000015104

CALCULATIONS

SUBMARINE DISPOSAL OPTIONS - NORMAL DOSE ASSESSMENT CALCULATIONS

SUBMARINE DISPOSAL / TAF 005

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This document has been released as background information to support the Submarine Dismantling Consultation (28 Oct 2011 – 17 Feb 2012). It has been redacted in order to protect:

- **personal information; and**
- **information that could compromise UK Defence or National Security.**

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AMENDMENTS

To assist in identifying the amendments in each revised issue of this document, a vertical line is displayed in the right hand margin opposite new or revised text. Vertical lines marking previous amendments are deleted at each revised issue of the document.

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1.0 EXECUTIVE SUMMARY

The following options are considered viable for submarine dismantling:

- Option 1 – Reactor Compartment (RC) Cut Out and Store.
- Option 2 - RC Cut Up and delayed Reactor Pressure Vessel (RPV) dismantling.
- Option 3 – RC Cut Up and immediate RPV dismantling.

A normal dose assessment has been produced with the aim of generating a 'best estimate' collective dose associated with each submarine dismantling option. Key aspects of the methodology which ensure a 'best estimate' are detailed below:

- The normal dose assessment is based directly on submarine LOP(R) experience with particular attention being paid to de-planting of the Reactor Compartment (RC) (the most dose intensive activity). For example, the dose estimate for removal of the Steam Generators (SGs) from the RC is based on actual collective doses accrued during similar operations undertaken during LOP(R) and similar packages of work. The actual collective dose is scaled to take account of:
    - The dose rate at time of disposal will be lower.
    - The task duration is reduced, as there is no requirement to safeguard the Nuclear Steam Raising Plant (NSRP) integrity for future operation.
    - As equipment is removed progressively more space will be made available.
- Using actual dose data and scaling accordingly provides a more robust collective dose estimate than a simple occupancy model approach.
- The normal dose assessment examines each boat on an individual basis and considers dose accrual at the time of disposal.
- A representative boat sequence has been used which optimises dose reduction and maintenance requirements. This ensures that a representative cumulative dose profile for all options is provided.

Across the PWR1 fleet, the maximum difference in collective dose between options 1 and 3 for a single submarine is 41 man mSv. On average, the difference in collective dose between option 1 and 3 is only 17 man mSv. At this level of dose accrual it is unlikely that a long lay up period for dose reduction purposes can be justified.

At this level of collective dose accrual it is considered that an ALARP justification could be readily made for Option 2 or 3 when other factors such as cost, environmental sustainability etc. are addressed.

In terms of the through life management plan where the through life dose is a key consideration, the predicted levels of collective dose accrual associated with immediate dismantling are < 1% of collective dose associated with maintaining and operating a Trafalgar Class submarine. Accrual of long term lay up costs can not be justified.

It is considered that compliance with dose rate targets and limits will be readily demonstrated and a supporting ALARP justification made for either option.

2.0 CALCULATION SUMMARY

2.1 Calculation Description

The following options are considered viable for submarine dismantling:

- Option 1 – Reactor Compartment (RC) Cut Out and Store.
- Option 2 - RC Cut Up and delayed Reactor Pressure Vessel (RPV) dismantling.
- Option 3 – RC Cut Up and immediate RPV dismantling.

As part of a formal option selection process it is necessary to consider a number of key attributes i.e. cost, radiation dose uptake, radioactive waste arisings, environmental impact etc.. The purpose of this calculation is to provide a normal dose assessment for each of the proposed options.

The calculation is based on a candidate submarine [redacted]

The calculation has been extended to cover the PWR1 fleet and provide a cumulative collective dose for systematic submarine dismantling.

The estimate has been developed from the collective dose associated with similar tasks undertaken during [redacted] refits and are based upon operational experience gained at Devonport Royal Dockyard (DRD) and Rosyth Royal Dockyard.

This assessment shows a collective dose burden for each of the options as follows:

Table 1: Collective Dose Summary for Dismantling Options

Option	Description	Collective Dose[1] (man mSv)	Cumulative Collective Dose[2] (man mSv)
1	RC Cut Out and Store.	9	201
2	RC Cut Up and delayed RPV dismantling.	47	523
3	RC Cut Up and immediate RPV dismantling.	50	589[3]

1. [redacted].

2. Cumulative collective dose for systematic submarine disposal this includes all PWR1 vessel in accordance with a projected disposal programme.

3. *A variation in the boat sequence where* [redacted] *may reduce the collective dose accrual for Option 3 to 556 man mSv, and the maximum collective dose associated with a single submarine of 32 man mSv.*

It is considered that further collective dose reduction may be achieved by the utilisation of composite shielding materials. Additional shielding combined with standard dose management techniques and introduction of specialist equipment may deliver additional collective dose saving.

It is also anticipated that the actual collective doses will reduce as experience of the disposal process is gained. Operational experience has shown a successive reduction in Refit collective doses as knowledge improves with each project.

The average dose to a radiation worker undertaking immediate submarine dismantling is anticipated to be < 1mSv (based on approximately fifty operators comprising mechanical fitters, electrical fitters, welders, health physics, cleaners, laggers etc.).

In isolation it is not considered unreasonable to assume that the average dose associated with submarine dismantling will be < 1mSv per annum (fifty percent less than the average annual radiation background in the UK of 2.2 mSv). However, it is possible that in conjunction with more dose intensive tasks undertaken on a Dockyard Licensed Devonport site certain key operators may exceed 1mSv.

It is considered unlikely that the additional dose accrual associated with submarine dismantling will result in an increase in the average individual doses to workers on an existing Licensed Site undertaking submarine related work activities.

It is noted that dose statistics for the Devonport site show that < 10% of radiation workers receive greater the 1mSv per annum and over the past twenty years no single worker has exceeded 5mSv. It is not anticipated that SDP will significantly alter or effect these levels.

2.2 Aim

The aim of this calculation is to provide a robust normal dose assessment for the proposed submarine dismantling options. This normal dose assessment will be one of the inputs in to a formal option selection meeting.

2.3 Method

The project team in liaison with health physics developed a listing of proposed work packages. The proposed work package for each submarine disposal option is detailed in Appendix 1.

For each proposed work package a comparison was made to [redacted] operational refit data and a similar activity identified. The associated collective dose was determined and scaled accordingly, see Appendix 2.

Collective doses were scaled to take account of the following:

- Variation in average Low Level Dose Rate (LLDR) between a boat in refit and a submarine undergoing dismantling/ disposal.

- Variation in task durations - additional time is spent during a refit to maintain the integrity of the Nuclear Steam Raising Plant (NSRP) this will not be necessary during submarine dismantling.

- Variation in average LLDR during operations i.e. scheduling the work so that high dose rate items are removed early in the work package.

2.4 Generic Assumptions

The following assumptions are applicable to all options:

- Actual doses for similar tasks undertaken during refits have been used rather than a simple occupancy model where estimates are based on man hours spent in the RC and environmental dose rates.

- The dose assessment is 'best estimate' rather than conservative this is consistent with NII guidance '*for the purposes of ALARP considerations the dose estimates should be based on best estimate values'.*

- The RC environmental dose rates for laid up submarines have been corrected to the time of disposal [Reference 1], see Appendix 3. It is assumed that in service submarines will be disposed of three years post shutdown.

2.5 RC Cut Out and Store Assumptions

The following assumptions have been made:

- The dose estimate does not include any additional activities that may be required to prepare the internals of the RC to satisfy the requirements of the Transport Regulations.

- The dose estimate includes RC preparatory work i.e. drain Primary Shield Tank (PST), removal of neutron test source.

- The dose estimate includes activities associated with preparing the separated RC for transport i.e. welding the RC to the transport barge.

- Maintenance and inspection of the RC during the interim storage period is not considered to contribute significantly to the overall collective dose ~ 1 man mSv per submarine.

- It is assumed that the dose reduction measures utilised during the deferred RPV dismantling are the same as those deployed for immediate dismantling i.e. the facility provided will afford the same degree of shielding, remotely operated equipment etc.. Consequently the collective dose accrued during deferred dismantling is estimated to be < 0.2man mSv this is due to the reduction in dose rate as a result of Co60 decay and an unchanged level of shielding.

- The assessment is comprehensive and includes removal and processing of all components located in the RC.

The detailed collective dose calculations are provided in Reference 2.

A summary of the collective dose associated with the key activities is provided in Appendix 4 and Figure 1.

2.6 RC Cut Up Assumptions

The following assumptions have been made:

- The total collective dose associated with immediate RPV size reduction will be limited to 5 man mSv. This estimate is based on the assumption that size reduction is undertaken ashore. The facility will be designed to meet modern standards and doses to operators are ALARP.

- It is assumed that the dose reduction measures utilised during the deferred RPV dismantling are the same as those deployed for immediate dismantling i.e. the facility provided will afford the same degree of shielding, remotely operated equipment etc.. Consequently the collective dose accrued during deferred dismantling is estimated to be < 0.2man mSv this is primarily due to the reduction in dose rate as a result of Co60 decay.

- Maintenance and inspection of the RPV or packaged Intermediate Level Waste (ILW) during the interim storage period is not considered to contribute significantly to the overall collective dose ~ 1 man mSv per submarine.

- The Low Level Waste processing activity is assumed to be ~ 2man mSv. This estimate is derived from operational collective dose accrual associated with LLW handling in existing facilities on site.

- The dose rate in the RC during PST/RPV removal will be significantly reduced as high dose rate items have been removed. During RPV removal the PST shall remain full initially. When the PST is drained temporary shielding will be installed to ensure that the dose rate associated with the RPV does not unduly influence RC dose rates.

The detailed collective dose calculations are provided in Reference 2.

A summary is provided in Appendix 4.

2.7 Life Time Dose Accrual for Submarine Dismantling Programme

The lifetime dose accrual for each submarine dismantling option has been calculated.

The detailed information is presented in Appendix 5.

The assumptions applicable to all options are as follows:

- The dose estimate for systematic submarine dismantling is based on PWR1 submarines only i.e. 23 PWR1 submarines.
- The Geological Disposal Facility (GDF) is not available until 2040.
- The normal dose uptake associated with transport of ILW packages to GDF is not considered significant.
- One RC is processed per annum post 2040 (Option 1).
- Five RPVs are processed per annum post 2040 (Option 2).
- It is assumed that the interim store can be emptied of packaged ILW to the GDF in one year (Option 3).

The calculations supporting this estimate are given in Reference 2.

2.8 Collective Dose Accrual During a [redacted] Lifecycle

For the purposes of comparison the collective dose accrual associated with [redacted] related activities whilst in service, during maintenance, lay-up and final disposal has been assessed.

The collective dose data have been derived primarily from operational data. Estimated data has been used for the submarine dismantling and Defuel, De-equip and Lay Up (DDLP) collective dose.

Figure 1 illustrates the relative dose accrual associated with submarine related activities.

Early submarine dismantling, represents ~1% of the overall collective dose accrual associated with maintaining and operating [redacted]

3.0 CONCLUSIONS

Across the PWR1 fleet, the maximum difference in collective dose between options 1 and 3 for a single submarine is 41 man mSv.

The collective dose for Option 3 ranges between 17 man mSv and 50manmSv. On average, the difference in collective dose between option 1 and 3 is only 17 man mSv per submarine. It is unlikely that long lay up periods for dose reduction purposes can be justified when comparing the relatively low does against the lay up costs.

At this level of collective dose accrual it is considered that an ALARP justification could be readily made for Option 2 or 3 when other factors such as cost, environmental sustainability etc. are addressed.

In terms of the MoDs through life management plan where the through life collective dose is a key consideration, the predicted levels of collective dose accrual associated with immediate dismantling are < 1% of collective dose associated with maintaining and operating a [redacted].

It is considered unlikely that the additional dose accrual associated with submarine dismantling will result in an increase in the average individual doses to workers on an existing Licensed Site undertaking submarine related work activities.

It is noted that dose statistics for the Devonport site show that < 10% of radiation workers receive greater the 1mSv per annum and over the past twenty years no single worker has exceeded 5mSv. It is not anticipated that SDP will significantly alter or effect these levels.

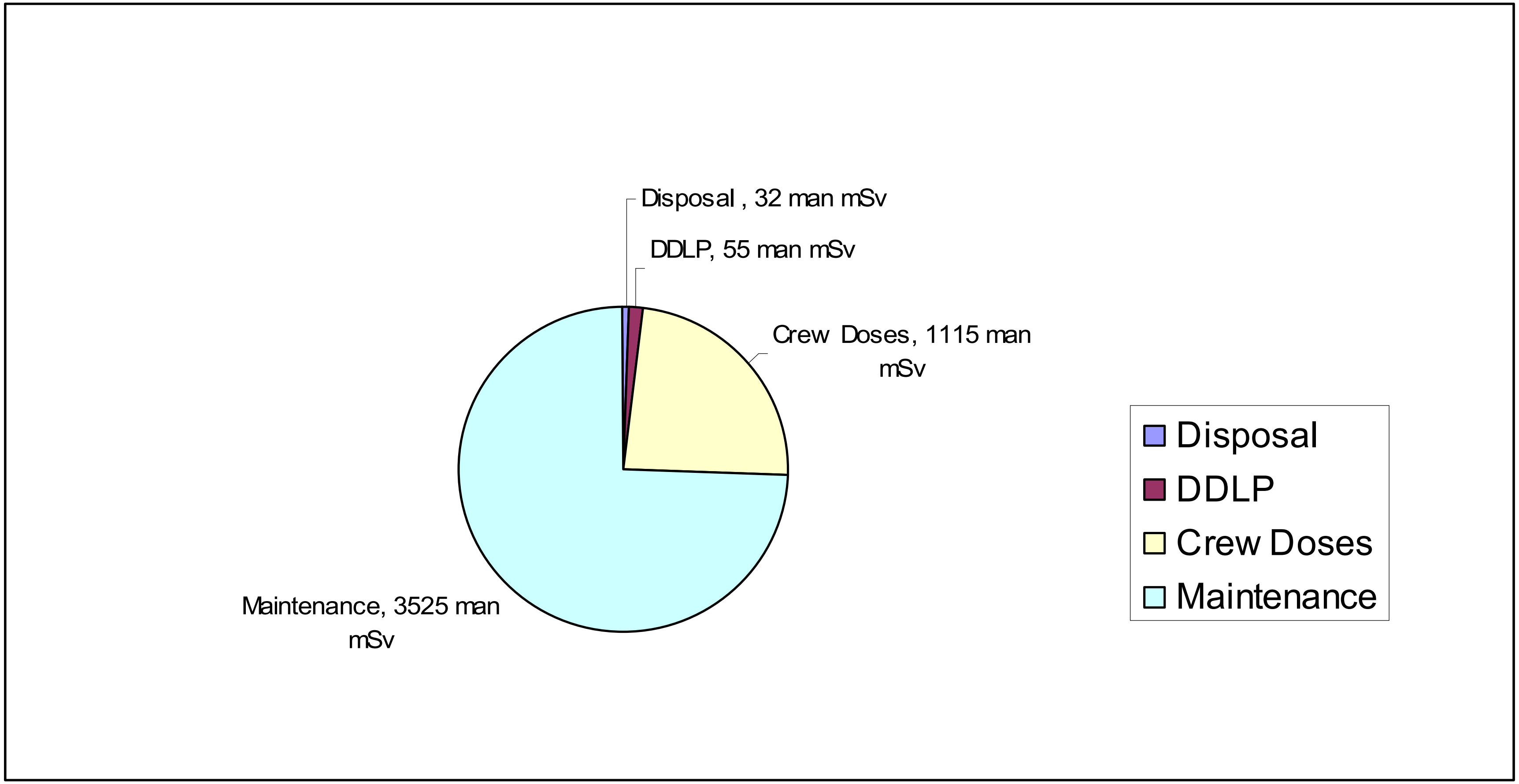
Compliance with dose rate targets and limits will be readily demonstrated and a supporting ALARP justification made for either option.

4.0 REFERENCES

1. 000015136, Issue 1.0, November 2009, Submarine Disposal Options, Estimated Dose Rates. Excel Spreadsheet.
2. 000015150, Issue 1.0, November 2009, Submarine Disposal Options, Normal Dose Assessment Calculations. Excel Spreadsheet.
3. RRMP33348, Version 1.0, November 2008, Naval Nuclear Propulsion Plant (NNPP) Radiological Review for 2007.

4. KRB-A: Dismantling Operations and Related Techniques, Dismantling of the Reactor Pressure Vessel

Figure 1 Collective Dose Accrual (man mSv) During a [redacted] Lifecycle



5.0 APPENDIX 1

5.1 Submarine Dismantling Option Work Activities

The table below lists work activities related to submarine dismantling. Against each submarine dismantling option the applicability of the work item has been identified by '✓'.

Table 1: Submarine Dismantling Work Activity Breakdown

Process step	Work Item	Option 1	Option 2	Option 3
RC Cut Out Preparatory Activities	Weld on canning plates to RC	✓		
	Remove Paint	✓		
	Weld Support Brackets	✓		
	NDT	✓		
	Weld Repairs	✓		
	Preparation for transport	✓		
	Weld to barge	✓		
	NDT and weld repairs	✓		
	Additional activity - drain PST	✓		
Remove internal WIW of hull cut & remove systems from Tunnel	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
Remove radiologically implicated systems from Non RC/RSC areas	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
Create shipping routes	Create Pressure hull cuts for shipping routes	✓	✓	✓
	Create internal structural cuts for shipping routes	✓	✓	✓
	Remove Structure of Tunnel	✓	✓	✓
WiW + Lagging	Remove lagging	✓	✓	✓
	Remove Pipe work WiW including deck grate	✓	✓	✓
	[redacted]	✓	✓	✓

Process step	Work Item	Option 1	Option 2	Option 3
Remove SGs from RC	Clear WiW SGs	✓	✓	✓
	Separate and remove SG pipe work	✓	✓	✓
	Remove SG's	✓	✓	✓
Remove MCP, Pressuriser + Associated pipe work	Cut MCP toroids	✓	✓	✓
	Remove MCPs from RC	✓	✓	✓
	Remove Pressuriser from RC	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	Remove remaining Primary Pipework	✓	✓	✓
Remove Non Dose items (assume left to last)	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
	[redacted]	✓	✓	✓
Remove non active/Low dose Components	Remove RC drain systems	✓	✓	✓
	Remove RC drain tank	✓	✓	✓
	Remove ATUs & Recirculation fans	✓	✓	✓
	Remove Ventilation Trunking etc	✓	✓	✓
Remove RPV Head, Detectors etc	Remove RPV Head (if fitted)	✓	✓	✓
	Remove Detectors	✓	✓	✓
Process and Remove RPV & PST	Fit RPV Blanking plate/lift plate	✓	✓	✓
	Remove PST /Nozzle retaining plates	✓	✓	✓
	Cut RPV nozzle/Primary circuit connections	✓	✓	✓
	Fit Nozzle blanking plates	✓	✓	✓
	[redacted]	✓	✓	✓
	Remove RPV from PST/Compartment	✓	✓	✓
	Remove potassium chromate solution from PST	✓	✓	✓
	Flush PST	✓	✓	✓
	De humidify PST	✓	✓	✓
	Remove inner pocket of PST	✓	✓	✓
	Remove remainder of PST	✓	✓	✓
Workshop based size reduction	Move shielded RPV shipping container to W/S	✓	✓	✓
	Discharge and cut RPV/internal furniture into rings	✓	✓	✓
	Perform secondary size reduction of RPV/Furniture	✓	✓	✓
	Load Cut sections into 3M boxes	✓	✓	✓
	Move 3M boxes to holding area	✓	✓	✓
	Load 3M boxes into overpack and dispatch off site	✓	✓	✓
	Perform cutting equipment maintenance	✓	✓	✓

Process step	Work Item	Option 1	Option 2	Option 3
	activities			
	Perform fault recovery	✓	✓	✓
	Dispatch RPV shipping container to vessel	✓	✓	✓
	Receive RPV shipping container loaded with PST inner sleeve	✓	✓	✓
	Discharge [redacted] size reduce (horizontal)	✓	✓	✓
	Size reduce [redacted] and separate ILW	✓	✓	✓
	Load ILW into 3M box	✓	✓	✓
	Move 3M boxes to holding area	✓	✓	✓
	Load 3M boxes into overpack and dispatch off site	✓	✓	✓
	Perform cutting equipment maintenance activities	✓	✓	✓
	Perform fault recovery	✓	✓	✓
	Perform RPV shipping container maintenance at end of campaign	✓	✓	✓
	Perform W/S decontamination and package secondary wastes	✓	✓	✓
	Size reduce Primary circuit components for packaging	✓	✓	✓
	Package Primary circuit components	✓	✓	✓
	Ship primary circuit components for processing	✓	✓	✓
	Receive processing waste return	✓	✓	✓
	Dispatch waste return to LLWR	✓	✓	✓
	Additional Task - LLW Processing by Waste Treatment Subcontractor	✓	✓	✓
General RC support and domestics	Fit and maintain temporary shielding	✓	✓	✓
	Erect and maintain staging	✓	✓	✓
	Safety & HP	✓	✓	✓
RC final sealing, clean-up and certification All active components removed	Remove/size reduce Activated FWD bulkhead	✓	✓	✓
	Remove/size reduce activated sections of pressure hull	✓	✓	✓
	Shot blast RC	✓	✓	✓
	Confirm contamination removed	✓	✓	✓
	Replace upper hull insert	✓	✓	✓
	Weld Patch on pressure hull to replace above	✓	✓	✓

6.0 APPENDIX 2

6.1 Estimated Collective Dose

The table below presents the estimated collective dose for Option 3, RC Cut Up and Immediate RPV Dismantling, [redacted]

This assessment results in a collective normal operations dose for Option 3 of 80 manmSv assuming an average LLDR of 35μSv/h on Conqueror at the time of dismantling. However, programming the work packages such that high dose rate items are removed early on in the dismantling sequence will result in significant reductions in average LLDR.

To provide a more realistic estimate that reflects the lowering of RC dose rates as high dose rate components are removed a dose reduction factor has been applied.

Consequently the collective normal operations dose for Option 3 is 50 manmSv.

The detailed collective dose estimate and the effect of the dose reduction factors applied is given in Reference 2.

Table 1: Option 3 - RC Cut Up and Immediate RPV Dismantling, Estimated Collective Dose [redacted]

Work Activity	Process step	Estimated Collective Dose (man μSv)	
		Worst Case	Optimise
Remove internal WIW of hull cut & remove systems from Tunnel	Remove casing	0	0
	Establish containment structure	0	0
	[redacted]	0	0
	[redacted]	63	63
	[redacted]	0	0
	[redacted]	0	0
	[redacted]	0	0
	[redacted]	0	0
	[redacted]	0	0
	[redacted]	0	0
	[redacted]	35	35
Remove radiologically implicated systems from Non RC/RSC areas		0	0
Create shipping routes	Create Pressure hull cuts for shipping routes	195	195
	Create internal structural cuts for shipping routes	285	285
	Remove Structure of Tunnel	2	2
WiW + Lagging	Remove lagging	2516	2516
	Remove Pipe work WiW including deck grate	2886	2886

Work Activity	Process step	Estimated Collective Dose (man µSv)	
		Worst Case	Optimise
	Remove WiW Pressuriser & MCP	784	550
Remove SGs from RC	Clear WiW SGs	1064	1064
	Separate and remove SG pipe work	3233	2260
	Remove SG's	8169	8169
Remove MCP, Pressuriser + Associated pipe work	Cut MCP toroids	1125	787
	[redacted]	4129	2890
	[redacted]	688	482
	[redacted]	391	274
	[redacted]	18642	13050
	Remove remaining Primary Pipework	688	482
Remove Non Dose items (assume left to last)	[redacted]	0	0
	[redacted]	0	0
	[redacted]	0	0
	[redacted]	0	0
	[redacted]	0	0
Remove non active/Low dose Components	Remove RC drain systems	300	0
	Remove RC drain tank	286	0
	Remove ATUs & Recirculation fans	380	0
	Remove Ventilation Trunking etc	45	0
Remove RPV Head, Detectors etc	Remove RPV Head (if fitted)	10914	
	Remove Detectors	3266	
Process and Remove RPV & PST	Fit RPV Blanking plate/lift plate		
	Remove PST /Nozzle retaining plates		
	Cut RPV nozzle/Primary circuit connections		
	Fit Nozzle blanking plates		5000
	Remove source range detectors		
	Remove RPV from PST/Compartment	5000	
	[redacted]		
	Flush PST		
	De humidify PST		
	Remove inner pocket of PST		
	Remove remainder of PST		
Workshop based size reduction	Move shielded RPV shipping container to W/S	5000	5000
	Discharge and cut RPV/internal furniture into rings		
	Perform secondary size reduction of RPV/Furniture		
	Load Cut sections into 3M boxes		
	Move 3M boxes to holding area		
	Load 3M boxes into over pack and dispatch off site		
	Perform cutting equipment maintenance activities		
	Perform fault recovery		
	Dispatch RPV shipping container to vessel		
	Receive RPV shipping container loaded with PST inner sleeve		

Work Activity	Process step	Estimated Collective Dose (man μSv)	
		Worst Case	**Optimise**
	[redacted] (horizontal)		
	[redacted]		
	Load ILW into 3M box		
	Move 3M boxes to holding area		
	Load 3M boxes into over pack and dispatch off site		
	Perform cutting equipment maintenance activities		
	Perform RPV shipping container maintenance at end of campaign		
	Perform W/S decontamination and package secondary wastes		
	Size reduce Primary circuit components for packaging		
	Package Primary circuit components		
	Ship primary circuit components for processing		
	Receive processing waste return		
	Dispatch waste return to LLWR		
	Additional Task - LLW Processing by Waste Treatment Subcontractor		
General RC support and domestics	Fit and maintain temporary shielding	545	200
	Erect and maintain staging	1383	500
	Safety & HP	6519	2000
RC final sealing, clean-up and certification All active components removed	Remove/size reduce Activated FWD bulkhead	0	0
	Remove/size reduce activated sections of pressure hull	0	0
	Shot blast RC	0	0
	Confirm contamination removed	0	0
	Replace upper hull insert	0	0
	Weld Patch on pressure hull to replace above	0	0
Interim ILW Store		1000	1000
	Total (man μSv)	79533	49690
	Total (man mSv)	**80**	**50**

The collective dose estimate for Option 1 and Option 2 are derived from the base data presented above. A detailed analysis is presented in Reference 2.

Additional activities associated with preparing the RC for transport (Option 1) have been identified and the collective dose accrual estimated. This represents < 2 manmSv and has been based on dose rates external to the pressure hull and estimated task durations.

The collective dose associated with deferred RPV dismantling (Option 2) has been scaled to reflect the reduction in dose rate.

7.0 APPENDIX 3

7.1 Decay Corrected Dose Rates

Submarine	Current Status	Current Location	DDLP date	Disposal date[1]	Average LLDR [2] (μSv/h)	Year of Survey	Av LLDR at time of disposal (μSv/h)[3]	Predicted Average LLDR (μSv/h)[4]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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1. A representative boat sequence has been used which balances dose reduction and maintenance requirements. This ensures that a representative cumulative dose profile for all options is provided.
2. The average low level dose rates have been extracted from the standard S3/ 500 Effective Full Power Hours (500 EFPH) surveys.
3. Dose rates have been decay corrected to the data of disposal. The half life of Co60 is assumed to be 5.27 years.
4. It has been shown by theoretical calculation that dose rates on board could be less than background at the time of disposal. However, the calculation is based on an average low level dose rate figure, and as this decreases, dose rates associated with localised hot spots may start to dominate. Consequently, the dose rate is assumed to never drop below 5 μSv/h.
5. The excel spreadsheet is detailed in Reference 1.

8.0 APPENDIX 4

8.1 Option 1 - Reactor Compartment Cut Out - Collective Dose Accrual

Work Activity	Collective Dose (man mSv) - Initial Activities	Collective Dose (man mSv) - Deferred Activities
RC Transport Preparations	1.7	-
Create Shipping Routes		<< 0.1
Work in Way + Remove Lagging	-	1
Remove non active/low dose components	-	<< 0.1
General RC support and domestics	-	0.5
Remove SGs from RC	-	2
Remove MCP, Pressuriser + Associated pipe work	-	2
Remove RPV Head, Detectors etc	-	0.2
Remove Non Dose items (assume left to last)	-	0
Workshop based size reduction	-	0.2
Process and Remove RPV & PST	-	0.2
Remove internal WIW of hull cut & remove systems from Tunnel	0.1	-
Remove radiologically implicated systems from Non RC/RSC areas	-	<<0.1
RC final sealing, clean-up and certification All active components removed	-	<<0.1
Interim ILW Storage	1	-
Total	3	6

A more detailed breakdown is given in Reference 2.

8.2 Option 2 - RC Cut Up and Delayed RPV Dismantling - Collective Dose Accrual

Work Activity	Collective Dose (man mSv) - Initial Activities	Collective Dose (man mSv) - Deferred Activities
RC Transport Preparations	0	
Create Shipping Routes	0.5	
Work in Way + Remove Lagging	6	
Remove non active/low dose components	0.1	
General RC support and domestics	4	
Remove SGs from RC	12	
Remove MCP, Pressuriser + Associated pipe work	15	
Remove RPV Head, Detectors etc	1	
Remove Non Dose items (assume left to last)	0	
Workshop based size reduction	2	0.1
Process and Remove RPV & PST	5	
Remove internal WIW of hull cut & remove systems from Tunnel	0.1	
Remove radiologically implicated systems from Non RC/RSC areas	0	
RC final sealing, clean-up and certification All active components removed	0	
Interim ILW Storage	1	
Total	47	

A more detailed breakdown is given in Reference 2 .

8.3 Option 3 - RC Cut Up and Immediate RPV Dismantling - Collective Dose Accrual

Work Activity	**Collective Dose (man mSv)**
RC Transport Preparations	0
Create Shipping Routes	0.5
Work in Way + Remove Lagging	6
Remove non active/low dose components	0.1
General RC support and domestics	4
Remove SGs from RC	12
Remove MCP, Pressuriser + Associated pipe work	15
Remove RPV Head, Detectors etc	1
Remove Non Dose items (assume left to last)	0
Workshop based size reduction	5
Process and Remove RPV & PST	5
Remove internal WIW of hull cut & remove systems from Tunnel	0.1
Remove radiologically implicated systems from Non RC/RSC areas	0
RC final sealing, clean-up and certification All active components removed	0
Interim ILW Storage	1
Total	50

A more detailed breakdown is given in Reference 2.

8.4 Figure 1 Dose Associated with Key Disposal Activities

Figure 1 illustrates the cumulative collective dose and the dose associated with key activities for each submarine dismantling option. The data presented in section 6.0 has been used as the basis of this assessment.

9.0 APPENDIX 5

9.1 Submarine Fleet Dismantling - Cumulative Collective Dose Accrual

Disposal Date	Boat	LLDR at Time of Disposal (μSv/h)	Cumulative Collective Dose Accrual (man mSv) – Option 1	Cumulative Collective Dose Accrual (man mSv) – Option 2	Cumulative Collective Dose Accrual (man mSv) – Option 3
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Disposal Date	Boat	LLDR at Time of Disposal (μSv/h)	Cumulative Collective Dose Accrual (man mSv) – Option 1	Cumulative Collective Dose Accrual (man mSv) – Option 2	Cumulative Collective Dose Accrual (man mSv) – Option 3
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Notes to Table:

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9.2 Figure 2 Submarine Fleet Dismantling - Cumulative Collective Dose Accrual