Westinghouse

Westinghouse Electric Sweden AB

Halden and Kjeller Decommissioning - Task 4 – Cost Estimation

Author, telephone
Niklas Leveau, +46 (0)21-34 70 23
Jan Nordin, +46 (0)21-440 18 20

Dept
WP

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Abstract

This report presents a cost estimate for the decommissioning of the Halden and Kjeller nuclear research facilities. The cost estimate has been done for the decommissioning programme and its main purpose is to serve as input for the KVU-report made by DNV-GL. The cost is calculated for three decommissioning strategies, three different end states and three different waste management options. In total 18 for Halden and 19 for Kjeller different cost scenarios are calculated. The cost estimate will cover the whole decommissioning project from shutdown of normal operation to hand-over of the site for the chosen end state. Due to insufficient inventory data describing the sites, information from previous studies have been used to some extent, modified to the present conditions. The results are presented in a WBS structure and the internationally accepted ISDC structure.

The results show that the lowest costs are achieved for the immediate dismantling strategy, and the highest costs are for the entombment strategy. The base estimate for all the different alternatives ranges from 1 273 to 1 934 (Halden) and 1 200 to 2 373 (Kjeller) MNOK.

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ABBREVIATIONS

IFE	Institutt For Energiteknikk
NOK	Norwegian Currency
NPP	Nuclear Power Plant
NRPA	Norwegian Radiation Protection Authority
RI	Reactor Internals
RPV	Reactor Pressure Vessel
SEK	Swedish Currency
WBS	Work Breakdown Structure

0 SUMMARY

This report presents a cost estimate for the decommissioning of the Halden and Kjeller nuclear research facilities. The cost estimate has been done for the decommissioning programme. The cost is calculated for three decommission strategies (immediate dismantling, deferred dismantling and entombment), three different end states (unrestricted access, light industry, other nuclear activities) and three different waste management options (direct disposal, recycling off-site, recycling on site). In total 18 for Halden and 19 for Kjeller different cost scenarios are calculated. The cost estimate will cover the whole decommissioning project from shutdown of normal operation to hand-over of the site for the chosen end state. Due to insufficient inventory data describing the sites, information from previous studies have been used to some extent, modified to the present conditions. The results are presented in a WBS structure and the internationally accepted ISDC structure.

The results show that the lowest costs are achieved for the immediate dismantling strategy, and the highest costs are for the entombment strategy. The base estimate (WBS estimate + contingency) for all the different alternatives ranges from 1 273 to 1 934 (Halden) and 1 200 to 2 373 (Kjeller) MNOK.

1 INTRODUCTION AND METHOD

1.1 PURPOSE

This report was prepared as a part of the concept choice study (KVU) for future decommissioning of the nuclear facilities in Norway. The KVU is conducted by DNV GL with Studsvik, Westinghouse and Samfunns- og Næringslivsforskning (SNF) commissioned by the Ministry of Industry and the Ministry of Fisheries in Norway (NFD).

The KVU will provide a recommendation on the most optimal socio economic level for decommissioning when the facilities in Halden and Kjeller are shut down in the future. In addition the KVU will provide a recommendation on decommissioning strategies and provide input to the decision about how to allocate the total costs.

The Institute for Energy Technology (IFE) has a license for the operation of Norway's two research reactors at Kjeller and in Halden. It is not decided when or if any decommissioning of the nuclear facilities is to take place.

During previous applications for operating licenses IFE has established decommissioning plans that vary somewhat from this study both in regards to scope – what buildings and areas are included - and the way the level of decommissioning is defined.

The report presents a cost estimate for the decommissioning of the Halden and Kjeller nuclear research facilities. The cost estimate has been done for the decommissioning programme described in [1]. An uncertainty analysis will be performed on the results of this report which will in turn be input to the socio-economic analysis.

1.2 METHOD

The cost estimate will cover the whole decommissioning phase from shutdown of normal operation (including the initial planning that starts 2 years prior to shutdown) to hand-over of a site for the chosen end state. However, it is limited to activities that the site owner is responsible for and that are related to decommissioning and defueling. Consequently, activities during the normal operation period which are primarily aimed at keeping the facilities in the intended state (i.e. activities not associated to the decommissioning) are excluded. In this study it is assumed that Halden and Kjeller facilities can be dismantled immediately after the defueling period. Preparation in the normal operation and the defueling period would be required when the site is prepared for dismantling. The site functions that need to be used during dismantling are maintained.

The costs of activities after the radiological declassification (release of radiological control) of the site, i.e. non-radioactive building demolition (conventional) and restoration of the ground is also included in this study.

The cost estimates are presented both according to the WBS and according to the internationally accepted structure (ISDC) developed jointly between the EC, IAEA and OECD/NEA [2].

1.3 SCOPE AND ASSUMPTIONS

A number of conditions have influence on the decommissioning costs. In addition, a number of assumptions have been made during the estimation of the costs. The conditions and assumptions are as follows:

- All conditions and assumptions in [3] (dismantling techniques) and in [1] (decommissioning program) are also valid for the cost estimation.

- The waste management system will be designed to handle only wastes arising from the Halden and Kjeller sites.

- The waste categories are NC (Not Contaminated), VLL (Very Low Level waste), LL (Low Level waste), LM (Low Medium level waste), LH (Low High level waste) and H (High level waste) [4].

- The waste categories (previous point) are based on gamma emitting nuclides, mainly Co-60.

- Based on the data in the inventory, the predominant part of the total waste is anticipated to be NC waste on arising. A major portion of this waste is accounted for concrete in building structures. The remaining radioactive concrete waste is assumed to be short-lived LL and VLL, although some may be found to be suitable, either on arising or after minimal decontamination, for free release.

- The reactor coolant circuits (primary circuits) will be chemically decontaminated prior to dismantling. The reactor itself and the core are discussed briefly in general terms in [3] and it is included in the cost estimation WBS 4.3.1.

- The anticipated waste inventory requiring processing through the waste management system will be based on the data given from Management of Radioactive and Potentially Radioactive Waste composed by Studsvik Nuclear AB [4].

- The waste will include concrete arising from areas such as the fuel ponds (possibly contaminated following leaks) and the activated parts of the concrete biological shield.

- All waste will be dry; therefore no liquid effluents will be present. The heavy water used as moderator is not considered.

- Some of the waste might undergo some size reduction at the workplace in order to facilitate retrieval and loading into drums or containers.

- Categories of waste will be initially determined at source and will be confirmed during sentencing.

- There will not be any costs for transportation of non-radioactive concrete since it will be used as backfill material in the underground cavities. However at the Kjeller site the non-active waste might exceed the requirements for backfilling, if that is the case extra transports will be necessary but not considered.

- The cost estimates have been based on typical Swedish rates for different staff categories. The base estimate is calculated into year 2013 value and then transferred into NOK.

- Costs have in general been calculated as cash costs at the cost level of 2013. Discounting for costs in the future has not been done.

- The programme of work and the resulting cash flows have been compiled on the basis that cash is available on demand. No attempt has been made to smooth cash flows throughout the project.

- The potential commercial or industrial benefits obtained by future use of the site, equipment or materials and the financial benefits of the decommissioning funds are, in general, not considered.

- No commercial benefits of recycling of materials such as copper or other metals have been considered.

- Suitable contingencies are developed to handle unspecific costs and uncertainties.

- Due to uncomplete inventory data describing the sites, information from previous studies have been used (mainly IFE decommissioning studies), also other relevant reference studies and engineering judgment when needed.

2 BACKGROUND

2.1 PRESENT SITUATION IN NORWAY

IFE has delivered several decommissioning studies with cost and waste volumes estimations to the NRPA. The latest report was made in 2012.

2.2 INTERNATIONAL EXPERIENCE

The decommissioning cost estimates in this report is based on key factors from previous D&D, modernization and power uprate projects and international experience.

3 CONCLUSIONS AND RECOMMENDATIONS

It is very important that funding is available at the time for decommissioning. Since it was a decision made by the Norwegian government to start up these reactors with its nuclear programmes it might be the case that they will have to contribute to a large extent. This is also in coherence with international praxis that the government pay for the remnants of their old nuclear programmes.

The decommission organization is important to establish at an early phase. Workers from the sites with key expertise of the site and the site history are important to involve directly in the organization. The division of responsibility and work needs to be clearly defined. In the report it is assumed that the owner will still be in charge of the site and have the overall responsibility but all major decommissioning work will be executed as projects with separate project management and administration for each project.

The base estimation in this report includes several high contingencies due to several uncertainties in the inventory. A number of the cost items in the WBS estimation are based on other studies and their inventories, adjusted to the circumstances at Halden and Kjeller or by using engineering judgement.

After summarizing all the base estimations it becomes clear that the immediate dismantling (with the present conditions and best known prognosis of the future) is the most financially sound strategy. A summary of all the base estimates for the Halden and Kjeller sites are presented in Table 1.

Table 1: The base estimations for the Halden and Kjeller sites in kNOK.

Alternative	Appendix	Halden	Appendix	Kjeller
1Aa	3	1 402 576	39	1 412 661
1Ab	4	1 357 081	40	1 377 570
1Ac	5	1 428 211	41	1 415 340
1Ba	6	1 377 083	42	1 392 877
1Bb	7	1 331 587	43	1 357 785
1Bc	8	1 385 256	44	1 395 555
1Ca	9	1 273 001	45	1 235 221
1Cb	10	1 227 505	46	1 200 130
1Cc	11	1 298 636	47	1 237 899
2Aa	12	1 908 774	48	1 918 859
2Ab	13	1 863 279	49	1 883 767
2Ac	14	1 934 409	50	1 921 537
2Ba	15	1 883 280	51	1 899 074
2Bb	16	1 837 785	52	1 863 983
2Bc	17	1 908 915	53	1 901 753
2Ca	18	1 378 404	54	1 340 625
2Cb	19	1 332 909	55	1 305 533
2Cc	20	1 404 040	56	1 343 303
3			57	2 373 996

4 TASK 4 COST ESTIMATION

The cost is calculated for three decommissioning strategies (1, 2 and 3), three different end states (A, B, C) and three different waste management options (a, b, c). The different waste management options are described in detail in section 4.1.11.1 and in [4]. All alternatives are summarized in Table 2. Strategy 1 and 2 combines with end state A, B and C, and waste management options a, b, c to form 18 different combinations. The third (3) strategy is entombment which can be considered as an in-situ decommissioning. Entombment does not involve any different end states or waste management options. The end states have the following meaning:

- Unrestricted use where everything down to one meter below ground is free released and demolished

- Light industry where everything is free released, but the buildings are left standing

- Other nuclear activities where the process equipment is dismantled, but the buildings are left standing without being free released, so there is still radiological activity at the site after the decommissioning. The process equipment needs to be removed so that other nuclear activities can operate unhindered of remnants from previous activities.

Table 2: Summary of the different decommissioning strategies, end states and waste management options.

Decommissioning strategy	End state	Waste management
1. Immediate	A. Un-restricted usage	a. Direct disposal
2. Deferred	B. Industrial	b. Recycling off-site
3. Entombment	C. Other nuclear activity	c. Recycling on-site

4.1 COST ELEMENTS

4.1.1 General

The main cost elements in the WBS cost matrix are explained in more detail in the following subsections.

The utility costs presented in [4], [6] and [7] as well as the staff number in the project organization are based on experience from Barsebäck NPP unit 1.

Cost figures calculated in this study are presented both without (WBS estimate) and with associated contingency factors (base estimate). Thus, in a further analysis it is possible to apply different contingencies depending on the particular case that is being studied. There is otherwise a risk that factors are applied on each other in several steps, reflecting an unjustified level of risk. Suitable contingencies are however submitted in the base estimation. Estimated (i.e. not calculated) WBS items, in particular figures based on experience, naturally include lower contingencies.

4.1.2 Personnel Rates

Each category of labour is classified, in a typical Swedish rate for each category and the cost-index of 2013, according to the presented values in Table . While the personnel in category M, E and P are employed by the Utility (P as a consultant), the other categories (1-5) are employed by Contractors. The rates for category M and E correspond to wages including payroll tax only while the rate for the other categories should cover all costs, mark-ups and profits associated to the work performed by the personnel employed by the Contractors.

Table 3: Personnel cost rates used in this study in SEK.

Category	Typical kind of labour	Rate (SEK/hr)
M	Utility Manager	700
E	Utility Engineer	350
P	Project Manager	1350
1	Engineer	1050
2	Foreman	800
3	HP Technician	650
4	Craftsman	650
5	Labourer	450

4.1.3 Utility Personnel and Project Costs

The planning for decommissioning, including information gathering and EIA work, starts 2 years before the defueling period. During the 3 years of defueling the planning continues adding up to a total of 5 years. These WBS items comprise 10 positions; 2 planning engineers, 1 EIA engineer, 1 information engineer, 1 project manager, 0.5 documentalist, 0.5 IT engineer, 1 environmental engineer, 1 planner, 1 controller and 1 purchaser. When the defueling starts more preparations are needed and the utility site organization increases to approximately 41 positions, see Table and Table 5. These personnel are adapted to keep the site in a safe and good condition, remove spent fuel and to prepare the site for the decommissioning. In addition to the utility site organization working with issues related to decommissioning, an ordinary operational organization is required during the normal operation period. This organization works with regular maintenance of the site, not related to decommissioning, and is thus not included in the cost estimate, and therefore these personnel is not presented here.

The utility site organization comprises the Lead Project Manager and his/her staff and below a subdivision in two main branches; one including the Project Managers and the other including the operation and executing personnel. The Project subdivision is fully concentrated on preparing the future decommissioning work while the other has a dual role, one to operate and perform maintenance and the other to assist the Project Managers with various technical services. The Site Manager is responsible for the operating personnel and other personnel except the Project Managers, who reports directly to the Lead Project Manager. The organization in this report is adapted according to the organization chart shown in Figure 1 and it is an example of how a real organization could look like. Similar organization charts can be found in [8].

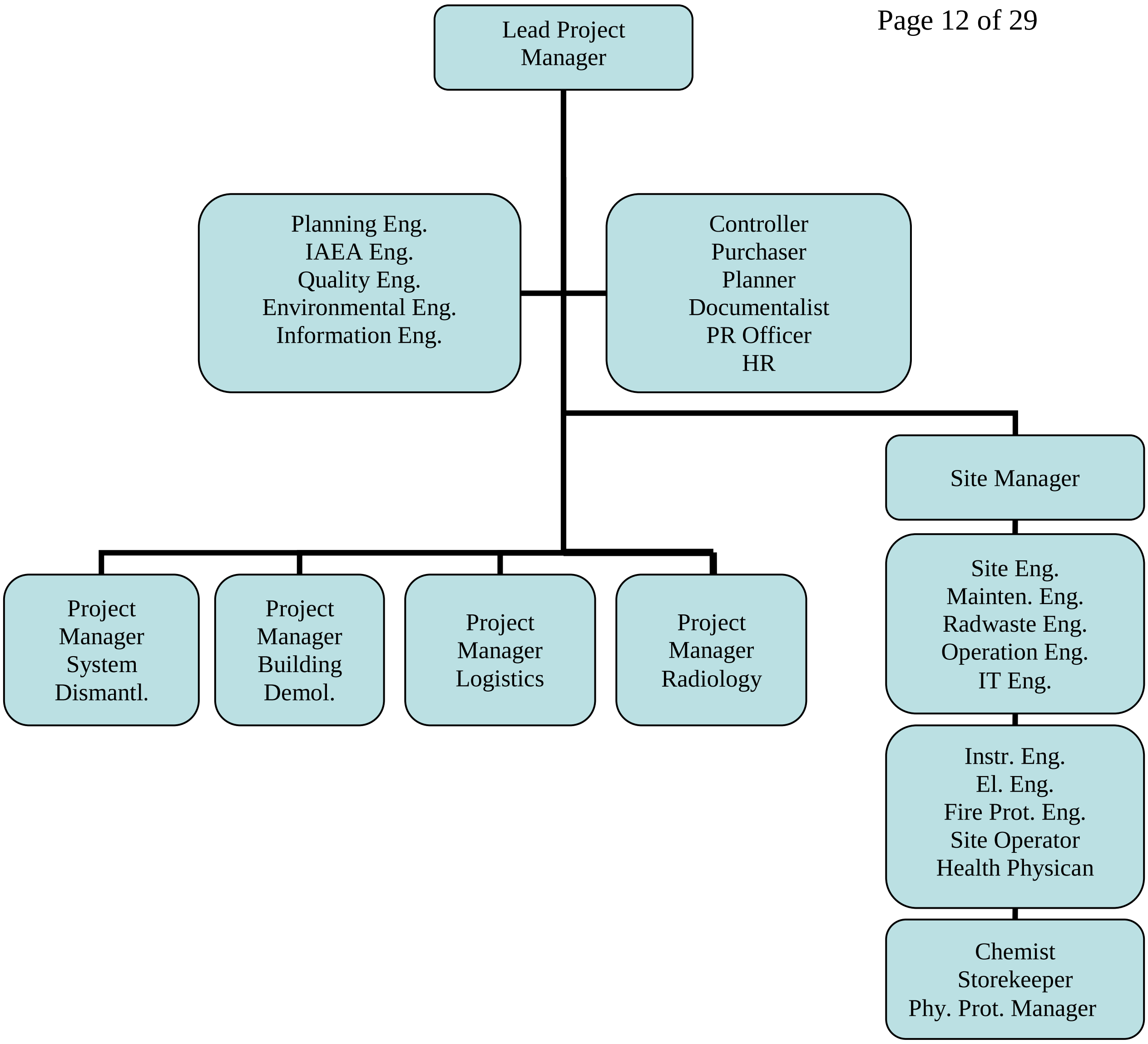

Figure 1: Example of organization chart for decommissioning.

When the defueling period begins after regular operation a larger organization is needed. The utility site organization then increases from 10 to 41 positions. The number of positions decreases during the second period, nuclear dismantling, to about 30 positions. The last period is conventional demolition and it requires a smaller organization than the previously two periods since all the active material has been removed. The amount of positions needed then decreases from 30 down to 13. The number of positions presented in Table and Table 5 are set after considering previously done projects and experience.

Table 4: Organizational Utility Personnel Allocation.

Personnel Category	Time Period			
	Normal Operation	Defueling	Nuclear Dismantl.	Conv. Demol.
Site Manager (M)	0	1	0,5	0,5
Site Operator (E)	0	4	1	1
Site Engineer EIA (E)	1	1	0,5	0
Site Engineer Planning (E)	2	1	1	0,5
Site Engineer Information (E)	1	1	0,5	0
Maintenance Engineer (E)	0	1	1	0,5
Radwaste Engineer (E)	0	0,5	1	0,5
Health Physics (E)	0	1	1	0,5
Chemist (E)	0	1	1	0,5
Storekeeper (E)	0	1	0,5	0
Physical Protection Manager (E)	0	1	0,5	0
Project Manager (P)	1	2	1	1
Instrument Engineer (E)	0	1	0,5	0,3
Electric Engineer (E)	0	1	1	0,3
Fire Protection (E)	0	1	1	0,5
Documentalist (E)	0,5	1	0,5	0,5
IT Engineer (E)	0,5	1	0,5	0,3
Environmental Engineer (E)	1	1	1	0,5
Planner (E)	1	1	0,5	0,5
Quality Engineer (E)	0	1	0,5	0
PR Officer (E)	0	0,5	0,5	0,5
Controller (E)	1	1	0,5	0,3
HR (E)	0	1	0,5	0,5
Purchaser (E)	1	1	0,5	0
Total	**10**	**27**	**17**	**9**

4.1.4 Operational Costs

The operational costs during the normal operation period (WBS 1.1.2) and the defueling period (WBS 2.1.2) are limited to the costs which are classified as decommissioning costs, i.e. decommissioning preparation work [1]. The costs are due to operational utility personnel costs and purchase of goods, services etc. In the present study WBS 1.1.2 is set to zero because it is not considered necessary to begin with purchase of goods, services etc at this early stage.

The operational costs for the dismantling and demolition periods (WBS 4.1.2 and 5.1.2) include utility personnel costs and all purchase of goods, services, energy etc. necessary for the operation and maintenance of the site [6].

The utility personnel that are required for the operation and maintenance, connected to the decommissioning are given in Table 5 [7].

Table 5: Operational Utility Personnel Allocation.

Personnel Category	Normal	Defuel.	Nuclear Dismantling	Conventional Demolition
HP Techicans (E)	0	3	1	0
Quality Engineer (E)	0	1	1	0
Chemist (E)	0	1	1	0
Environmental Engineer (E)	0	1	1	0,5
Physical Protection Guards (E)	0	0	2	0,5
Mechanic (E)	0	1	1	0,5
Electrician (E)	0	1	1	0,5
I&C Technician (E)	0	1	1	0
Cleaner (E)	0	1	1	1
Storage (E)	0	1	1	0
Controller (E)	0	1	1	0,3
Legal and Contracts (E)	0	1	1	0,3
Secretary (E)	0	1	1	0,5
Planning (E)	0	0	1	0
Total	**0**	**14**	**13**	**4**

4.1.5 Fixed Costs

The fixed costs (WBS 4.1.3 and 5.1.3) include other fees, inspection costs, taxes and insurances. The NRPA fee (WBS 3.7, 4.1.3.1, 5.1.3.1 and 6.5) is a fee that is paid annually to the NRPA today by IFE. Taxes are however not included in this study.

4.1.6 Organizational Costs

Organizational costs (WBS 1.1.3, 2.1.3, 4.1.4 and 5.1.4) include costs for administration (personnel administration, legal and contracts, office equipment and supplies) and data processing hardware and software [1], [6].

4.1.7 Project Costs during Defueling

The decommissioning preparation activities are in total 5 years, 2 years will take place in the normal operation period and 3 in the defueling period. What differ preparation activities in the two periods are the three main subprojects during the defueling period. These are the primary circuit decontamination, radiological inventory characterization and the process and auxiliary system adaptation. A number of objects will be decontaminated or conserved and general preparatory activities will take place. In addition, the EIA and the decommissioning planning work will be completed prior to the nuclear dismantling.

4.1.8 Fuel Handling

Besides the preparation activities, all the remaining fuel on site is packed into especially manufactured transport containers ready to be transported to repository or interim storage. The cost for Fuel handling (WBS 2.2.3) is based on the cost developed by IFE for the Halden site [9]. For Kjeller, the Fuel handling is based on the same information. However, the cost item Handling and processing (WBS 2.2.3.4) is adjusted to the properties at Kjeller. The cost for interim storage (WBS 2.2.3.3) is taken from the Interim storage project [10].

4.1.9 Deferred Dismantling

The second strategy, deferred dismantling, includes (cost) activities during the time period prior to dismantling. The WBS items cover supervision, environmental protection and knowledge transfer.

During the delay period, the site needs surveillance and environmental protection. Two guards are set to work on 24-hour shifts (round-the-clock service). The facility surroundings require constant monitoring and measurement to detect emissions of radioactivity. One engineer performs the task on full time. The operation of the site has ceased, however the knowledge about the site needs to be transferred for future requirement and updates against new regulations are necessary. New documentation and site knowledge is 1.5 engineers on full time. Prior to decommissioning, a system adaption is performed and a characterization is made of the site.

The gain of waiting 50 years before decommissioning is basically lower radio activity levels at the site. This will reduce the need for radiation protection and the amounts of high active waste, facilitating the decommissioning as a whole. Since it is difficult to estimate costs for the actual situation after 50 years of deferment same calculations has been used for the WBS items as for immediate dismantling, adding conservatism to the results.

4.1.10 Nuclear Dismantling and Demolition

4.1.10.1 Reactor Vessel and Internals

There are two ways to remove a reactor vessel, either by segmentation or by one-piece removal. In this study both the Halden and the Kjeller reactor will be removed by segmentation. Cost estimation for segmentation of RPV and internals has been done by Westinghouse's experts on the area. The strategy will initially be; remove and segment the reactor internals and then start with the reactor vessel. For the Halden reactor one-piece removal is possible but not evaluated.

4.1.10.2 Process Equipment Apart from Reactor Pressure Vessel and Internals

The amount of work ("man-hours") associated with the dismantling and the following treatment of the waste arising is calculated by means of a number of work procedures. For a certain equipment type, a number of procedures are generally used. For each procedure a "work team" is defined and in addition one or several formulas are developed to calculate the duration necessary for the work team to carry out dismantling, transport etc. The formulas are based on various parameters like number, length, weight or thickness.

The calculated duration is valid (with some exceptions) if the conditions were perfect, i.e. if the amount of work is carried out in workshop environment or similar, with no radioactivity and with ideal temperature, lighting, position etc. In order to take the real working conditions into consideration a factor, denominated Site Factor (SF), is used. The Site Factor is included in the calculation of the duration.

In order to obtain the amount of work, the resulting duration is multiplied with the number of individuals of the work team.

To use the formulas it is necessary to have very detailed information about all components and piping. From the inventory presented in [11], so-called macro-components have been defined. This implies that components, piping etc. have been subdivided into intervals with respect to size and for each interval a characteristic quantity like length or weight is calculated. This way of dealing with data facilitates future revisions of the study.

The work procedures, WP, used in the present study are presented in Table .

Table 6: Work Procedures used in decommissioning.

WP Description
Preparations of work area - radiological areas
Preparations of work area – non-radiological areas
Removal of insulation from pipes and components
Dismantling of intermediate level active pipes >DN50
Dismantling of low level active pipes >DN50
Dismantling of pipes up to and including DN50
Dismantling of valves and actuators
Internal transports of waste
Dismantling and internal transportation of large components and tanks
Dismantling of steel (pipe supports, gratings, ladders, beams etc.)
Dismantling of cables and cable trays etc.
Dismantling of HVAC ducts
Dismantling of HVAC components
Dismantling and transportation of cranes
Dismantling and transportation of cabinets
Dismantling and transportation of electrical components

The Site Factor in the present study is generally set to 2.5 for Halden and 2.2 for Kjeller, i.e. the duration for a certain work at the site is 2.5 respectively 2.2 times longer than if it is carried out under ideal conditions. The Site Factor cannot be 2.5 respectively 2.2 in all areas of the site, hence different Site Factors have been calculated for each area. Examples of these areas are the reactor building and other controlled areas. The Site Factors in this study have been differentiated based on engineering judgements made by individuals with extensive experiences from installation and dismantling work in nuclear power plants.

The calculation of the amount of work for Halden and Kjeller has been carried out separately for each site and area. Quantity values from the inventory are collected from [11]. The work has been summarized for each area and linked to the cost matrix (WBS 4.3.2 and 4.3.3).With the amount of work and the labour cost per hour, see Table , the resulting costs are calculated. In addition the average number of workers in each personnel category during the corresponding duration, which is collected from the time schedule in [1], is calculated.

The project management and administration work within the process dismantling contractor's organization has been collected from [12] and inserted in WBS 4.3.6.1.

The contractor's costs for the procurement and consumption of tools are given in WBS 4.3.6.2. The costs are based on an analysis made in [12] but in the present study the tools are conservatively assumed to have no surplus value.

4.1.11 Waste Handling and Storage

The waste handling and storage costs include the following:

- Waste Management System (WBS 4.4.1)
- Drums and boxes for transport and storage (WBS 4.4.2)
- Transport to repository and recycling (WBS 4.4.3 and 5.4.1)
- Repository and storage fees (WBS 4.4.4)

A majority of all the waste that is treated is process equipment and other steel, only a small part is contaminated concrete. There are three different options for waste treatment (management):

- a, direct disposal
    - All nuclear waste is transported directly, without any further treatment, to interim storage or repository. Some adaptation of the waste system and buildings will be needed for characterization and measurement but the waste management does not need to be excessive.
- b, recycling off-site
    - All nuclear waste is transported off-site for waste reduction and recycling. The remaining waste after off-site treatment is sent to interim storage or repository.

Adaption of the waste system and buildings will be needed for characterization and radiological inventory before transport off-site.

- c, recycling on site
    - All nuclear waste is treated on-site for waste reduction and recycling. The waste management system will be a purpose-built building or a purpose built facility in an existing building i.e. a room or building will be cleared out and specifically re-equipped for waste processing before waste production starts. The remaining waste after treatment is sent to interim storage or repository.

4.1.11.1 Waste Management System

The waste management strategy is that buildings and rooms are emptied and decontaminated of all contaminated wastes, so the remaining structural material of a building plus possibly some equipment, will be surveyed as clean in-situ and never need to go to a waste facility. For all three end states and options the waste facility will be the last building to be decontaminated and dismantled on site.

The costs for the waste management systems are presented in Table 7.

Table 7: Costs for the waste management system for option a, b and c in kNOK.

Option	Halden	Kjeller
a, direct disposal		
Adaption of waste systems and buildnings	20 000	18 100
Waste management	20 101	15 768
Decontamination and dismantling of the Waste Facility	2 252	2 252
b, recycling off-site		
Adaption of waste systems and buildnings	10 000	17 100
Waste management	27 120	21 735
Decontamination and dismantling of the Waste Facility	1 126	2 117
c, recycling on-site		
Adaption of waste systems and buildnings	40 000	22 600
Waste management	22 772	18 305
Decontamination and dismantling of the Waste Facility	4 503	2 815

4.1.11.2 Drums and Boxes for Transport and Storage

The costs and amount of the waste drums and boxes has been calculated for the waste production. In Table 8 the results for both Halden and Kjeller are presented.

Table 8: Cost for drums and boxes for option a, b and c.

Option	Halden	Kjeller
a, direct disposal		
Packaged volume for disposal NC-LL+unknown (m^3)	440	390
Packaged volume for disposal LM-LH (m^3)	470	330
Number of packages NC-LL+unknown	660	410
Number of packages LM-H	240	170
Total number of drum eq	4 340	3 430
Cost of packages (kNOK)	9 180	6 900
b, recycling off-site		
Packaged volume for disposal NC-LL+unknown (m^3)	90	50
Packaged volume for disposal LM-LH (m^3)	470	310
Number of packages NC-LL+unknown	80	70
Number of packages LM-H	240	160
Total number of drum eq	2 710	1 770
Cost of packages (kNOK)	8 070	5 060
c, recycling on-site		
Packaged volume for disposal NC-LL+unknown (m^3)	360	310
Packaged volume for disposal LM-LH (m^3)	470	330
Number of packages NC-LL+unknown	510	400
Number of packages LM-H	240	170
Total number of drum eq	3 970	3 070
Cost of packages (kNOK)	8 930	6 060

4.1.11.3 Transport to Repository and Recycling

The costs for the transport to repository and recycling are presented in Table 9. Option b requires transports from Halden respectively Kjeller to a treatment facility off-site and then back to the repository in Himdalen. Option a and c only require one direct transport to the repository at Himdalen.

Table 9: Cost for the transports to repository and recycling for option a, b and c in kNOK.

Option	Halden	Kjeller
a, direct disposal		
Cost for transports	190	150
b, recycling off-site		
Cost for transports	580	540
c, recycling on-site		
Cost for transports	180	130

4.1.11.4 Repository and Storage Fees

The fees for storage in Himdalen have been estimated in [4] and are presented in Table 10. The cost is dependent on the waste amount and the activity level of the waste.

The cost for interim storage of fuel is presented in [13].

Table 10: Cost for the repository and storage fees for option a, b and c in kNOK.

Option	Halden	Kjeller
a, direct disposal		
Himdalen storage fee	86 880	68 560
b, recycling off-site		
Himdalen storage fee	54 180	35 440
c, recycling on-site		
Himdalen storage fee	79 320	61 300

4.1.12 Conventional Demolition

4.1.12.1 Dismantling and Demolition Activities

The costs for conventional demolition of non-contaminated concrete are presented in WBS 5.3.1 to 5.3.3. After conventional demolition at Kjeller the concrete can be used as backfill in cavities below 1 m underground in for example cellars. In Halden it is not considered necessary to remove any concrete from the reactor hall. Instead all the non-contaminated concrete from surrounding buildings can be positioned in the reactor hall. Calculations have shown that there is plenty of volume in the reactor hall at Halden and in the cellars at Kjeller for the non-contaminated concrete. In this way unnecessary transports can be avoided.

4.1.12.2 Waste Handling and Storage

Cost item WBS 5.4.1 is set to zero. This is because there is not any material that needs to be transported off-site during the conventional demolition. The building material (mainly concrete) is used to fill the basement below 1 meter. The cost for recycling off-site is covered in the WBS section 4.4.3.

4.1.12.3 Site Restoration

When both nuclear dismantling and conventional demolition is finished removal of contaminated soil and ground restoration can start. Ground restoration is not needed if the site will be used for other industry or nuclear purposes.

The cost item removal of contaminated soil (mud) is applicable for the Kjeller site. The mud is considered to be free released but will be removed and transported to a normal waste deposit for storage.

4.1.12.4 Surveillance and Monitoring

The cost item is specifically for end state C when the site is aimed for other nuclear activities. The purpose is to present costs related to other nuclear activities which includes protection, documentation and knowledge transfer.

4.1.13 Entombment

During entombment there will not be decontamination of the buildings where activity has been observed. For the JEEP II reactor at Kjeller the volume will be filled with non-active concrete. The fuel is removed in advance from the site. The site and the buildings aimed for entombment are prepared, that is windows, doors and ventilation are plugged etc. After discussion with IFE and the Ministry of Trade, Industry and Fisheries entombment in Halden is not considered to be a realistic scenario due to the leakage of water from the mountain and is therefore left out of the study. This is discussed further in the KVU under section Mulighetsstudiet.

The basic principle is to fill the buildings with concrete. Prior to that the buildings are prepared and openings and ventilation are plugged with cased plugs made from concrete. The entombed building requires fence and environmental protection and supervision. The building subject considered as a near surface repository after entombment [14].

The constraints with the developed costs are that it may not be practically to perform an entombment in a simple manner. Filling a building with concrete requires likely stabilization of the construction to cope with the force acting on it from the concrete.

4.2 COST ESTIMATION RESULTS

4.2.1 WBS Structure

A summary table of the WBS estimates (the total decommissioning costs) can be seen in Table 11. The detailed WBS for each alternative can be found in Appendix 3 to 20 and 39-57. The detailed WBS is written in SEK with 2013 cost index and the change to NOK is 1.1 SEK per NOK as per 2014-07-04.

Table 11: WBS estimate summary of the alternatives for Halden and Kjeller sites in kNOK.

Alternative	Appendix	Halden	Appendix	Kjeller
1Aa	3	1 108 788	39	1 116 245
1Ab	4	1 071 263	40	1 086 037
1Ac	5	1 125 893	41	1 115 881
1Ba	6	1 087 486	42	1 101 276
1Bb	7	1 049 961	43	1 071 068
1Bc	8	1 385 256	44	1 100 913
1Ca	9	1 116 048	45	1 088 486
1Cb	10	1 078 522	46	1 058 278
1Cc	11	1 133 152	47	1 088 122
2Aa	12	1 571 854	48	1 579 311
2Ab	13	1 534 328	49	1 549 102
2Ac	14	1 588 958	50	1 578 947
2Ba	15	1 550 551	51	1 564 342
2Bb	16	1 513 026	52	1 534 133
2Bc	17	1 567 656	53	1 563 978
2Ca	18	1 216 404	54	1 188 843
2Cb	19	1 178 879	55	1 158 634
2Cc	20	1 233 508	56	1 188 479
3			57	1 858 294

4.2.2 ISDC Structure

For establishing the ISDC structure reference [2] has been used. The results in ISDC structure can be viewed in Appendix 21 to 38 (Halden) and Appendix 58 to 76 (Kjeller).

4.2.3 Cost per year

An example of annual cost is shown in Figure 2 presenting the annual variation during the whole decommissioning. The results are for alternative Halden 1Ab.

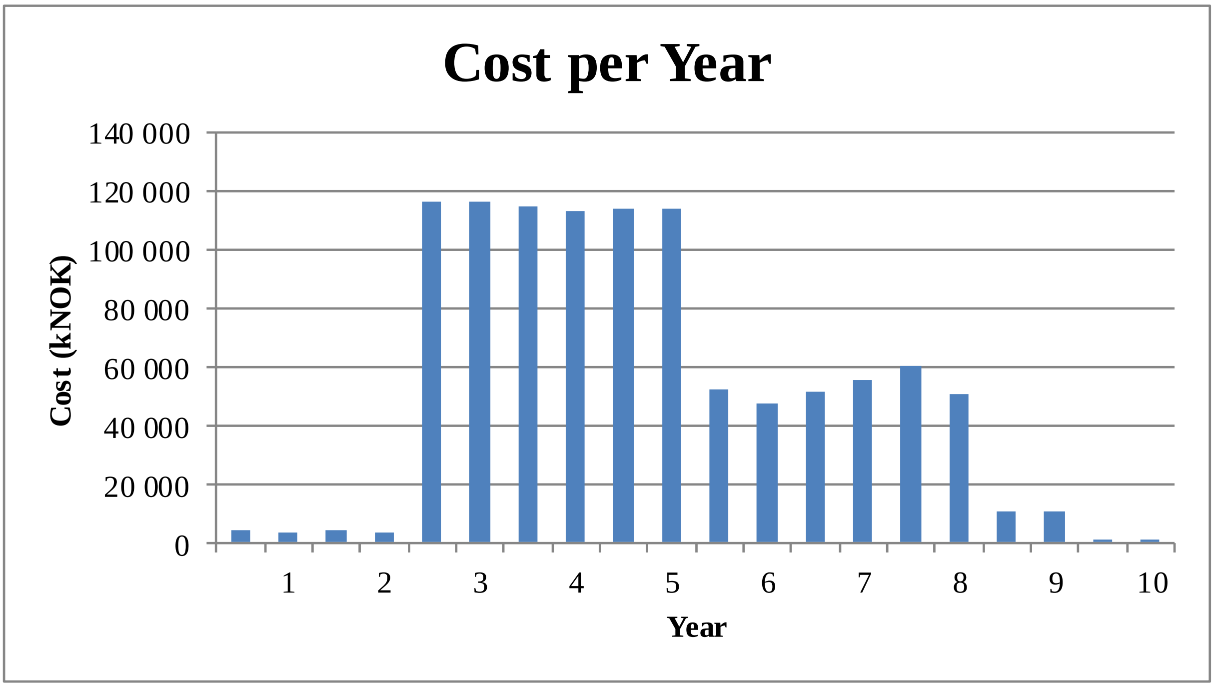

Figure 2: Cost per year for Halden 1Ab in kNOK.

4.2.4 Contingency

This section contains an estimate of the project contingency. Contingency costs are for unforeseen, uncertain and unpredictable conditions typically encountered in decommissioning (unspecified cost and uncertainty estimate). The contingency can be as a general value (percentage) to all cost items or as a general percentage of the total cost or as individual percentages for each cost category. The latter case is used in this study.

In general, all unspecified costs are spent as the project progresses, as these unforeseen events occur throughout the project.There are of two basic types of unspecified costs in the WBS:

- Unspecified costs related to material and equipment inventory

- Unspecified costs related to the specific activities (resources, technique etc.)

The following are some of the reasons for additional unspecified costs:

- Decontamination campaigns are difficult to estimate and the amount of work tends to increase i.e. the number of flushes increases.
- The adaption of process systems, both preparing for decommissioning and the re-construction of present systems needed for decommissioning, are difficult to estimate.

- The handling of waste tends to increase if the specified equipment list is not complete. That also affects the waste management facility and the handling equipment included in the building. In general several dismantling activities are increased when the material or the work required are not fully specified [7].

For the dismantling activities the contingencies are estimated on the basis of the accuracy in the inventory and the fact that the duration/work is increased due to difficulty in activity sequencing, tool troubles, not specified equipment etc. The contingency for the handling of fuel are estimated on the basis of the accuracy in the inventory and the expected duration of the work to be performed. The contingencies for the room preparation costs are based on the fact that the costs are derived from the number of rooms in the building, not the size of the rooms. The contingencies have been estimated, in percent values, for individual cost items on a lower level in the ISDC structure. Contingency related to accuracy in the inventory and accuracy in activity categorisation is connected with costs for e.g. drums and boxes and landfill fees. The compensation for the missing information in the inventory is called estimate uncertainty and has been included in the contingency.

What effects unspecified costs and estimate uncertainties have on the base estimate are discussed in the uncertainty analysis in the KVU.

The base estimate contains both high and low contingency values, a preliminary cost calculation contain normally high contingencies and a revised cost calculation contains lower contingency values. The diversity in the contingencies within this report is due to high uncertainness in cost tasks were the available information has been limited, e.g. the dimensions and weights of the RPV and the RI. Base estimate with contingency is presented in Table 12.

Table 12: Base cost for all alternatives in kNOK.

Alternative	Appendix	Halden	Appendix	Kjeller
1Aa	3	1 402 576	39	1 412 661
1Ab	4	1 357 081	40	1 377 570
1Ac	5	1 428 211	41	1 415 340
1Ba	6	1 377 083	42	1 392 877
1Bb	7	1 331 587	43	1 357 785
1Bc	8	1 385 256	44	1 395 555
1Ca	9	1 273 001	45	1 235 221
1Cb	10	1 227 505	46	1 200 130
1Cc	11	1 298 636	47	1 237 899
2Aa	12	1 908 774	48	1 918 859
2Ab	13	1 863 279	49	1 883 767
2Ac	14	1 934 409	50	1 921 537
2Ba	15	1 883 280	51	1 899 074
2Bb	16	1 837 785	52	1 863 983
2Bc	17	1 908 915	53	1 901 753
2Ca	18	1 378 404	54	1 340 625
2Cb	19	1 332 909	55	1 305 533
2Cc	20	1 404 040	56	1 343 303
3			57	2 373 996

History

Review and approval status (Organization, name)

Rev No	Prepared	Reviewed	Approved	Date
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Revision record

Rev No	Section	Cause

APPENDIX 1

CONTRIBUTORS

Jan Nordin, Engineer, Decontamination, Decommissioning & Remediation, Westinghouse Electric Sweden AB

Niklas Leveau, Engineer, Decontamination, Decommissioning & Remediation, Westinghouse Electric Sweden AB

Niklas Bergh, Product Lead, Decontamination, Decommissioning & Remediation, Westinghouse Electric Sweden AB

APPENDIX 2

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