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Ringhals Site Study 2013

– An assessment of the decommissioning cost for the Ringhals site

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Mars 2013

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The original report, dated Mars 2013, was found to contain editorial errors which have been corrected in this updated version.

Ringhals - Studie för avveckling av de kärntekniska anläggningarna

I Kärntekniklagen 10 § framgår det att den som har tillstånd för kärnteknisk verksamhet skall svara för att åtgärder vidtas för att på ett säkert avveckla anläggningarna i vilken verksamheten inte längre ska bedrivas.

Som tillståndshavare har Ringhals AB tagit sitt ansvar enligt Kärntekniklagen och genomfört denna avvecklingsstudie som beskriver tillvägagångssätt, inventerade avfalls- och aktivitetsmängder, tidplan, organisation och kostnader vid nedmontering och rivning av anläggningarna.

Övergripande strategiska förutsättningar har tagits fram av tillståndshavarna gemensamt och är i överensstämmelse med Ringhals avvecklingsplan.

Ringhals AB

Björn Sjöström
vVD

Executive summary

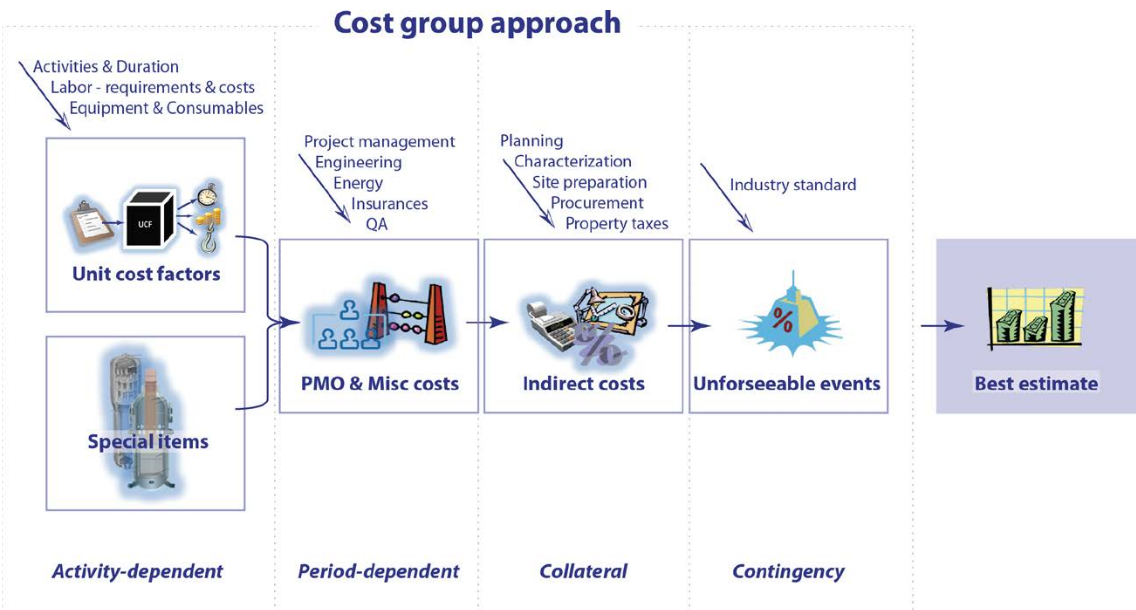
This report presents the decommissioning cost for the Ringhals site as of 2013. The objective has been to make a best estimate of the costs within the uncertainties of a budgetary estimate. To achieve this, the decommissioning costs have been assessed with support from TLG Services Inc., utilizing their knowledge and experience from U.S. decommissioning projects incorporated in their cost estimation platform DECCER.

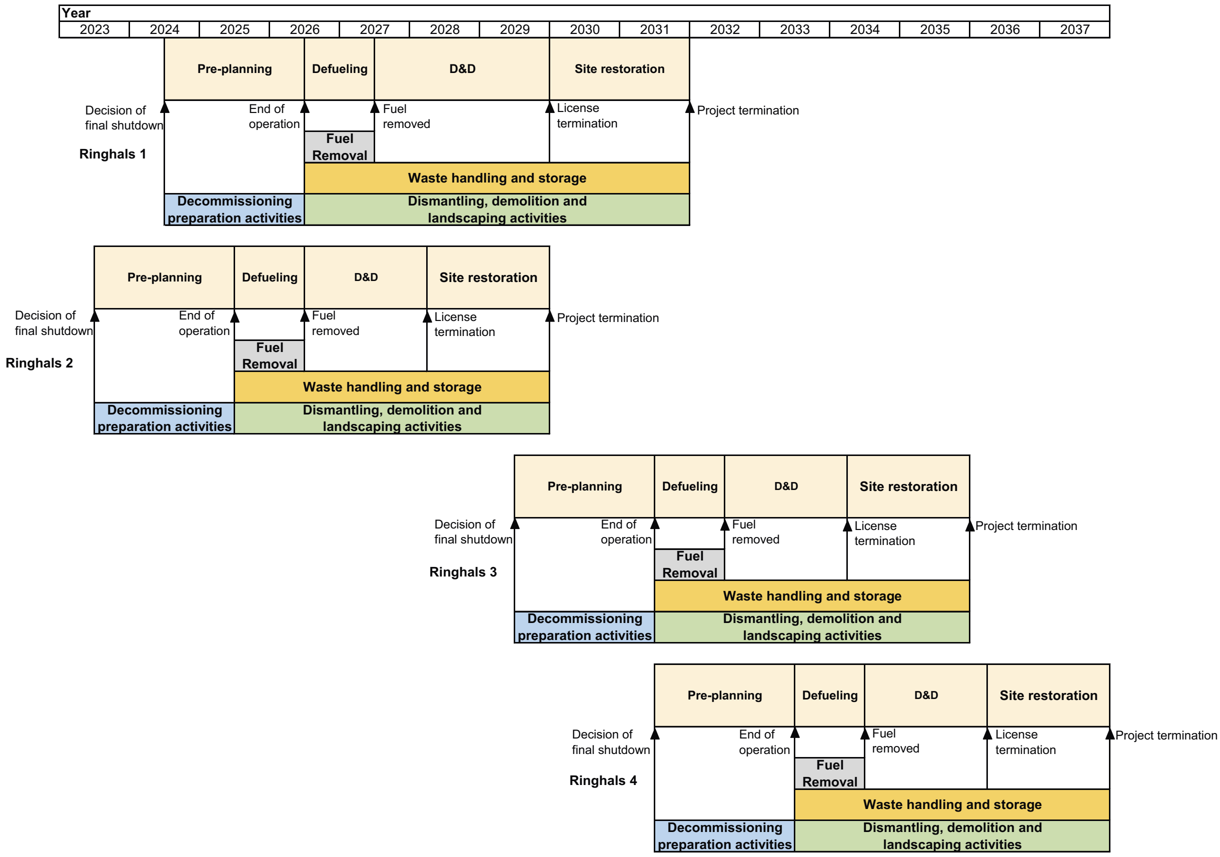
The 2013 estimate has included the development of a Ringhals-specific cost estimation method that allows for successive improvement in the future. In-house experiences have been included and the method is based on the present decommissioning strategy according to Ringhals decommissioning plan.

Two basic approaches have been used in the cost assessment; a bottom up approach to develop unit cost factors (UCF) for recurrent work; and a specific analogy approach for cost estimating special items. The basic, activity-dependent, costs have been complemented by period-dependent costs, derived, among other things, from SKB's newly developed reference planning and organizational model for a Swedish decommissioning project. Furthermore, collateral costs based on the experiences of Barsebäck have been included. As a final point, all costs have been adjusted for industrial standard contingencies, as suggested by TLG, to achieve a best estimate.

In order to make the cost intelligible a comprehensive description of the assumptions, boundary conditions and general basis of the estimate is included in this report. All costs have been reported both according to the International Structure for Decommissioning Costing (ISDC) of Nuclear Installations published by OECD/NEA and according to the SKB developed EEF structure. Furthermore, common costs have been isolated to a theoretical unit 0 to make the cost for respective unit even more comparable on a national and international scale.

The calculations show that the total cost for the decommissioning of the Ringhals site is 6.74 billon SEK (January 2010 Swedish kronor), whereof the estimated cost for license termination corresponds to approximately 75%. Labour costs represent around two thirds of the total; the last third include expenses for equipment and consumables (including energy). A preliminary schedule for the site decommissioning is shown below.

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Ringhals 1
Ringhals 2
Ringhals 3
Ringhals 4
Pre-planning
Defueling
D&D
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End of operation
Fuel removed
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Project termination
Fuel Removal
Waste handling and storage
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1 Introduction

As part of the Swedish Nuclear Fuel and Waste Management Co's (SKB's), program for research, development and demonstration (FUD) 2010, unit-specific decommissioning studies were to be conducted by SKB together with the nuclear power companies during 2010–2012. In 2011 however, a decision was taken in the SKB chaired Decommissioning group to abandon the idea of unit-specific studies in favour of a complete decommissioning site study for each nuclear power site.

The advantage of site studies was that the outcome better represented the expected "real case" with respect to, e.g., common buildings, scheduling issues, organizational issues and synergetic effects of multiple units dismantling. Furthermore, site studies were easier to adapt to the specific conditions prevailing at the site with regard to the physical layout of power plant buildings and with regard to the licensee's decommission plan. Hence, the change from unit-specific studies to site studies did not lower the level of detail, but rather completed the studies with a general view of the entire decommissioning process of a nuclear power site.

This report presents the Ringhals decommissioning cost study as of 2013. It is a complete re-make that differs from earlier studies (Gustavsson et al. 2006, Johansson and Hansson 2010). The cost is no longer a simple arithmetic calculation based on power and size, but has been based on the actual inventories of materials and radioactivity for each unit together with a realistic project organization and planning.

In the Ringhals 2013 site study the level of detail in the inventories is moderate and general assumptions have many times been applied to be able to complete the calculations. Consequently, there is room for improvement.

Though, as the Ringhals units, all have more than 10 years of remaining operation before permanently being taken out of service, the aim of the 2013 site study has been to develop a best estimate of the decommissioning costs and also to build an understanding for how decommissioning studies are made. The uncertainty in this work, and its underlying inputs, well represents the expected level of detail for a site with more than a decade of remaining power operation according to the graded approach philosophy.

As new knowledge is acquired in the decommissioning field the decommissioning plan will be updated and as the inventories of the Ringhals units have been better determined, the site study will be further improved. The Ringhals site study and decommissioning plan will thereby be progressively improved in an iterative process until they have reached a level of uncertainty that is acceptable for a final decommissioning project planning. This level of detail should have been achieved by the time the reactors are permanently taken out of operation.

1.1 Objective

The objective of the study has been to make a best estimate of the costs associated with the decommissioning of the Ringhals site.

1.2 Scope

A best estimate of the site decommissioning cost should be established with the uncertainties of a budgetary estimate, 15% to +30%, i.e., constructing a Class 3 estimate according to the Association for the Advancement of Cost Engineering International's (AACEI's) classification system (AACEI 2005), see Table 1-1. A class 3 estimate is well in line with the expected level of detail for a Nuclear Power Plant (NPP) with more than 10 years of remaining power operation.

Table 1-1. Categorization of the Association for the Advancement of Cost Engineering International's (AACEI's) five cost estimating classes (AACEI 2005).

	Primary Characteristics	Secondary Characteristics			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** **Express as % of complete definition**	**END USAGE** **Typical purpose of estimate**	**METHODOLOGY** **Typical estimating method**	**EXPECTED ACCURACY RANGE** **Typical variation in low and high ranges [a]**	**PREPARATION EFFORT** **Typical degree of effort relative to least cost index of 1**
CLASS 5	0% – 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment or Analogy	L: –20% to –50% H: +30% to +100%	1
CLASS 4	1% – 15%	Study of Feasibility	Equipment Factored or Parametric Models	L: –15% to –30% H: +20% to +50%	2 to 4
CLASS 3	10% – 40%	Budget, Authorization or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: –10% to –20% H: +10% – +30%	3 to 10
CLASS 2	30% – 70%	Control or Bid/Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: –5% to –15% H: +5% to +20%	4 to 20
CLASS 1	50% – 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: –3% to –10% H: +3% to +15%	5 to 100

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/– value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

The reporting structure follows the International Structure for Decommissioning Costing (ISDC) of Nuclear Installations as published by OECD/NEA (OECD/NEA 2012). To serve as a reference for the Plan report 2013, costs has also separately been allocated to the External Economic Factors (EEFs), as defined by SKB. All costs are presented as January 2010 Swedish kronor (SEK).

During the cost estimation process, waste amounts arising during the decommissioning project are assessed. These waste volumes are reported as a secondary delivery of this report as a reference for SKB to be used for estimation of disposal costs and repository volumes.

There are no legal requirements on the production of the present report.

1.3 Regulatory Framework

There are four principal authorities that in the future are expected to express requirements to control decommissioning activities in Sweden. These are:

- Swedish Radiation Safety Authority, SSM.
- Environmental Court.
- The local municipality, Varbergs kommun.
- The county administrative board, Länsstyrelsen.

SSM is responsible for issues related to nuclear safety and radiation protection. The Environmental Court is, together with the county administrative board, responsible for environmental approvals, including Environmental Impact Assessments (EIA). The local municipality is responsible for building and demolition permits.

Today, the Swedish regulatory guidance on decommissioning of NPPs is under development. The discussions have started and are partly ongoing, especially with concern to the forthcoming decommissioning of the Barsebäck plant. This cost assessment has been based mostly on the U.S. regulatory environment (NRC) as provided by TLG Services Inc. (TLG) in the Barsebäck site study (SKBdoc 1403739). The regulatory environment used in this work is further described in Appendix A.

Costs associated with the production of legally required decommissioning documents have been included in this estimate. These documents are:

- The final decommissioning plan.
- A decommissioning safety report.
- A decommissioning Environmental Impact Assessment (EIA).
- An article 37 report.

1.4 Site Description

Four nuclear units are located at the Ringhals site, see Figure 1-1. Ringhals 1 is a Boiling Water Reactor (BWR) and Ringhals 2–4 are Pressurized Water Reactors (PWR).

The four units are placed in one large operating area with some common buildings shared either by Ringhals 1 and 2, Ringhals 3 and 4 or by all four units on the site. Outside the operating area there is a fenced industrial area where common buildings like offices, storage buildings etc are located. In this study, the concept of a unit 0 has been established for common buildings, in order to simplify the comparison of costs associated to specific units, both on-site and in a national perspective.

For more information about the site from a decommissioning perspective, see Appendix B.

Ringhals 1		**Ringhals 2**	
Reactor type:	BWR	Reactor type:	PWR
Reactor supplier:	ASEA-Atom	Reactor supplier:	Westinghouse Monitor AB
Commercial operation:	January 1976	Commercial operation:	May 1975
Nett out put (electric):	878 MW	Nett out put (electric):	865 MW
Thermal out put:	2,540 MW	Thermal out put:	2,652 MW
Planned operation:	50 years (1976–2026)	Planned operation:	50 years (1975–2025)
Ringhals 3		**Ringhals 4**	
Reactor type:	PWR	Reactor type:	PWR
Reactor supplier:	Westinghouse Monitor AB	Reactor supplier:	Westinghouse Monitor AB
Commercial operation:	September 1981	Commercial operation:	November 1983
Nett out put (electric):	1,063 MW	Nett out put (electric):	940 MW
Thermal out put:	3,135 MW	Thermal out put:	2,775 MW
Planned operation:	50 years (1981–2031)	Planned operation:	50 years (1983–2033)

Figure 1-1. *3D-schematic of the Ringhals site.*

2 Basis of estimate

The basis of estimate (BoE) and its sources of information, site-specific considerations and assumptions are described in this section. The aim has been to give a compiled description of all assumptions made to make the cost estimate transparent and easily comparable. The assumptions, conditions and exclusions are all based on Ringhals decommissioning plan (Ringhals 2013a), general RAB conditions or on general conditions as stated by SKB.

The BoE have been divided into three main categories; a definition of the project context, a record of the technical assumptions and an explanation of the economical inputs. In the end of the chapter, the major sources of data are presented.

2.1 Project context

The decommissioning projects are bounded by the preceding power operation of respective unit and the succeeding transport and final storage of the decommissioning waste; see Figure 2-1. During parts of the decommissioning phase, either one or both of the bounding activities will be ongoing in parallel. This puts requirements on clear separation of the responsibilities for respective activity in order not to create dependencies or constraints.

Ringhals AB (RAB) plans to realize the decommissioning of each unit as a well defined and well planned project, much in agreement with the recent modernization projects. In order to achieve this, the projects will have to start-up at a date determined by the licensee. Table 2-1 shows the present planning.

The main activity at the Ringhals site during the decommissioning of unit 1-4 will be power production. The units to be decommissioned are assumed to be replaced by other nuclear, or non-nuclear, power production.

Table 2-1. Year of final shutdown assumed in the cost estimate.

Unit	Year of shutdown
Ringhals 1	2026
Ringhals 2	2025
Ringhals 3	2031
Ringhals 4	2033

Figure 2-1. *The decommissioning project and bounding activities. The crossing circles symbolizes that actions, not part of the decommissioning project, will be ongoing in parallel with the decommissioning on the site.*

During the decommissioning of unit 1, 2 and a large part of the nuclear dismantling of unit 3, nuclear power production will exist on the site. During decommissioning of unit 4 new nuclear or non-nuclear power production is assumed to be operational on the site. Most likely all costs for infrastructure and services on site will be allocated to the power producing units. Nevertheless, in the present estimate, all four decommissioning projects bears the costs for necessary surrounding services despite the ongoing power production; but, RAB will provide non-decommissioning specific basic infrastructure to the project (as snowplowing, parking lots, etc.).

For planning purposes it is assumed that the dismantling activities start immediately on the day of final shutdown of respective rector. No delay occurs due to external factors, i.e., all necessary permissions have been granted by the regulating authorities etc beforehand. No service period is planned, neither to allow for decay nor to allow for simultaneous dismantling and demolition of two or more units. A nearby unit in power production is not a limiting factor for most dismantling activities as long as the systems are physically separated. Due to slightly shifted schedules between two projects, synergetic effects have been considered in some instances.

The decommissioning of each unit is divided into four phases with activities running in parallel, see Figure 2-2:

1. **Pre-planning:** commences the day RAB decides that a reactor will be permanently shutdown and continues till the day of final shutdown. During this time the dismantling and decommissioning activities are prepared in detail. Preparations include engineering and final planning, site preparations and the assembly of a project management organization. The project organization will start to be assembled two years before final shutdown.
2. **Defueling:** starts at final shutdown and ends when all fuel has left the unit one year after shutdown. During this time dismantling and demolition activities are carried out on systems and structures not related to the fuel cooling or its corresponding safety e.g. segmentation of internals, turbine systems etc.
3. **Dismantling and demolition, D&D:** starts after defueling and ends when all radioactive material has been removed. During this time, nuclear dismantling continues until all remaining contaminants are removed. Radiation protection and security is adapted to the lowered risk level. Conventional dismantling of radiologically clean systems and demolition of clean and decontaminated structures take place as well as landscaping.
4. **Site restoration:** starts after finalized nuclear dismantling and continues until the desired end-state has been reached. Remaining structures to be removed are demolished and verification is carried out to ensure that the site release criteria have been met. Landscaping to a brown field is conducted. No radiation protection is required and the need for physical protection is significantly lower than in the preceding phases.

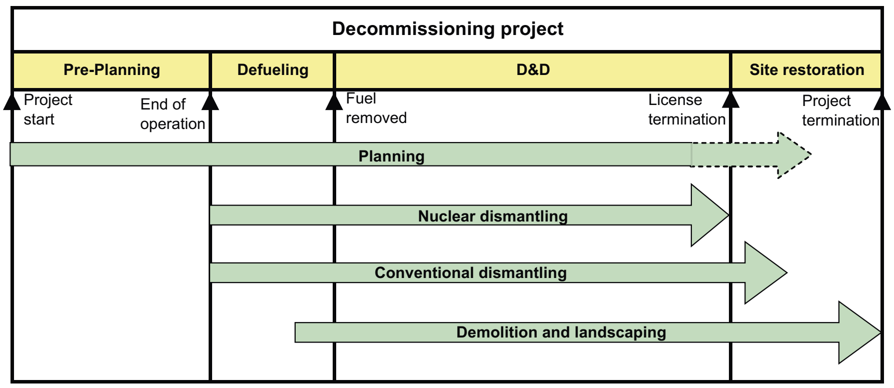

***Figure 2-2.** The decommissioning phases and activities performed during the project.*

2.1.1 Transition from Operation

There are no socioeconomic costs associated with the transition from operation to decommissioning within this study, as all non-technical aspects are outside the scope.

At the unit to be decommissioned, the operating staff will perform the following activities at no additional cost or credit to the decommissioning project:

- Drain and collect fuel oils, lubricating oils, and transformer oils for recycle and/or sale.
- Drain and collect acids, caustics, and other chemical stores for recycle and/or sale.
- Furniture, tools, mobile equipment such as forklifts, trucks, bulldozers, and other such items of personal property will be removed. Disposition may include relocation to other operating facilities.
- Existing warehouses and lay-down areas will be cleared of non-essential material and remain for use by the decommissioning project.
- Manage spent fuel and maintain the operation of fuel-related process and safety systems. Remove all fuel from the facility within a year from final shutdown.
- Package and ship control blades/rods from the final core load.
- General house-keeping where all material not necessary for the decommissioning project are removed.

2.1.2 Interface towards Transport and Disposal

The cost assessment includes all costs until the waste has been packaged, conditioned and is ready for shipping on the site border. All cost for off-site transport and disposal of conditioned Low Level Waste (LLW) and Intermediate Level Waste (ILW) are outside the scope of this estimate. Transports for standardized waste containers are covered by the SKB transport system and the corresponding costs are accounted for by SKB in the Plan report.

SFR is assumed to have the capacity to directly receive all short lived decommissioning wastes. The BWR-pressure vessel will be disposed in SFR, the PWR-pressure vessels are stored together with other long-lived waste on-site until final disposal in SFL in year 2045. Costs for on-site storage are covered in the estimate.

A shallow ground disposal will be available on-site for disposing of Very Low Level Waste (VLLW)-type decommissioning waste.

Costs for off-site waste treatment, and the transports associated, are covered in the estimate. Off-site treatment facilities are assumed to be prepared and sized to directly receive and treat all wastes from the decommissioning projects. Consequently, off-site treatment is assumed to be finished long before respective project is terminated.

2.2 Technical assumptions

The technical BoE presented below sets the scope of work for the decommissioning of the process equipment, buildings, and the site itself, i.e. defines the boundaries within the projects themselves.

2.2.1 General

The work will as far as possible be carried out by external contractors. An unlimited availability of qualified resources is assumed. The decommissioning activities will be carried out in parallel by multiple crews to the extent possible regarding efficiency and safety measures.

All necessary auxiliary buildings, e.g. stores, administrative buildings and waste treatment buildings exist at the site and will be possible to use during the decommissioning. Systems and devices needed for the fuel removal and the D&D phase are in proper condition.

For cost estimating purposes, rates of productivity for known industrial techniques have been used. Hence, only techniques that are available today have been considered. These techniques do not differ significantly from techniques used in remodeling work/replacements during today's outages. No costs are considered for technology development. Appendix C gives a more detailed description of the decommissioning program and the techniques used in this estimate.

2.2.2 Primary system decontamination and water wash

The reactor coolant system will be decontaminated using chemical agents prior to the start of cutting operations. Decontamination can be expected to have a significant ALARA impact and lower the worker dose exposure during the nuclear dismantling activities. Additionally, the decontamination will simplify the decommissioning activities due to a lower risk of spreading loose contamination and by simplifying and minimizing the waste management. A decontamination factor (DF) of 10 is assumed for the process and the isotopic concentration adjusted accordingly.

Similarly it is assumed that a surface decontamination via water wash of designated steel liners and tanks will take place prior to removal with a DF of 2.

Disposal of the decontamination solution effluent is included within the estimate as a part of the "process liquid waste" charge.

2.2.3 Special Items

The Reactor Pressure Vessels (RPVs) from the PWRs are removed intact together with its internal components. For the BWR vessel the internal components are segmented and packaged on site. The vessel itself is removed as one-piece. The vessels are extracted through new openings in respective containment.

The PWR steam generators and pressurizers will also be extracted in one-piece through the new opening in the containment. Once the component has been extracted, it will be moved to the shipping dock area and transferred to an external waste treatment facility.

Reactor recirculation pumps and motors are lifted out intact, segmented and packaged for transport and disposal. Heat exchangers, tanks, pumps, large valves etc will also to the extent possible be removed in one-piece and sent for further segmentation and packaging. All openings in the component are properly sealed before transportation to the waste processing area.

2.2.4 Systems

The remaining contaminated components are dismantled using proven methods according to standard nuclear procedures. The material is transferred to the waste treatment area where it will be prepared for transportation to the disposal or off-site waste treatment facility.

Equipment and materials are considered radioactive waste if the internal surfaces are either known to be, or are assumed to have a risk of being contaminated. They are also considered radioactive waste if the materials are located in an area with known contaminated surfaces, or if any risk of contamination could be assumed.

Radiologically clean components suitable for free-release are dismantled using conventional techniques and disposed as scrap metal.

2.2.5 Structures

The study includes costs for removing free-released structures to a nominal depth of one meter below the local grade level. Tunnels, internal floors etc are collapsed to avoid voids. Foundations or walls deeper than one meter below grade are left in place. Concrete rubble generated from demolition activities is processed and made available as clean fill for the unit foundations and similar cavities.

2.2.6 Ground

The site is re-graded following the D&D to prepare it for future industrial use. The end state assumed in this study is brown-field.

2.2.7 Waste Management and Disposal

The waste is sorted at the source, and transported for further treatment and storage depending on the sort of waste and activity level.

Active material

The radioactive waste is categorized according to its radioactivity level. The waste management and disposal of active material is shown in Figure 2-3.

Melting is used for the PWR steam generators and pressurizers, and the reheaters for Ringhals 1 to reduce the amount of active material. These large components will act as their own waste package after tight sealing of all openings. Generally 75% of the large components mass is assumed to be free-released after metal melt. However, RAB specific experience based data have been used for the steam generators and pressurizers to improve the accuracy of the estimate.

The conditioned waste packages are transported to, and disposed at, one of the following repositories depending on their level of radioactivity:

- SFR: Final repository for short lived LLW or ILW.
- SFL: Final repository for long lived LLW or ILW. The long lived radioactive waste will be stored in a local interim storage for long lived wastes until SFL is completed in 2045.
- Landfill: Repository for VLLW.

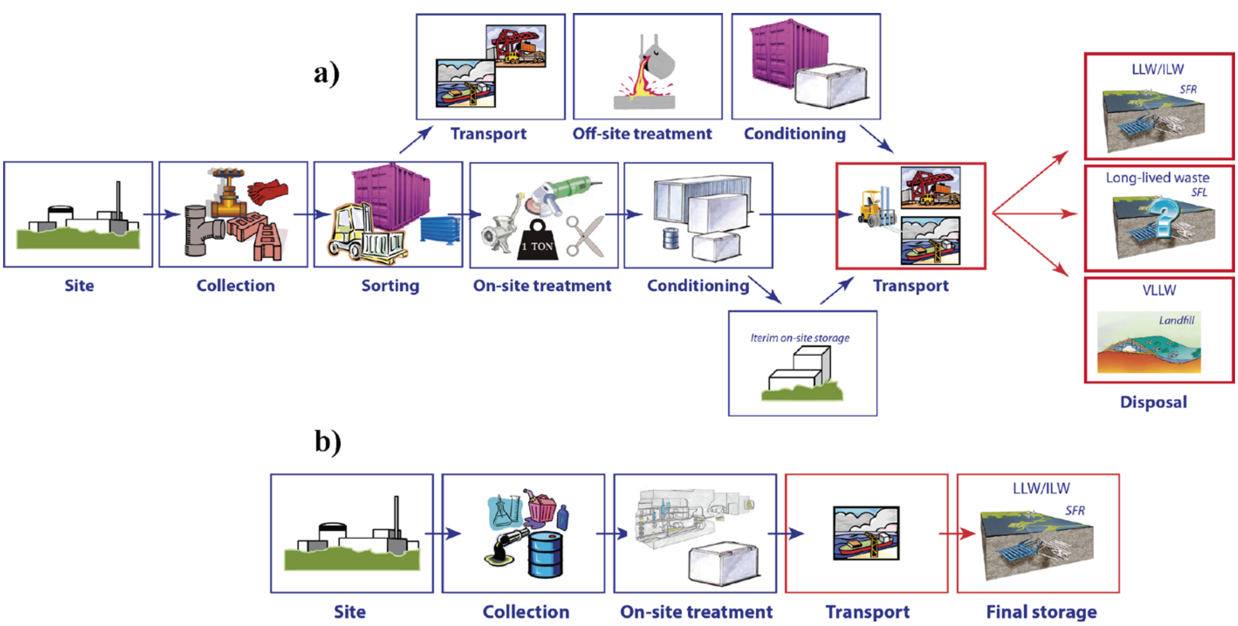

Figure 2-3. *a)Waste routes for solid radioactive decommissioning waste. The waste is treated either on-site (cutting, milling, compacting) or in an off-site waste treatment facility. Long-lived waste is intermediately stored on-site until the final repository, SFL, has opened; the other waste-streams are packaged and shipped directly to final disposal. b) Waste route for contaminated liquids. All liquids are solidified in the existing waste treatment building and sent for final disposal. (Blue squares define actions covered in this estimate, red defines actions that are outside the scope of this study.)*

Conventional waste

The conventional waste is treated and disposed of according to Figure 2-4. Materials are recycled as far as reasonably possible; if not possible the material will be used for energy production. Ashes and non-combustible materials will be disposed on an off-site disposal or used locally as backfill.

All equipment is considered obsolete and suitable for scrap only. Although there may be economically reasonable efforts to salvage equipment following final plant shutdown, dismantling techniques assumed in this estimate are not necessarily compatible with salvage of equipment.

Any value received from the sale of scrap generated in the conventional dismantling and demolition process would be offset by the on-site handling costs. Therefore no cost or credit associated with disposing of scrap metal is included in the estimate.

Waste package criteria and costs

During decommissioning no new waste types appear that hasn't already been handled and disposed of during operation of the plant, only greater volumes and simultaneous flows will be handled.

Standard containers or other packages already qualified for transport or disposal of conditioned radioactive waste is used, with the addition of a planned large steel box. Costs for the waste containers have been included in the estimate. The waste containers and their costs are presented in Table 2-2.

ISO containers are used for all wastes that have a total isotopic concentration of less than 1.0E+06 Bq/kg. Waste expected to have a total isotopic concentration of less than 500 Bq/kg, is packaged into containers designated as "ISO containers (<500 Bq/kg)".

Steel boxes are used to package all waste associated with chemical decontamination and water processing. Also melted material is packaged into steel containers to minimize difficulties handling the high density material.

Neutron activated wastes from the reactor core region are packaged into BFA tanks. Large steel boxes are used to package all remaining wastes.

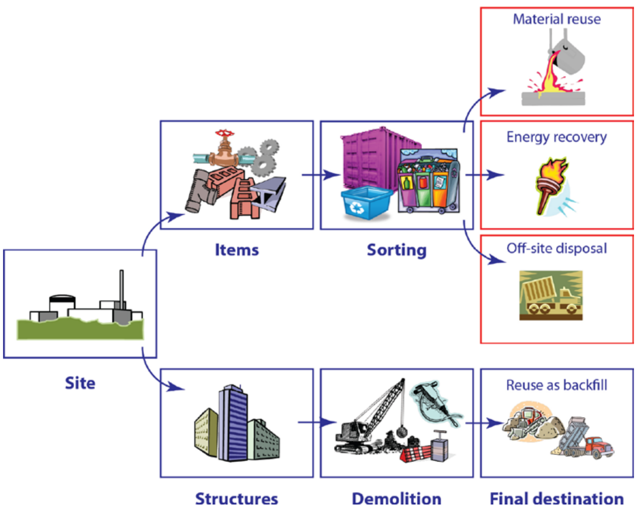

Figure 2-4. *Waste route for conventional decommissioning waste.*

Table 2-2. Costs for waste containers.

Type	Dimensions (m) (l,h,w)	Packing Density (kg/m^3)	Package Volume (m^3)	Container Cost (SEK)
ISO container	6.06x1.3x2.5	1,100	19.7	23,000[1]
ISO container (<500 Bq/kg)	6.06x1.3x2.5	1,100	19.7	23,000[1]
Steel Box	1.2x1.2x1.2	1,100	1.7	23,000[1]
Large Steel Box	2.4x1.2x2.4	1,100	6.9	92,000[2]
BFA Tank	3.3x2.3x1.3	6,700 kg/unit	10	562,000[3]

1. Purchase price as of 2010.
2. Four times the cost for a steel box.
3. Price as provided by SKB.

2.3 Economical inputs

All costs in the estimate refer to January 2010 SEK. The financial results are reported according to the 2012 ISDC report structure and according to the EEF structure.

2.3.1 Labor Costs

The labor costs have been based on salary levels according to RAB as of 2010. Overhead costs are included in the respective salary. The staffing level and prices are shown in Table 2-3.

For own personnel a working year of 1,700 h has been used. Contractors are hired by the hours. For scheduling purpose a general a working time of 8 hours a day, 5 days a week, year-round has been used. Activities related to segmentation of the internals, the one-piece lifting of the reactor vessels and the waste management will be conducted 16 hours a day.

Table 2-3. Labor salary including overhead.

Staffing level	Annual cost (SEK)	Hourly cost (SEK)
Ringhals Staff		
Senior Manager	1,608,000	
Department Manager	1,223,000	
Professional	790,000	
Supervisor and Technical Specialist	838,000	
Technicians	603,000	
General Administrative	459,000	
General Worker	424,000	
Radiation Protection Technicians	555,000	
Security Guard	512,000	
Security Supervisor	559,000	
Contractor		
General Foreman		780
Foreman		710
Craftsman		650
Laborer		470
Radiation Protection Technicians		460

2.3.2 Currency Conversion

All currencies have been converted to SEK. In those instances U.S. costs were used as an estimating basis (mainly equipment and consumables), a currency conversion of 6.88 SEK to 1 U.S. Dollar (USD) has been used.

2.3.3 Taxes

There are no property taxes included within the estimate. Value Added Tax (VAT) payments (if any) are assumed to be deductible; therefore no VAT has been applied to purchased equipment and consumables.

2.3.4 Regulatory Agency Fees

Regulatory agency fees are not included within the cost estimate. This is covered by the SKB Plan report.

2.4 Major data sources

This section presents the sources of data for the physical inventory and for the inventory of radioactivity. It also gives details on the origin of the program management organization applied in the estimate.

2.4.1 Site inventory of materials and radioactivity

The site inventory of both radioactive material and conventional material has been assessed by TLG and are shown in Appendix D and Appendix E (Ringhals 2013b, c).

The site material inventory has been assessed from drawings and equipment information. Provided information for Ringhals 2, 3 and 4 has been complemented by TLG with information from a representative U.S. reference plant (Westinghouse 3-loop PWR with a nominal power 5% higher than the average of Ringhals 2–4). In those instances where information was not available for Ringhals 1, information from the Barsebäck study has been used (SKBdoc 1403739) and in a limited number of cases from a representative plant in U.S.

The primary sources of information of radioactivity are the ALARA Engineering reports (Ringhals 2013d). These reports contain an estimate of the activity level and mass of each system and structure potentially contaminated at the time of decommissioning. It should be stressed that contamination is mainly found in the systems and components. Contaminated structures are found in limited amounts behind concrete anchored steel liners and on floors in rooms containing contaminated systems and components. Activation of the building structures is confined to the reactor shield wall. No known contamination of ground exists at Ringhals.

Based on the ALARA-Engineering inventory, and the physical inventory of systems and structures, TLG has estimated the number of contaminated, respectively non-contaminated, units of each inventory detail. In this evaluation process TLG added own experience for the systems not covered in the ALARA Engineering study.

Due to the scope of the ALARA reports the reported masses differ from the TLG-developed inventory of contaminated systems and structures for the Ringhals units. Where the TLG-developed inventory estimated a total greater mass of waste for a system, this difference was accounted for. Since this mass was typically expected to be associated with equipment and material not directly exposed to reactor coolant (or similar source of contamination), the activity concentration of this additional mass was determined by an analyst's judgment. Generally a small fraction (1% or less) of the isotopic concentration for the same or a similar system were chosen. There are a few systems not included in the ALARA reports which TLG experience says could contain minimal, but measurable amounts of contamination. The masses of these systems where obtained from the developed inventory and the activity levels were determined as mentioned above.

2.4.2 Consumables and Equipment

Costs for consumables and equipment needed during the decommissioning projects are included in the study. The references for equipment and consumable costs (McMaster 2012, Means 2005, Sections 01540-800-0200, 01590-400-6360) are provided by TLG.

Costs that are dependant on the length of the decommissioning project; e.g. subscription and consumption costs for gas, electricity and water as well as insurance and emergency response fees, are also provided by TLG based on costs developed for the Barsebäck decommissioning study (SKBdoc 1403739).

2.4.3 Removal Rates

The removal rates and material costs for the disposition of components and structures rely upon information available in Means (2005, Section 01540-800-0200), as provided by TLG.

2.4.4 Reference Organization

The industry's reference planning and organizational model for a Swedish decommissioning project has been applied in this cost estimate (SKBdoc 1359832). The reference model has been developed to separate project functions from licensee support functions with the purpose of isolating the project-specific costs from those normally covered by a project sponsor. The reference model defines a project management organization that, in average, consists of 27 man-year/year. And in addition to this, a licensee support organization of 41 man-year/year is assumed.

In this estimate a combined organization covering both the project management organization and licensee support organization has been developed and all specified functions have been covered, see Figure 2-5.

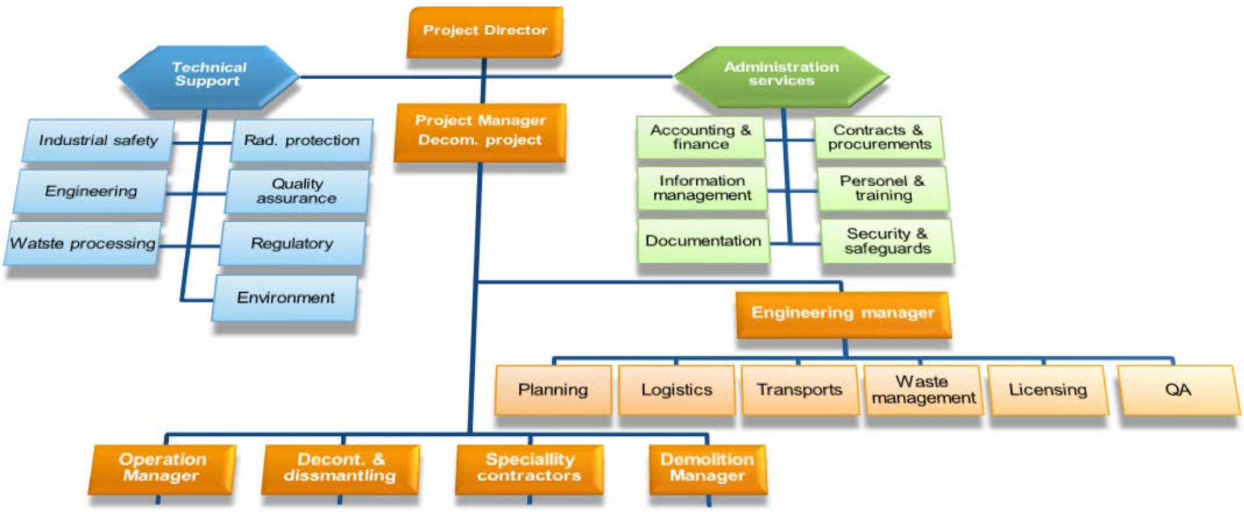

Figure 2-5. *Schematic description of the interpreted planning and organization model (SKBdoc 1359832) as applied in the RAB decommissioning projects.*

3 Cost estimate

The present estimate has included the development of a Ringhals-specific cost estimation method. The starting-point for this development was the Barsebäck decommissioning study and TLG Services Inc.'s DECCER model described therein (SKBdoc 1403739). During the development, in-house experiences have been included and the method has been aligned with the present decommissioning strategy according to Ringhals decommissioning plan (Ringhals 2013a).

The method development has been made with support from TLG Services Inc., utilizing their knowledge and experience from U.S. decommissioning projects as incorporated in the DECCER platform. Two basic approaches have been used in the cost assessment; a bottom up approach to develop unit cost factors (UCF) for recurrent work; and a specific analogy approach for cost estimating special items.

The basic, activity-dependent, costs have been complemented by period-dependent costs, derived, among other things, from SKB's newly developed reference planning and organizational model for a Swedish decommissioning project. Furthermore, collateral costs based on the experiences of Barsebäck have been included. As a final point, all costs have been adjusted for industrial standard contingencies to achieve a best estimate. Figure 3-1 shows a schematic presentation of the main components of the model.

This chapter describes the acquired cost estimation methodology, and explains the nature of, and basis for the Ringhals-specific assumptions and experiences introduced. The structure of chapter follows the cost group approach presented in the figure.

In order not to create conflicting versions of the DECCER model or TLG cost assessments, the Ringhals cost estimate is a stand-alone report defended by RAB alone. TLG is not to be held responsible for the calculations or numbers presented in this work.

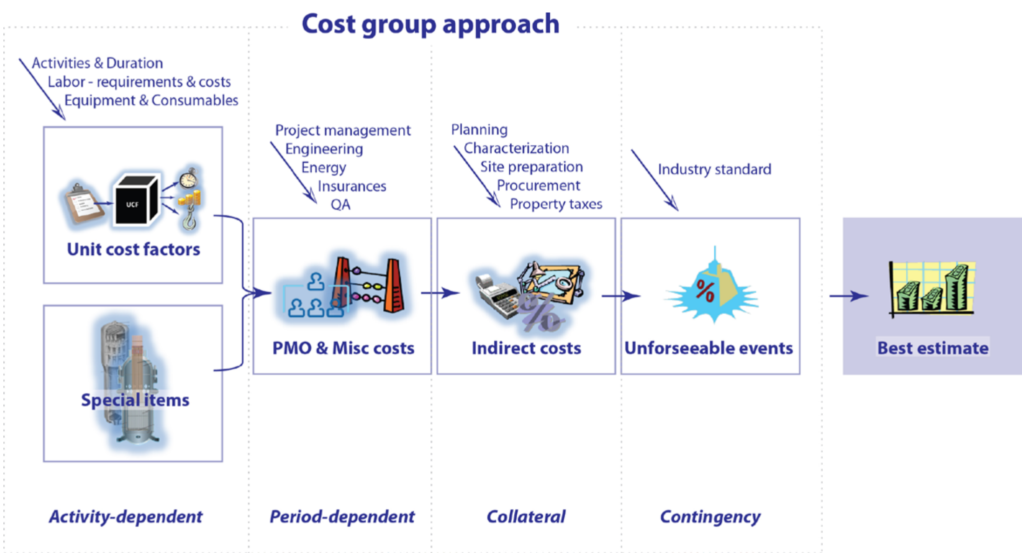

Figure 3-1. *The four groups representing the main components of the estimate.*

3.1 Activity-dependent costs

Activity-dependent costs are costs associated directly with performing decommissioning activities.

3.1.1 Unit cost factor development

Three types of UCFs have been used to convert the site inventory to a cost estimate:

- System removal UCFs.
- Structure removal UCFs.
- Site remediation UCFs.

All three types of UCFs provide a detail of activities that assures that no cost elements has been omitted in the assessment of respective task.

In this work the TLG UCFs from the Barsebäck study (SKBdoc 1403739) has been used together with complementing UCFs for Ringhals. Together, these UCFs represent a condensate of the lessons learned from the decommissioning of several large commercial U.S. NPPs over the past 15 years as well as the planning for NPPs in the U.K., Japan, Kazakhstan, and Canada.

To adapt the UCFs to a Swedish working environment, RAB has introduced work-teams with a composition better representative for typical Ringhals outage projects. The positive consequence of utilizing staff with higher educational levels and multiple competences is fewer workers on foreman level; but, this comes at the expense of higher average salary.

This subchapter presents the development of UCFs in a general way with emphasis on the changes introduced in the present study as compared to the Barsebäck study. Appendix F presents the detailed development of a typical unit factor. Appendix G provides the values contained within a typical set of factors developed for this analysis.

Activity description

Each unit factor must be broken up into discrete activities in order to be reliably priced. The description of these activities rests heavily on the experience of TLG. Consequently, none of these activities has been altered by RAB in this study.

Duration

The second step of the UCF development is to allocate time to each activity of the unit factor, and to determine the critical duration of the work. The total time is important for the activity-dependent cost development, whereas the critical time is important for the decommissioning program schedule and, hence, for the period-dependent costs for program management, administration, field engineering, equipment rental, etc.

As in the case of activity description, the allocation of time requires great experience within the field of decommissioning. Accordingly, RAB did not change TLG's duration values.

Work difficulty factors

The duration initially set for each activity assumes perfect industrial working conditions. Therefore, work difficulty adjustment factors (WDFs) must be applied to account for the inefficiencies in working in a NPP environment.

Five different WDFs were assigned to each unique set of unit cost factors to match the inefficiencies associated with working in confined, hazardous environments. The factors and their associated range of values were developed by TLG in conjunction with the AIF/NESP-036 study (LaGuardia 1986), and have not been altered by RAB. The WDFs and their ranges used in the estimate are presented in Table 3-1.

Table 3-1. WDFs used in the study.

Type	Work difficulty factors
Access Factor	10% to 20%
Respiratory Protection Factor	0% to 50%
Radiation/ALARA Factor	0% to 37%
Protective Clothing Factor	0% to 30%
Work Break Factor	8.33%

The WDFs lengthen a task's critical duration, and hence, increase costs and lengthen the overall schedule for the decommissioning. In this way time and funds are reserved to assure that the ALARA principle is followed. However, it should be mentioned that ALARA planning is considered also in the costs for engineering and planning, and in the development of activity specifications and detailed procedures.

The WDF values are somewhat higher than in the Barsebäck study. Most significant is the increase in the ALARA factor. This is a direct consequence of the short time between shutdown and start of decommissioning operations at Ringhals as compared to the long service operation at Barsebäck.

The application of the WDFs, and the factors themselves, are discussed in more detail in Appendix F and in LaGuardia (1986).

Labor requirements by craft

Once the type of work and total time has been determined and adjusted for difficult working conditions, the work-team necessary to solve the task could be estimated. In the Barsebäck study, TLG used a rather hierarchical structure containing both foremen and general foremen. This is not considered to be common practice in Sweden. As a result, RAB has modified the composition of the teams to represent only one hierarchical level. Except for these changes, the standard TLG allocation of crafts and labors has been left unaltered by RAB.

Equipment and consumables

No changes have been introduced as compared to the Barsebäck study. TLG's experience-based values on required amounts has, together with tabulated U.S. costs for consumables, tool rental etc, served as basis for the estimate.

3.1.2 Special items

The treatment of the reactor vessels, their internals, and the PWR steam generators and pressurizers are not covered by the UCFs due to the complex procedures required to handle these items.

The estimated scope of work and cost for the one-piece reactor vessel removal has, as in the Barsebäck study, been based on the one-piece reactor vessel projects successfully completed at Trojan and other U.S. NPPs.

Costs for removing and packaging the reactor vessel were developed by adjusting the Trojan costs to reflect the difference in physical size and weight between the Trojan and Ringhals vessels. Costs were escalated to January 2010 USD, and converted to SEK.

Costs for removal, segmentation, and packaging of the BWR reactor internals were extracted from TLG's base reactor vessel disposition model. RAB has not modified the assumptions made by TLG.

The costs for steam generator and pressurizer removal have been based on RAB's experiences from modernization projects and added to the estimate as a fixed value in SEK.

3.2 Period dependent costs

Period-dependent costs include those activities associated primarily with the project duration: e.g. engineering, project management, dismantling management, licensing, health and safety, security, energy and quality assurance.

3.2.1 Project Management

As described in the basis of estimate, the decommissioning of the Ringhals units will be carried out as clearly defined and bounded projects and the recommended staffing level found in the industry's reference planning and organizational model for a Swedish decommissioning project (SKBdoc 1359832) will be implemented. Since the reference model is based on the decommissioning of a non-specified standard unit it has to be slightly modified and concretized depending on each specific decommissioning project.

In the present cost study a project management organization with an average of 68 man-years/year is assumed for a total time of 6.5 years for Ringhals 1 and 5.5 years for Ringhals 2–4. To this a contingency factor of 15% is added. The resulting project management organization is shown in Table 3-2. A description of each worker category is presented in greater detail in Appendix H.

The distribution on different staffing levels shown in Table 3-3 determines, together with the tabulated salaries for respective position in Table 2-3, the program management costs.

Table 3-2. Project management organization for Ringhals 1–4.

Worker category	Ringhals 1 (Man-years)	Ringhals 2-4 (Man-years)
Management	36	30
Quality Assurance	18	15
Licensing & Regulatory Compliance	5	5
Work Management / Maintenance	63	54
Plant Operations	39	33
Radiation and Health Physics	35	30
Tech Support: Chemistry / Environmental Monitoring /EP	15	12
Tech Support: Waste Processing	88	75
Engineering / Planning	65	55
Security	58	48
Administrative Services	85	72
Total	**508**	**430**

Table 3-3. Project management organization distributed on different staffing levels.

Staffing level	Distribution (%)
Senior Management	7%
Department Manager	6%
Professional	12%
Supervisor and Techncal Specialist	15%
Technicians	27%
General Administrative	8%
General Worker	6%
Radiation Protection Technicians	8%
Security Guard	10%
Security Supervisor	1%
Total	**100%**

In additional to the project management organization, engineering services adding up to a total of 86, 81, 61 and 47 man-years for Ringhals 1–4 are included for handling, e.g., the detailed planning during the preparation phase and during the dismantling of special items. To the additional engineering a contingency factor between 15–75% is added depending on the complexity of the specific project, see Table 3-5. The cost for engineering is distributed on each specific activity.

3.2.2 Consumption and annuals fees

The periodic costs for consumption and annual fees for subscriptions and services are presented in Table 3-4. The bases for these are projected costs for service operation at Barsebäck, adjusted to reflect the number of personnel and level of activity during each of the stages of the project.

3.3 Collateral costs

In addition to activity- and period-dependent costs, there are costs, such as for procurement of construction or dismantling equipment, site preparation, insurance etc. Such items do not fall in either of the other categories and are grouped in the cost group for collateral costs.

3.3.1 Characterization of the site

Large parts of the preparatory characterization work will be completed during the power operation, see Ringhals (2013a). Nevertheless, a final verification of the site characterization must be undertaken once the reactors have been taken out of operation. The cost for the characterization work is, based on Barsebäck experience, estimated to 13.8 MSEK for Ringhals 1 and 11.9 MSEK for Ringhals 2–4.

3.3.2 Environment Impact Assessment

The estimated cost for an EIA is 3.4 MSEK for Ringhals 1 and 1.7 MSEK for Ringhals 2, 3 and 4, respectively. The EIA must be approved before the D&D phase starts. The cost estimate is based on Barsebäck experience.

3.3.3 Full system decontamination

The cost for full system decontamination has been based on the amount of decontamination fluid required to fill respective primary system together with a standard price per volume as recommended by TLG. The total cost is approximately 28 MSEK for Ringhals 1 and 34 MSEK for Ringhals 2–4.

Table 3-4. Periodic costs during the decommissioning of Ringhals.

	Annual cost (MSEK)		
	Defueling[1]	D&D[2]	Site restoration[3]
Electricity	8.02	10.16	1.07
Gas	5.61	5.61	1.87
Water	1.60	2.03	0.43
Nuclear liability insurance	3.53	4.28	0.00
Emergency response	2.25	2.25	2.25
Corporate expenses	1.07	1.07	1.07

1. Defueling starts at final shutdown and stops when all fuel has left the unit.
2. D&D satarts after defueling ands stops when all radioactive material has been removed.
3. Site restoration starts after D&D and continues until the desired end-state has been reached.

3.4 Contingency

Contingencies are defined in AACE International's (the Association for the Advancement of Cost Engineering) "Project and Cost Engineers' Handbook" (Humphreys 2005) as:

"...specific provision for unforeseeable elements of cost within the defined project scope" and that this is: *"...particularly important where previous experience relating estimates and actual costs has shown that unforeseeable events which will increase costs are likely to occur."*

The cost elements in the Ringhals estimate are based upon ideal conditions and maximum efficiency. All activities in the base estimate are performed within the defined project scope, without delay or interruption, inclement weather, tool/equipment breakdown, etc. Such is not the real world of any human endeavor; hence, a contingency factor must be applied. The purpose of the contingency is to allow for the costs of high probability program problems occurring in the field where the occurrence, duration, and severity cannot be accurately predicted.

In this report, contingencies have been applied in accordance with the TLG values used in U.S. estimates, and in the Barsebäck estimate (SKBdoc 1403739). These contingencies are applied on a line-item basis, using one or more of the contingency types listed below. Individual activity contingencies ranged from 10% to 75%, depending on the degree of difficulty judged to be appropriate from TLG's actual decommissioning experience, see Table 3-5. The overall contingency, when applied to the appropriate components of the estimate, on a line item basis, results in an average of approximately 22% for the Ringhals study.

It should be emphasized that contingency funds are expected to be fully expended throughout the program. They provide assurance that sufficient funding is available to accomplish the intended tasks, i.e., contingency funds are not a safety factor providing funds for situations that may never occur.

Table 3-5. Contingency values used in this study (SKBdoc 1403739).

Activity	Contingency
Decontamination	50%
Contaminated Component Removal	25%
Contaminated Component Packaging	10%
Reactor vessel removal and segmentation of internals	75%
Reactor Waste Packaging	25%
Non-Radioactive Component Removal	15%
Heavy Equipment and Tooling	15%
Supplies	25%
Engineering	15%
Energy	15%
Characterization and Termination Surveys	30%
Insurance	10%
Staffing	15%
Waste Processing (metal melt)	15%

4 Results

4.1 Scheduling

High level decommissioning schedules have been assembled for the Ringhals units; see Appendix I. The schedules show the decommissioning phases with the most significant activities and their estimated length during the decommissioning of each unit. Figure 4-1 shows a summarized decommissioning schedule for Ringhals 1–4.

The length of each activity has been based on the amount of work to be executed, and the number of persons that can work on one activity simultaneously. The work duration is calculated using the UCF and special analogy methods described in chapter 3.

Due to the early stage in the planning process, the level of detail in the present schedule is low. It is possible to shorten the projects by involving more personnel and allow longer working days. However, in order to optimize the cost/time parameters more information is required than is available today. Hence, a conservative approach has been used when compiling the 2013 schedules.

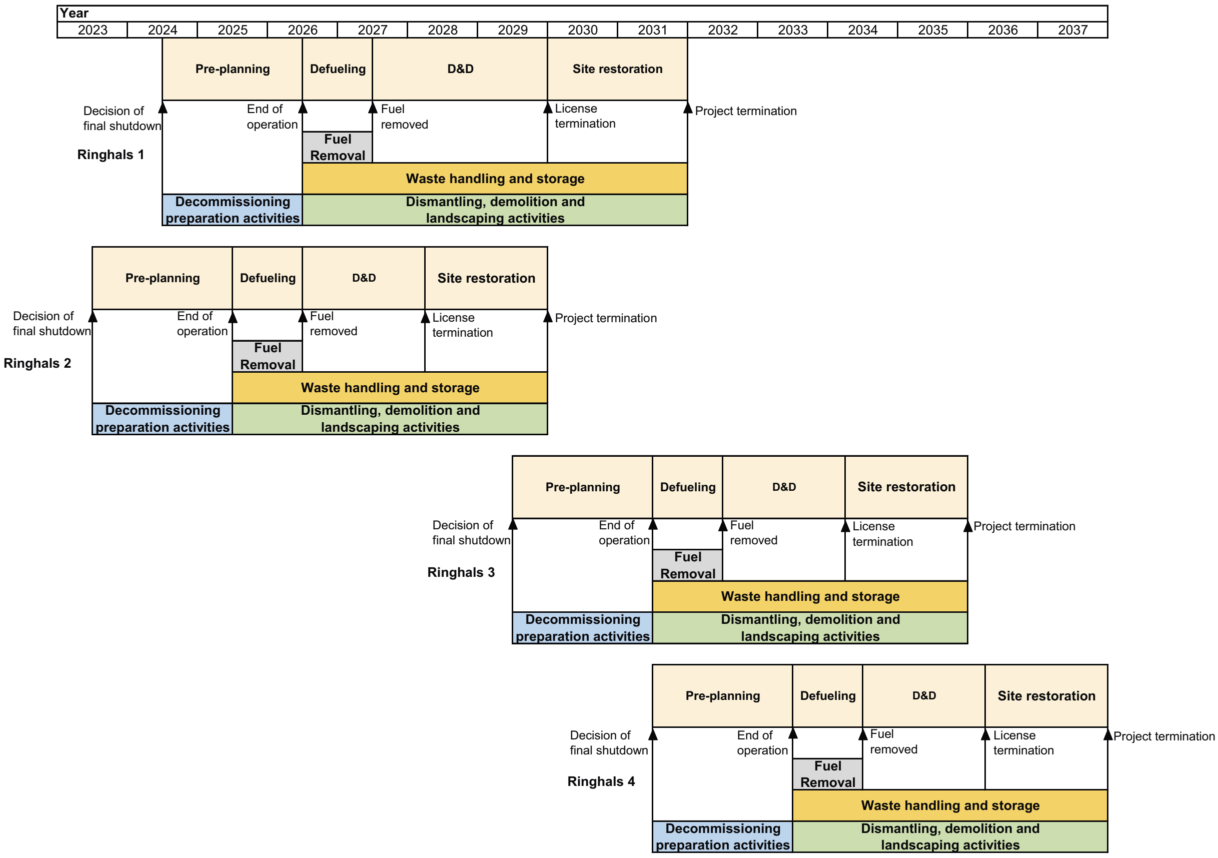

Figure 4-1. Combined decommissioning schedule for Ringhals 1–4.

4.2 Decommissioning Costs

The site decommissioning costs distributed as EEFs, are presented in Table 4-1. The decommissioning costs are distributed on three main EEFs:

[EEF 0] Payroll costs per unit produced in the service sector; 2.5 billion SEK.

[EEF 1] Payroll costs per unit produced in the construction industry; 2.0 billion SEK.

[EEF 4] Price trend for consumable supplies; 1.7 billion SEK.

In total, the salary costs represent approximately two thirds of the total cost, whereas equipment and consumables, including energy, represent the last third. This is expected as the decommissioning projects heavily depend on hands-on work and additionally require a large project support for e.g. radiation protection, engineering and waste treatment.

Table 4-2 presents the decommissioning costs separated between nuclear decommissioning required for license termination and conventional decommissioning (conventional dismantling, demolition and landscaping) for the four units and for the common buildings, unit 0.

Table 4-1. First level ISDC costs presented as EEFs, in kSEK. The costs separated between Ringhals 1–4 and unit 0 is presented in Appendix K.

	ACTIVITY	EEF-CODE					
		0	1	2	4	7	TOTAL
1	Pre-decommissioning activities	194,853	–	–	–	–	194,853
2	Facility shutdown activities	175,887	–	–	–	–	175,887
3	Additional activities for safe enclosure or entombment	–	–	–	–	–	–
4	Dismantling activities within the controlled area	–	881,445	347,190	853,260	–	2,081,895
5	Waste processing, storage and disposal	285,702	28,021	–	385,114	–	698,838
6	Site security, surveillance and maintenance	89,426	–	–	167,612	256,061	513,098
7	Conventional dismantling, demolition and site restoration	349,870	1,077,926	–	291,987	–	1,719,784
8	Project management, engineering and site support	1,229,377	–	–	72	–	1,229,448
9	Research and development	–	–	–	–	–	–
10	Fuel and nuclear material	–	–	–	–	–	–
11	Miscellaneous expenditures	130,960	–	–	–	–	130,960
	TOTAL	**2,456,074**	**1,987,393**	**347,190**	**1,698,045**	**256,061**	**6,744,763**

The variables that have been defined are:

EEF 0 − Real payroll costs per unit produced in the service sector.

EEF 1 − Real payroll costs per unit produced in the construction ind.

EEF 2 − Real price trend for machinery.

EEF 3 − Real price trend for building materials.

EEF 4 − Real price trend for consumable supplies.

EEF 5 − Real price trend for crude copper.

EEF 6 − Real price trend for bentonite and similar materials.

EEF 7 − Real price trend for energy.

Table 4-2. Costs separated on nuclear and conventional decommissioning, in kSEK.

	R1	R2	R3	R4	Unit 0	Totalt
Conventional decommissioning	355,443	361,896	397,564	407,723	155,398	1,678,024
Nuclear decommissioning	1,513,475	1,203,665	1,160,842	1,160,418	28,338	5,066,738
Total	**1,868,919**	**1,565,561**	**1,558,406**	**1,568,141**	**183,736**	**6,744,763**

It can be noted that it is more expensive to achieve a license termination for a BWR than a PWR. This is expected due to the larger inventory of contaminated systems in the BWR. However, the conventional decommissioning costs are similar for both reactor types as these costs are related to the footprint of the unit.

Within a decommissioning context, the Financial Act (SFS 2006:647) requires funding for removal of, so called, rest-products, i.e., cost for removal of the nuclear decommissioning waste (3§, 4§ 2. and 6§). In Figure 4-2, the decommissioning cost for the site has been separated in a nuclear and a conventional share.

It can be seen that the total estimated cost for decommissioning of the Ringhals site according to the BoE stated in chapter 2, and the method presented in chapter 3, is 6.74 billon SEK. Of these, the financial act requires a deposit of 5.07 billion SEK in the waste fund.

The total decommissioning cost for the Ringhals site is presented according to the ISDC structure in Table 4-3. The costs at the first reporting level follow an expected hierarchy:

[04] Dismantling activities within the controlled area; 2.4 billion SEK.

[07] Conventional dismantling, demolition and site restoration; 1.4 billion SEK.

[08] Project Management, Engineering and Site Support; 1.2 billion SEK.

The numbers on specific second-level categories should be seen as indicative; re-location between different posts could easily find support in the ISDC guide.

In order to assess the need for funding, the cash flow in the decommissioning project is of interest. Figure 4-3 shows a schematic representation of the costs for the site decommissioning as a function of time. In this early estimate, the level of detail is low and the cash flow is to be seen as indicative. Nevertheless, the assessment indicates that a nearly linear spending of the 6.74 billion SEK could be expected between the years 2023 and 2037.

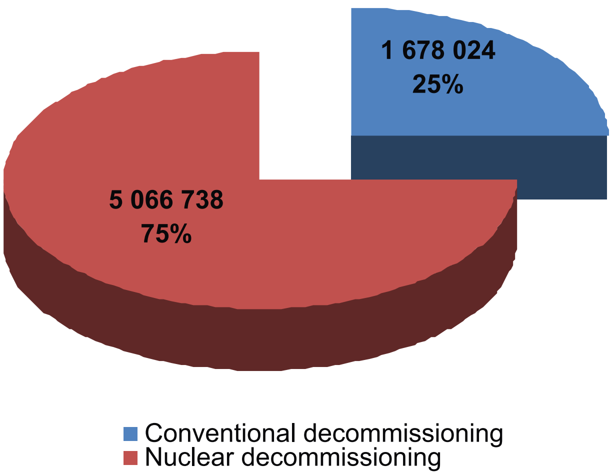

Figure 4-2. *Total costs in kSEK for nuclear decommissioning, required for license termination, and conventional decommissioning (incl. conventional dismantling of systems, demolition of structures and landscaping.*

Table 4-3. Decommissioning costs for the Ringhals site distributed as ISDC items. The costs separated between Ringhals 1–4 and unit 0 is presented in Appendix J.

ISDC NO.	ACTIVITY DESCRIPTION	TOTAL COST (kSEK)
01	**PRE-DECOMMISSIONING ACTIONS**	
1,01	Decommissioning planning	161,031
1,03	Safety, security and environmental studies	14,319
1,04	Waste management planning	12,238
1,05	Authorisation	7,265
		194,853
02	**FACILITY SHUTDOWN ACTIVITIES**	
2,01	Plant shutdown and inspection	113,287
2,04	Radiological inventory characterisation to support detailed planning	62,599
		175,887
04	**DISMANTLING ACTIVITIES WITHIN THE CONTROLLED AREA**	
4,01	Procurement of equipment for decontamination and dismantling	559,865
4,02	Preparations and support for dismantling	96,271
4,03	Pre-dismantling decontamination	279,401
4,05	Dismantling of main process systems, structures and components	761,940
4,06	Dismantling of other systems and components	291,403
4,07	Removal of contamination from building structures	93,357
4,09	Final radioactivity survey for release of buildings	345,285
		2,427,522
05	**WASTE PROCESSING, STORAGE AND DISPOSAL**	
5,01	Establishing the waste management system	157,573
5,08	Management of decommissioning intermediate-level waste	49,438
5,09	Management of decommissioning low-level waste	479,002
5,10	Management of decommissioning very low-level waste	12,344
		698,357
06	**SITE SECURITY, SURVEILLANCE AND MAINTENANCE**	
6,01	Site security operation and surveillance	89,426
6,03	Operation of support systems	288,668
6,04	Radiation and environmental safety monitoring	135,005
		513,098
07	**CONVENTIONAL DISMANTLING,DEMOLITION,AND SITE RESTORATION**	
7,02	Dismantling of systems and building components outside the controlled area	458,773
7,03	Demolition of buildings and structures	852,354
7,04	Final cleanup, landscaping and refurbishment	56,590
7,05	Final radioactivity survey of site	7,075
		1,374,792
08	**PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT**	
8,02	Project management	452,074
8,03	Support services	663,986
8,04	Health and safety	113,235
		1,229,295
11	**MISCELLANEOUS EXPENDITURES**	
11,01	Owner costs	73,097
11,03	Insurances	57,862
		130,960
	DECOMMISSIONING TOTAL	**6,744,763**

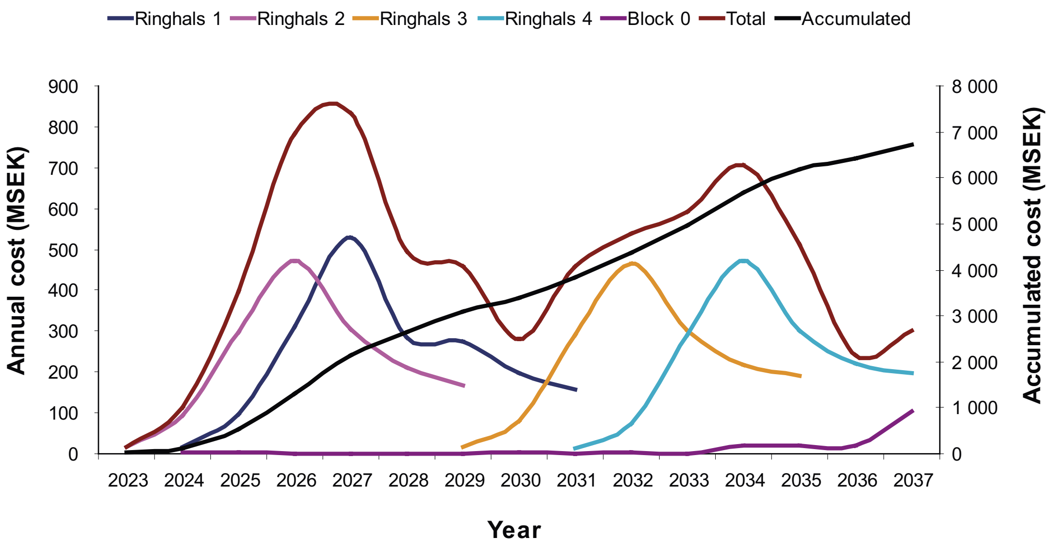

Figure 4-3. *Schematic cash flow during the site decommissioning. On the left hand scale, the costs for individual units are seen; on the right hand the accumulated cost for the site can be seen (black curve).*

4.3 Decommissioning Waste Amounts

The number of waste packages and their corresponding contents has been calculated from the activity inventory and the masses of waste, and the waste package criteria. The calculation has been carried out on a subsystem basis as there occasionally are large variations in isotopic concentration within a system. Table 4-4 presents an overview of the result of the calculation. A more detailed presentation is given in Appendix L.

It should be noted that some minor changes have been introduced as compared to the TLG Waste Package Analysis (Ringhals 2013f). Firstly, waste arising from metal melt of steam generators has been updated with data from the actual waste treatment of steam generators from Ringhals 2–4. Secondly, due to the compacted schedule the waste is now assumed to be packaged in average one year after unit shutdown, instead of the original three. The isotopic concentration has been adjusted accordingly.

Table 4-4. Waste amounts and number of waste containers for the Ringhals site.

Waste type	Total weight (metric ton)	ISO Containers <500 Bq/kg	ISO Containers	Steel Boxes	Large Steel Boxes	BFA Tanks
Systems	13,448	315	318	154	286	
Buildings & Structures	3,558		59		352	
Reactor Vessel and Internals	2,421		5		28	9
Secondary Wastes	946		94	41		
Total	**20,373**	**315**	**476**	**195**	**665**	**9**

Figure 4-4 shows the relative amount of different waste packages as percentage of quantity, mass and purchase price. It can be seen that the ISO containers dominate the quantity and mass fraction, whereas the large steel boxes completely governs the cost. Despite the very small quantity of BFA tanks, and their negligible share of waste, these still represent a fair share of the total waste package cost.

Table 4-5 and Table 4-6 show the total amount of scrap metal and the relative quantities of the main metals, respectively. In the cost estimate, no income has been allocated to scrap sale. The figures are, nevertheless, interesting as they indicate the potential recovery of reusable metals.

Table 4-5. Total waste amounts of scrap metal for Ringhals 1–4 and unit 0.

Unit	Total weight (metric ton)
Ringhals 1	31,075
Ringhals 2	46,358
Ringhals 3	47,595
Ringhals 4 incl. unit 0	59,337
Total	**184,365**

Table 4-6. Estimated material distribution of scrap metals for Ringhals.

Metal	Total weight (metric ton)
Carbon Steel	169,491
Stainless Steel	7,121
Copper	5,938
Titanium	1,604
Other	212
Total	**184,365**

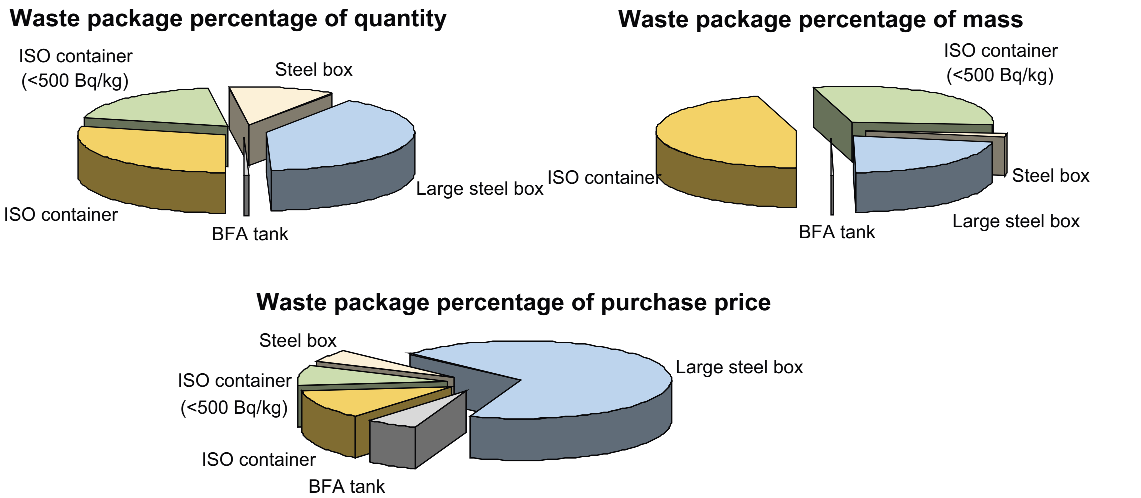

Figure 4-4. *Schematic waste package distribution visualized as percentage of quantity, mass and purchase prize. It should be noted that the total handling cost is significantly higher than the purchase prize.*

5 Discussion

Many U.S.-based assumptions regarding the regulatory environment still remain in the 2013 cost estimate. However, the remake of the model has made it possible for the RAB staff to progressively "Swedify" the estimate in the coming years. Hence, the remake was a necessary first step in order to make future improvements possible. The Swedish aspects that have been introduced in this version, coupled with the preserved experience-based TLG-data, well represent the status required for a site with more than 10 years of remaining power operation and the uncertainties of a budgetary estimate.

To strengthen this conclusion, a discussion of the major cost drivers and conservatisms are presented in the following pages.

5.1 Major cost drivers

In this section major cost drivers are discussed from a literature point of view and from the specific conditions in the present study.

5.1.1 Literature on major cost drivers

Published material on major decommissioning cost drivers (Laraia 2012, O'Sullivan and Pescatore 2009, OECD/NEA 2003, 2010) could, largely, be summarized under the following five areas:

General circumstances

The type of reactor, its size and operating history will, together with the overall decommissioning strategy (entomb, safstore, prompt), be the major drivers in determining the total cost of the decommissioning. Additionally, the number of units on the site, both regarding possible constraints and synergetic effects, and any plan for site-reuse after decommissioning, will play an important role for the overall size of the costs.

Basic project assumptions

This area contains the boundaries of the decommissioning project, i.e., the transition from operation to decommissioning including social and political factors, the relation to other ongoing operations on the site that are not specific to the decommissioning, and the project scope in general. Cost drivers are, for example: potential changes to the project plan, changes in the physical and radiological materials inventory, regulatory changes and increased requirements for additional information and detail etc.

Cost estimation model

The UCF-based method introduces major cost drivers for the estimate. The main cost drivers within this area are: the assumed duration of the dismantling, demolition and clean-up activities, labor costs, strategies for procurement and overall project management, and material and equipment cost.

Assumptions for waste management

The fourth major cost driver area during decommissioning will be the waste management. Of primary importance is the total amount of waste, both nuclear and conventional, and the choices made for disposition of major components, structures and infrastructure. Furthermore, the availability of off-site disposal facilities and on-site storage and disposal facilities will be of importance in the estimate, as will the options of waste canisters and transport solutions.

Technical assumptions

The final cost driver area is technical assumptions. A major cost driver within this area is the potential need for construction of new facilities or modification of existing facilities to facilitate decommissioning. Other main cost drivers are the removal rates associated with intervention techniques and the contingency application.

5.1.2 Cost drivers in the present study

Due to the technical approach of this study, many of the major cost drivers fall outside the scope of this estimate, c.f. basis of estimate. Remaining, within respective area are:

General: Decommissioning strategy and plan for site reuse

Basic assumptions: Physical and radiological inventories and the regulatory environment

UCF: All apply

Waste: Disposition of large components and waste canisters

Technical: All apply

General circumstances

The decommissioning strategies are in a world wide perspective moving towards shorter transition periods. In line with this, RAB's strategy is prompt decommissioning without unnecessary delay after final shutdown. This strategy is expected to minimize the overall doses, ensure availability of key-competences and minimize the total cost for the decommissioning period.

As mentioned in the basis of estimate, RAB plans for future energy production on the site. This requires decommissioning of the present units to a brown-field state. A change in the plan for future site reuse to, e.g., green field, would affect the overall project costs, but not significantly. The present estimate includes costs for removal of all radioactivity, relevant buildings and structures, and landscaping to re-create an environment close to the surrounding land. The difference to a green-field state is removal of remaining structures that, in this estimate, are considered useful for future energy production (roads etc.) together with a more thorough survey of potential ground contamination of non-radioactive environmentally harmful agents (oils etc.).

Basic project assumptions

The physical inventories assumed in this study are to a significant extent based on reference data from other NPPs. The reference plants have been chosen to be as similar as possible to respective Ringhals unit, but on the conservative side considering size, volume, weight and amount. For a budgetary estimate, this is a standard approach and well within the uncertainties of the estimate. RAB has initiated a physical inventorying of the PWR units during 2013. The result of this work will be included in future cost estimates to reduce the uncertainties and conservatisms. From a cost driver perspective, this work is expected to lower the total cost in the future.

The radioactive inventory has been based on present activity levels at respective reactor and an extrapolation based on the assumption that remaining production years will progress in line with the past decade. Major changes in the inventory, e.g., due to fuel cladding failure in one of the last cycles, would increase the costs. However, the increase would mainly be associated with an increased need for primary system decontamination. In the present estimate, an extremely conservative DF of 10 has been applied. In the real case, a factor between 100–1,000 is expected (Ringhals 2013e). As the decontamination, additionally, is most effective on new contamination, the clean-up after a potential late fuel failure is expected to be efficient. The additional need for decontamination is thereby considered to fall within the conservatisms of this estimate.

The second aspect regarding the radioactive inventory is the total amount of contaminated surfaces. In this case, the reference inventory provided by TLG is considered conservative since it assumes that all components that could potentially have been contaminated is contaminated, and hence are already treated as active waste in the estimate. As a result, it is held unlikely that the estimated amount of radioactive waste will increase if not a major accident happens. The inventorying of the Ringhals PWR units that has started during 2013 is, in line with this, expected to lower the costs in the present assessment by reducing the contaminated share of the inventory.

As described in the basis of estimate, the regulatory environment assumed in this study is based on NRC's guidance. It is expected that changes will be introduced that affects the cost once a Swedish regulatory guidance has been established. Nevertheless, the cost-impact of these changes is expected to be small in comparison to the large overall sum of the project due to the large similarities that are normally found between Swedish and US nuclear regulations.

Cost estimation model

In the present estimate, one of the focal areas has been to shorten the project time in order to: i) lower the total dose, ii) ensure availability of experienced personnel, iii) lower the costs, and iv) to make the site free for new energy production as soon as possible. As a result, a large part of the planning has been shifted prior to the final shutdown in order to make a full scale dismantling and demolition possible from day one. In comparison to previous studies, more work is planned to be carried out in parallel during the D&D phase as well as the Site restoration phase, which results in more personnel on the site simultaneously. Due to this optimization, the period dependent cost will be reduced, but any delay in the decommissioning program will be related to larger costs than previously. The duration of the dismantling and clean-up activities are therefore expected to be major cost drivers in the project, which must be associated with low uncertainties in order not to become an unacceptable risk. In the present study a significant post for planning has been introduced. Additionally, RAB has already started up a decommissioning group with the sole purpose to plan for the decommissioning during the remaining years of power operation. As the optimization in this study has been left at levels that find support in outage and modernization projects, these measures are expected to assure that the project will meet its target time. It is held for likely that the total time for each decommissioning project will be possible to shorten even further in the future, once the detailed planning phase has been initiated.

The labor costs used in the assumption are based on present experience of contractor rates and salaries for own personnel. Changes in labor cost will significantly affect the total price for the project. This, however is treated as a risk, and accounted for, in the Plan-report. In the best estimate assumption made in this work, the labor costs are associated with relatively small uncertainties since they are well known in comparison to other parameters.

SKB has, in cooperation with the licensees, developed a new standard project management organization for a Swedish decommissioning project. This organization has been based on experiences from Swedish reactor constructions and recent large modernization projects carried out at the nuclear sites. The functions identified in the project management organization have been based on both project needs and decommissioning specific needs. One aim of the work has been to clarify the roles of the licensee regarding direction and support and separate these functions from the project management organization. If the decommissioning projects are considered as standard nuclear undertakings by a licensee, it can be argued that the costs related to the licensee's support and direction should be allocated to the licensee and not the project. This would significantly lower the costs for the decommissioning projects. Nevertheless, in this estimate the total cost for both the PMO and necessary licensee organization is included. As a result, this major cost driver is expected to be estimated with relatively large conservatism in the present study.

Equipment rental and purchase costs have in this estimate been taken from the same references as TLG used in the Barsebäck study. Hence, all costs for equipment are U.S. based and reported in USD. Conversion to SEK has, together with a consumer price index adjustment, given the numbers used in this estimate. Presently, no cross-comparison has been made between Swedish and U.S. costs for equipment on a detailed level. A brief scan of major costs within this post, e.g. crane rental for RPV removal, indicates a good agreement with Swedish experiences. But until a more detailed review has been made, the costs for equipment remain relatively uncertain.

Assumptions for waste management

RAB has recent experience of treating many large components from the modernization projects. These experiences have been included in the estimate. Hence, the relatively large cost for treating steam generators etc is expected to be associated with small uncertainties.

In the estimate, the same waste canisters are expected to be used as is presently used during operation. The only exemption is the, so called, large steel box or "4-kokillslådan". The costs associated with these canisters, i.e., ISO-containers, steel- and, BFA-tanks, are based on recent purchase prizes. The large steel box is expected to cost four times more than the normal steel box. As the waste canister costs for a Swedish decommissioning, additionally, is relatively minor in comparison to other cost drivers, this cost driver is expected to be related to small uncertainties both in the absolute numbers and as percentage.

Technical assumptions

New facilities are not considered necessary for the Ringhals decommissioning, and it is presently held for unlikely that this would change in the future. If any new structure is found needed in the future, it is likely that this structure will be useful also during operation and, hence, be completed before the decommissioning starts.

The removal rates used in this estimate are the same as TLG used in the Barsebäck study. TLGs experience is that hard/rough dismantling methods together with careful protection of surrounding surfaces are to prefer both from an ALARA and economic point of view, hence these types of methods are used in the estimate. Nevertheless, as the dismantling and demolition methods used in the estimate is completely based on productivity rates, other methods could with a relatively limited effort be included in the estimate. Though, the only rationale for doing this is if new methods are found to be more efficient, or cost effective, than the present ones. From a radiation protection point of view, the methods used in the study are already associated with doses far below present limits.

The contingency application in this estimate has been presented in chapter 3.4. It is completely based on published industrial experiences and is in line with TLG standard approach to contingencies. In Laraia (2012) the TLG cost estimate prior to start-up of the Main Yankee decommissioning (880 MWe, PWR) is presented together with the outcome of the project. In the estimate, the contingency was assessed to 42.1 MUSD, whereas the actual contingency cost was 16.5 MUSD. This, despite major cost-increasing project changes as compared to the original plan, see reference for details. Even though the conclusion is based on a single experience, the TLG way of assessing contingencies seems to be conservative by a factor 2-3. In the coming years, hopefully, more documented real costs from decommissioning projects will be published world-wide. Until then, the standard industry approach for contingencies is assumed to be conservative in a nuclear decommissioning perspective.

5.2 Assessment of conservatisms

In the previous section, the discussion around uncertainties and cost drivers frequently touched the issue of conservatism in the estimate. This section aims to clarify in what perspective the present estimate is conservative in its assumptions. As described in the introduction, the aim of the study has been to find a best estimate for the decommissioning costs; hence, conservatisms are generally unwanted. Nevertheless, in order not to underestimate the total cost any uncertain assumption has, as far as present knowledge allows, been made in a mildly conservative way throughout the entire study.

5.2.1 Basic data

The physical inventory has been based on data from the Ringhals units and complemented with data from known inventories of comparable NPPs. The reference inventory for the PWRs provided by TLG is representative for a Westinghouse 3-loop reactor with a thermal output approximately 5% greater than the average of the Ringhals PWRs. With the assumption that there exists a correlation between power and size, the PWR reference inventory is assessed to be conservative. For Ringhals 1, the major part of the inventory comes from actual Ringhals records. Based of the experience from expert judgments of operators with long experience from Ringhals 1 and the Barsebäck units, the Ringhals 1 inventory has been complemented with Barsebäck data as-is or with an addition of 20%. This methodology is assessed to result in a near realistic inventory for Ringhals 1, negligibly conservative.

The costs associated with the radioactive inventory are mainly related to the size of the contaminated system surfaces and to the weight of the contaminated components, there is only a weak correlation to the level of contamination in the systems. As a result, the uncertainties in the activity levels reported in the ALARA Engineering reference, spanning from ± 50% for the reactor internals to a factor of 10 for waste treatment systems (Ringhals 2013d), are of minor importance for the cost estimation since contaminated systems has an associated cost that is more or less constant regardless of the contamination level (at least for changes within a factor ±10). TLG has, based on the ALARA Engineering report and U.S. experiences, predicted the amount of contaminated systems and components for respective Ringhals unit at the time for decommissioning. In the TLG-prediction, the ALARA Engineering level of contamination in different systems has been coupled to significantly higher component weights than in the original ALARA Engineering estimate. Additionally, TLG has complemented the contaminated inventory with systems parts not previously considered contaminated. Altogether, this leads to a conservative assessment of the amount of contaminated systems and components of, at least, 10% (mainly due to the U.S. based assumptions since the U.S. plants, in general, are more contaminated than the Swedish).

5.2.2 Activity dependent costs

The activity durations in the UCFs have been based on real experiences from decommissioning projects. They are constantly updated by TLG to account for new knowledge and experiences from the decommissioning field world wide. The target has been (and is) to construct best estimate cost factors, hence this part of the cost assessment is assumed to be close to the actual duration, i.e., neither conservative or optimistic.

The source for labor salaries is RAB internal costs for project planning; hence, the salary for respective category is expected to be close to the actual cost. In the overall labor costs, activity dependent overheads are included, these are conservatively based on the Barsebäck study. In the case of Ringhals, most of these overhead costs are assumed to be covered by the licensee (e.g., telephones, computers, offices etc.) but they are kept in the present estimate since more analysis is needed before they permanently could be removed. This results in an estimated conservatism on the labor costs at about 5–10%.

Equipment rental and purchase prices are, as discussed above, taken from U.S. references. A brief cross-comparison indicates good agreement between the Swedish and U.S. market. Consequently, the costs associated with equipment rental and purchases are expected to be close to the actual, i.e., a best estimate without significant conservatisms.

Costs developed using a specific analogy approach, i.e., mainly the reactor vessel removal costs derived from the Trojan decommissioning project, are associated with greater uncertainties than the costs assessed by the bottom up approach used in the UCFs. As there is no general formula for converting costs between one country and another or one reactor size to another, a certain level of qualified estimating is needed. In this work, mainly physical factors as size and weight have been used together with logistical considerations to compare the Ringhals and Trojan conditions in order to estimate the Ringhals costs. Moreover, the, by far, largest contingency has been added to the reactor vessel removal (+ 75% on the total cost) to cover for unspecified events. This contingency factor is normally used for complicated reactor vessel segmentation procedures, but has also been used in the Ringhals study for the one piece removal. Overall, this approach is assumed to lead to a conservative assumption of the cost. However, the level of conservatism is hard to assess, the best presumption presently is a conservatism somewhere between +10% and +75%.

5.2.3 Period dependent costs

In the program management organization, described in chapter 2 and 3, the project costs have been separated from the licensee costs. As described the major management costs are associated with the undertakings of the licensee and its associated organization, 41 man-year per year, and only 27 man-year per year is associated with the project management for the decommissioning project. During the decommissioning of the first three units at the Ringhals site, it is likely that the licensee organization is supported by funds from the power producing units. Despite this, all four units have been allocated funds in this estimate for the entire organization of 41+27 man-years/year. Together, this represents a very conservative approach for the management organization, which, could be argued, is far from a best estimate. Nevertheless, as the introduction of a new project management organization has far-reaching consequences on the pre-planning and decommissioning schedule it requires a more thorough analysis before any numbers are adjusted. As a result, RAB has chosen to stay with the conservatisms in the 2013 estimate, and plans to analyze the impact until the next revision in order to lower the conservatisms.

In the present estimate, the period dependent costs from the Barsebäck study for electricity, water and gas; insurances; emergency response; and corporate expenses, have been introduced without further assessment. It is held for likely that these costs are significantly lower per unit at the Ringhals site since power production will continue in parallel with the decommissioning projects. Hence, costs for grid and water connections, and emergency response are assumed to be covered by the power producing units. Additionally, the cost for corporate expenses is presently unclear regarding its contents. However for conservative reasons, all these costs have been left unaltered until a deeper analysis has been carried out. At the present, an estimate is that these period dependent costs are up to twice as large as required.

5.2.4 Collateral costs

The collateral costs in this study have been introduced as estimated in the Barsebäck study. BKAB has great experience from preparatory work as characterization, safety assessments, full system decontamination, and environment impact assessments. The cost assessment made for these costs are, therefore, assumed to be close to the expected, i.e., associated with an insignificant conservatism.

No income has been allocated to scrap or salvage even though it is clear from the present operation that e.g. cupper, stainless steel and normal steel are possible to sell with a relatively great return. However as the market is hard to predict, potential incomes from scrap and salvage are to unreliable to account for in this estimate. Consequently, scrap and salvage is left with a conservative assumption of unknown size in this estimate.

5.2.5 Contingency

The conservatisms in the contingency addition have been discussed in chapter 5.1. Presently available data from the Main Yankee decommissioning project, which was cost-estimated by TLG prior to project start, indicate that the contingency addition well covers the unforeseeable events. The single dataset shows a great conservatism for the TLG method of about 250%. Nevertheless, as the contingency levels used in this work are standard for the industry, RAB has not made any changes to lower the conservatism.

5.3 Uncertainty and associated concepts

Within this study, a number of concepts are used that, at a first glance, are easy to confuse; uncertainty, contingency, conservatism and risk. In the literature, slightly varying definitions are found for respective concept, which adds to the confusion. Nevertheless, in this study a strict use of the concepts has been applied as follows:

Uncertainty: is the estimated percentage by which the calculated value may differ from the true value. The costs presented in this work represent a budgetary estimate, i.e., a best estimate with an unevenly distributed uncertainty between –15% and +30%. All uncertainties in the inputs are propagated to result in this overall uncertainty. Due to the complexity of the analysis, statistical error propagation has not been possible. Hence, the level of uncertainty is based on judgments of data accuracy, contingency and conservatism.

Contingency: is a specific provision for unforeseeable elements of cost within the defined project scope. The contingency addition is necessary to compensate for deliberately over-optimistic assumptions regarding the work carried out in the project. In projects of this size, delays and interruptions take place, e.g., due to weather problems, equipment breakage etc. Experience based contingency additions are therefore necessary to scale up the base estimate to a best estimate. Without contingency addition, statistical corrections would have been necessary on all UCF posts, e.g. +25% average time, +25% on listed prices for supplies etc. This would have been significantly less transparent.

A tempting option is to use the contingency additions to account for synergetic effects (lower them) due to repetitive performance of certain tasks. This, however, is not made in the Ringhals estimate as the contingency in this work is seen as a purely statistical correction for events that are just as likely to occur on the hundredth repetition as on the first. Synergetic effects are corrected for separately.

Conservatism: is, in nuclear engineering, added to lower the risk in an estimate, i.e., to deliberately shift the uncertainty distribution in one direction. In a cost estimate, the major risk is to underestimate the costs due to unidentified aggravating factors; additionally, an underfinanced decommissioning project presents as a considerably greater risk than an over financed. In order to correct for this, conservatism is added to ensure that any assumptions made in the estimate results in a slightly higher cost than expected. The larger the uncertainty associated with the specific assumption is, the larger conservatism is added to the value.

Risk: is any uncertain event that can have an impact on the success of the project. Project risks are not considered in this estimate, all risk factors will be addressed as part of the Plan 2013 report. Some examples of risks that are not covered in this estimate are:

- Delays in approval of the decommissioning plan due to intervention, public participation in local community meetings, legal challenges, and national and local hearings.
- Changes in the project work scope from the baseline estimate, involving the discovery of unexpected levels of contaminants, contamination in places not previously expected, contaminated soil previously undiscovered (either radioactive or hazardous material contamination), variations in plant inventory or configuration not indicated by the as-built drawings.
- Regulatory changes, e.g., affecting worker health and safety, site release criteria, waste transportation, and disposal.
- Policy decisions altering national commitments, e.g., in the ability to accommodate certain waste forms for disposition, or in the timetable for such.
- Pricing changes for basic inputs, such as labor, energy, and materials.

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1403739 ver 1.0	Decommissioning cost analysis for Barsebäck nuclear station. Document S33-1567-002,Rev. 0, TLG Services, Inc.	TLG, 2008

Abbreviations and acronyms

AACE/AACEI	The Association for the Advancement of Cost Engineering / International
AIF/NESP	Atomic Industrial Forum/National Environmental Studies Project
ALARA	As Low As Reasonably Achievable
BKAB	Barsebäck Kraftgrupp AB
BoE	Basis of Estimate
BWR	Boiling Water Reactor
D&D	the “Dismantling and Demolition” phase
DECCER	DECommissioning Costs, Exposures and Radwaste
DF	Decontamination Factor
EEF	External Economic Factors
EIA	Environmental Impact Assessment
FUD	Forskning, Utveckling och Demostration (Research, Development and demostration)
ILW	Intermediate Level Waste
ISDC	International Structure for Decommissioning Costing
LLW	Low Level Waste
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
PMO	Project Management Organization
PWR	Pressurized Water Reactor
RAB	Ringhals AB
RPV	Reactor Pressure Vessel
Rx	Ringhals unit x, x = 1, 2, 3 or 4.
SSM	StrålSäkerhetsMyndigheten (Swedish radiation safety authority)
SEK	SvEnska Kronor (Swedish currency)
SFL	Slutförvar för långlivat avfall (Final repository for long-lived waste)
SFR	Sluftörvar för kortlivat låg- och medelaktivt avfall (Final repository for short lived LLW and ILW)
SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Co)
TLG	TLG Services Inc.
UCF	Unit Cost Factor
USD	U.S. Dollars
VAT	Value Added Tax
VLLW	Very Low Level Waste
WDF	Work Difficulty Factor

Appendix A

Regulatory framework

The regulatory framework in Sweden is not sufficiently defined to construct an analysis on. Therefore, in the TLG study the regulations from the U.S. NRC are followed.

The NRC provides decommissioning guidance in its rule “General Requirements for Decommissioning Nuclear Facilities” and in the Regulatory Guide 1.159 “Assuring the Availability of Funds for Decommissioning Nuclear Reactors”. The rule set forth technical and financial criteria for decommissioning licensed nuclear facilities.

Also the NRC published “Radiological Criteria for License Termination” of the Code of Federal Regulations” (10 CFR §20) has been used in the decommissioning estimate of Ringhals, as the radiological criteria for releasing the site for unrestricted use. The regulation provides that the site can be released for unrestricted use if radioactivity levels are such that the average member of a critical group would not receive a Total Effective Dose Equivalent in excess of 0.25 mSv per year, and provided residual radioactivity has been reduced to levels that are As Low As Reasonably Achievable (ALARA).

In addition to the U.S. regulations, Regulations in Sweden have been accounted for when applicable. Below the regulations are presented.

– The act on Nuclear Activities

Under the Act on Nuclear Activities the holder of a licence to operate a nuclear reactor is responsible for the safe handling and disposal of spent fuel and radioactive waste produced by the reactor as well as the decommissioning of the facility.

– Radiation protection act

Under the Radiation Protection Act, the holder of a license is responsible to take all measures and precautions necessary to prevent or counteract injury to human health and the environment by radiation.

– The act on Financing of management of Residual Products from Nuclear Activities

The Act on the Financing of Future Expenses on Spent Nuclear Fuel lays down the principles for the financing of expenses for decommissioning and disposal of spent nuclear fuel and nuclear waste. The basic requirement stipulates that the holder of a licence to operate a nuclear power reactor must pay a fee per delivered kWh of electricity to the Nuclear Waste Fund.

– The environmental Code

The Environmental Code regulates, amongst other things, the environmental impact statement that must accompany a license application.

– Euratom Treaty – Article 37

Article 37 of the Euratom Treaty lays down that each Member State shall provide the Commission with such general data relating to any plan for the disposal of radioactive waste in whatever form as will make it possible to determine whether the implementation of such plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State.

Appendix B

Site description From a Decommissioning Perspective

Well-functioning logistics is essential for an optimal decommissioning of a nuclear power plant. Developing a logistics plan is a complex process that requires information with a level of detail, that today with more than 10 years till decommissioning of the first unit, is not available. The aim of this appendix is to discuss the Ringhals site and logistical conditions from a decommissioning perspective.

The four Ringhals units are located in pairs within the same operating area (red line in Figure B-1). When a decommissioning project starts it is desirable to separate the units that are still in operation from those in decommissioning. The layout of the operating area makes it very easy to separate Ringhals 1&2 from Ringhals 3&4. By some modifications in the fences it is also possible to separate a single reactor if desired.

For an efficient decommissioning project it is very important that waste material is transported away from the immediate vicinity of the unit as soon as possible. To avoid bottlenecks it is therefore very important to have enough storage areas to handle the large waste flows, either on site or at the site of the waste receiver.

The Ringhals industrial area (blue line in the figure) is generously sized and has the ability to handle the waste flows and the storage of all waste generated during decommissioning, until it is transported to its final repository for disposal or to a waste treatment facility. Assuming that the need for storage reach the equivalent of 1,000 ISO containers from the decommissioning of Ringhals 1–4, the required storage area is approximately 7,600 m^2. This corresponds to area no. 1 in the figure, which is only a small part of the total space available at the Ringhals site.

Besides the large storage areas, Ringhals has a number of approved storage buildings for storage of low and intermediate level operational waste. One of these is the storehouse "Kokillförrådet" (no. 2 in the figure), which has a capacity to store up to 6,000 steel boxes. Another building is the Mausoleum (no. 3 in the figure) which has the capacity to store the reactor vessels and internals until SFL is in operation 2045. These buildings reduce the decommissioning activities dependence on the SFR extension time schedule and buffer capacity nearby.

At the time of decommissioning, the need to transfer large amounts of waste is great. Even today there are a large number of options for this (green line in the figure) and, if necessary, additional routes could be addressed. It should also be noted that the roads that are used today for heavy transports are reinforced and will cope with the transports needed during decommissioning without any additional reinforcements. Transportation of waste to the final repository or for further waste treatment will, like today, be done mainly by sea. Ringhals port, Videbergshamn (no. 5 in the figure), is located about 1 km from Ringhals industrial area and has the ability to accommodate ships of larger character.

Today there is a surface repository for very low level operational waste available at the site (no. 4 in the figure). In connection to this repository there is plenty of room for expansion of a surface repository for decommissioning waste. Having a surface repository at site highly reduces the need for transport, saving both the environment and the need of resources from the decommissioning project.

Figure B-1. *Layout of the Ringhals site. The blue line delineates the industrial area and the red line the operating area. The green line represents the transport route options. Area no. 1 shows the required storage area for the waste from decommissioning of Ringhals 1–4. No. 2 shows storehouse "Kokillförrådet", no 3. the mausoleum, no. 4 the surface repository and no.5 shows the Ringhals port, Videbergshamn.*

Appendix C

Decommissioning program

This chapter describes a generic decommissioning program[1] for the Ringhals units 1–4 based on a prompt dismantling strategy. The program comprises the main activities associated with nuclear dismantling and demolition, and the restoration of the site after license termination has been achieved.

The decommissioning of each Ringhals unit is as described in the basis of estimate divided into four phases. In this decommissioning program phases two and three are discussed as one called "Dismantling and demolition", as they from a program perspective have too large overlap to be separated.

The initial phase "Pre-planning" commences the day when Ringhals AB decides that one of its power plants will be permanently shutdown and continues till the day of final shut-down. The objective is to prepare in detail for the actual dismantling and demolition activities. The second phase "Dismantling & demolition" encompasses primarily the decommissioning actions; removing contaminated and activated equipment and materials, decontaminating the site buildings, and verifying that the site release criteria has been met. During the final phase "Site restoration" the remaining structures are demolished. The boundary between phases is not distinct. When applicable, activities from the different phases will carry on in parallel as different parts of the power plant will have different radiological status and importance to the decommissioning project at different times.

Although detailed procedures for each activity identified in the program are not provided, and the actual sequence of work may vary, these activity descriptions provide a basis not only for estimating cost, but also for estimating the expected scope of work, i.e., engineering and planning at the time of decommissioning.

Pre-planning

Prior to the commencement of the decommissioning actions, preparations are undertaken to prepare the plant for decommissioning. Preparations include engineering and planning, and preparing the site for the coming decommissioning actions.

Engineering and planning

Without any pre-defined order the following significant engineering and planning activities are anticipated during this period:

- All documents required for decommissioning will be prepared and submitted to the appropriate regulatory authorities.
- Activity specifications and detailed work procedures are prepared for all the activities to take place during decommissioning.
- Preparation and finalization of procurements for contractors, machines and tools, shipping canisters, cask liners, industrial packages, etc.
- Specifying transport and disposal requirements for activated materials and/or hazardous materials, including shielding and waste stabilization.
- Developing procedures for occupational exposure control, control and release of liquid and gaseous effluent, processing of radwaste (including dry-active waste, resins, filter media, metallic and non-metallic components generated in decommissioning), site security and emergency programs, and industrial safety.

[1] Due to design differences between BWR and PWR, activities only applicable on one of the designs are noted with a **BWR** or **PWR**.

Site preparations

In preparation for the actual decommissioning activities, the following significant activities are initiated:

- Detailed characterization of the site and surrounding environs (work areas, major components, sampling of internal piping contamination levels, and of the citadel structure.)
- Preparing the logistics; create laydown areas, locations for loading, create transport routes etc.
- If needed, construction of temporary facilities and/or modification of existing facilities to support dismantling and demolition activities.
- General house-keeping where material redundant for the remaining power operation and the decommissioning activities are removed from the power plant (process waste, tools, etc.)
- Preparations for temporary power during the decommissioning activities.
- Prepare for adjustments needed in the HVAC systems (heating, ventilation and air conditioning.)
- Historical fuel will be sent off-site before power operation ends.
- **BWR:** Preparations for the segmentation of internals (prepare storage pools, remote cutting equipment, lifting equipment, etc.)
- Preparations for the primary system decontamination.
- Design and fabrication of temporary and permanent shielding to support removal and transportation activities, construction of contamination control envelopes, and the procurement of specialty tooling.
- Free release measurements in buildings with no historical contamination, e.g. the PWR turbine building, storage buildings, offices etc.
- Demolition of non-important buildings to create space for the decommissioning activities.

Dismantling & demolition

When power operation ends the dismantling and demolition activities starts immediately. The project shall be operated in a rational and efficient manner where the decommissioning activities are carried out in parallel by multiple crews simultaneously in as many buildings as possible, while optimum efficiency, adequate access for cutting, removal and laydown space, and with the stringent safety measures necessary during the dismantling is maintained. Since the entire project is already planned the task for the project management organization is to keep the project on track regarding time schedule, budget, and monitor that the developed work procedures and safety guides are followed. Engineering and planning only takes place in a remedying purpose.

The following sub-sections describe the most significant decommissioning activities anticipated during this period.

Defueling

The nuclear fuel is outside the scope of this decommissioning study and the cost for defueling is therefore not included. The defueling activities are however very important for the development of a decommissioning program because of the requirements of operating cooling systems for fuel safety and residual heat removal. The presence of fissile material also places demands on security and emergency planning.

Fuel on-site is however not a vast limitation on most decommissioning activities. Almost all activities performed during decommissioning have been preformed on the different power plants in Ringhals (or other Swedish nuclear power plants) during remodeling work/replacements on the yearly outages or during the lifetime extensions/power increase projects carried out recently.

Approximately one year after final shutdown all nuclear fuel has been transported off-site. The removal of the fuel means a significant reduction in the plant radiological inventory which significantly reduces the total radiological hazard present on site. This will most likely allow a reduction in the nuclear and physical safety measures that must be taken, although the ALARA-principle is still being strictly followed.

Initial activities

Due to limitations in access and for plant and worker safety all preparations needed for decommissioning are not possible to commence during power operation. In addition to the activities taking place during "Pre-planning" the following tasks will take place:

- Adaptations to the HVAC systems, power systems, and waste systems to support decommissioning activities. As the decommissioning project progresses temporary systems will be installed/dismantled when needed.
- Systems/components not needed for plant and/or worker safety, or following decommissioning activities will be prepared for dismantling. This includes removal of insulation, drainage of systems, etc.
- Systems/components needed for plant and/or worker safety, or the decommissioning activities are separated from the rest of the systems/components and marked up so that there is no doubt about their further importance.
- A final verification of the site characterization will take place.
- In the initializing phase of decommissioning an extensive primary system decontamination will take place. In accordance with the ALARA principle this will minimize the worker dose exposure during the nuclear dismantling activities. This will also simplify the decommissioning activities due to a lower risk of spreading loose contamination and by simplifying and minimizing the waste management.

General dismantling activities

Initially systems and components no longer essential to fuel and/or worker safety, or support for the decommissioning actions are removed. As the decommissioning project progresses more systems and components are made redundant and are handed to the decommissioning project for dismantling.

Cutting techniques are in general divided upon two categories; mechanical and thermal methods. In this decommissioning estimate and in accordance with the Barsebäck TLG-study (SKBdoc 1403739) both will be used.

Decontamination of buildings and structures will run continuously during the decommissioning using mostly manual techniques as scrubbing, washing, etc., but also mechanical techniques e.g. scrabbling will be used when removing contaminated concrete. For more robust structures e.g. the biological shield controlled blasting techniques will be used.

Dismantling of large components

Dismantling of larger and/or more complex components/systems will need special developed tools and procedures. Today there are a number of specialized companies with experience from every one of the procedures needed during a decommissioning. These procedures have in most cases already been accomplished during outages and the experiences have been taken care of and saved within the Ringhals organization. The largest difference during decommissioning is that the methods can be rougher and the component removed will not need to remain in a condition to be put back into the power plant.

The general approach for handling large components is in this report to remove them in one-piece for further waste management outside of the unit.

The following sections describe procedure for some of the larger and/or more complex components/systems during a decommissioning.

Reactor vessel and internal components

Dismantling of the reactor vessel and its internals is by far the most complex task commenced during a decommissioning project. Due to design differences between the BWR and PWRs and also due to today assumed constraints in the final repository SFR the dismantling procedure and waste management for the vessel and its internals will differ between the blocks.

According to present assumptions, components containing a certain level of long lived low and intermediate nuclides will be deposited in the final repository SFL. It is assumed that parts of the internals from the BWR, all internals from the PWRs and the PWR vessels need to be deposited into SFL. The BWR vessel will be deposited into SFR.

Since the dismantling strategy for all vessels are one-piece removal the BWR internals needs to be removed from the vessel and segmented while they are left intact in the PWR vessels.

Depending on the activity level the internal parts will be put in adequate waste containers including ISO containers, large steel boxes, and BFA containers.

Since the internals contains a significant part of the activity left in the plant (excluding the spent nuclear fuel) it is of great importance to get it off-site as soon as possible to reduce the radiological hazard present on site. The segmentation of internals will start as soon as the fuel has been placed in the fuel storage pools.

The estimate for this study assumes that the vessels will be lifted through a hole in the containment/reactor building with a large crane and put in a shielding cask at a transportation vehicle. The BWR transportation vehicle will then be put on a barge/ship for transportation to SFR while the PWR vessels will be stored on Ringhals until 2045 when SFL will be in operation.

Large primary side components

Reactor recirculation piping is cut from the reactor vessel once the vessel has been emptied of its internal parts and the systems decontamination has been performed. The reactor recirculation/coolant pumps and motors are lifted out intact and packaged for transport and disposal.

PWR: The steam generators will be removed using the same techniques as used during the replacement of steam generators at Ringhals 2–4. Once the steam generator has been removed they will be transported to a processing facility for metal-melt.

Other large components

The main turbines are dismantled using conventional maintenance procedures. The main condensers are due to their size disassembled and transferred to the waste processing area in pieces.

Heat exchangers, feed water heaters/de-aerators, moisture separator/re-heater, large valves, etc will to the extent possible be removed in one-piece. All penetrations will be properly sealed before transported to the waste processing area.

License Termination Survey

A final radiological survey to ensure that all radioactive materials in excess of permissible residual levels have been remediated will be made as soon as an area has been cleared and decontaminated. When a room or part of a building is free for release it will be locked and secured pending conventional demolition.

Site restoration

The decision to demolish, reuse, or modify remaining free-released structures is an owner decision. This study includes the estimated costs for demolition of the structures and restoration of the site after completion of radioactive license termination activities. These costs are segregated and do not need to be covered by the national fund. The scope of demolition and restoration is based on the following:

1. Demolition of the remaining portions of the power block structure and interior portions of the reactor building. Internal floors below grade level are removed from the lower levels upward, using controlled blasting techniques. Concrete rubble is crushed and processed for use as clean fill.
2. Removal of the remaining buildings using conventional demolition techniques for above ground structures.

3. Foundations and exterior walls are assumed to be removed to a nominal depth of one meter below grade whenever possible. The one-meter depth allows for the placement of gravel for drainage and topsoil so that vegetation can be established for erosion control.
4. Site areas affected by the demolition activities are cleaned and the plant area graded as required to prevent ponding and inhibit the refloating of subsurface materials.

Design differences between a BWR and a PWR from a decommissioning perspective

As mentioned in the decommissioning program there are some major design differences between a BWR and a PWR, see Figure C-1 and Figure C-2. These design differences will significantly affect the decommissioning program, time schedule, and cost for the both reactor types. Beneath some of the major differences from a decommissioning point of view is described.

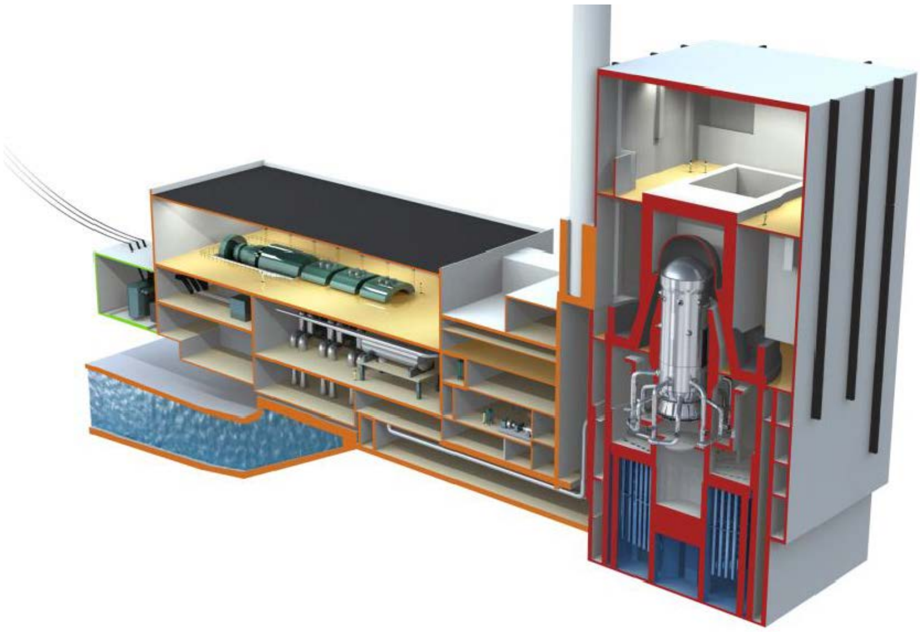


Figure C-1. *Boiling Water Reactor.*

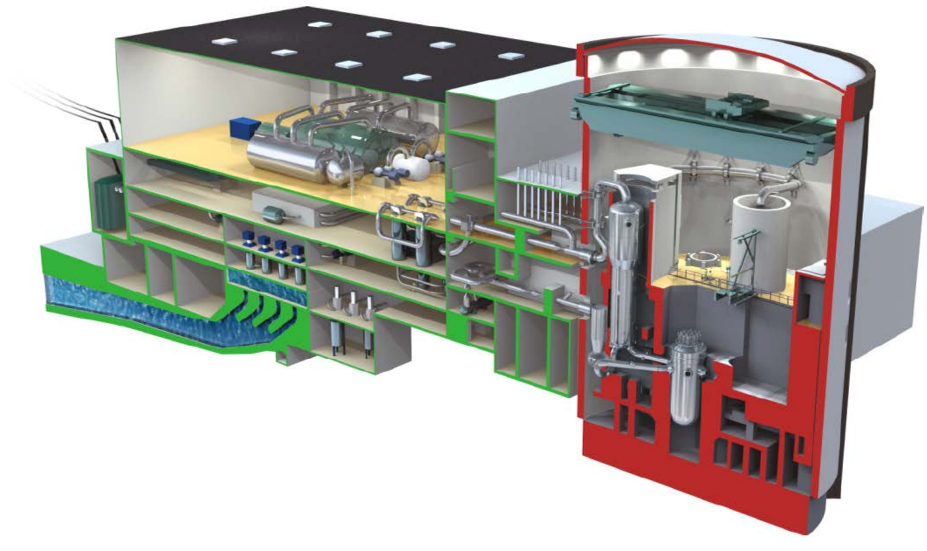


Figure C-2. *Pressurized Water Reactor.*

A BWR contains one large process loop where contaminated water run through the whole system while the PWR contains of one contaminated primary loop and one radiologically clean secondary loop separated from the primary loop by three steam generators. This results in significantly less radioactive systems and components in a PWR than a BWR. A comparison between the ALARA Engineering reports for Ringhals 1 and 2 (Ringhals 2013d) shows that the surfaces in contact with contaminated process water is 2.6 times larger and the area of contaminated concrete is 2.3 times larger in Ringhals 1 than Ringhals 2.This results in a shorter dismantling time, less radiological measurements, easier waste management, etc for the PWRs. Due to the fact that a large part of the building, including the turbine, has no radiological restraints during operation it is also possible to conduct more preparations within the PWR buildings prior to shutdown.

In a PWR the spent fuel is stored in a separate fuel building while the spent fuel pit for the BWR is located in the containment. This makes it possible to proceed with rougher decommissioning action in the containment at an earlier stage in a PWR.

Since there is no segmentation of internals at the PWRs, decontamination and removal of e.g. the reactor pools will be possible at an earlier stage.

The size of the reactor vessel is much smaller for the PWRs. They do however contain internals which requires more safety analysis's for the heavy lifting and also a thicker shielding for transportation.

The primary system in a PWR contains more large heavy contaminated components than a BWR, e.g. stream generators and the pressurizer.

Appendix D

Inventory of systems

Ringhals 1

The quantities of systems material used in the decommissioning estimate for Ringhals 1 is based on site-specific information gathered from drawings and physical walkdowns, and where site-specific data is missing complemented with data from the Barsebäck units and/or a similar U.S. nuclear power plant.

Site-specific information include component mass and dimensions for large components (reactor vessel and internals, heat exchangers, tanks, turbine system, generator, condenser, transformers, overhead cranes etc.), process components (pumps, motors, valves, etc.), and some but not all piping.

Data from Barsebäck complement the Ringhals inventory mainly with data for piping and in a few instances component data. Depending on a judgement made by personnel with long experience from both Ringhals 1 and the Barsebäck units the Barsebäck inventory data has been used "as-is" or with an addition of 20%. Data from the U.S. plant has only been used in three instances when data from both Ringhals and Barsebäck is missing. Detailed information of the compiled inventory can be found in Ringhals (2013b).

A summary of the system material inventory used for estimating decommissioning cost and waste amounts for Ringhals 1 can be found in Table D-1 where the data is organized by the TLG unit cost factor methodology also used in the Barsebäck study (SKBdoc 1403739).

Ringhals 2–4

The quantities of systems material used in the decommissioning estimate for Ringhals 2, 3, and 4 is based on a combination of site-specific information for large primary system components (reactor, steam generator, pressurizer, reactor coolant piping, pumps and motors), and an inventory for "other" components based on site-specific data used in an estimate prepared by TLG for a similar U.S. nuclear power plant.

The primary system components, which constitute 60% of the estimated system mass, are based on site-specific information extracted from drawings and isotopic quantity / concentration information extracted from the ALARA Engineering report (Ringhals 2013d). The "Other" components inventory is based on site-specific data from a similarly rated U.S. 3-loop Westinghouse reactor design, with a power rating approximately 5% larger than the average of the 3 Ringhals PWRs. This approach resulted in incorporating a substantial amount of site-specific information into the estimate (particularly for higher radioactivity components), and a reasonable estimate of the quantity of other contaminated components expected to require removal / disposal during decommissioning (in excess of the mass extracted from the ALARA Engineering report). For purposes of waste management and financial planning, the system inventories used in the estimate reflect reasonably conservative values. More information can be found in Ringhals (2013b).

A summary of the system material inventory used for estimating decommissioning cost and waste amounts for Ringhals 2–4 can be found in Table D-2 where the data is organized by the TLG UCF methodology also used in the Barsebäck study (SKBdoc 1403739).

Table D-1. Summary of system material inventory for Ringhals 1. The inventory is divided into active and inactive amounts.

UCF	Unit 1	
	Active	Inactive
Removal of pipe 6.35 to 50.8 mm dia, meters	7,090	14,872
Removal of pipe >50.8 to 101.6 mm dia, meters	5,906	10,780
Removal of pipe >101.6 to 203.2 mm dia, meters	6,185	5,965
Removal of pipe >203.2 to 355.6 mm dia, meters	3,525	2,971
Removal of pipe >355.6 to 508 mm dia, meters	1,682	132
Removal of pipe >508 to 914.4 mm dia, meters	299	135
Removal of pipe >914.4 mm dia, meters	1,088	240
Removal of valves 6.35 to 50.8 mm dia,each	–	106
Removal of valves >50.8 to 101.6 mm dia,each	931	1,819
Removal of valves >101.6 to 203.2mm dia,each	225	426
Removal of valves >203.2 to 355.6 mm dia,each	450	367
Removal of valves >355.6 to 508 mm dia,each	151	131
Removal of valves >508 to 914.4 mm dia,each	4	4
Removal of valves >914.4 mm dia,each	69	58
Removal of pipe fittings >50.8 to 101.6 mm dia,each	–	–
Removal of pipe fittings >101.6 to 203.2 mm dia,each	114	108
Removal of pipe fittings >203.2 to 355.6 mm dia,each	108	91
Removal of pipe fittings >355.6 to 508 mm dia,each	15	1
Removal of pipe fittings >508 to 914.4 mm dia,each	–	–
Removal of pipe fittings >914.4 mm dia,each	7	2
Pipe hangers for small bore piping, each	3,713	7,407
Pipe hangers for large bore piping, each	1,841	1,472
Removal of pumps, <135.9 kg, each	83	642
Removal of pumps, 135.9–453.1 kg, each	44	36
Removal of pumps, 453.1–4,531 kg, each	39	38
Removal of pumps, >4,531 kg, each	10	19
Removal of pump motors, 135.9–453.1 kg, each	32	16
Removal of pump motors, 453.1–4,531 kg, each	37	36
Removal of pump motors, >4,531 kg, each	10	19
Removal of heat exchanger <1,359.3 kg, each	30	21
Removal of heat exchanger >1,359.3 kg, each	28	18
Feedwater heater/deaerator	10	–
Moisture separator/reheater	4	–
Seismic pipe/structure support, kg	57,048	–
Tanks, <1,363.8 liters, filters, and ion exchangers	41	215
Removal of clean tanks, 1,363.8–13,638 liters	53	46
Tanks, >13,638 liters, 0.09 m2	1,354	1,170
Removal of electrical equipment, <135.9 kg, each	71	2,654
Removal of electrical equipment, 135.9–453.1 kg, each	2	1,389
Removal of electrical equipment, 453.1–4,531 kg, each	2	19
Removal of electrical equipment, >4,531 kg, each	–	6
Removal of electrical transformers < 27.22 Mg	–	21
Removal of electrical transformers > 27.33 Mg	–	2
Standby diesel-generator, 100 kW to 1 MW	–	4
Electrical cable tray, meters	–	131,631
Electrical Conduit, meters	–	13,163
Removal of mechanical equipment, <135.9 kg, each	240	854
Removal of mechanical equipment, 135.9–453.1 kg, each	227	167
Removal of mechanical equipment, 453.1–4,531 kg, each	157	215
Removal of mechanical equipment, >4,531 kg, each	8	17
Removal of HVAC equipment, <135.9 kg, each	171	133
Removal of HVAC equipment, 135.9–453.1 kg, each	71	111
Removal of HVAC equipment, 453.1–4,531 kg, each	16	17
HVAC ductwork, kgs	54,808	18,463

Table D-2. Summary of system material inventory for Ringhals 2, 3 and 4. The inventory is divided into active and inactive amounts.

UCF	Unit 2		Unit 3		Unit 4	
	Active	Inactive	Active	Inactive	Active	Inactive
Removal of instrument and sampling tubing, (m)	17,340	17,340	17,340	17,340	17,340	17,340
Removal of pipe 6.35 to 50.8 mm dia, (m)	11,472	31,985	11,472	26,672	11,472	32,462
Removal of pipe >50.8 to 101.6 mm dia, (m)	4,041	13,954	4,041	11,674	4,041	14,601
Removal of pipe >101.6 to 203.2 mm dia, (m)	721	8,446	721	7,589	721	8,814
Removal of pipe >203.2 to 355.6 mm dia, (m)	714	5,123	714	4,981	714	5,254
Removal of pipe >355.6 to 508 mm dia, (m)	68	3,647	68	3,614	68	3,662
Removal of pipe >508 to 914.4 mm dia, (m)	–	3,593	–	3,593	–	3,593
Removal of pipe >914.4 mm dia, (m)	–	24	–	–	–	32
Removal of valves 6.35 to 50.8 mm dia, (each)	–	–	–	–	–	–
Removal of valves >50.8 to 101.6 mm dia, (each)	245	817	245	679	245	857
Removal of valves >101.6 to 203.2mm dia, (each)	46	540	46	483	46	562
Removal of valves >203.2 to 355.6 mm dia, (each)	29	207	29	201	29	212
Removal of valves >355.6 to 508 mm dia, (each)	2	116	2	114	2	116
Removal of valves >508 to 914.4 mm dia, (each)	–	84	–	84	–	84
Removal of valves >914.4 mm dia, (each)	–	16	–	–	–	21
Removal of pipe fittings >50.8 to 101.6 mm dia, (each)	42	86	42	80	42	88
Removal of pipe fittings >101.6 to 203.2 mm dia, (each)	–	63	–	56	–	66
Removal of pipe fittings >203.2 to 355.6 mm dia, (each)	–	27	–	27	–	27
Removal of pipe fittings >355.6 to 508 mm dia, (each)	–	7	–	7	–	7
Removal of pipe fittings >508 to 914.4 mm dia, (each)	–	9	–	9	–	9
Removal of pipe fittings >914.4 mm dia, (each)	–	7	–	3	–	14
Pipe hangers for small bore piping, (each)	5,000	17,275	5,000	14,454	5,000	18,077
Pipe hangers for large bore piping, (each)	321	3,812	321	3,566	321	3,932
Removal of pumps, <135.9 kg, (each)	101	140	101	116	101	140
Removal of pumps, 135.9–453.1 kg, (each)	49	91	49	78	49	91
Removal of pumps, 453.1–4,531 kg, (each)	12	39	12	33	12	39
Removal of pumps, >4,531 kg, (each)	1	16	1	12	1	16
Removal of pump motors, 135.9–453.1 kg, (each)	49	91	49	78	49	91
Removal of pump motors, 453.1–4,531 kg, (each)	12	34	12	29	12	34
Removal of pump motors, >4,531 kg, (each)	1	14	1	11	1	14
Turbine-driven pumps < 4,531 kg, (each)	–	2	–	2	–	2
Removal of heat exchanger <1,359.3 kg, (each)	28	46	28	41	28	46
Removal of heat exchanger >1,359.3 kg, (each)	6	24	6	24	6	24
Feedwater heater/deaerator, (each)	–	12	–	12	–	12
Moisture separator/reheater, (each)	–	2	–	2	–	2
Seismic pipe/structure support, (kg)	–	–	–	–	–	–
Tanks, <1,363.8 liters, filters, and ion exchangers, (each)	49	273	49	224	49	273
Removal of clean tanks, 1,363.8–13,638 liters, (each)	–	43	–	28	–	43
Tanks, >13,638 liters, 0.09 m2	3,542	6,591	3,542	5,035	3,542	6,591
Removal of electrical equipment, <135.9 kg, (each)	464	2,425	–	1,450	464	2,425
Removal of electrical equipment, 135.9–453.1 kg, (each)	54	270	–	162	54	270
Removal of electrical equipment, 453.1–4,531 kg, (each)	4	22	–	13	4	22
Removal of electrical equipment, >4,531 kg, (each)	–	–	–	–	–	–
Removal of electrical transformers < 27.22 Mg, (each)	–	–	–	–	–	–
Removal of electrical transformers > 27.33 Mg, (each)	–	6	–	3	–	6
Standby diesel-generator, <100 kW, (each)	–	5	–	4	–	5
Standby diesel-generator, >1 MW, (each)	–	4	–	4	–	4
Electrical cable tray, (m)	5,101	15,783	–	11,013	2,684	18,447
Electrical Conduit, (m)	27,711	143,740	–	113,685	27,711	171,238
Removal of mechanical equipment, <135.9 kg, (each)	51	43	51	34	51	43
Removal of mechanical equipment, 135.9–453.1 kg, (each)	26	11	26	9	26	11
Removal of mechanical equipment, 453.1–4,531 kg, (each)	16	31	16	28	16	31
Removal of mechanical equipment, >4,531 kg, (each)	10	21	10	14	10	21
Removal of HVAC equipment, <135.9 kg, (each)	559	289	559	100	559	289
Removal of HVAC equipment, 135.9–453.1 kg, (each)	87	146	103	65	103	130
Removal of HVAC equipment, 453.1–4,531 kg, (each)	55	–	55	–	55	–
HVAC ductwork, kgs	115,510	97,894	115,510	95,114	115,510	97,894

Appendix E

Inventory of structures

Utilizing plant drawings provided by RAB, TLG Service Inc. extracted the quantities of building materials that would be removed during decommissioning (Ringhals 2013c). Quantities, including areas, lengths and volumes were estimated using ROCTEK WinScale software program. The system allows the user to extract measurements directly from drawings (using a digital light pen) and directly transfer the data to a spreadsheet program.

For purposes of the estimate and with few exceptions only building materials located at an elevation of 1 meter below grade and above are assumed to be removed as part of the decommissioning project.

A summary of the building material inventories for Ringhals 1–4 and unit 0 can be found in Table E-1 where the data is organized by the TLG UCF methodology also used in the Barsebäck study (SKBdoc 1403739). Figure E-1 – E-3 and Table E-2 – E-4 provides information of structures assigned to each unit. Unit 0 includes common site buildings utilized by all four units as well as miscellaneous site structures.

Table E-1. Summary of building material inventory for Ringhals 1–4 and unit 0.

UCF	units	Unit 1	Unit 2	Unit 3	Unit 4	Unit 0
Clean concrete < .61 meter thick	m^3	30,322	24,685	29,633	30,691	30,374
Grade Slab Concrete	m^3	865	398	2,712	3,164	7,316
Contaminated concrete < .61 meter thick	m^3	114	0	0	0	37
Clean concrete > .61 meter thick	m^3	23,357	17,760	26,783	29,419	4,224
Clean concrete > .92 meter thick	m^3	853	9,823	9,823	10,965	0
Concrete floors removed to eliminate below grade voids	m^3	3,205	2,436	543	543	952
Clean monolithic concrete structures	m^3	404	2,055	2,055	2,055	0
Activated concrete adjacent to reactor vessel (elevation 122.5 m to 134m)	m^3	291	208	208	208	0
Clean hollow masonry block wall	m^3	–	–	–	0	694
Concrete block wall, concrete plugs	m^3	0	0	0	0	0
Concrete installed to fill below-grade voids	m^3	0	2,153	0	1,728	0
Tunnel roof collapsed to eliminate below grade voids (Note 1)	m	0	545	0	756	0
Amount of material required to fill below grade voids	m^3	198,262	102,416	212,555	98,350	62,478
Excavation of clean soil (Note 2)	m^3	0	6,265	392	12,631	0
Clean concrete rubble	m^3	240	0	0	0	0
General Purpose Building Volume (Note 3)	m^3	0	10,015	0	3,781	78,468
Building Siding (clean)	m^2	1,333	513	938	5,681	498
Building Roofing (clean)	m^2	7,627	9,306	6,707	2,109	11,016
Scarifying contaminated concrete floors (Note 4)	m^2	2,466	1,283	1,292	1,292	2,022
Scarifying contaminated concrete walls (Note 5)	m^2	159	298	299	299	0
Cranes / monorails with capacity of < 9.1 metric tons (clean)	ea	37	26	21	27	29
Cranes / monorails with capacity of < 9.1 metric tons (potentially contaminated)	ea	1	0	0	0	2
Cranes / monorials with a capacity of 9.1–45.3 metric tons (clean)	ea	10	9	6	6	7
Cranes with a capacity of > 45.3 metric tons (clean)	ea	4	5	4	4	1
Structural steel (clean)	Metric ton	1,956	1,966	1,956	2,160	385
Steel floor grating (clean)	m^2	2,163	8,034	4,824	6,619	426
Steel floor grating (potentially contaminated)	m^2	1,044	793	793	793	82
Free-standing steel liner-type material (clean) (Note 6)	m^2	0	0	0	0	0
Concrete anchored steel liner (clean) (Note 7)	m^2	–	4,809	4,809	4,809	0
Concrete anchored steel liner (contaminated) (Note 7)	m^2	3,110	2,465	2,465	2,465	156
Scaffolding Area (clean areas) (Note 8)	m^2	37,328	28,274	21,135	21,135	11,961
Scaffolding Area (potentially contaminated areas) (Note 9)	m^2	1,770	1,261	5,350	5,350	185
Chain link fence	m	0	2,885	0	2,711	4,709
Asphalt pavement	m^2	0	59,584	0	71,468	123,311
Selective demolition of concrete (Note 10)	m^3	414	0	0	0	0
Building interior floor area (Note 11)	m^2	55,176	44,823	51,813	49,125	82,051
Building interior free volume (Note 12)	m^3	439,231	328,361	462,595	341,854	347,484
Additional decon of surfaces by washing (Note 13)	m^2	3,376	2,712	2,712	2,712	156

Note 1: Based on length of below-grade concrete tunnels connecting buildings / structures (roof to be collapsed to preclude below grade voids).

Note 2: Material to be removed to permit acces to below-grade structures (tunnel roofs, underground tanks) to permit below grade excavations (sloping for personnel safety).

Note 3: The basis for the cost of demolishing miscellaneous buildings (generally steel frame on concrete slab).

Note 4: Based on mass as provided in the ALARA Report.

Note 5: Spot decontamination behind concrete anchored steel liner (10% of liner area).

Note 6: Plate-steel structures not continuously anchored to concrete (vessel head enclosure).

Note 7: Steel liner anchored to concrete (spent fuel pool liner, containment pool, lined sumps).

Note 8: Floor area (clean) where scaffolding is installed.

Note 9: Floor area (potentially contaminated) where scaffolding is installed.

Note 10: Concrete surrounding containment pool downcomers.

Note 11: Total floor area of building including grating (information only).

Note 12: Total builidng interior volume excluding concrete volume (information only).

Note 13: Surface areas washed prior to scarifying.

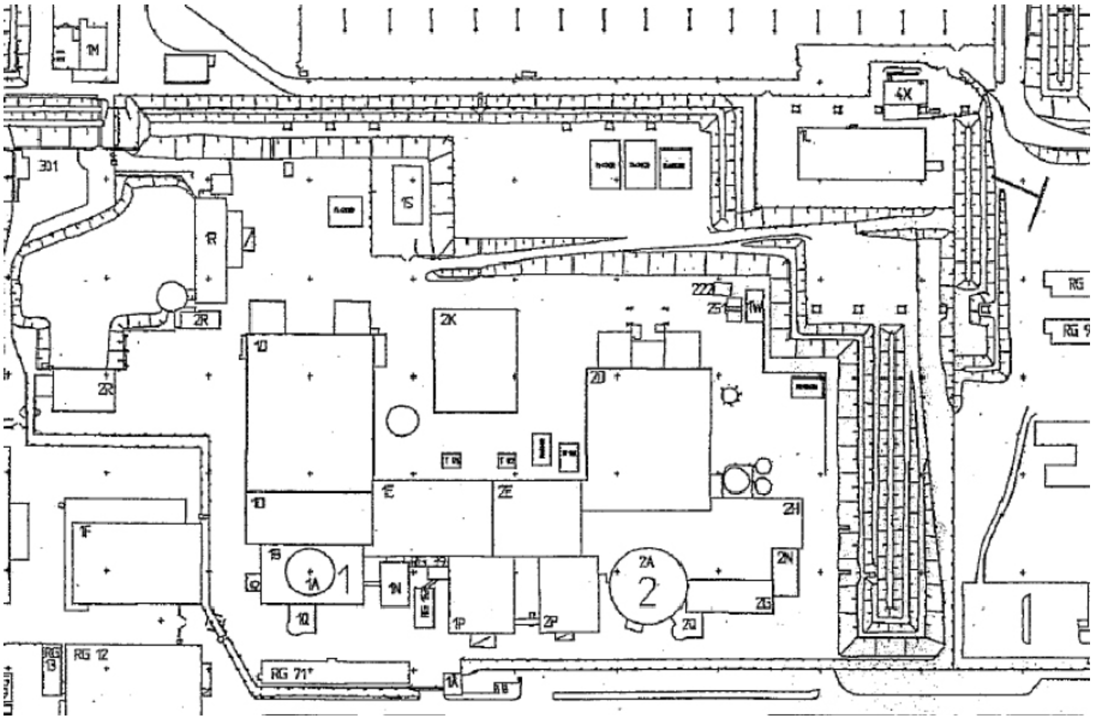


Figure E-1. *Basic layout of Ringhals 1 and 2.*

Table E-2. Structures included in the Ringhals 1 and 2 inventories.

Structures included in Ringhals 1 cost estimate	Structures included in Ringhals 2 cost estimate
1A/B Reactor Building	2A Reactor Bldg
1D Intermediate Building	2D Turbine/Generator Bldg
1D Turbine Building	2E Electrical Bldg
1E Electrical Building	2G Fuel Bldg
1J Component Cooling	2H Auxiliary Bldg
1L Lagreservoar	2K Diesel Bldg
1N Radioactive Service Bldg	2N Control Area Workshop
1P Personal Building	2P Personnel Bldg
1Q Filter Building Structure	2Q Filter Bldg
1R Intake Structure	2R Intake/ Pumpstation
1R Pump Station	T92 Transformers
1V DPS	R1/R2 Miscellaneous Structures:
1W Pumphouse	– RG71
R1 Main Transformer	– 4X
RG 39 Personnel Tunnel	– 1S
T91 Transformer Pad	– RG153b
	– R1/R2 Tunnels

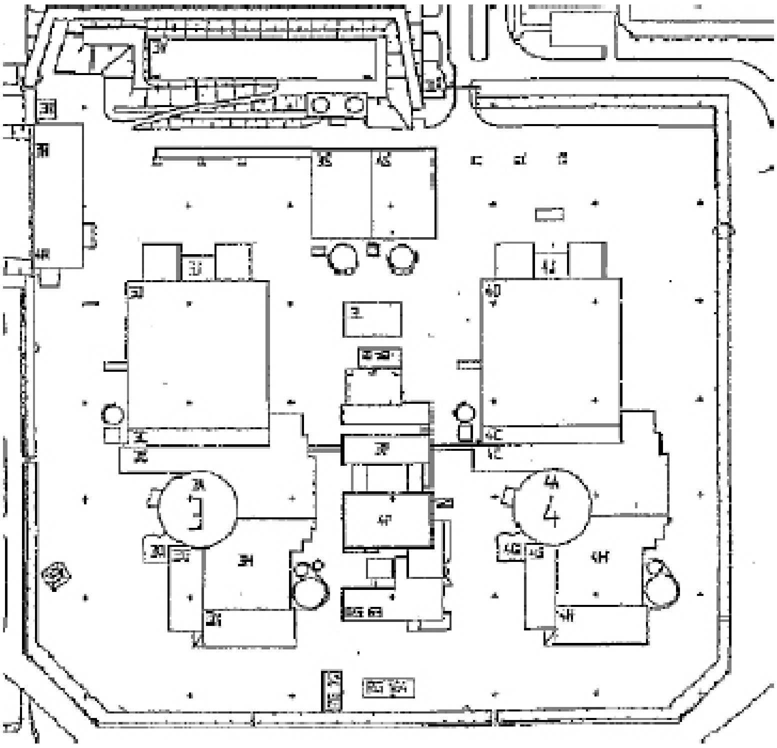


Figure E-2. *Basic layout of Ringhals 3 and 4.*

Table E-3. Structures included in the Ringhals 3 and 4 inventories.

Structures included in Ringhals 3 cost estimate	Structures included in Ringhals 4 cost estimate
3A Reactor Bldg	4A Reactor Bldg
3C Intermediate Bldg	4C Intermediate Bldg
3D Turbine Bldg	4D Turbine Bldg
3E Electrical Bldg	4E Electrical Bldg
3G Fuel Bldg	4G Fuel Bldg
3H Auxiliary Bldg	4H Auxiliary Bldg
3J Transformer Structure	4J Transformer Structure
3L Desalination Bldg	4N Active Service Bldg
3N Active Service Bldg	4P Personal Bldg
3P Personal Bldg	4Q Filter Bldg
3Q Filter Bldg	4R Pump Station
3R Pump Station	4R_3R Intake Structure
3S Service Bldg	4S Service Bldg
3V Freshwater Reservoir	Miscellaneous Structures R3_R4
	– RG72
	– 3U
	– RG63
	– RG225A
	– RG225B
	– RG222
	– R3/R4 Tunnels

Table E-4. Structures included in the Unit 0 inventory.

Structures included in Unit 0	
1F Kokillforrad	RG 22 Central Workshop
1F Waste Treatment	RG 23
RG 16	RG 26 Mockup Bldg
RG 17 Central Workshop	RG 37
RG 18	RG 64 Firestation
RG 19	Site Storage Bldgs:
RG 21	– RG11
Site Miscellaneous Structures:	– RG20
– 1M (Hydrogen Plant)	– RG24
– RG 43	– RG30
– RG 29	– RG36
– RG 77A	– RG40
– RG77B	– RG41
– RG 25	– RG42
– RG13	– RG45
– RG12	– RG46
– RG48a	– RG47

Appendix F

Development of unit cost factors

A UCF presents the total cost for an action of the dismantling or demolition. The UCF is developed by knowledge of the work duration of all required activities, the required labour and the need of consumables.

The work duration is dependent on the conditions at the work location. Therefore different sets of UCFs are used in the cost estimate. Depending on where the task is to be performed three categories are available:

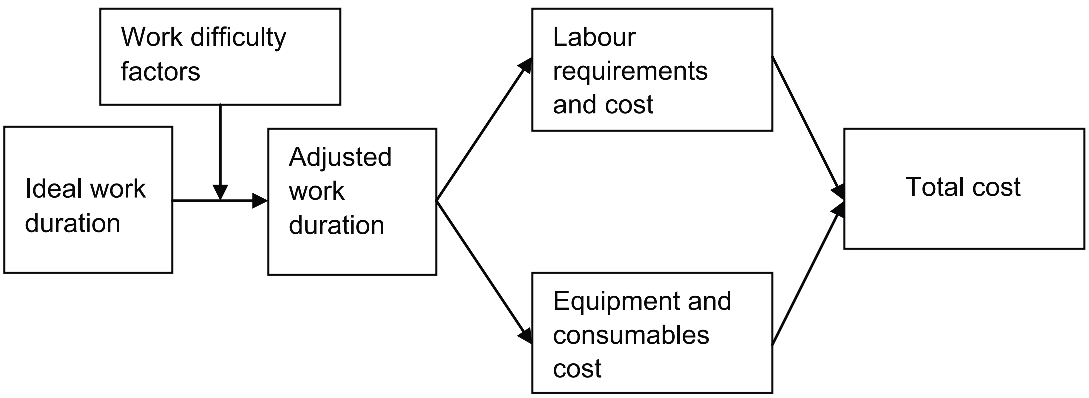
- Non-Power block
  This category represents work performed outside of the power block.
- Power block
  This category represents work performed in the power block.
- Set #2 with PC/ALARA/Resp on clean UCFs.

These categories are then further divided into insulted or non-insulated sets of UCF. This results in six different sets of UCFs depending on where the task is performed and if the task involves removal of insulation or not. Depending in the set, the UCF therefore contains different activities and different work durations.

The development of the UCF is divided into several steps:

1. Description of the scope, activities required and calculation of the total activity duration as well as critical duration under ideal conditions.
2. Adjustments of the critical time due to WDFs.
3. Labour requirements and costs.
4. Equipment and consumables cost.
5. Calculation of the total cost.

These steps are further described below. An example of the development for a UCF for the removal of a contaminated heat exchanger <1,359 kg is presented in the end of the appendix.



1. Activities and work duration calculations

Each UCF contain a defined number of discrete activities and the required time for the task to be performed in ideal conditions. Depending on the set of UCF time for removal of insulation is included or excluded.

A total work duration for all activities to be performed are calculated as well as a critical time, where the fact that certain activities can take place at the same time by several persons are taken into account.

2. Work difficulty factors

The application of the WDFs intends to account for the productivity losses associated with working in difficult or hazardous environment. The approach is widely used at operating plants to account for difficulty in performing maintenance activities during outages (SKBdoc 1359832).

The WDFs adjust the critical work duration. These adjustments are different between the sets of UCFs due to the different conditions given by the location.

a. Access Factor: The access factor is intended to account for difficulty of working on scaffolding, on ladders, in pipe tunnels, or in other confined spaces. The limited degree of motion possible under these working conditions reduces the worker productivity. The access factor ranges in this study from 10% to 20% of the critical duration.
b. Respiratory Protection Factor: The respiratory protection factor is intended to account for the difficulty of a worker performing activities while wearing a full-face respirator, or supplied-air mask. The respirator impedes breathing, obscured vision due to the mask window and fogging, and adds stress from the straps around the head. The respiratory protection factor ranges in this study from 0% to 50%.
c. Radiation/ALARA Factor: The ALARA factor is intended to account for the time spent preparing for an entry into a high radiation or high contamination area. This time is used to alert the crew the potential hazards in the area, the specific activities to be accomplished while in the area, and emergency procedures to be implemented for immediate evacuation. This factor also accounts for the periodic training the crew would receive to maintain their radiation training and certification. The ALARA factor ranges in this study from 0% to 37%.
d. Protective Clothing Factor: The protective clothing factor is intended to account for the time and worker needs to put on protective clothing for each entry and exit from a radiation control area. Typically, this represents four changes per day. The protective clothing factor ranges in this study from 0% to 30%.
e. Work Break Factor: The work break factor is intended to account for the time a worker needs to take a morning break, a lunch break, and an afternoon break. A work break factor of 8.33% has been used in this work.

3. Labour required

Depending on the task to be performed different crew members and numbers of them are needed. The following are the possible crew members:

Labourers
Craftsmen
Foreman
General foreman
Fire watch
Health Physics Technician

The same person can be divided between several simultaneously tasks, e.g. the foreman and the general foreman can be responsible for more than one crew. Not all of the crew members are needed for all tasks, e.g. a health physics technician is not needed for removal of clean equipment.

The total labour cost is calculated by the adjusted total work duration, the number of workers and their salary.

4. Equipment and consumables cost

For each task some equipment and consumables might be needed, e.g. gas torch consumables used for pipe cutting.

Overhead and profits are added to the summarized equipment and material costs, giving the total costs for equipment and material.

5. Total cost

Finally the total cost for labour and material costs is summarized.

Example: Unit Factor for Removal of Contaminated Heat Exchanger < 1,359 kg.

1

SCOPE

Heat exchangers weighing < 1,359 kg. will be removed in one piece using a crane or small hoist. They will be disconnected from the inlet and outlet piping. The heat exchanger will be sent to the waste processing area.

Description of the action to be performed

CALCULATIONS WORK DURATION

This set includes the activity "removal of insulation"

Act. ID	Activity description	Activity duration	Critical duration
a	Remove insulation	60	(b)
b	Mount pipe cutters	60	60
c	Install contamination controls	20	(b)
d	Disconnect inlet and outlet lines	60	60
e	Cap openings	20	(d)
f	Rig for removal	30	30
g	Unbolt from mounts	30	30
h	Remove contamination controls	15	15
i	Remove, wrap in plastic, send to packing area	60	60
	Totals (Activity/Critical)	*355 min*	*255 min*

These activities can take place at the same time as b (mount pipe cutters). The critical time is therefore not increased.

2

These adjustments are different between the sets of UCFs.

Duration adjustment(s):	
+ Access adjustment (0% of critical duration)	0
+ Respiratory protection adjustment (50% of critical duration)	128
+ Radiation/ALARA adjustment (37% of critical duration)	95
Adjusted work duration	*478*
+ Protective clothing adjustment (30% of adjusted duration)	143
Productive work duration	*621*
+ Work break adjustment (8.33 % of productive duration)	52
Total work duration	*673 min*
	11.217 h

These adjustments of the critical duration results in adjusted work duration

Clothing adjustments of the adjusted work duration (calculated above) results in productive work duration

Break adjustments of the productive work duration (calculated above) results in the total work duration

3

LABOUR REQUIRED

Crew	Number	Duration (hr)	Rate (SEK/hr)	Cost (SEK)
Labourers	3.00	11.217	470	15 815
Craftsmen	2.00	11.217	650	14 582
Foreman	1.00	11.217	710	7 964
General Foreman	0.25	11.217	780	2 187
Fire Watch	0.05	11.217	470	264
Health Physics Technician	1.00	11.217	460	5 160
Total labour cost				*47 964*

The general foreman is working with several crews at the same time. Only 25% of his time is required for this task.

4

EQUIPMENT & CONSUMABLES COSTS

Equipment Costs	none
Consumables/Materials Costs	
-Blotting paper 50 @ 3.44 / .093 sq meter	172
-Plastic sheets/bags 50 @ 2.53 / .093 sq meter	126
-Gas torch consumables 1 @ 52.28/hr x 1 hr	60
Subtotal cost of equipment and materials	*358*
Overhead & profit on equipment and materials @ 10.0% (excluding VAT)	36
Total costs, equipment & material	*394*

The amount of material needed and the cost per unit

Overhead and profit added, resulting in total cost of material and equipment

5

TOTAL COST (SEK):	**48 358**
Total labour cost:	47 964
Total equipment/material costs:	394
Total craft labour man-hours required per unit:	81.9

Finally, the total cost for removal of the heat exchanger is calculated

Appendix G

Representative unit cost factors

Table G-1 shows a representative unit cost factor set used in the cost estimate.

Table G-1. Representative unit cost factor set.

Unit Cost Factor	Cost/Unit (SEK)	Man [Hrs.]	Crew [Hrs.]
Removal of clean pipe 6.35 to 50.8 mm diameter, 0.3 m	50	0.10	0.05
Removal of clean pipe 50.8 to 101.6 mm diameter, 0.3m	63	0.13	0.06
Removal of clean pipe 101.6 to 203.2 mm diameter, 0.3m	134	0.25	0.08
Removal of clean pipe 203.2 to 355.6 mm diameter, 0.3m	267	0.51	0.12
Removal of clean pipe 355.6 to 508 mm diameter, 0.3m	350	0.66	0.16
Removal of clean pipe 508 to 914.4 mm diameter, 0.3m	510	0.97	0.23
Removal of clean pipe 914.4 mm diameter, 0.3m	607	1.15	0.27
Removal of clean valves 50.8 to 101.6 mm	717	1.39	0.56
Removal of clean valves 101.6 to 203.2 mm	1,341	2.47	0.76
Removal of clean valves 203.2 to 355.6 mm	2,666	5.07	1.19
Removal of clean valves 355.6 to 508 mm	3,499	6.64	1.56
Removal of clean valves 508 to 914.4 mm	5,100	9.69	2.27
Removal of clean valves >914.4 mm	6,068	11.53	2.71
Removal of clean pipe fittings 50.8 to 101.6 mm	996	1.84	0.56
Removal of clean pipe fittings 101.6 to 203.2 mm	1,608	2.97	0.91
Removal of clean pipe fittings 203.2 to 355.6 mm	2,666	5.07	1.19
Removal of clean pipe fittings 355.6 to 508 mm	3,499	6.64	1.56
Removal of clean pipe fittings 508 to 914.4 mm	5,100	9.69	2.27
Removal of clean pipe fittings >914.4 mm	6,068	11.53	2.71
Removal of clean pipe hangers for small bore piping	262	0.50	0.43
Removal of clean pipe hangers for large bore piping	1,044	2.10	0.97
Removal of clean pumps, <135.9 kg	2,253	4.12	1.26
Removal of clean pumps, 135.9–453.1 kg	6,566	11.53	2.71
Removal of clean pumps, 453.1–4,531 kg	25,677	46.11	6.17
Removal of clean pumps, >4,531 kg	49,617	88.98	11.92
Removal of clean pump motors, 135.9–453.1 kg	2,800	4.94	1.17
Removal of clean pump motors, 453.1–4,531 kg	10,724	19.28	2.60
Removal of clean pump motors, >4,531 kg	24,130	43.39	5.85
Removal of clean heat exchanger <1,359.3 kg	13,195	23.69	4.33
Removal of clean heat exchanger >1,359.3 kg	33,080	59.22	10.83
Removal of clean feedwater heater/deaerator	97,557	174.72	23.40
Removal of clean moisture separator/reheater	206,088	369.20	39.00
Removal of clean seismic piping/structural supports, 0.45 kg	4	0.01	0.00
Removal of clean tanks, <1,363.8 liters	2,894	5.29	1.62
Removal of clean tanks, 1,363.8–12,638 liters	9,226	16.94	5.20
Removal of clean tanks, >13,638 liters, 0.09 m2	80	0.14	0.03
Removal of clean electrical equipment, <135.9 kg	1,256	2.32	0.72
Removal of clean electrical equipment, 135.9–453.1 kg	4,523	7.98	1.90
Removal of clean electrical equipment, 453.1–4,531 kg	9,046	15.96	3.79
Removal of clean electrical equipment, >4,531 kg	19,789	34.45	7.80
Removal of clean electrical transformers < 27,216 kg	13,743	23.92	5.42
Removal of clean electrical transformers > 27,216 kg	39,579	68.90	15.60
Removal of clean standby diesel-generator, 100 kW to 1 MW	31,333	54.55	12.35
Removal of clean electrical cable tray, 0.3 m	116	0.21	0.06
Removal of clean electrical conduit, 0.3 m	50	0.09	0.03

Unit Cost Factor	Cost/Unit (SEK)	Man [Hrs.]	Crew [Hrs.]
Removal of clean mechanical equipment, <135.9 kg	1,256	2.32	0.72
Removal of clean mechanical equipment, 135.9–453.1 kg	4,523	7.98	1.90
Removal of clean mechanical equipment, 453.1–4,531 kg	9,046	15.96	3.79
Removal of clean mechanical equipment, >4,531 kg	19,789	34.45	7.80
Removal of clean HVAC equipment, <135.9 kg	1,507	2.78	0.87
Removal of clean HVAC equipment, 135.9–453.1 kg	5,428	9.57	2.27
Removal of clean HVAC equipment, 453.1–4,531 kg	10,855	19.15	4.55
Removal of contaminated pipe 6.35 to 50.8 mm diameter, 0.3 m	185	0.32	0.12
Removal of contaminated pipe 50.8 to 101.6 mm diameter, 0.3 m	306	0.56	0.20
Removal of contaminated pipe 101.6 to 203.2 mm diameter, 0.3 m	524	0.93	0.22
Removal of contaminated pipe 203.2 to 355.6 mm diameter, 0.3 m	1,044	1.92	0.36
Removal of contaminated pipe>355.6 to 508 mm diameter, 0.3 m	1,267	2.35	0.45
Removal of contaminated pipe 508 to 914.4 mm diameter, 0.3 m	1,766	3.32	0.63
Removal of contaminated pipe >914.4 mm diameter, 0.3 m	2,093	3.96	0.75
Removal of contaminated valves 50.8 to 101.6 mm	3,432	6.57	1.90
Removal of contaminated valves 101.6 to 203.2 mm	4,805	8.90	2.09
Removal of contaminated valves 203.2 to 355.6 mm	10,132	19.17	3.65
Removal of contaminated valves 355.6 to 508 mm	13,024	24.79	4.71
Removal of contaminated valves 508 to 914.4 mm	17,352	33.23	6.32
Removal of contaminated valves >914.4 mm	20,626	39.62	7.53
Removal of contaminated pipe fittings 50.8 to 101.6 mm	3,290	6.00	1.41
Removal of contaminated pipe fittings 101.6 to 203.2 mm	5,562	10.35	2.43
Removal of contaminated pipe fittings 203.2 to 355.6 mm	10,132	19.17	3.65
Removal of contaminated pipe fittings 355.6 to 508 mm	13,024	24.79	4.71
Removal of contaminated pipe fittings 508 to 914.4 mm	17,352	33.23	6.32
Removal of contaminated pipe fittings >914.4 mm	20,626	39.62	7.53
Removal of contaminated pipe hangers for small bore piping	1,224	2.41	1.46
Removal of contaminated pipe hangers for large bore piping	4,303	8.39	3.16
Removal of contaminated pumps, <135.9 kg	8,631	15.89	3.73
Removal of contaminated pumps, 135.9–453.1 kg	20,820	36.94	7.03
Removal of contaminated pumps, 453.1–4,531 kg	67,894	123.46	14.58
Removal of contaminated pumps, >4,531 kg	165,131	300.42	35.48
Removal of contaminated pump motors, 135.9–453.1 kg	8,735	14.87	2.85
Removal of contaminated pump motors, 453.1–4,531 kg	27,360	49.09	5.83
Removal of contaminated pump motors, >4,531 kg	61,560	110.46	13.12
Removal of contaminated heat exchanger <1,359.3 kg	39,477	72.41	11.20
Removal of contaminated heat exchanger >1,359.3 kg	114,033	207.30	32.06
Removal of contaminated feedwater heater/deaerator	289,932	522.65	61.73
Removal of contaminated moisture separator/reheater	651,101	1,175.22	112.28
Removal of contaminated seismic/structural steel support, 0.45 kg	10	0.02	0.00
Removal of contaminated tanks, <1,363.8 liters	14,312	26.18	6.15
Removal of contaminated tanks, >1,363.8 liters, 0.09 m2	295	0.54	0.10
Removal of contaminated electrical equipment, <135.9 kg	6,829	12.94	3.07
Removal of contaminated electrical equipment, 135.9–453.1 kg	17,138	30.88	5.93
Removal of contaminated electrical equipment, 453.1–4,531 kg	33,026	59.46	11.42
Removal of contaminated electrical equipment, >4,531 kg	60,321	106.63	19.69
Removal of electrical transformers < 27,216 kg	43,458	78.49	14.49
Removal of electrical transformers > 27,216 kg	118,074	213.26	39.37
Removal of standby diesel-generator, 100 kW to 1 MW	89,649	161.92	29.89
Removal of contaminated electrical cable tray, 0.3 m	328	0.62	0.15

Unit Cost Factor	Cost/Unit (SEK)	Man [Hrs.]	Crew [Hrs.]
Removal of contaminated electrical conduit, 0.3 m	154	0.27	0.06
Removal of contaminated mechanical equipment, <135.9 kg	7,553	14.32	3.40
Removal of contaminated mechanical equipment, 135.9–453.1 kg	18,943	34.18	6.56
Removal of contaminated mechanical equipment, 453.1–4,531 kg	36,502	65.82	12.64
Removal of contaminated mechanical equipment, >4,531 kg	60,321	106.63	19.69
Removal of contaminated HVAC equipment, <135.9 kg	7,553	14.32	3.40
Removal of contaminated HVAC equipment, 135.9–453.1 kg	18,943	34.18	6.56
Removal of contaminated HVAC equipment, 453.1–4,531 kg	36,502	65.82	12.64
Removal of contaminated HVAC ductwork, 0.45 kg	17	0.03	0.02
Removal of clean standard reinforced concrete, 0.76 m3	1,075	1.47	0.33
Removal of grade slab concrete, 0.76 m3	1,570	2.37	0.32
Removal of contaminated standard reinforced concrete, 0.76 m3	2,989	4.39	0.81
Removal of clean heavily rein concrete w/#9 rebar, 0.76 m3	1,576	1.77	0.24
Removal of clean heavily rein concrete w/#18 rebar, 0.76 m3	1,991	2.24	0.31
Removal of below grade suspended floors, 0.76 m3	2,453	3.02	0.42
Removal of clean monolithic concrete structures, 0.76 m3	6,460	9.19	1.26
Removal of contaminated monolithic concrete structures, 0.76 m3	15,559	23.44	2.82
Removal of clean hollow masonry block wall, 0.76 m3	857	1.44	1.44
Removal of clean solid masonry block wall, 0.76 m3	857	1.44	1.44
Placement of concrete for below grade voids, 0.76 m3	794	0.29	0.04
Removal of subterranean tunnels/voids, 0.3 m	1,036	1.62	0.54
Backfill of below grade voids, 0.76 m3	141	0.06	0.01
Excavation of clean material, 0.76 m3	22	0.02	0.01
Removal of clean concrete rubble, 0.76 m3	154	0.12	0.02
Removal of building by volume, 0.028 m3	2	0.00	0.00
Removal of clean building metal siding, 0.09 m2	11	0.02	0.02
Removal of standard asphalt roofing, 0.09 m2	20	0.04	0.01
Scabbling contaminated concrete floors 0.09 m2	61	0.10	0.04
Scabbling contaminated concrete walls 0.09 m2	165	0.29	0.11
Removal of clean overhead cranes/monorails < 9,071 kg capacity, each	6,225	10.43	3.25
Removal of contaminated overhead cranes/monorails < 9,072 kg capacity, each	17,333	30.68	7.29
Removal of clean overhead cranes/monorails 9,072–45,359 kg capacity, each	14,940	25.02	7.80
Removal of gantry cranes > 45,359 kg capacity, each	247,366	430.62	48.75
Removal of clean structural steel, 0.45 kg	2	0.00	0.01
Removal of clean steel floor grating, 0.09 m2	40	0.06	0.02
Removal of contaminated steel floor grating, 0.09 m2	117	0.19	0.04
Removal of contaminated free-standing steel liner, 0.09 m2	347	0.63	0.12
Removal of clean concrete anchored steel liner, 0.09 m2	60	0.11	0.02
Removal of contaminated concrete anchored steel liner, 0.09 m2	401	0.73	0.14
Placement of scaffolding in clean areas, 0.09 m2	111	0.09	0.03
Placement of scaffolding in contaminated areas, 0.09 m2	205	0.29	0.07
Removal of chain link fencing, 0.3 m	32	0.05	0.02
Removal of asphalt pavement, 0.09 m2	7	0.01	0.00
Diamond wire cutting, concrete 0.9 to 1.8 m, 0.76 m3	7,400	8.93	1.65
Cost of ISO Container & preparations for use	29,740	5.64	4.51
Cost of Steel Box & preparation for use	26,099	2.93	2.35
Cost of Large Steel box & preparation for use	99,929	2.93	2.35
Cost of BFA tank & preparation for use	610,097	2.93	2.35

Appendix H

Program management

This appendix provides a description of the responsibilities of the worker categories utilized in the development of this decommissioning estimate.

Management – Senior managers and project managers responsible for completing the decommissioning project.

Quality Assurance – This organization is responsible for ensuring that the work complies with appropriate standards, and procedures, primarily work associated with radioactive material. Due to the physical hazards associated with decommissioning work, the quality assurance organization is supplemented with an Industrial Safety Specialist(s). This person would be expected to conduct worker training, review implementing procedures for safety compliance, as well as monitor the work force and facility during the project.

Licensing & Regulatory Compliance – This organization is responsible for ensuring that decommissioning programs are consistent with regulatory requirements, and that the decommissioning is conducted and completed in accordance with the regulatory requirements.

Work Management/Maintenance – This organization is responsible for the planning and oversight of the physical decommissioning work, maintenance of the physical facilities (electrical, heating, cooling, ventilation, communications, etc.), and support tasks necessary to ensure that the work crews have the facilities and tools necessary to complete their work.

Plant Operations – This organization is primarily responsible for operating the systems necessary to maintain a suitable work environment, particularly ventilation and water management during the most active radioactive material removal phases of the decommissioning project.

Radiation and Health Physics – This organization is responsible to operate and maintain the radiation and health physics programs needed to maintain an effective radiation protection program, including planning, implementation, and oversight of the radioactive material removal, and workforce training. Technicians assigned to conduct routine surveys or maintain the necessary infrastructure (dosimetry, instrument calibration, personal protective equipment maintenance and issue, laundry services) are included in this organization. Radiation protection technicians directly assigned to the work crews are included in plant systems or structures disposition costs and are not included in the program management organization.

Tech Support: Chemistry/Environmental Monitoring – This organization is principally responsible for maintaining an effective environmental monitoring program (environmental sampling and analysis), and maintaining appropriate spent fuel pool and reactor cavity water chemistry while these areas are being used for underwater vessel internals segmentation.

Tech Support: Waste Processing – This organization is responsible for managing all waste materials after the components have been removed. This includes the physical handling of waste packages, preparing and maintaining waste documentation, and ensuring compliance with regulatory requirements.

Engineering / Planning – This organization is responsible for doing the engineering, planning, and scheduling associated with the decommissioning project. The project will require engineers to modify the infrastructure as the project proceeds (ventilation, electrical, creating openings in walls/floors), develop plans for dismantling unique or large components, and developing written instructions for completing work activities. The following disciplines are required to accomplish this work: mechanical, electrical, instrument and control, nuclear, environmental, and civil/structural. Planners and schedulers assigned to this organization will maintain project schedules, write and issue specific work packages, and maintain the status of the station as it progresses through the decommissioning process.

Security – This organization is responsible for maintaining control for personnel and material entering and exiting the station.

Administrative Services – This organization is responsible for the general support services necessary to support the project. The types of services provided include:

- Accounting and finance.
- Public relations.
- Procurement.
- Document control (overseeing the control and distribution of procedures and drawings, and the archiving of required records).
- Computer support.

Appendix I

Decommissioning schedules

This appendix shows the high level schedules developed in this report. Figure I-1 – I-4 shows the most significant activities and its estimated length during the decommissioning of each plant.

The length of each decommissioning activity is based on the amount of work to be executed and the amount of workers that can be in a building at the same time. The amount of work that needs to be executed are in most cases calculated using the UCF method. This method takes into account the time for a work team to execute the dismantling activity including adjustments for access, protective clothing, respiratory protection, radiation/ALARA and work breaks. More complex activities e.g. the reactor vessels, steam generators, and defueling time are based on experiences from already executed decommissioning projects and/or remodeling work during outages.

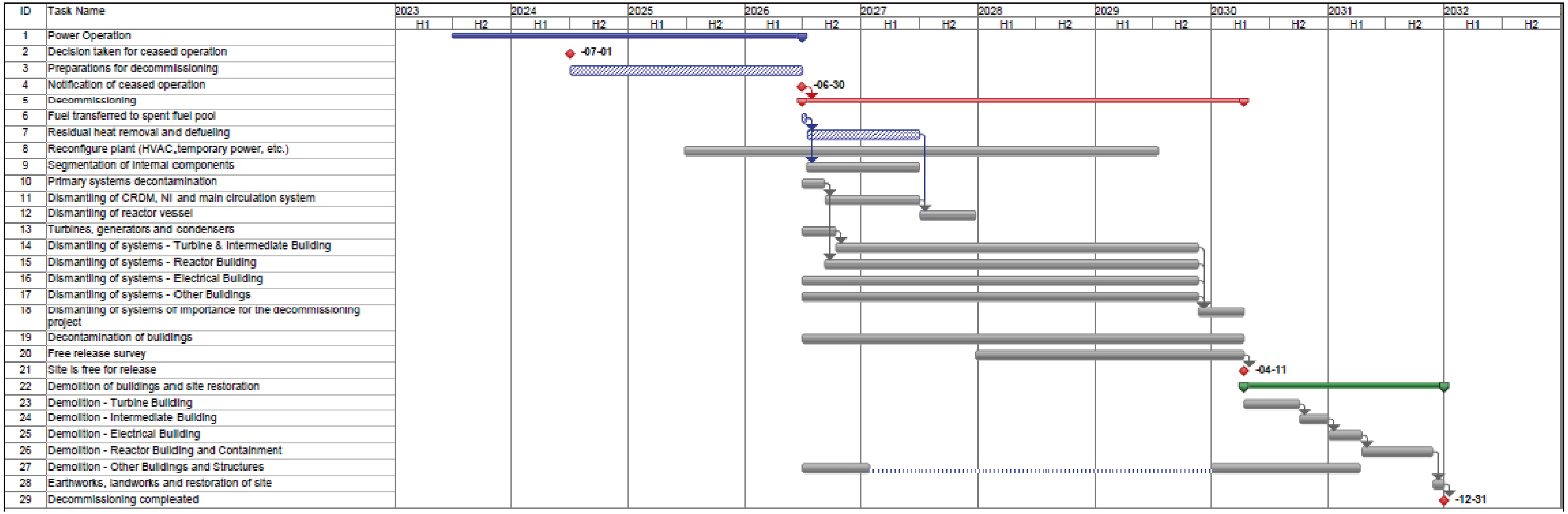


***Figure I-1.** The decommissioning schedule for Ringhals 1.*

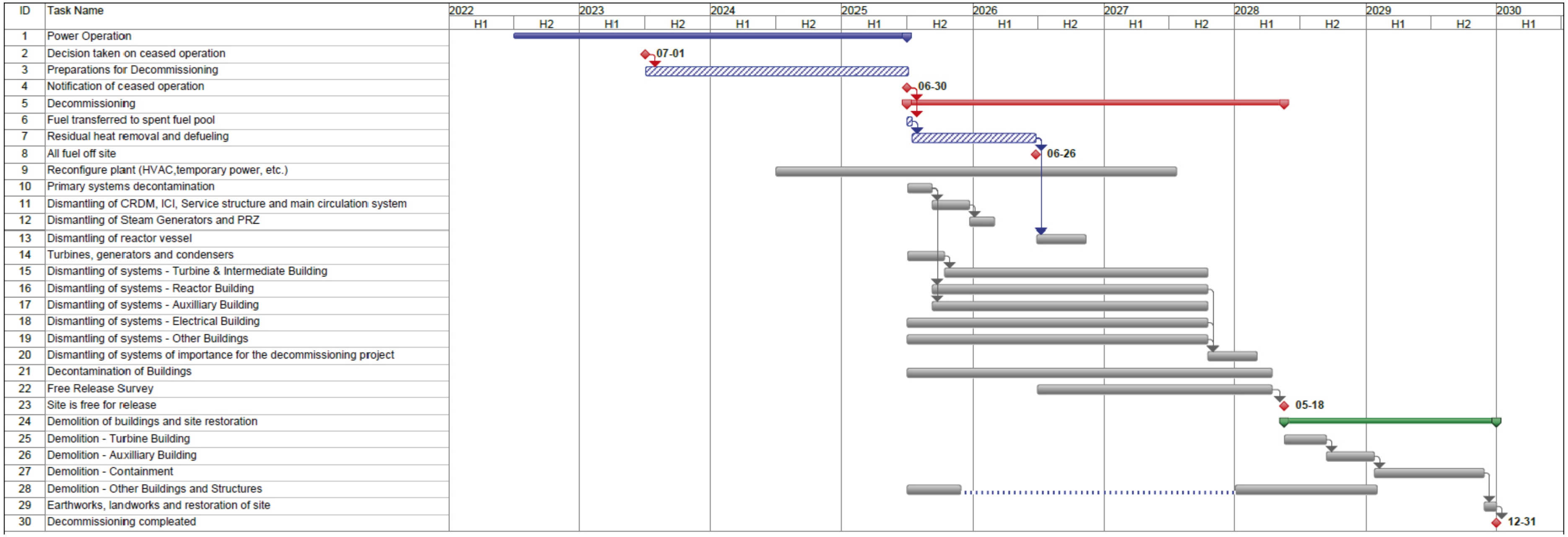


Figure I-2. *The decommissioning schedule for Ringhals 2.*

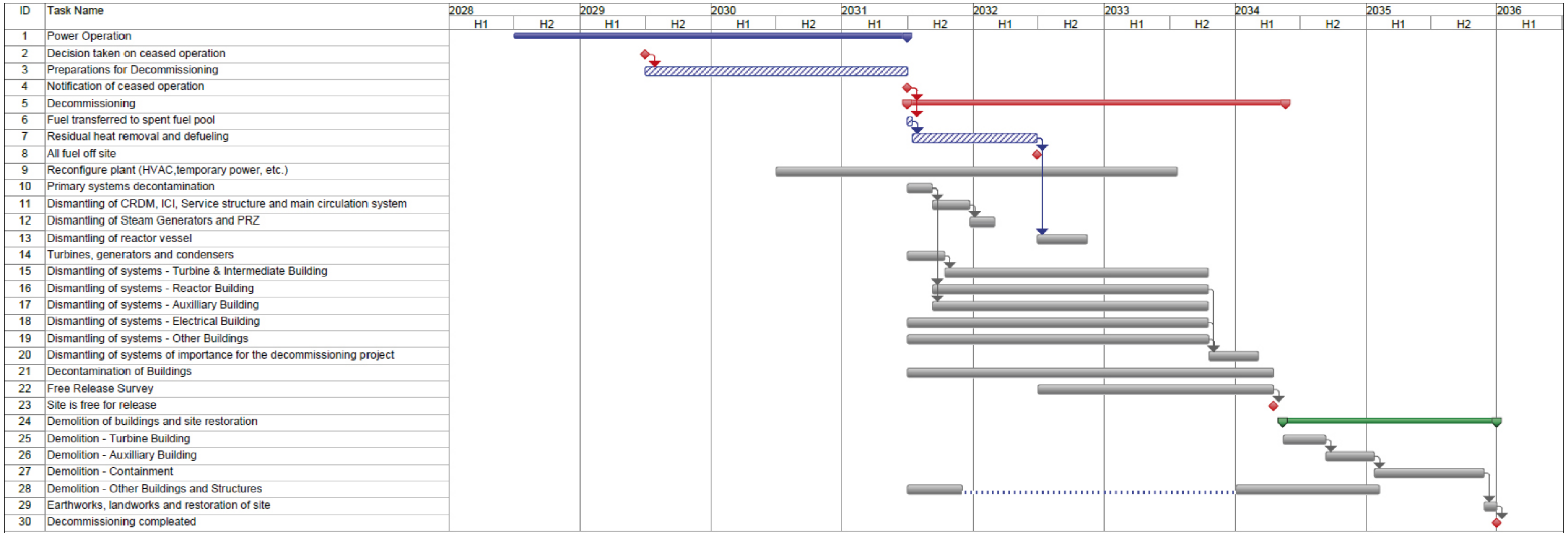


Figure I-3. *The decommissioning schedule for Ringhals 3.*

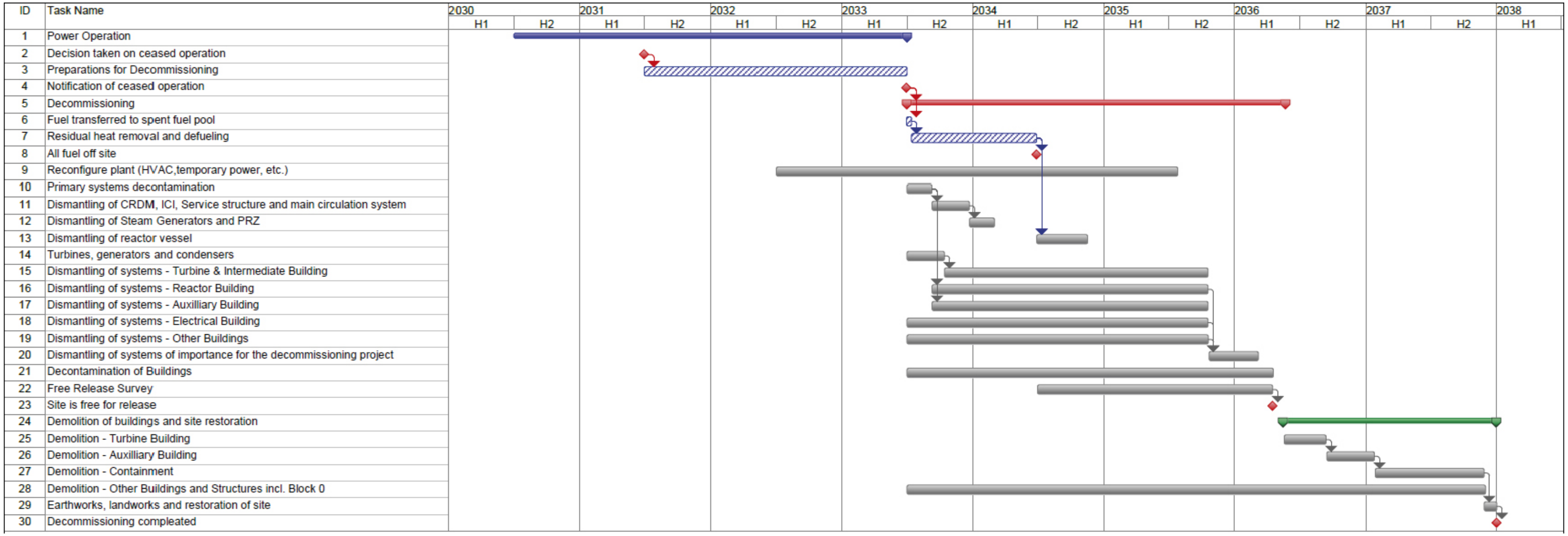


Figure I-4. *The decommissioning schedule for Ringhals 4 including Unit 0.*

Appendix J

ISDC cost tables

Table J-1. Total decommissioning cost, i.e., Ringhals 1–4 incl. Unit 0, distributed as ISDC items.

ISDC NO.	ACTIVITY DESCRIPTION	COST (kSEK)	CONTINGENCY (kSEK)	TOTAL COST (kSEK)
01	**PRE-DECOMMISSIONING ACTIONS**			
1,01	Decommissioning planning	140,027	21,004	161,031
1,03	Safety, security and environmental studies	12,800	1,519	14,319
1,04	Waste management planning	10,642	1,596	12,238
1,05	Authorisation	6,317	948	7,265
		169,786	**25,067**	**194,853**
02	**FACILITY SHUTDOWN ACTIVITIES**			
2,01	Plant shutdown and inspection	98,511	14,777	113,287
2,04	Radiological inventory characterisation to support detailed planning	48,153	14,446	62,599
		146,664	**29,223**	**175,887**
04	**DISMANTLING ACTIVITIES WITHIN THE CONTROLLED AREA**			
4,01	Procurement of equipment for decontamination and dismantling	468,746	91,120	559,865
4,02	Preparations and support for dismantling	77,017	19,254	96,271
4,03	Pre-dismantling decontamination	186,267	93,134	279,401
4,05	Dismantling of main process systems, structures and components	495,194	266,746	761,940
4,06	Dismantling of other systems and components	233,143	58,260	291,403
4,07	Removal of contamination from building structures	72,013	21,344	93,357
4,09	Final radioactivity survey for release of buildings	265,604	79,681	345,285
		1,797 983	**629,539**	**2,427,522**
05	**WASTE PROCESSING, STORAGE AND DISPOSAL**			
5,01	Establishing the waste management system	137,020	20,553	157,573
5,08	Management of decommissioning intermediate-level waste	37,850	11,588	49,438
5,09	Management of decommissioning low-level waste	403,506	75,496	479,002
5,10	Management of decommissioning very low-level waste	11,221	1,122	12,344
		589,597	**108,760**	**698,357**
06	**SITE SECURITY, SURVEILLANCE AND MAINTENANCE**			
6,01	Site security operation and surveillance	77,762	11,664	89,426
6,03	Operation of support systems	251,015	37,652	288,668
6,04	Radiation and environmental safety monitoring	108,004	27,001	135,005
		436,781	**76,317**	**513,098**
07	**CONVENTIONAL DISMANTLING,DEMOLITION,AND SITE RESTORATION**			
7,02	Dismantling of systems and building components outside the controlled area	394,536	64,237	458,773
7,03	Demolition of buildings and structures	741,178	111,177	852,354
7,04	Final cleanup, landscaping and refurbishment	49,209	7,381	56,590
7,05	Final radioactivity survey of site	5,702	1,372	7,075
		1,190,625	**184,167**	**1,374,792**
08	**PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT**			
8,02	Project management	393,108	58,966	452,074
8,03	Support services	577,379	86,607	663,986
8,04	Health and safety	98,465	14,770	113,235
		1,068,952	**160,343**	**1,229,295**
11	**MISCELLANEOUS EXPENDITURES**			
11,01	Owner costs	65,492	7,606	73,097
11,03	Insurances	52,602	5,260	57,862
		118,094	**12,866**	**130,960**
	DECOMMISSIONING TOTAL	**5,518,482**	**1,226,281**	**6,744,763**

Table J-2. Decommissioning cost for Ringhals 1 distributed as ISDC items.

ISDC NO.	ACTIVITY DESCRIPTION	COST (kSEK)	CONTINGENCY (kSEK)	TOTAL COST (kSEK)
01	**PRE-DECOMMISSIONING ACTIONS**			
1,01	Decommissioning planning	47,839	7,176	55,015
1,03	Safety, security and environmental studies	4,736	550	5,286
1,04	Waste management planning	3,402	510	3,912
1,05	Authorisation	2,020	303	2,323
		57,997	**8,539**	**66,536**
02	**FACILITY SHUTDOWN ACTIVITIES**			
2,01	Plant shutdown and inspection	24,628	3,694	28,322
2,04	Radiological inventory characterisation to support detailed planning	10,644	3,193	13,838
		35,272	**6,887**	**42,160**
04	**DISMANTLING ACTIVITIES WITHIN THE CONTROLLED AREA**			
4,01	Procurement of equipment for decontamination and dismantling	137,103	38,467	175,570
4,02	Preparations and support for dismantling	23,172	5,793	28,965
4,03	Pre-dismantling decontamination	41,297	20,649	61,946
4,05	Dismantling of main process systems, structures and components	153,406	94,106	247,512
4,06	Dismantling of other systems and components	102,049	25,486	127,535
4,07	Removal of contamination from building structures	17,588	4,503	22,091
4,09	Final radioactivity survey for release of buildings	77,904	23,371	101,276
		552,519	**212,374**	**764,894**
05	**WASTE PROCESSING, STORAGE AND DISPOSAL**			
5,01	Establishing the waste management system	34,006	5,101	39,106
5,08	Management of decommissioning intermediate-level waste	25,202	6,671	31,873
5,09	Management of decommissioning low-level waste	83,216	17,749	100,965
5,10	Management of decommissioning very low-level waste	8,061	806	8,867
		150,485	**30,327**	**180,812**
06	**SITE SECURITY, SURVEILLANCE AND MAINTENANCE**			
6,01	Site security operation and surveillance	22,510	3,376	25,886
6,03	Operation of support systems	76,639	11,496	88,135
6,04	Radiation and environmental safety monitoring	29,052	7,263	36,315
		128,201	**22,135**	**150,336**
07	**CONVENTIONAL DISMANTLING,DEMOLITION,AND SITE RESTORATION**			
7,02	Dismantling of systems and building components outside the controlled area	100,218	15,043	115,260
7,03	Demolition of buildings and structures	138,328	20,749	159,077
7,04	Final cleanup, landscaping and refurbishment	368	55	424
7,05	Final radioactivity survey of site	1,593	363	1,956
		240,507	**36,210**	**276,717**
08	**PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT**			
8,02	Project management	112,800	16,920	129,720
8,03	Support services	162,399	24,360	186,759
8,04	Health and safety	27,679	4,152	31,831
		302,879	**45,432**	**348,311**
11	**MISCELLANEOUS EXPENDITURES**			
11,01	Owner costs	18,958	2,202	21,160
11,03	Insurances	16,358	1,636	17,994
		35,316	**3,837**	**39,154**
	DECOMMISSIONING TOTAL	**1,503,176**	**365,742**	**1,868,919**

Table J-3. Decommissioning cost for Ringhals 2 distributed as ISDC items.

ISDC NO.	ACTIVITY DESCRIPTION	COST (kSEK)	CONTINGENCY (kSEK)	TOTAL COST (kSEK)
01	**PRE-DECOMMISSIONING ACTIONS**			
1,01	Decommissioning planning	44,721	6,708	51,429
1,03	Safety, security and environmental studies	3,132	390	3,522
1,04	Waste management planning	3,402	510	3,912
1,05	Authorisation	2,020	303	2,323
		53,275	**7,911**	**61,186**
02	**FACILITY SHUTDOWN ACTIVITIES**			
2,01	Plant shutdown and inspection	24,628	3,694	28,322
2,04	Radiological inventory characterisation to support detailed planning	9,124	2,737	11,861
		33,751	**6,431**	**40,183**
04	**DISMANTLING ACTIVITIES**			
4,01	Procurement of equipment for decontamination and dismantling	109,245	16,776	126,021
4,02	Preparations and support for dismantling	16,180	4,045	20,225
4,03	Pre-dismantling decontamination	48,356	24,178	72,534
4,05	Dismantling of main process systems, structures and components	123,760	60,005	183,765
4,06	Dismantling of other systems and components	46,349	11,587	57,936
4,07	Removal of contamination from building structures	16,836	5,153	21,989
4,09	Final radioactivity survey for release of buildings	67,655	20,296	87,951
		428,380	**142,040**	**570,420**
05	**WASTE PROCESSING, STORAGE AND DISPOSAL**			
5,01	Establishing the waste management system	34,404	5,161	39,565
5,08	Management of decommissioning intermediate-level waste	3,046	1,398	4,444
5,09	Management of decommissioning low-level waste	103,599	18,847	122,447
5,10	Management of decommissioning very low-level waste	1,167	117	1,284
		142,216	**25,523**	**167,739**
06	**SITE SECURITY, SURVEILLANCE AND MAINTENANCE**			
6,01	Site security operation and surveillance	18,417	2,763	21,180
6,03	Operation of support systems	58,125	8,719	66,844
6,04	Radiation and environmental safety monitoring	26,456	6,614	33,070
		102,999	**18,095**	**121,094**
07	**CONVENTIONAL DISMANTLING,DEMOLITION,AND SITE RESTORATION**			
7,02	Dismantling of systems and building components outside the controlled area	91,936	15,221	107,156
7,03	Demolition of buildings and structures	149,129	22,369	171,498
7,04	Final cleanup, landscaping and refurbishment	542	81	624
7,05	Final radioactivity survey of site	1,593	363	1,956
		243,200	**38,034**	**281,234**
08	**PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT**			
8,02	Project management	93,277	13,992	107,269
8,03	Support services	138,039	20,706	158,745
8,04	Health and safety	23,555	3,533	27,089
		254,872	**38,231**	**293,103**
11	**MISCELLANEOUS EXPENDITURES**			
11,01	Owner costs	15,511	1,801	17,313
11,03	Insurances	12,081	1,208	13,290
		27,593	**3,009**	**30,602**
	DECOMMISSIONING TOTAL	**1,286,286**	**279,275**	**1,565,561**

Table J-4. Decommissioning cost for Ringhals 3 distributed as ISDC items.

ISDC NO.	ACTIVITY DESCRIPTION	COST (kSEK)	CONTINGENCY (kSEK)	TOTAL COST (kSEK)
01	**PRE-DECOMMISSIONING ACTIONS**			
1,01	Decommissioning planning	28,326	4,249	32,575
1,03	Safety, security and environmental studies	2,674	321	2,995
1,04	Waste management planning	2,382	357	2,739
1,05	Authorisation	1,414	212	1,626
		34,795	**5,139**	**39,934**
02	**FACILITY SHUTDOWN ACTIVITIES**			
2,01	Plant shutdown and inspection	24,628	3,694	28,322
2,04	Radiological inventory characterisation to support detailed planning	9,124	2,737	11,861
		33,751	**6,431**	**40,183**
04	**DISMANTLING ACTIVITIES**			
4,01	Procurement of equipment for decontamination and dismantling	109,594	16,828	126,423
4,02	Preparations and support for dismantling	18,833	4,708	23,541
4,03	Pre-dismantling decontamination	48,315	24,157	72,472
4,05	Dismantling of main process systems, structures and components	107,665	55,981	163,646
4,06	Dismantling of other systems and components	42,373	10,593	52,966
4,07	Removal of contamination from building structures	16,845	5,156	22,001
4,09	Final radioactivity survey for release of buildings	61,363	18,409	79,772
		404,988	**135,833**	**540,821**
05	**WASTE PROCESSING, STORAGE AND DISPOSAL**			
5,01	Establishing the waste management system	34,222	5,133	39,356
5,08	Management of decommissioning intermediate-level waste	3,250	1,497	4,747
5,09	Management of decommissioning low-level waste	103,196	18,807	122,002
5,10	Management of decommissioning very low-level waste	1,166	117	1,282
		141,833	**25,554**	**167,387**
06	**SITE SECURITY, SURVEILLANCE AND MAINTENANCE**			
6,01	Site security operation and surveillance	18,417	2,763	21,180
6,03	Operation of support systems	58,125	8,719	66,844
6,04	Radiation and environmental safety monitoring	25,949	6,487	32,436
		102,492	**17,969**	**120,461**
07	**CONVENTIONAL DISMANTLING,DEMOLITION,AND SITE RESTORATION**			
7,02	Dismantling of systems and building components outside the controlled area	100,564	16,870	117,434
7,03	Demolition of buildings and structures	179,308	26,896	206,204
7,04	Final cleanup, landscaping and refurbishment	491	74	565
7,05	Final radioactivity survey of site	1,362	351	1,713
		281,726	**44,190**	**325,916**
08	**PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT**			
8,02	Project management	93,277	13,992	107,269
8,03	Support services	138,039	20,706	158,745
8,04	Health and safety	23,555	3,533	27,089
		254,872	**38,231**	**293,103**
11	**MISCELLANEOUS EXPENDITURES**			
11,01	Owner costs	15,511	1,801	17,313
11,03	Insurances	12,081	1,208	13,290
		27,593	**3,009**	**30,602**
	DECOMMISSIONING TOTAL	**1,282,050**	**276,356**	**1,558,406**

Table J-5. Decommissioning cost for Ringhals 4 distributed as ISDC items.

ISDC NO.	ACTIVITY DESCRIPTION	COST (kSEK)	CONTINGENCY (kSEK)	TOTAL COST (kSEK)
01	**PRE-DECOMMISSIONING ACTIONS**			
1,01	Decommissioning planning	19,140	2,871	22,012
1,03	Safety, security and environmental studies	2,258	259	2,516
1,04	Waste management planning	1,456	218	1,675
1,05	Authorisation	864	130	994
		23,719	**3,478**	**27,197**
02	**FACILITY SHUTDOWN ACTIVITIES**			
2,01	Plant shutdown and inspection	24,628	3,694	28,322
2,04	Radiological inventory characterisation to support detailed planning	9,124	2,737	11,861
		33,751	**6,431**	**40,183**
04	**DISMANTLING ACTIVITIES**			
4,01	Procurement of equipment for decontamination and dismantling	112,804	19,049	131,853
4,02	Preparations and support for dismantling	18,833	4,708	23,541
4,03	Pre-dismantling decontamination	48,299	24,150	72,449
4,05	Dismantling of main process systems, structures and components	110,362	56,655	167,017
4,06	Dismantling of other systems and components	42,373	10,593	52,966
4,07	Removal of contamination from building structures	16,845	5,156	22,001
4,09	Final radioactivity survey for release of buildings	58,681	17,604	76,286
		408,197	**137,915**	**546,112**
05	**WASTE PROCESSING, STORAGE AND DISPOSAL**			
5,01	Establishing the waste management system	34,388	5,158	39,546
5,08	Management of decommissioning intermediate-level waste	3,268	1,559	4,827
5,09	Management of decommissioning low-level waste	107,967	19,284	127,251
5,10	Management of decommissioning very low-level waste	828	83	911
		146,451	**26,084**	**172,535**
06	**SITE SECURITY, SURVEILLANCE AND MAINTENANCE**			
6,01	Site security operation and surveillance	18,417	2,763	21,180
6,03	Operation of support systems	58,125	8,719	66,844
6,04	Radiation and environmental safety monitoring	26,546	6,637	33,183
		103,089	**18,118**	**121,207**
07	**CONVENTIONAL DISMANTLING,DEMOLITION,AND SITE RESTORATION**			
7,02	Dismantling of systems and building components outside the controlled area	101,819	17,103	118,922
7,03	Demolition of buildings and structures	184,445	27,667	212,111
7,04	Final cleanup, landscaping and refurbishment	2,647	397	3,043
7,05	Final radioactivity survey of site	1,153	297	1,450
		290,063	**45,463**	**335,527**
08	**PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT**			
8,02	Project management	93,753	14,063	107,816
8,03	Support services	138,902	20,835	159,737
8,04	Health and safety	23,675	3,551	27,227
		256,330	**38,449**	**294,779**
11	**MISCELLANEOUS EXPENDITURES**			
11,01	Owner costs	15,511	1,801	17,313
11,03	Insurances	12,081	1,208	13,290
		27,593	**3,009**	**30,602**
	DECOMMISSIONING TOTAL	**1,289,193**	**278,948**	**1,568,141**

Table J-6. Decommissioning cost for Unit 0 distributed as ISDC items.

ISDC NO.	ACTIVITY DESCRIPTION	COST (kSEK)	CONTINGENCY (kSEK)	TOTAL COST (kSEK)
02	**FACILITY SHUTDOWN ACTIVITIES**			
2,04	Radiological inventory characterisation to support detailed planning	10,138	3,041	13,179
		10,138	**3,041**	**13,179**
04	**DISMANTLING ACTIVITIES**			
4,07	Removal of contamination from building structures	3,899	1,376	5,275
		3,899	**1,376**	**5,275**
05	**WASTE PROCESSING, STORAGE AND DISPOSAL**			
5,08	Management of decommissioning intermediate-level waste	3,084	463	3,547
5,09	Management of decommissioning low-level waste	5,528	810	6,338
		8,612	**1,272**	**9,884**
07	**CONVENTIONAL DISMANTLING,DEMOLITION,AND SITE RESTORATION**			
7,03	Demolition of buildings and structures	89,969	13,495	103,464
7,04	Final cleanup, landscaping and refurbishment	45,160	6,774	51,934
		135,129	**20,269**	**155,398**
	DECOMMISSIONING TOTAL	**157,777**	**25,959**	**183,736**

Appendix K

EEF cost tables

Table K-1. EEF Ringhals 1–4 incl. unit 0.

	Activity	EEF-code								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
1	Pre-decommissioning activities	194,853	–	–	–	–	–	–	–	194,853
2	Facility shutdown activities	175,887	–	–	–	–	–	–	–	175,887
3	Additional activities for safe enclosure or entombment	–	–	–	–	–	–	–	–	–
4	Dismantling activities within the controlled area	–	881,445	347,190	–	853,260	–	–	–	2,081,895
5	Waste processing, storage and disposal	285,702	28,021	–	–	385,114	–	–	–	698,838
6	Site security, surveillance and maintenance	89,426	–	–	–	167,612	–	–	256,061	513,098
7	Conventional dismantling, demolition and site restoration	349,870	1,077,926	–	–	292,059	–	–	–	1,719,856
8	Project management, engineering and site support	1,229,377	–	–	–	–	–	–	–	1,229,377
9	Research and development	–	–	–	–	–	–	–	–	–
10	Fuel and nuclear material	–	–	–	–	–	–	–	–	–
11	Miscellaneous expenditures	130,960	–	–	–	–	–	–	–	130,960
	Total	**2,456,074**	**1,987,393**	**347,190**	**–**	**1,698,045**	**–**	**–**	**256,061**	**6,744,763**

The variables are defined as:

EEF 0 − Real payroll costs per unit produced in the service sector.

EEF 1 − Real payroll costs per unit produced in the construction industry.

EEF 2 − Real price trend for machinery.

EEF 3 − Real price trend for building materials.

EEF 4 − Real price trend for consumable supplies.

EEF 5 − Real price trend for crude copper.

EEF 6 − Real price trend for bentonite and similar materials.

EEF 7 − Real price trend for energy.

Table K-2. EEF Ringhals 1.

	Activity	EEF-code 0	1	2	3	4	5	6	7	Total
1	Pre-decommissioning activities	66,536	–	–	–	–	–	–	–	66,536
2	Facility shutdown activities	42,160	–	–	–	–	–	–	–	42,160
3	Additional activities for safe enclosure or entombment	–	–	–	–	–	–	–	–	–
4	Dismantling activities within the controlled area	–	302,768	84,874	–	275,960	–	–	–	663,602
5	Waste processing, storage and disposal	46,788	22,563	–	–	111,706	–	–	–	181,057
6	Site security, surveillance and maintenance	25,886	–	–	–	46,289	–	–	78,161	150,336
7	Conventional dismantling, demolition and site restoration	100,794	225,749	–	–	51,139	–	–	–	377,682
8	Project management, engineering and site support	348,392	–	–	–	–	–	–	–	348,392
9	Research and development	–	–	–	–	–	–	–	–	–
10	Fuel and nuclear material	–	–	–	–	–	–	–	–	–
11	Miscellaneous expenditures	39,154	–	–	–	–	–	–	–	39,154
	Total	**669,709**	**551,080**	**84,874**	**–**	**485,094**	**–**	**–**	**78,161**	**1,868,919**

Table K-3. EEF Ringhals 2.

	Activity	EEF-code 0	1	2	3	4	5	6	7	Total
1	Pre-decommissioning activities	61,186	–	–	–	–	–	–	–	61,186
2	Facility shutdown activities	40,183	–	–	–	–	–	–	–	40,183
3	Additional activities for safe enclosure or entombment	–	–	–	–	–	–	–	–	–
4	Dismantling activities within the controlled area	–	192,212	86,531	–	203,664	–	–	–	482,407
5	Waste processing, storage and disposal	76,688	1,664	–	–	89,387	–	–	–	167,739
6	Site security, surveillance and maintenance	21,180	–	–	–	40,615	–	–	59,300	121,094
7	Conventional dismantling, demolition and site restoration	89,897	228,311	–	–	51,039	–	–	–	369,248
8	Project management, engineering and site support	293,103	–	–	–	–	–	–	–	293,103
9	Research and development	–	–	–	–	–	–	–	–	–
10	Fuel and nuclear material	–	–	–	–	–	–	–	–	–
11	Miscellaneous expenditures	30,602	–	–	–	–	–	–	–	30,602
	Total	**612,839**	**422,188**	**86,531**	**–**	**384,704**	**–**	**–**	**59,300**	**1,565,561**

Table K-4. EEF Ringhals 3.

	Activity	EEF-code 0	1	2	3	4	5	6	7	Total
1	Pre-decommissioning activities	39,934	–	–	–	–	–	–	–	39,934
2	Facility shutdown activities	40,183	–	–	–	–	–	–	–	40,183
3	Additional activities for safe enclosure or entombment	–	–	–	–	–	–	–	–	–
4	Dismantling activities within the controlled area	–	190,723	87,205	–	183,103	–	–	–	461,030
5	Waste processing, storage and disposal	76,479	1,649	–	–	89,655	–	–	–	167,783
6	Site security, surveillance and maintenance	21,180	–	–	–	39,981	–	–	59,300	120,461
7	Conventional dismantling, demolition and site restoration	81,453	262,089	–	–	61,769	–	–	–	405,311
8	Project management, engineering and site support	293,103	–	–	–	–	–	–	–	293,103
9	Research and development	–	–	–	–	–	–	–	–	–
10	Fuel and nuclear material	–	–	–	–	–	–	–	–	–
11	Miscellaneous expenditures	30,602	–	–	–	–	–	–	–	30,602
	Total	**582,934**	**454,460**	**87,205**	**–**	**374,508**	**–**	**–**	**59,300**	**1,558,406**

Table K-5. EEF Ringhals 4.

	Activity	EEF-code 0	1	2	3	4	5	6	7	Total
1	Pre-decommissioning activities	27,197	–	–	–	–	–	–	–	27,197
2	Facility shutdown activities	40,183	–	–	–	–	–	–	–	40,183
3	Additional activities for safe enclosure or entombment	–	–	–	–	–	–	–	–	–
4	Dismantling activities within the controlled area	–	190,897	88,581	–	190,102	–	–	–	469,579
5	Waste processing, storage and disposal	76,289	2,115	–	–	94,078	–	–	–	172,482
6	Site security, surveillance and maintenance	21,180	–	–	–	40,727	–	–	59,300	121,207
7	Conventional dismantling, demolition and site restoration	77,726	267,327	–	–	67,059	–	–	–	412,112
8	Project management, engineering and site support	294,779	–	–	–	–	–	–	–	294,779
9	Research and development	–	–	–	–	–	–	–	–	–
10	Fuel and nuclear material	–	–	–	–	–	–	–	–	–
11	Miscellaneous expenditures	30,602	–	–	–	–	–	–	–	30,602
	Total	**567,956**	**460,339**	**88,581**		**391,966**			**59,300**	**1,568,141**

Table K-6. EEF unit 0.

	Activity	EEF-code 0	1	2	3	4	5	6	7	Total
1	Pre-decommissioning activities	–	–	–	–	–	–	–	–	–
2	Facility shutdown activities	13,179	–	–	–	–	–	–	–	13,179
3	Additional activities for safe enclosure or entombment	–	–	–	–	–	–	–	–	–
4	Dismantling activities within the controlled area	–	4,845	–	–	432	–	–	–	5,277
5	Waste processing, storage and disposal	9,458	30	–	–	288	–	–	–	9,776
6	Site security, surveillance and maintenance	–	–	–	–	–	–	–	–	–
7	Conventional dismantling, demolition and site restoration	–	94,450	–	–	61,054	–	–	–	155,504
8	Project management, engineering and site support	–	–	–	–	–	–	–	–	–
9	Research and development	–	–	–	–	–	–	–	–	–
10	Fuel and nuclear material	–	–	–	–	–	–	–	–	–
11	Miscellaneous expenditures	–	–	–	–	–	–	–	–	–
	Total	**22,637**	**99,326**	**–**	**–**	**61,774**	**–**	**–**	**–**	**183,736**

Appendix L

Waste amounts

Table L-1. Waste amounts and number of waste containers for Ringhals 1.

Waste type	Total weight (Metric ton)	ISO Containers <500 Bq/kg	ISO Containers	Steel Boxes	Large Steel Boxes	BFA Tanks
Systems	7,820	253	162	12	116	
Buildings & Structures	1,064		17		107	
Reactor Vessel and Internals	922				28	9
Secondary Wastes	231		25	6		
Total	**10,037**	**253**	**204**	**18**	**250**	**9**

Table L-2. Waste amounts and number of waste containers for Ringhals 2.

Waste type	Total weight (Metric ton)	ISO Containers <500 Bq/kg	ISO Containers	Steel Boxes	Large Steel Boxes	BFA Tanks
Systems	1,866	30	47	47	47	
Buildings & Structures	762		12		77	
Reactor Vessel and Internals	500		2			
Secondary Wastes	226		22	12		
Total	**3,354**	**30**	**83**	**59**	**125**	

Table L-3. Waste amounts and number of waste containers for Ringhals 3.

Waste type	Total weight (Metric ton)	ISO Containers <500 Bq/kg	ISO Containers	Steel Boxes	Large Steel Boxes	BFA Tanks
Systems	1,885	29	48	47	46	
Buildings & Structures	762		12		77	
Reactor Vessel and Internals	500		2			
Secondary Wastes	245		24	12		
Total	**3,392**	**29**	**85**	**59**	**123**	

Table L-4. Waste amounts and number of waste containers for the Ringhals 4.

Waste type	Total weight (Metric ton)	ISO Containers <500 Bq/kg	ISO Containers	Steel Boxes	Large Steel Boxes	BFA Tanks
Systems	1,875	3	62	47	77	
Buildings & Structures	762		6		91	
Reactor Vessel and Internals	500		2			
Secondary Wastes	244		24	12		
Total	**3,381**	**3**	**93**	**59**	**167**	

Table L-5. Waste amounts and number of waste containers for unit 0.

Waste type	Total weight (Metric ton)	ISO Containers <500 Bq/kg	ISO Containers	Steel Boxes	Large Steel Boxes	BFA Tanks
Systems						
Buildings & Structures	208		13			
Reactor Vessel and Internals						
Secondary Wastes						
Total	**208**		**13**			

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