100 | **PACKAGING - SCALE MODEL** | | | |
| 2.101 | ***Manufacture***: Scale model for drop testing, assumed to be 1/3. Includes a rough-machined billet to simulate the RPV. Gross weight is approx 2800 kg. Care will need to be taken over correct scaling of welds etc., so assume a fabrication cost of [redacted] | | | |
| | Manufacturing | | | [redacted] |
| | Inspection | [redacted] | [redacted] | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 2.102 | ***Management***: Project management | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for Package Model manufacture** | | | [redacted] |
| 2.200 | **PACKAGING - FULL SIZE** | | | |
| 2.201 | ***Manufacture***: One off full size packaging. Gross weight is approx 16 te. Assume a fabrication cost of [redacted] | | | |
| | Manufacturing | | | [redacted] |
| | Inspection | [redacted] | [redacted] | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 2.202 | ***Management***: Project management | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for Full Size Package manufacture** | | | [redacted] |
| 2.300 | **RPV LIFTING EQUIPMENT** | | | |
| 2.301 | ***Procurement***: Proprietary equipment plus manufactured items as necessary. The design is currently not defined so the bought-in costs are a notional sum. | | | |
| | Procurement | | | [redacted] |
| | Inspection | [redacted] | [redacted] | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 2.302 | ***Management***: Project management | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for RPV Lifting Equipment** | | | [redacted] |
| 2.400 | **PACKAGE TURNING + LIFTING EQUIPMENT** | | | |
| 2.401 | ***Procurement***: Proprietary equipment plus manufactured Turning Frame. The design is currently not defined so the procurement costs are a notional sum. The Turning Frame might weigh around 5 te but will be a simple fabrication, so assume a cost of £[redacted]. The lifting equipment also includes any tie-down equipment. | | | |
| | Procurement | | | [redacted] |
| | Inspection | [redacted] | [redacted] | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 2.402 | ***Management***: Project management | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |

| | | Man-days | £/day | £ |
|---|---|---|---|---|
| **2.000** | **MANUFACTURE** | | | |
| | **Total for Package Turning and Lifting Equipment** | | | [redacted] |
| 2.400 | **REPLACEMENT HEAD** | | | |
| 2.401 | ***Procurement***: The Replacement Head will weigh around 2 te and, although relatively straightforward, will be a high-integrity fabrication; so assume a cost of £[redacted] | | | |
| | Procurement | | | [redacted] |
| | Inspection | [redacted] | [redacted] | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 2.402 | ***Management***: Project management | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for Package Turning and Lifting Equipment** | | | [redacted] |
| | **TOTAL FOR MANUFACTURE** | | | [redacted] |

| | | Man-days | £/day | £ |
|---|---|---|---|---|
| **3.000** | **OPERATIONS** | | | |
| 3.100 | **REMOVAL FROM VESSEL + LOADING ONTO TRANSPORT** | | | |
| 3.101 | ***Transfer to dry-dock*** | These activities are covered by another part of the project | | |
| 3.102 | ***Fit new Head***: | | | |
| 3.103 | ***Open vessel hull***: | | | |
| 3.104 | ***RPV removal***: | | | |
| 3.105 | ***Prepare method statements, risk assessments etc.***: Includes writing, reviewing and approvals. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.106 | ***Hire of crane(s)***: Hire 1000 te high-integrity crane for approx [redacted] days. | | | [redacted] |
| 3.107 | ***Operations team:*** Assume a team of four operators, one foreman and one engineer; and that the duration of the activity is four days. This covers one day for site preparations, one for the lift out of the sub and into the container, one for fitting the top half of the container and rotating to the horizontal, and one for any subsequent tidying away. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Foreman | [redacted] | [redacted] | [redacted] |
| | Operators | [redacted] | [redacted] | [redacted] |
| 3.108 | ***Management***: Allowance for planning, attending meetings and cost control | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for Removal from vessel and loading onto transport** | | | [redacted] |
| 3.200 | **ROAD TRANSPORT** | | | |
| 3.201 | ***Hire of vehicle***: Budget price from King Heavy Haulage | | | [redacted] |
| 3.202 | ***Transport assessments***: Should be at least partly included in the vehicle hire, but assume an additional allowance for general liaison is made. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.203 | ***Liaison with police, LAs, DfT etc***: General allowance. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.204 | ***Ops + support team***: Assuming that the duration of the journey is 3 days and that there is a vehicle escort with one engineer and a foreman grade at all times. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Foreman | [redacted] | [redacted] | [redacted] |
| 3.205 | ***Management***: Allowance for planning, attending meetings and cost control. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for road transport** | | | [redacted] |
| 3.300 | **RAIL TRANSPORT** | | | |

| **3.000** | **OPERATIONS** | **Man-days** | **£/day** | **£** |
|---|---|---|---|---|
| 3.301 | ***Hire of wagon***: Provisional sum - awaiting confirmation from DRS | | | [redacted] |
| 3.302 | ***Hire of train***: Approximate cost received from Network Rail. Awaiting confirmation from DRS. | | | [redacted] |
| 3.303 | ***Transport assessments***: Should be at least partly included in the vehicle hire, but assume an additional allowance for general liaison is made. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.304 | ***Liaison with Network Rail, LAs, DfT etc***: General allowance | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.305 | ***Road transport to and from the rail heads***. An allowance for road travel over a short distance, probably within a secure site. | | | [redacted] |
| 3.306 | ***Ops + support team***: The duration of the journey could be several days, but minimal support is required during that time. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.307 | ***Management***: Allowance for planning, attending meetings and cost control. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for rail transport** | | | [redacted] |
| | | | | |
| 3.400 | **SEA TRANSPORT** | | | |
| 3.401 | ***Hire of vessel:*** Budget price from Henry Abrams [redacted] for 2-day voyage plus [redacted] demurrage. Assume additional 2 days delay. | | | [redacted] |
| 3.402 | ***Transport assessments***: Carried out by sub-contractor. Assume an additional allowance for general liaison. | | | |
| | Sub-contractor | | | [redacted] |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.403 | ***Liaison with Coast Guard etc***: General allowance | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.404 | ***Road transport to and from the dock***. An allowance for road travel over a short distance, probably within a secure site. | | | [redacted] |
| 3.405 | ***Ops + support team***: The duration of the journey could be several days, but minimal support is required during that time. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| 3.406 | ***Management***: Allowance for planning, attending meetings and cost control. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | **Total for sea transport** | | | [redacted] |
| | | | | |
| 3.500 | **OFF-LOADING AT STORAGE SITE** | | | |
| 3.501 | ***Hire of crane(s)***: Budget price from Ainscough. One day only at [redacted] | | | [redacted] |

| | | Man-days | £/day | £ |
|---|---|---|---|---|
| **3.000** | **OPERATIONS** | | | |
| 3.502 | ***Hire of road vehicle (rail or sea only)***: This assumes that a short journey is required between the rail/sea unload point into the facility. It is also assumed that the facility has sufficient crane capacity not to require the mobile crane again. | | | [redacted] |
| 3.503 | ***Operations team:*** Assume a team of four operators, one foreman and one engineer; and that the duration of the activity is three days. This covers one day for site preparations, one for the lift and one for any subsequent tidying away. | | | |
| | Engineer | [redacted] | [redacted] | [redacted] |
| | Foreman | [redacted] | [redacted] | [redacted] |
| | Operators | [redacted] | [redacted] | [redacted] |
| | **Total for off-loading** | | | [redacted] |
| | **TOTAL FOR ROAD TRANSPORT** | | | [redacted] |
| | **TOTAL FOR RAIL TRANSPORT** | | | [redacted] |
| | **TOTAL FOR SEA TRANSPORT** | | | [redacted] |

# C Annex C: PROJECT PROGRAMME

[redacted]