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Decommissioning Study of Oskarshamn NPP

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June 2013

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Oskarshamnsverket - Studie för avveckling

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

Som tillståndshavare har OKG AB låtit genomföra denna studie som beskriver tillvägagångssättet vid avveckling med inventerade avfalls- och aktivitetsmängder, tidplan, organisation och kostnader.

OKG AB har därigenom tagit sitt ansvar enligt Kärntekniklagen genom en omfattande delaktighet i arbetet med studien såsom materialinventering, projektmöten, seminarium samt granskning och remiss av underlag. Övergripande strategiska förutsättningar har tagits fram av tillståndshavarna gemensamt och är i överensstämmelse med OKGs avvecklingsplan.

Deltagandet har skett mellan åren 2008-2013 och som tillståndshavare för OKG AB ställer vi oss bakom genomförd studie och det presenterade resultatet.

Med vänlig hälsning

OKG Aktiebolag

Johan Svenningsson

Abstract

By Swedish law it is the obligation of the nuclear power utilities to satisfactorily demonstrate how a nuclear power plant can be safely decommissioned and dismantled when it is no longer in service as well as calculate the estimated cost of decommissioning of the nuclear power plant. Svensk Kärnbränslehantering AB (SKB) has been commissioned by the Swedish nuclear power utilities to meet the requirements of current legislation by studying and reporting on suitable technologies and by estimating the costs of decommissioning and dismantling of the Swedish nuclear power plants.

The present report is an overview, containing the necessary information to meet the above needs, for Oskarshamn NPP. Information is given for the plant about the inventory of materials and radioactivity at the time for final shutdown. A feasible technique for dismantling is presented and the waste management is described and the resulting waste quantities are estimated. Finally a schedule for the decommissioning phase is given and the costs associated are estimated as a basis for funding.

Contents

1 Introduction and Methodology

1.1 Introduction

1.1.1 General

According to Sweden's Act on Nuclear Activities ("*kärntekniklagen*") (SFS 1984:3) it is the obligation of the nuclear power companies to satisfactorily demonstrate how a nuclear power plant can be safely decommissioned and dismantled when it is no longer in service. In addition, the Financing Act ("*finansieringslagen*") (SFS 2006:647) states that a reactor owner shall calculate the estimated cost of decommissioning of the nuclear power plant.

Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Co, SKB) has been commissioned by the Swedish nuclear power utilities to meet the requirements of current legislation by studying and reporting on suitable technologies and by estimating the costs of decommissioning and dismantling of the Swedish nuclear power plants. SKB shall every third year present updated cost data to the authorities in order to define a proper size of the national fund that has been established by the utilities to cover for the nuclear waste management and plant decommissioning costs for the Swedish reactor sites. These data are presented in the Plan report (SKB 2010).

The fund covers for two areas related to decommissioning, one for "Operation of Nuclear Power Plant Units after Final Shutdown" and one for "Dismantling & Demolition Costs", the first for the costs generated before the actual dismantling work starts and the latter for the costs after the dismantling start.

The Swedish system for handling of radioactive waste is described in Figure 1-1. The short-lived low and intermediate level waste from both nuclear plants and other industries is transported by ship to the final repository for short-lived radioactive waste (SFR) at Forsmark. The spent nuclear fuel is transported by the same ship to the central interim storage facility for spent nuclear fuel (CLAB) at Oskarshamn. The strategy is to encapsulate the spent fuel in copper and send it to the final repository for spent nuclear fuel, approx. 500 meter below ground. Neither the encapsulation plant nor the final repository for spent nuclear fuel is yet constructed.

1.1.2 Earlier studies

SKB has performed a large number of investigations and studies to establish a reference technology for decommissioning and, based on that, estimate the costs to carry out decommissioning of the Swedish nuclear power plant sites. Examples of such studies are presented in Section 1.1.5.

The conclusions have been summarized a number of times, two of the latest being in the reports "Swedish BWR Reference Plant Decommissioning study, June 2006" (Gustafsson et al. 2006) and "Technology and costs for decommissioning Swedish nuclear power plants, June 2004" (Hedin et al. 2004).

The previous decommissioning plans for the Swedish nuclear power plants, which serve as the basis for the SKB cost estimates for the Swedish national back-end funds, are based on several in-depth studies that each of them describes a specific part of the decommissioning technology or programme. Separate studies have in this manner been carried out for areas such as dismantling of process systems, reactor pressure vessels and plant buildings as well as for the plant shutdown operation. These studies have been done over a longer period of time (some of the still used reference reports are from the early nineties) and by different authors and organizations. The reports could thus have been made with somewhat different boundary conditions. The emphasis of different aspects could also have been changed or developed over time. The consequence is that the different pieces of information do not necessarily fit perfectly together when they are added into the overall plan. In certain areas there might be an overlap, where the costs are calculated twice, and in other there might be gaps, where the costs are neglected. With this approach it might also be quite complicated to update single pieces of information as the report as a whole needs to be revised in order to change specific data.

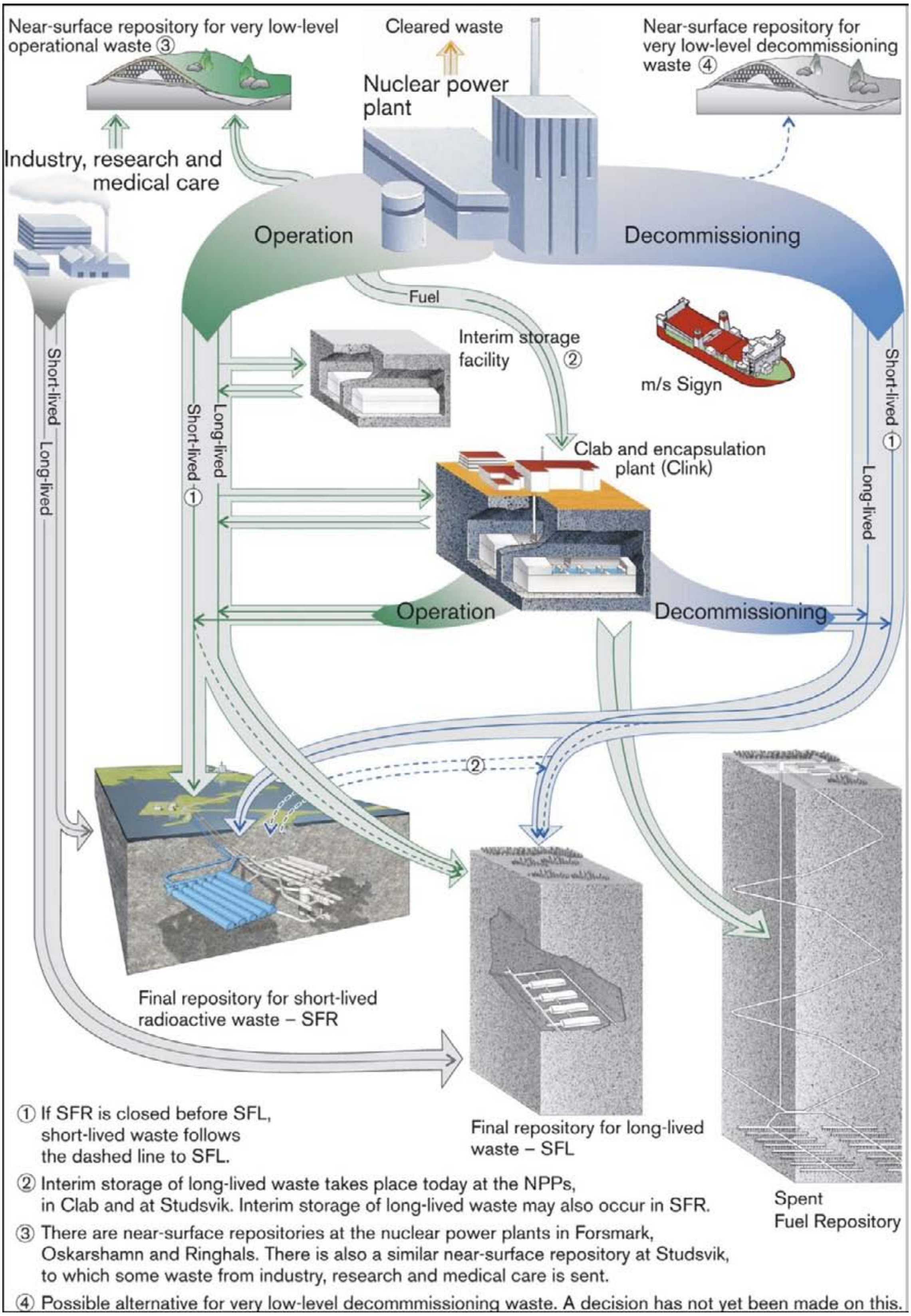


Figure 1-1. *The Swedish system.*

1.1.3 Present study

For the present study, Westinghouse was given the task to use the methodology developed in the previous studies (mainly Gustafsson et al. 2006), apply it on the Oskarshamn Site and summarize the findings.

For the reasons stated above present studies are made with the objective to obtain a basis for the time schedule, costs, waste production and waste types for the decommissioning of Swedish nuclear power plants. The studies should summarize and complete the previous studies. They should also be performed in such a way that it becomes apparent which data are included and which are not, so that individual cost items can be easily revised when new information are at hand.

The overall objectives are that the study should provide a base for an extension of the Swedish SFR with quantities of decommissioning waste arising. The extension is planned to be finished in the year 2022. It should also provide an improved input to the Plan cost evaluation work and the study is aiming at providing a final result where:

- All assumptions that form the basis for the chosen scenario and resulting cost estimates will be well documented.
- The total cost estimate will cover all relevant items regarding decommissioning to be financed by the national waste fund and by the plant owner (each item only calculated once).
- The cost estimate is transparent so that it will be easy to identify what it covers.
- It will be relatively easy to update the total information by replacement of individual data to reflect new experience or new overall strategies.
- The cost could also be presented in the OECD/NEA developed format, for the ease of international comparisons and to import other's experience.
- The technical basis in the form of dismantling procedures and technical solutions are well thought through, based on both national and international experience, such as e.g. segmentation of internals, and adapted to Swedish conditions.
- The time schedule is well thought through and possible to revise in a detailed level.
- It is possible to identify the primary dismantling waste and transform it to number of waste containers, in order to provide a basis for calculation of waste transport and disposal costs as well as for the extension of the SFR.
- The nuclide content of the waste containers is assessed in order to be used as a base for the extension of the SFR.
- The waste quantities and activities are presented for each type of final repository. Uncertainties adherent to the waste quantities and activities are presented as well.
- The total decommissioning costs including the preparatory work and planning during operation, service and shutdown will form the base. Operational costs during power and defueling operation are excluded. The cost compilation is structured according to OECD/NEA's "International Structure of Decommissioning Costing (ISDC) of Nuclear Installations"and in a way that suit SKB's routines (OECD/NEA 2012).
- The study is based on available data from 2009. Data later than 2009 is excluded.

1.1.4 Prerequisites

The overall prerequisites for the Oskarshamn study are summarized in this section.

1.1.4.1 Plant boundaries

The study will cover all the buildings at the Oskarshamn Nuclear Power Plant. The buildings included are described in Chapter 2.

1.1.4.2 Programme boundaries

The study covers the whole decommissioning phase from shutdown of power production after 60 years of operation (including the initial planning that might be done during the last five years of power operation) to hand-over of the cleared and decontaminated site for other industrial purposes. See Figure 1-2 for the decommissioning phases.

The phases are defined as follows:

- **Defueling operation**
  The period from final shutdown of a unit until all fuel has been transported away from the unit (in Swedish: "avställningsdrift"). Activities included in this study are only those directly related to decommissioning and are e.g. fuel management, adaptation to new requirements (revision of the Safety Analysis Report and other documents such as the STF), adjustment of the organization and development of new plant management guidelines. The activities also include primary circuit decontamination including radiological inventory characterization and the objects decontamination as well as the process and auxiliary system adaptation.
- **Shutdown operation**
  Shutdown operation begins when all the fuel has been transported away from a unit and lasts until more extensive dismantling of process systems and plant components begins (in Swedish: "servicedrift"). No shutdown operation is intended for Oskarshamn.
- **Dismantling operation**
  Dismantling operation is the operation of a unit during the period from the start of physical dismantling until clearance of the entire unit (in Swedish: "nedmontering och rivning").
- **Building demolition and site remediation**
  This period covers conventional demolition and remediation of the site area and takes place after the units is cleared. The assumed end-state in this study is cleared, decontaminated and free released facilities demolished and backfilled with crushed free-released concrete up to one meter below ground level. The last meter up to ground level will be backfilled with some other appropriate material depending on the future use of the land. The site will assumedly be used for other industrial purposes

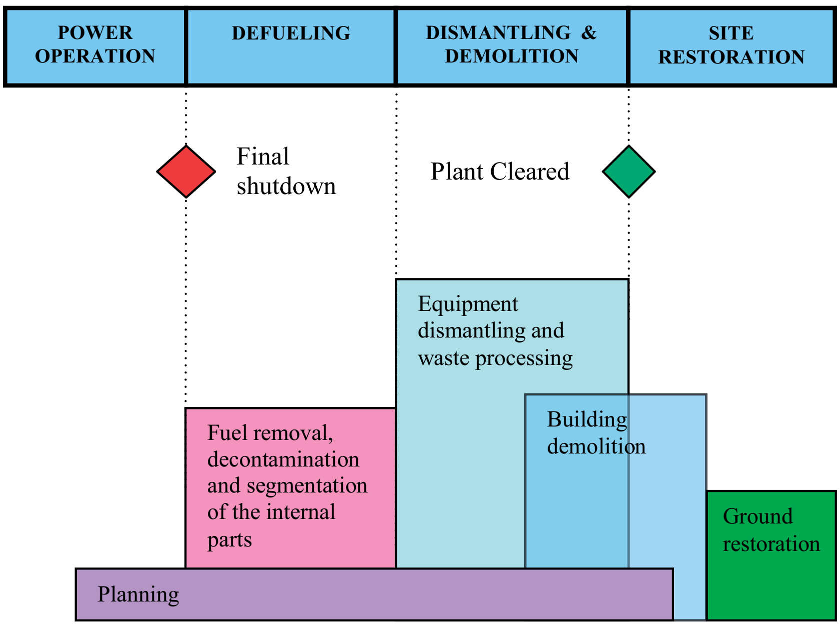


Figure 1-2. The decommissioning phases.

1.1.4.2.1 Decommissioning phases chronology

The decommissioning phase starts with the defueling operation for about 1 year with fuel still on the units. After the defueling operation the plant goes into dismantling operation. The following conditions would have to be fulfilled before entering the dismantling operation period and are planned to be done during the power and defueling operation:

- The project organization for managing dismantling activities is established.
- The most significant dismantling packages are purchased.
- Investments in equipment for treatment and measurement of dismantling waste are prepared.
- Necessary plant documentation is identified and arranged in a specific decommissioning archive.
- All operational waste from power operation and defueling operation has been removed so that only decommissioning waste is still present in the plant.
- The decommissioning plan and the environmental impact assessment are approved. An application for a dismantling permit has been made.
- The radiological survey has been completed.
- Decontamination of the reactor pressure vessel and the primary process systems has been carried out and the decontamination waste has been taken care of.
- Individual decontamination has been carried out for selected components.
- Nuclear fuel, control rods, neutron flux detectors and scrapped components from the pools have been transported away (operational waste).
- Systems not to be utilized during the dismantling phase are drained of its medium, if necessary dried, and the waste is taken care of.
- Electrical equipment that is no longer needed is disconnected.
- The generator is dismantled and the turbine is in drained
- Existing systems, lifting devices etc that are needed during the dismantling phase are in proper condition and if needed rebuilt to suit the need from the dismantling operations.
- Staffs with proper competence for operation and maintenance of the plant are available.
- Temporary systems and equipment necessary during decommissioning are installed.

1.1.4.3 Cost calculation boundaries

The cost summary will contain all cost items that the plant owner is responsible for during the decommissioning except for the operational costs during power and defueling operation.

Cost items associated with activities after the radiological declassification of the plant, i.e. non-radioactive building demolition and restoration of the ground to a state adapted to the further use of the site can be regarded as a sole interest of the site owner, not necessarily to be covered by mutual funds, and will thus be presented separately.

Costs for fees to authorities are not part of the study, as these are not normally covered in the Plan reports. Instead, these are discussed separately.

It is foreseen that the plant owner carries out the plant operation during the dismantling phase partly with its own personnel. These efforts might consist of overall project management, public information activities, plant surveillance, maintenance, plant operation, physical protection, entrance control, housekeeping etc. Other parts of the decommissioning programme, such as the main dismantling work packages will be the responsibility of specialized contractors.

1.1.4.4 Technical prerequisites

There is little information on the different materials in the process equipment waste. Therefore it is assumed that all process equipment is made of steel.

1.1.4.4.1 Handling of the reactor pressure vessel

The reactor pressure vessel, RPV (without its internals), could generally be handled according to two different main strategies. These are segmentation into pieces that are small enough to be handled according to the normal waste routes for the repository, or lifting out of the reactor building as one intact component to be disposed of as a separate package.

Both alternatives have been discussed for the Swedish decommissioning programme. In Farías et al. (2008) it is described that the handling of the RPVs as intact components to be disposed of as separate packages is preferred.

1.1.4.4.2 Waste transport and disposal

The costs for transport and final disposal of the radioactive dismantling waste are presented separately in the Plan reports. These activities and corresponding costs are not handled in this study; the waste transports ends with the containers being delivered to the dock of the site. However, handling of the RPV, non-radioactive waste and free release material is covered by the study.

1.1.4.4.3 Decontamination for free release of materials

The level of ambition for efforts aiming at allowing material to be regarded as non-radioactive should be based on ALARA considerations, environmental impacts as well as an economical evaluation of the costs for decontamination versus the costs for final disposal of radioactive waste. For this study it is assumed that moderate decontamination efforts are justified, i.e. normally with only simpler cleaning methods (water flushing, moderate blasting etc). For large amounts of heavy goods with smooth surfaces, more extensive and time-consuming treatment could be justified, while smaller objects with complicated geometry would not be treated at all.

1.1.5 Reference reports

The present study is to a large extent based on the data that has been developed for SKB in previous studies. The main reports from the previous studies are the following:

- Report Westinghouse SEP 06-055, Swedish BWR Reference Plant Decommissioning Study (Gustafsson et al. 2006).
- Report Westinghouse NM 94-627, Rivningsstudie för Oskarshamn 3 – Processutrustning (study of process systems) (Lönnerberg 1994).
- Report Westinghouse SEP 03-503, Studie av byggnadsrivning av de svenska kärnkraftverken – Slutrapport (study of building demolition) (Ericsson 2005).
- Report Westinghouse SEP 03-508, Studie av avställnings- och servicedrift för svenska kärnkraftverk (study of defueling and shutdown operation) (Pålsson et al. 2003).
- Report Siemens NR-R/93/041 – Conceptual Study of the Dismantling of Reactor Pressure Vessel and Reactor Pressure Vessel Internals (Pillokat 1993).
- Report Westinghouse SEW 07-182, Rivningsstudie av demontage, lyft, transport, mellanlagring och slutförvaring av hel reaktortank (Decommissioning study of intact RPV) (Farías et al. 2008).
- Report Westinghouse SEP 04-214, Studie av anläggningsdrift vid rivning och återställande av anläggningsplatsen (study of dismantling operation) (Pålsson and Hedin 2005).
- Plan OKG 2005-13693, Planering inför avveckling av Oskarshamnsverket (Olsson 2005).
- Report SKB 1359832, Avveckling och rivning av kärnkraftsblock (SKBdoc 1359832).

1.1.6 Structure of the report

The report is organized with a structure and content according to the following:

1. *Introduction and methodology*
   Description of the background, the purpose and the contend of the study. The applied overall methodology for the study is defined in this chapter.

2. *General description of the Oskarshamn nuclear power plant*
   General description of the plant and the units, both from the physical and from the operational point of view. The characterization is intended to provide general data for the plant decommissioning analysis and to give a basis for comparison with other plants. The description will include the following aspects:
   - Units
   - Site
   - Buildings and Structures
   - Systems and Components

3. *Dismantling and waste management techniques*
   Suitable techniques for plant dismantling and decontamination are suggested under this chapter. The techniques are chosen from experiences of similar plants and objects. Demands for competence and equipments, waste production and production costs will be assumed for the decommissioning objects.

   The logistics for the decommissioning operations will be evaluated and suitable sequences for the decommissioning will be suggested. A customized waste flow with necessary handling and sorting stations is suggested for the plant as well as systems for nuclide and dose rate measurements. For each type of waste the proper waste container to be used is specified.

4. *Material inventory, radioactivity inventory and resulting waste amounts*

4.1 *Material inventory*
The plant materials inventory data of building elements, equipment and components necessary for the estimate of waste production, time schedule and dismantling costs are presented in this chapter.

4.2 *Activity inventory*
The assessment of the different decommissioning and dismantling alternatives for a plant requires a characterization of the nature and extent of contamination at the different areas of the facility under consideration. A characterization based on the expected levels one year after plant shutdown is provided under this chapter. Nuclide vectors for different types of waste as well as limits for the free release of waste will also be presented in this chapter. The activity characterization is provided by Studsvik ALARA Engineering, denominated only as ALARA Engineering in the rest of the report.

4.3 *Waste amounts*
Based on the inventory data, the number of waste containers of different types is calculated and the nuclide content is specified. The container types are specified by SKB.

5. *Decommissioning programme*
   The decommissioning programme will be based on previous studies (Gustafsson et al. 2006, Olsson 2005). A general dismantling programme is developed, covering all relevant phases, in sufficient detail for overall planning and the cost estimation. The organization during the decommissioning and the duration of the defueling is provided by OKG and SKB.

6. *Decommissioning cost estimates*
   With the frame defined and all information generated in the previous chapters, the total dismantling and demolishing costs for the plant will be estimated and calculated in this chapter.

   From the chosen techniques and the inventory of the plant, the resource and equipment needs for each activity will be defined at a suitable level in the cost estimation.

The cost analysis will be structured according to the WBS and to the method that EC, IAEA and OECD/NEA present in "International Structure of Decommissioning Costing (ISDC) of Nuclear Installations". This is to guarantee that all aspects are covered and to facilitate an international comparison.

7. *Summary, results and conclusions*
   The main results, uncertainties and conclusions of the study are summarized in this chapter. The result from the waste volume and cost estimations will be presented in table format.

1.2 Methodology

1.2.1 Introduction

1.2.1.1 Purpose of the chapter

The purpose of this chapter is to give an overview of the methodology used in the present study with special focus on the costs and the amount and type of waste to be disposed of. As an introduction, general aspects on nuclear power plant decommissioning cost estimating methodology and definitions will be discussed.

1.2.1.2 General aspects on cost estimating methodology

Reliable cost estimating is one of the most important elements of decommissioning planning. Alternative technologies may be evaluated and compared based on their efficiency and effectiveness, and measured against a baseline cost as to the feasibility and benefits derived from the technology. When the plan is complete, those cost considerations ensure that it is economically sound and practical for funding.

Estimates of decommissioning costs have been performed and published by many organizations. The results of an estimate may differ because of different work scopes, different labour force costs, different money values because of inflation, different oversight costs, the specific contaminated material involved, the waste stream and peripheral costs associated with that type of waste, or applicable environmental compliance requirements. A reasonable degree of reliability and accuracy can only be achieved by developing decommissioning cost estimates on a case-by-case site-specific basis. There is no universally accepted standard for developing cost estimates, or for that matter, any clear reference for terminology used in decommissioning.

One significant factor to consider in the cost estimation process is if there is a final repository available for the short-lived low and intermediate level waste, the long-lived low and intermediate level waste and the high level radioactive waste. In Sweden, final repositories will be available at the time of decommissioning, which brings with it that free releasing of materials must not be done at all cost, but some of the low level waste that could otherwise be decontaminated and free released can be deposited in the final repository. This has a huge impact on the cost estimation for the whole decommissioning programme.

1.2.1.2.1 Types of cost estimates

There are three types of cost estimates that can be used and each have a different level of accuracy (Taboas et al. 2004). These cost estimate types and corresponding accuracies, estimated with today's prerequisites such as authority requirements and value of money, are summarized in the following paragraphs.

- Order-of-Magnitude Estimate: One without detailed engineering data, where an estimate is prepared using scale-up or -down factors and approximate ratios. It is likely that the overall scope of the project has not been well defined. The level of accuracy expected is –30% to +50%.
- Budgetary Estimate: One based on the use of flow sheets, layouts and equipment details, where the scope has been defined but the detailed engineering has not been performed. The level of accuracy expected is –15% to +30%.

- Definitive Estimate: One where the details of the project have been prepared and its scope and depth are well defined. Engineering data would include plot plans and elevations, piping and instrumentation diagrams, one-line electrical diagrams and structural drawings. The level of accuracy expected is –5% to +15%.

It is apparent from these estimate types and levels of accuracy expected that even in the most accurate case, a definitive estimate is only accurate to –5% to +15%. The cost estimator needs to exercise his/her judgment as to the level that the input data will support. In developing a funding basis for a project, the estimator includes sufficient margin (or contingency) to account for a potential budget overrun to account for this level of uncertainty.

1.2.1.2.2 Developing the cost estimate

Costs may be estimated in a number of ways. Recorded experience from other decommissioning projects, estimating handbooks and equipment catalogue performance data are some of the sources used to develop cost data. The techniques used for preparing cost estimates will necessarily vary with the project's degree of definition; the state-of-the-art of the project; the availability of databases, cost estimating techniques, time, and cost estimators; and the level of engineering data available. Some of the more common estimating techniques are described in the following paragraphs.

- Bottom-up Technique: Generally, a work statement and set of drawings or specifications are used to extract material quantities required for executing each discrete task performed in accomplishing a given activity. From these quantities, direct labour, equipment, and overhead costs can be derived.
- Specific Analogy Technique: Specific analogies depend upon the known cost of an item used in prior estimates as the basis for the cost of a similar item in a new estimate. Adjustments are made to known costs to account for differences in relative complexities of performance, design and operational characteristics.
- Parametric Technique: Parametric estimating requires historical databases on similar systems or subsystems. Statistical analysis is performed on the data to find correlations between cost drivers and other system parameters, such as design or performance. The analysis produces cost equations or cost estimating relationships that may be used individually or grouped into more complex models.
- Cost Review and Update Technique: An estimate may be constructed by examining previous estimates of the same or similar projects for internal logic, completeness of scope, assumptions and estimating methodology.
- Expert Opinion Technique: This may be used when other techniques or data are not available. Several specialists may be consulted iteratively until a consensus cost estimate is established.

The method widely adopted in estimating and which is used in this study is the bottom-up technique, based on a building block approach known as the work breakdown structure (WBS). The building block approach follows the same logic whether the estimate is being generated to support a demolition or construction scenario. Using this approach, a decommissioning project is divided into discrete and measurable work activities. This division provides a sufficient level of detail so that the estimate for a discrete activity can apply to all occurrences of the activity.

1.2.1.2.3 Cost element definitions

It is constructive and helpful to group elements of costs into categories to better determine how they affect the overall cost estimate. To that end, the cost elements are broken down into activity-dependent, period-dependent, and collateral costs as defined in the following paragraphs. Contingency, another element of cost, is applied to each of these elements on a line-item basis (as will be described separately) because of the unique nature of this element of cost.

Activity-dependent costs:
Activity-dependent costs are those costs associated with performing decommissioning activities. Examples of such activities include decontamination; removal of equipment; and waste packaging,

shipping and burial. These activities lend themselves to the use of unit cost and work productivity factors (or work difficulty factors) applied against the plant and structure's inventories to develop the decommissioning cost and schedule.

Period-dependent costs:
Period-dependent costs include those activities associated primarily with the project duration: engineering, project management, dismantling management, licensing, health and safety, security, energy, and quality assurance. These are primarily management staffing level costs, developed by estimating the manpower loading and associated overhead costs based on the scope of work to be accomplished during individual phases within each period of the project.

Collateral and special item costs:
In addition to activity and period-dependent costs, there are costs for special items, such as construction or dismantling equipment, site preparation, insurance, property taxes, health physics supplies, liquid radioactive waste processing and independent verification surveys. Such items do not fall in either of the other categories. Development of some of these costs, such as insurance and property taxes, is obtained from owner-supplied data.

Contingency:
Contingency can be defined as "a specific provision for unforeseeable elements of cost within the defined project scope, particularly important where previous experience relating estimates and actual costs has shown that unforeseeable events that increase costs are likely to occur."

The cost elements in a decommissioning cost estimate are based upon ideal conditions where activities are performed within the defined project scope, without delays, interruptions, inclement weather, tool or equipment breakdown, craft labour strikes, waste shipment problems, or burial facility waste acceptance criteria changes, changes in the anticipated plant shutdown conditions, etc. However, as with any major project, events occur that are not accounted for in the base estimate. Therefore, a contingency factor is applied.

Early decommissioning cost estimates included a contingency of 25% that was applied to the total project cost. More recent and accurate approaches apply contingencies on a line item basis, yielding a weighted average contingency for the cost estimate.

Scrap and salvage:
The cost estimate includes an evaluation of the scrap and/or salvage values from material that are determined to be clean, or that were never exposed to radioactive or hazardous material contamination. The evaluation is based on recent cost data obtained from one or more of the references included in this section.

Salvage is defined as removed material that has an identified market for resale or reuse at a specific facility. Accordingly, pumps, motors, tanks, valves, heat exchangers, fans, diesel engines and generators, etc are the types of components that are candidates for salvage. Scrap is defined as removed material that is certified to be non-contaminated or -activated, and may be sold to a scrap dealer for ultimate recycling as a raw material.

Examples of scrap material are copper wires and bus bars, stainless steel plates and structural members, carbon steel and stainless pipes, carbon steel structural shapes, beams, plates, etc.

The market for salvageable material from facilities that have used radioactive material is limited, owing to the very specific purpose for which they were intended. Market prices fluctuate depending on the buyer's expense to remove the component intact and to package it and transport it to its new application in a reusable condition. These expenses reduce the resale value of salvaged material.

For steel scrap, material is sold on an as-is, where-is basis. There are no warrantees or representations as to the reusability of the item. Market prices are usually posted daily in newspapers and journals. Site reuse for new productive applications after decommissioning is another way of partly offsetting decommissioning costs.

Work breakdown structure (WBS):
The WBS is used to categorize cost elements and work activities into logical groupings that have a direct or indirect relationship to each other. The work groupings are usually related to the accounting system, or chart of accounts used for budgeting and tracking major elements of the decommissioning costs.

WBS levels:
The WBS elements are generally arranged in a hierarchal format similar to a company's organization chart. The topmost level of the WBS would be the overall project. The second level would be the major cost groupings under which project costs would be gathered. The next level would be the principal component parts of each direct or indirect cost category for that cost grouping. Subsequent levels are often used to track details of the component parts of the grouping so that a clear understanding of all the cost bases can be made.

1.2.1.2.4 Cost estimating process

A thorough cost estimating process flows from an overview of the project, to the scenarios evaluated or selected, to the assumptions critical to the approach, to the details of the cost elements and the work schedule, and then to a summary of the principal cost elements. While there are no hard and fast rules for formatting the process, there are logical guidelines to follow so that cost estimates can be easily tracked and compared.

Scope of work:
The scope of work for the project needs to be clearly stated at the outset of the estimate to ensure the estimator and reader understands what is included in the estimate, and the extent of effort required. The scope identifies assumptions and exclusions of the systems and structures to be removed and dismantled, and the amount of site restoration required.

Decommissioning strategies:
The decommissioning strategies to be evaluated are immediate dismantling, deferred dismantling or entombment.

Collection of information:
A unit-specific estimate uses defined engineering data, including site and plot plans, general arrangement and architectural drawings, piping and instrument diagrams, one-line electrical diagrams, equipment specifications, reference manuals, etc to provide a basis for the facility systems and structures requiring decontamination and dismantling. Data collection includes the site radiological and hazardous material characterization information; site specific inventory of systems and structures; local labour costs for skilled labour and management; local consumables and materials costs; and taxes, insurance, engineering and regulatory fees.

Preparation of the cost estimate:
The application of unit costs to the inventory of systems and structures for each dismantling activity provides the activity-dependent costs. The estimate of the project management staff costs for the duration of the project provides the period-dependent costs. Collateral costs and contingency are added to develop the total decommissioning cost.

Preparation of the schedule:
The overall schedule is developed from a logical and planned sequence of activities. The duration of each activity is estimated from the individual activity steps, and the sequence evaluated to obtain the critical path (longest time) to accomplish the work. Iterations are often necessary to arrive at a reasonable schedule. This work is usually performed using scheduling computer software. The decommissioning cost estimate and schedule are not stand-alone documents; they are an integral part of the planning for a project from the concept to the final implementation. The cost estimate and schedule are linked inseparably, as changes to the cost affect the schedule as to when activities may be accomplished, and changes to the schedule affect the overall cost. An accurate cost estimate and schedule provide the ability to track costs and project trends.

1.2.1.3 General aspects on waste amount estimation methodology

The accurate estimate of the waste quantities and activities to be generated during the dismantling operations and of the associated radiological burden requires a thorough and comprehensive inventory of all the plant system components and structures subject to potential radioactive contamination.

The information listed in the following sections is mainly obtained from Gustafsson et al. (2006). This information has been completed with data obtained from the plant owner OKG. In those instances where the inventory fails to include required data, e.g. equipment weights or piping length runs, the corresponding estimates are based on the application of duly justified criteria, assumptions and extrapolations. Engineering judgement has also been used to fill the gaps encountered in the available information. Building data are mainly obtained from system descriptions and layout drawings.

1.2.2 Methodology applied in the present study

1.2.2.1 Introduction

This section presents an overview of the methodology used in the present study of the Oskarshamn NPP with special focus on the costs estimate and the amount of waste to be disposed of. The methodology on a more detailed level can be found in the individual chapters.

The methodology used is similar to the methodology used in the Reference Plant Decommissioning Study (Oskarshamn 3) (Gustafsson et al. 2006).

1.2.2.2 Identifying the scope of work

The scope of work for the decommissioning work project needs to be clearly stated at the outset of the study to ensure the that author, cost estimator and reader understand what is included in the study, and the extent of effort required. The scope identifies assumptions and exclusions of the systems and structures to be removed and dismantled, and the amount of site restoration required. It also identifies the time period and the cost categories to be considered including the plant and site status at the starting point as well as the ultimate aim of the decommissioning. Also, the decommissioning strategies (immediate dismantling, deferred dismantling or entombment) have to be defined.

The scope is presented in Section 1.1.

1.2.2.3 Inventory of systems, components and structures

1.2.2.3.1 Plant Metal Inventory

The inventory of process and electrical equipment, piping, cables, insulation and all structures was obtained from the plant owner OKG. It is denominated as Plant Metal Inventory. This information was then supplemented by information from system descriptions, component specifications and drawings and stored in detailed form as MS-Excel lists. By using Pivot Table Reports the information has been compiled and on suitable levels presented in Chapter 4.

1.2.2.3.2 Building data and concrete inventory

The Building data and Concrete Inventory has been obtained from OKG. A summary of the information is presented in Chapter 4.

1.2.2.4 Radiological characterization and inventory

The nature and extent of contamination at the different areas of the facility under consideration have been characterized. The characterization is based on the expected levels one year after plant shutdown. Nuclide vectors for different types of waste with activated corrosion products and fission products and actinides are presented in Chapter 4. The activity in system 321, the shutdown cooling system, for Co-60 has been used as reference.

The materials inventory presented in Chapter 4 has been completed with a classification into contamination categories and the amount of material in each radiological classification has been estimated. The waste classification has been based on specific activity data from the databases used in Chapter 4 together with some complementary information and engineering judgements. By using pivot table reports the information has been compiled and presented in Chapter 4.

The activity inventory was obtained from ALARA Engineering (Jonasson 2012a, b, c).

1.2.2.4.1 Identifying suitable dismantling techniques

Information on the typical tools and techniques that could be used during the decommissioning of a Swedish BWR plant has been compiled. In general the techniques have been selected on the basis of previous experiences on both national and international decommissioning projects, particularly US experiences as more light water reactor decommissioning projects of this type have been completed or are in progress there. In some cases, the chosen technique may not be the same as might be chosen if a similar task were to be performed during a plant refurbishment or upgrade. This is a reflection of the less precise nature of the dismantling work and the fact that the plant will not need to be restored to an operational state upon completion, either by reinstatement of equipment or clean-up to the as-operated condition. Experience values have been used so the costs have not been overestimated in that regard.

Preferred sequences of decommissioning tasks and the required logistics, e.g. for waste item and waste package movement within the plant have been identified. This was based on previous experience or detailed studies made for other plants, suitably modified to reflect the specifics of the Oskarshamn Nuclear Power Plant.

The philosophy adopted within the present study has been that only proven existing techniques will be employed. This is so that:

- SKB and the Utilities can be confident that the technique described is suitable for the task and has already been used for a similar application, generally in the US where more decommissioning has been completed to date.
- There will be little or no tooling development works required, which would lead to development cost and time plus potential cost/programme risk to the delivery of the project if tools could not be developed and deployed in accordance with the overall project programme.

1.2.2.5 Identifying suitable waste management techniques

The options for the decommissioning of areas other than the reactor pressure vessel (RPV) and for the management of the associated wastes have been evaluated at a conceptual level.

The use of existing waste treatment buildings has been the option studied in this report with a fit-for-purpose, modular waste screening facility constructed within the turbine building or a similarly sized building that makes use of re-usable modular containment and shielding, combined with the use of existing waste treatment buildings and their waste screening, size reduction, packaging and shipping systems as well as a new building for handling and screening of possible free release waste. See more in Chapter 3. Finally, the numbers of waste containers have been calculated from the amount of waste, packing density and container volumes.

1.2.2.6 Preparation of decommissioning programme

The time schedule has been structured according to the project WBS. The milestones have mainly been collected from the study of dismantling operation (Pålsson et al. 2003) and from Olsson (2005) and SKBdoc 1359832.

The duration for the reactor internals segmentation and RPV segmentation have been based on experience from the BNFL/Westinghouse Group decommissioning projects and Westinghouse segmentation projects in Sweden and Finland. For less critical dismantling activities, like removal of ordinary sized process equipment (pumps, tanks, valves, pipes etc), a specific model has been used. This model was established during the Process System Dismantling Study (Lönnerberg 1994) and is mainly based on a combination of theoretical analysis and field experience, mostly from dismantling of equipment during repair work. Finally, the duration of the building demolition and site remediation activities have been based on the study of building demolition (Ericsson 2005).

1.2.2.7 Preparation of cost estimate

1.2.2.7.1 Introduction

The cost estimate can, in general, be regarded as a budgetary estimate, i.e. it is mainly based on the use of flow sheets, layouts, databases and equipment details. The scope has been defined but the detailed engineering has not been performed. However, the building demolition costs can be regarded as more accurate.

The Bottom-up Technique mentioned in Section 1.2.1.2.2 has mainly been used, in some cases in combination with the Specific Analogy Technique and expert opinions.

1.2.2.7.2 Establishing a work breakdown structure

Many different criteria could be applied when establishing a Work Breakdown Structure (WBS) for a large project. The following have been considered in the present study:

- The top level items should be divided by time-depending milestones and this leads to the division into the main phases: power production, defueling, shutdown operation, nuclear dismantling and conventional demolition. For all phases, except for the dismantling and conventional demolition phases, only activities related to dismantling and demolition activities should be included. However, for Oskarshamn there will be no shutdown operation.
- The classification of activities that has been used in the study of dismantling operation (Pålsson and Hedin 2005), and information in the study of personnel during decommissioning operation (SKBdoc 1359832), should also be used here, as far as reasonable. This implies that the classification of costs into own personnel, operational costs, fixed costs, organizational costs and project costs should not be changed.
- WBS items, whose sizes are dependent on time, should be separated from items whose sizes are dependent on the actual work or activities that are carried out.
- WBS items related to so-called conventional dismantling and demolition should be separated. With conventional dismantling is understood all dismantling/demolition that is executed after that the particular building has been classified as non-radioactive.
- A WBS item, after break-down to the most detailed level, should be able to be clearly linked to a single item in the OECD/NEA structure.
- Similar WBS structure as for other studies is a benefit as it enables comparisons.
- Break-down should be done to a level that enables existing data in the form of inventory lists etc to be used with reasonable additional efforts for data separation per building or similar.
- The basis for each item should be traceable.

It has been assumed that the plant owner has their own staff for operation of the site during the dismantling phase and that the project organization is established early in the process. This organization will purchase all services needed, mainly through larger contractors.

Based on the above mentioned criteria, a WBS has been established. The time schedule mentioned in the previous section has also been structured according to this WBS.

1.2.2.7.3 Utility personnel costs

The utility personnel costs have been calculated from a given organization combined with the duration and the direct yearly costs for the personnel categories in question. The number of personnel has been collected from the study of personnel during decommissioning operation (SKBdoc 1359832).

1.2.2.7.4 Operational costs

Some of the operational costs have been calculated from yearly costs given in the study of dismantling operation (Pålsson and Hedin 2005) combined with the duration of the work. The costs include operation and maintenance, organizational costs and fixed costs. Some personnel costs have been collected from the study of personnel during decommissioning operation (SKBdoc 1359832).

1.2.2.7.5 Project management and administration costs

The project management and administration costs have been calculated from a given utility project organization combined with the duration and the direct yearly costs for the personnel categories in question. The number of personnel has been collected from the study of personnel during decommissioning operation (SKBdoc 1359832).

1.2.2.7.6 Dismantling and demolition costs

Handling of the RPV and internals
Activities on a detailed level has been identified and the duration estimated. Personnel resources and allowances have been added, based on quoted rates from a specialist contractor, and finally the Contractor Company Overhead Recovery and Profit have been added.

Process equipment
In order to calculate the work associated with the dismantling of the process equipment, besides the RPV and its internals, the plant metal inventory has been divided into so-called macro-components. This implies that components, piping etc have been subdivided into intervals with respect to size and for each interval a characteristic quantity like length or weight have been calculated. The duration of the dismantling activities have then been calculated by means of efficiency figures and site factors, based on analyses and experiences and, by combining with work team compositions and hourly costs for various personnel categories, the work (manhours) and costs have been obtained. A detailed description of the methodology is given in Chapter 6.

The project management and administration work within the process dismantling contractor's organization has been collected from Lönnerberg (1994) and so have also the costs for the procurement and consumption of tools.

Building demolition and site remediation
The costs for the building demolition have been collected from the study of building demolition (Ericsson 2005) and are made up from basic costs and general site expenses and contractor fees.

The basic costs have been derived by means of a so called production cost estimate, which implies that the costs are determined at activity level. The need for material, work and equipment is assessed for each activity and then the cost is estimated. However, relevant experience values from a project of this nature are not available. Instead, information from large conventional (non-nuclear) demolition projects has been used after appropriate adaptation.

"General site expenses and contractor fees" includes costs for the resources necessary for the general work and facilities necessary for the primary demolition work.

The work necessary for cleaning and clearance of controlled area buildings has also been collected from Ericsson (2005).

1.2.2.7.7 Waste related costs

The cost for waste processing and packaging consists of equipment costs including installation and dismantling of the equipment and operating costs. The equipment costs have been estimated based on information from suppliers. The operating costs have been calculated from the amount of waste processed, similar to the process equipment dismantling costs.

The costs for the waste containers with radioactive waste, transports of conventional waste to landfill and landfill fees have been calculated from the number of containers, transports etc and the unit costs.

1.2.2.7.8 Contingency

Costs in the present study have been calculated without associated contingency factors. Thus, in a further analysis it is possible to apply different contingencies depending on the particular case that is being studied. There is otherwise a risk that factors are applied on each other in several steps, reflecting an unjustified level of risk. Suitable contingencies have been estimated and presented separately. It should be observed that contingencies are highly relevant for calculated cost figures while an estimated figure, based on experience, naturally includes most of the contingency in itself. That is, if the conditions and contexts are similar for the item that is estimated and the item that is experienced.

2 General description of Oskarshamn

2.1 Introduction

The purpose of this chapter is to give a general description of the Oskarshamn NPP, both from the operational and from the physical point of view, in order to extract necessary data for the decommissioning studies of the site, as well as being able to compare the units between each other. The chapter presents overall information for the Oskarshamn NPP such as main technical data and main operational data as well as a description of buildings belonging to O1, O2 and O3 and also buildings that are shared by all the units at the Oskarshamn NPP, called unit 0. The information in this chapter is based on available data from 2009

The information in this chapter is intended to describe the Oskarshamn NPP characteristics and may not be suitable for further precise calculations.

2.2 Main data

The Oskarshamn NPP is situated on the Simpevarps-peninsula next to the Baltic Sea, approximately 30 km north east of the city Oskarshamn in Sweden. Within the power plant area there are three (3) reactors, Oskarshamn 1, 2 and 3. In addition to the reactor units there are buildings owned by the Swedish Nuclear Fuel and Waste Management Co (SKB). These buildings mainly consist of a laboratory and storage buildings for spent nuclear fuel.

O1, O2 and O3 are all boiling water reactors (BWR) of ASEA-ATOM (presently Westinghouse Electric Sweden design). Water is used as reactor coolant and moderator and the containment is of pressure-suppression type. O1 and O2 have surface cooling water intakes, while O3´s cooling water intake is 18 m below sea level, about 500 m from the shore. Figure 2-1 presents a picture of the Oskarshamn power plants O3 with O1 and O2 in the background.

Figure 2-1. *O3 with O1 and O2 in the background.*

2.2.1 Main technical data

The main technical data for the Oskarshamn plants are presented in Table 2-1.

Table 2-1. Main technical data.

	Unit	O1	O2	O3
Main Supplier				
Reactor		ASEA-ATOM	ASEA-ATOM	ASEA-ATOM
Turbine		Stal-Laval	Stal-Laval/ Brown Boveri	Alstom
Schedule				
Construction Start		1966 (1965)	Oct 1969	May 1980
Commissioning		Feb 1972	Aug 1974	March 1985
Construction Volumes				
Reactor Building	m^3	63,000	106,000	148,000
Turbine Building	M^3	71,000	150,000	275,000
Work Volumes				
Total Construction Volume	m^3	200,000	320,000	840,000
Rockblasting	m^3	80,000	150,000	745,000
Formwork	m^3	75,000	180,000	512,000
Concrete	m^3	34,000	56,000	126,000
Reinforcement	tonnes	2,500	5,350	17,000
Other Construction Data				
Total Height Of Reactor Building	m	62	70	64
Height Above Ground Level	m	46	49	57
Stack Height	m	76	110	100
Reactor Plant				
Thermal Reactor Power	MW	1,375	1,800	3,900
Reactor Operating Pressure	MPa	7	7	7
Reactor Steam Temperature	ºC	286	286	286
Steam Flow	kg/s	650	910	2,115
Reactor Vessel				
Inner Height	m	17.6	20.0	21.1
Outer Height	m	18.0	20.2	21.4
Inner Diameter	m	5.0	5.2	6.43
Outer Diameter	m	5.3	5.5	6.75
Wall Thickness	mm	125	134	156
Weight With Head	tonne	414	530	760
Control Rods				
Absorber Material		B_4C	B_4C	B_4C
Number Of Control Rods (Cruciform)	no. of units	112	109	169
Electrohydraulic Drive Mechanism		112	109	169
Main Recirculation Pumps				
Number	no. of units	4	4	8
Maximum Flowrate Per Pump	M^3/s	2	2.55	1,860
Pressure	MPa			0.39
Rated Power	MWe	491	620	1,465
Fuel	type		Several types UO_2	SVEA-96
Number Of Fuel Assemblies	No. of units	448	444	700
Number Of Fuel Rods Per Assembly	No. of units		96	96/100
Cladding Material				Zr-2

2.3 General site description

The Oskarshamn NPP includes three nuclear reactors, O1, O2 and O3. O1 and O2 are located next to each other, while O3 is located somewhat further north from the others. The layout for Oskarshamn includes several buildings, the arrangements of which are shown in Figure 2-2 and Table 2-2.

Table 2-2. Building designations for Oskarshamn.

Building	O1	O2	O3
Reactor containment	RI	RI	A
Reactor building	R	R	B
Turbine and mid-section building	B	D	D
Auxiliary control building	E		H
Power and control building		E	
Auxiliary power building		N	
Office building and electric control building	M		E
Sea water cleaning building	R	F	
New electric control building	T		
Yard	U		
Containment venting filter building		Y	
Active workshop	V	V	N
Waste treatment building			F
Cooling water pump building			J
Diesel buildings			K
Off-gas building			L
Filtra building			M
Entrance building			P
Active culvert (under ground)			Q
Coolant intake building			R
Service building			S
Transformer building			T
Gas storage			U
High voltage switchgear building			X
Condense clean-up system building			Z

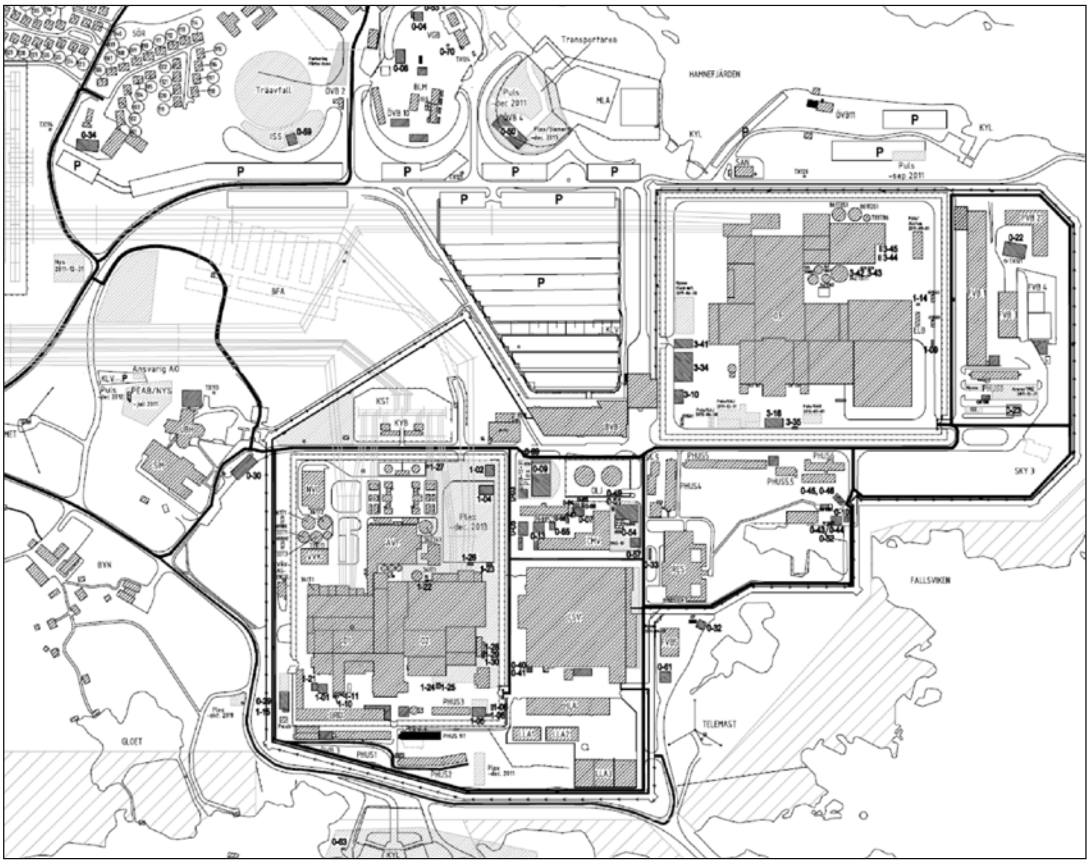


Figure 2-2. Building overview of Oskarshamn NPP.

2.3.1 Reactor building

The reactor building is the central part of the plant, around which the other buildings are grouped. The reactor building facilitates the process systems for plant operation. Consequently the building layout must be adequate for the systems layouts. The reactor building main tasks are summarised below:

- Facilitate and protect the equipment used for operation of the plant.
- Facilitate the reactor containment as well as a reactor pool, fuel handling pool and a pool for fuel transport equipment.
- Contribute to fulfil climate demands for installed equipment and personnel.
- Constitute a shield for radioactive radiation for the surroundings and working personnel at the plant.
- Collect and contribute to taking care of leakage in a prescribed way.
- Facilitate requisite service areas, transport and communication paths for operational and maintenance work.
- Limit the dispersal of a possible fire as well as facilitating necessary paths for evacuation and rescue personnel.

The reactor building mainly consists of the following parts: the reactor containment, the process systems which are located close to the reactor, the fuel handling pool and the reactor pool.

The reactor building is constructed on a mountainous solid. On some of the floors there are mid-section levels. The top floor facilitates the reactor hall, of which the floor level is at the same height as the pools upper side. The majority of the floor is accessible by the overhead crane needed for handling heavy components and equipment, for example during fuel outage. Other floors contain process equipment and components. Depending on the function of the system and the contamination grade of the system it is placed at different parts of the building as it is designed for constituting a shield for radioactivity.

The roof of the reactor building is mainly built out of steel for the roof structural support. The building walls are reinforced concrete which is according to standards for physical protection during crisis/war. The outer wall is covered with thick insulation, made out of mineral wool and finally covered with metal sheets.

2.3.2 Reactor containment

The reactor containment is surrounded by the reactor building, all around its periphery and above its top. The reactor containment can be divided in terms of description into two parts; the upper part and the cylindrical lower part. The upper part has thick walls. The lower cylindrical part also has thick walls. The wall is made of reinforced concrete divided in two shells. Between the two shells, there is a steel liner cast into the cylinder wall. The steel liner has the purpose to act as a gas-tight barrier and is protected from missiles, temperature gradients and corrosion by the surrounding concrete.

The fuel and reactor pools are located on top of the containment vessel. In the bottom of the reactor pool (i.e. in the roof of the containment vessel) there is a removable containment dome, made of carbon steel.

By removing the containment dome, the head of the rector pressure vessel can be unbolted and removed, and access to the interior of the reactor pressure vessel is obtained through the reactor pool.

The interior of the reactor containment is separated into two different volumes; the drywell, where the reactor pressure vessel and all connecting pipings are located, and the wetwell, which is a space in the bottom of the reactor containment containing the condensation pool.

2.3.3 Turbine building

The largest plant building is the oblong turbine building. Each building is furnished with a turbine part, generator part, high pressure pre-heaters and feedwater pumps.

The walls of the building are thick and made of concrete. The roof main frames consist of profiled steel plates carried by main beams of steel. The roof is isolated and covered with roofing cardboard.

The main task of the turbine building is:

- Facilitate and protect the equipment used for operation of the plant.
- Contribute to fulfil climate demands for installed equipment and personnel.
- Constitute a shield for radioactive radiation for the surroundings and working personnel in the plant.
- Collect and contribute to taking care of leakage in a prescribed way.
- Facilitate requisite service areas and transport and communication paths for operational and maintenance work.
- Limit the dispersal of a possible fire as well as facilitating necessary paths for evacuation and rescue personnel.
- Contribute to protecting the area from trespassing and prohibited access.

2.3.4 F – Waste treatment building (O3)

The waste treatment building has 3 floors below ground level and 3 floors above ground level. The largest base measures are 61×44 m and the height is approx. 22 m of which 11.5 m is below ground.

The main frame of the building mainly consists of reinforced in situ cast concrete of ordinary industrial type. The walls situated above ground level are isolated and clad with steel plate.

The roof frame over the service hall and over room F1.08 consists of pre-fabricated concrete elements. Remaining roof frame consists of cantilever reinforced, in situ cast concrete elements. The roof is isolated on the outside.

The 3 floors below ground level house pump rooms, evaporator, steam boiler and tanks. The 3 floors above ground contain filters, smaller tanks, switch gear, ventilation rooms, steam compressor room, service hall with a 5 tonnes overhead travelling crane, ventilation shafts etc.

2.3.5 AVF – Waste management building (unit 0)

The waste management building consists of the sewage system (system 342), the garbage disposal plant (system 343), the garbage storage facilities (system 343) and the laboratory (system 821).

The building is made of in situ cast concrete and elements of concrete. The building has three water sumps. Two is situated inside the building and receive system drainage and floor drainage. The third sump is a ground water sump situated outside the building.

The garbage disposal plant consists of a steel building with an area of approximately 350 m^2 and a height of 6 m. The floor is surrounded by a concrete border of height 20 cm. The garbage disposal plant is furnished with a 5 tonne overhead crane.

2.3.6 CSV – Central service workshop (unit 0)

The CSV is a service workshop situated to the south of the central mechanical workshop. The workshop area is approximately 2,010 m^2 and consists of an active mechanical workshop, installation workshops, welding workshop, mechanical workshop and a machine workshop. Furthermore, the CSV furnishes halls for pump service, decontamination and storage of chemicals, oil and repaired pumps and valves.

2.3.7 HLA – Waste management building for low active waste (unit 0)

HLA is a building for management of low active waste situated between the CSV (central service workshop) and the LLA (storage for low active waste) buildings. The building has the task to in a rational way, facilitate decontamination and cleaning of components, instruments, equipment and scrap metal. The area is approximately 1,700 m^2 and it is part of the controlled area.

2.4 General plant description and description of mutal buildings

The units O1 and O2 will be listed in the Table 2-3, Table 2-4 and O3 in the Table 2-5. There are buildings and facilities that can not be attached to a specific unit but serve more than one unit or the whole Oskarshamn NPP. These general buildings are called unit 0 and will be listed in Table 2-6.

Table 2-3. Building designations for O1.

Designation	Building	Designation	Building
RI	Reactor containment	R	Sea water cleaning building
R	Reactor building	T	New electric control building
B	Turbine and mid-section building	U	Yard
E	Auxiliary control building	V	Active workshop
M	Office building and electric control building		

Table 2-4. Building designations for O2.

Designation	Building	Designation	Building
RI	Reactor containment	F	Sea water cleaning building
R	Reactor building	N	Auxiliary Powerl building
D	Turbine building	Y	Containment venting filter building
E	Power and control building	V	Active workshop

Table 2-5. Buildings of the O3 Plant.

Designation	Building	Designation	Building
A	Reactor containment	N	Active workshop building
B	Reactor building	P	Entrance building
D	Turbine building	Q	Active culvert (under ground)
E	Control building	R	Coolant intake building
F	Waste treatment building	S	Service building
H	Auxiliary systems building	T	Transformer building
J	Cooling water pump building	U	Gas storage
K	Diesel buildings	X	High voltage switchgear building
L	Off-gas building	Z	Condense clean-up system building
M	Filtra building		

Table 2-6. Mutual buildings, unit 0.

Building	Building
AVF – Waste Management Building	OLJ – Oil Storage and Distribution Plant
BFA – Rock Cavern for Active Waste	RES – Restaurant (Simpan)
BLM – Blast and Painting Station	SAN – Sanitary Sewage Treatment Plant
BVB – Security Central	SIM – Simulator Building
BYN – Guest Room Building	SKY– Shelter
CMV – Central Mechanical Workshop	SVP – Simpevarp's Switchgear
CSV – Central Service Workshop	SÖR – Sörå Village
FVB – Storage and Workshop Building	UBH – Educational Building
GRD – Electric Workshop and Garage	VGB – Hydrogen Gas Building
HLA – Waste Management Building for Low Active Waste	VVK – Distribution Plant for Tap Water and Demineralized Water
KLV– Culvert Between O1/O2, O3 and CLAB	ÖVB1– Fire Drill Plant
KST– Distributing Sub–Station (System 623)	ÖVB3– Fire Water Central
KYB – Power Outer Load	ÖVB4 – Scrap Yard
KYL – Cooling Water Inlet Building	ÖVB8, ÖVB9 – Petersburg and Hamburg
LLA – Buildings for Storage of Low Active Waste	ÖVB10 – Management of Conventional Waste
MET – Meteorology Mast and House	ÖVB11 – Fishery Laboratory
MLA – Landfill for Low Active Waste	Embankments
NVO – Tap Water Plant	

3 Dismantling and waste management techniques

3.1 Dismantling techniques, sequences and logistics

3.1.1 Introduction

The purpose of this chapter is to provide information on the typical tools and techniques as they are today that could be used during the decommissioning of a Swedish BWR plant, in this case the Oskarshamn site. In general the techniques have been selected on the basis of previous experience on international decommissioning projects and national segmentation projects. Most of light water reactor decommissioning projects of this type have been completed or are in progress in the USA. For segmentation of reactor internal parts substantial experience is continuously made from the Nordic plants. In some cases, the chosen technique may not be the same as might be chosen if a similar task were to be performed during a plant refurbishment or upgrade. This is a reflection of the less precise nature of the work and the fact that the plant will not need to be restored to an operational state upon completion, either by reinstatement of equipment or clean-up to the as-operated condition.

In addition this chapter will present initial conclusions on the preferred sequences of decommissioning tasks and the required logistics, e.g. for waste items and waste packages movement within the site. These will again be based on previous experience or detailed studies made for other plants, suitably modified to reflect the specifics of Oskarshamn.

3.1.2 Dismantling techniques

Due to the variety of dismantling tasks to be carried out during the decommissioning of Oskarshamn, it is expected that a wide range of dismantling techniques will be employed, each selected for its suitability for the task in question.

The philosophy adopted within this study is that only proven existing techniques will be employed. This is so that:

- SKB and the Utilities can be confident that the technique described is suitable for the task and has already been used for a similar application, generally in the USA where more decommissioning has been completed to date.
- There will be little or no tooling development works required, which would lead to development cost and time plus potential cost/programme risk to the delivery of the project if tools could not be developed and deployed in accordance with the overall project programme.

In some instances, the most appropriate technique for dismantling an item will be the same technique as was used for maintenance when the plant was operational. For example the turbine may be dismantled in this way, taking advantage of installed lifting equipment such as the overhead traveling crane in the Turbine Building, and using a proven dismantling technique familiar to the plant staff and already covered by existing written instructions. The disassembled pieces would then be segmented for packaging or disposal as appropriate. For other tasks, segmentation or other destructive techniques will be faster and more appropriate given the material and its intended disposal route after removal. Given the wide range of equipment and material to be removed, a range of techniques will be required, each appropriate to the task. In the appendices suitable techniques for each task or group of tasks are described.

3.1.3 Assumptions

3.1.3.1 Fuel management

It is assumed that some significant dismantling work is carried out while fuel remains on-site, e.g. in the fuel storage pools. The following dismantling and demolition activities are assumed to start during this period: demolition of peripheral buildings, buildings with process equipment is being prepared for demolition, decontamination of process systems, segmentation of the reactor internals and final detailed planning of the demolition process.

3.1.3.2 Installed lifting equipment

It is assumed that existing installed lifting equipment will be properly maintained and remain serviceable and available for use to support decommissioning. This includes:

O1

- 110 tonne Z1 Overhead Traveling Crane in the Reactor Hall with 3 auxiliary (16, 10 and 1 tonne) telphers. When the O1 RPV was installed, the crane was used together with the trolley from the Turbine Hall. The Reactor Hall Overhead Crane is consequently classified for occasional lifts of around 400 tonne.
- 2 1 tonne telphers mounted on the Refueling Gantry.
- 220 tonne Z2 Overhead Crane with auxiliary (40 and 16 tonne) telphers servicing the entire Turbine Building and a 63 tonne Z13 Overhead Crane servicing the western part of the Turbine Building.

O2

- 130 tonne Steady Weight Load (SWL) Overhead Traveling Crane in the Reactor Hall. (160 tonne group 1).
- 1 tonne SWL hoist mounted on the Refueling Gantry.
- 120 tonne SWL Overhead Crane servicing the entire Turbine Building and associated auxiliary (25 tonne) crane.

O3

- 10 tonne Steady Weight Load (SWL) Overhead Beam Crane in the Active Mechanical Workshop.
- 165 tonne SWL Overhead Traveling Crane in the Reactor Hall.
- 1 tonne SWL hoist mounted on the Refueling Gantry.
- 130 tonne SWL Overhead Beam Crane servicing the entire Turbine Building and associated auxiliary (20 tonne) cranes.

3.1.3.3 Waste containers

It is assumed that the following waste containers are available for the project and that site infrastructure exists that will allow these containers to be used safely.

1. ISO freight container (20 tonne)
These are standard 20 ft long ISO Freight (“Sealand”) shipping containers for lightly contaminated wastes. In this study half height containers are assumed to be used. The maximum total weight of the container is 20 tonnes and the maximum loading is 18 tonnes.

2. Steel box (5 tonne)
This is a relatively small steel container with 1.2×1.2×1.2 external dimensions and a 5 mm wall thickness. The maximum total weight of the container with intermediate and/or low level waste material is 5 tonnes and the maximum loading is 4.6 tonnes. The containers are transported in a shielded transport container (ATB 12K).

3. Steel box for long-lived waste, BFA-Tank
This container will be used for components such as the core components containing significant amounts of long-lived nuclides (i.e. the core components originally situated close to the reactor core). There are four types of BFA-tanks. The different types depend on the wall thickness which is 50, 100, 150 or 200 mm. The outer dimensions are the same for all four types of the BFA-tanks and are 3.3×1.3×2.3 m (length × wide × height). The container is made of steel.

The waste material is placed in an insert tray before it is moved from the pool to the BFA-tank. There are four types of insert trays and each one is made to match the inner dimensions of the corresponding BFA-tank.

The external volume is approx. 10 m^3 and the internal volumes are 8.4, 7.1, 6.0 and 5.0 m^3. Maximum loading is 12 tonnes of waste material. The maximum total weights of the containers are 24, 34, 43 and 53 tonnes. The tanks are transported in a shielded transport container (ATB 1T).

4. Future developments
There is also the possibility that a larger Steel Box may be made available in advance of the Oskarshamn NPP decommissioning project.

This container would be a large version of the 5 tonne Steel Box above, and would be 5 mm thick, 2.4 m long×2.4 m wide×1.2 m high with a maximum total weight of 20 tonnes and maximum loading of 19 tonnes. This waste container would be transported in a shielded transport container (ATB 8K).

In this study it is assumed that the large steel box will be ready in time for the decommissioning. The large steel box is used for the calculations of the intermediate level waste.

3.1.3.4 Waste disposal

It is assumed that all radiological wastes will be packaged for the purpose of disposal off-site in a dedicated repository. On this basis, the option of disposal of very low level wastes in on site voids/building basements has not been considered.

3.1.4 Dismantling sequences

The removal of the Reactor Internals and the Reactor Pressure Vessel are expected to be on the critical path of the project. They are also expected to be among the more difficult project activities.

Due to the radiological condition of some parts of the reactor internals, it is proposed that they be segmented underwater. In order to support this activity, the systems that support the management and cleaning of the water in the reactor service and internals storage pools will need to remain operational. It is therefore proposed that the Reactor Internals are removed as early in the programme as possible so that these water management systems and their associated power supplies, tanks etc can be released for decommissioning. This minimizes the costs of maintaining these systems and retaining their operators in the period between end of fuel handling and internals segmentation.

There is also the potential advantage that, after the fuel, the reactor internals are likely to constitute the next significant contributor to the radiological inventory of the site. The reduction in site radiological inventory offered by removal of the fuel and early removal of the internals significantly reduces the total radiological hazard present on site. Depending on the regulatory regime in operation at the time, this may allow a reduction in the nuclear safety measures that must be maintained, e.g. standing emergency teams, emergency arrangements and arrangements for independent review of modification (decommissioning) proposals etc, with resulting cost savings.

Based on the above, it is therefore proposed that the reactor internals are the first major dismantling activity to be carried out inside the Reactor Building, and will be carried out after a pre-decommissioning decontamination of the primary systems in order to reduce worker doses incurred during the dismantling tasks.

Following removal of the internals, work will continue on other tasks within the Reactor Building, and on parallel work faces being established in other areas of the site, e.g. the Turbine Building, so that other systems can be released for decommissioning as they are made redundant by progress in the Reactor Building.

3.1.4.1 Planning and preliminary activities

In an ideal situation, the last 5 years of the plant operating life will be used to ensure that the period up to end of generation is carefully planned and managed, and to make suitable preparations for the decommissioning work that will follow. Some of these planning and preparatory activities will be required by regulations in force; others will be required only to ensure that resources are used efficiently during this period.

Some of the tasks to be completed during this period are as follows:

- Preparation of a submission to the European Commission as required by Article 37 of the Euratom Treaty – This submission provides the Commission with general data related to the dismantling of a reactor and disposal of resulting wastes such that the Commission can "determine whether the implementation of such a plan is liable to result in the radioactive contamination of the water soil or airspace of another Member State". Until such a submission is made and a favorable opinion received from the Commission, the national regulatory bodies regulating the decommissioning project in question are not permitted to grant permission for the decommissioning to proceed. Such a submission would not be required if a submission was prepared for the operation of the plant and included the required information relating to its decommissioning. UK experience is that the Commission takes approximately 6 months from receipt of the submission to provide an opinion.
- Preparation of an Environmental Impact Assessment for Decommissioning – The requirement for this assessment stems from EU Directive 97/11/EC (itself an amendment of 85/337/EEC) which requires that an "assessment of the effects of certain public and private projects on the environment" is made with the aim of "providing the competent authorities with relevant information to enable them to take a decision on a specific project in full knowledge of the project's likely significant impact on the environment"; the competent authorities being national regulators. The stated list of "certain projects" includes "nuclear power stations and other nuclear reactors including the dismantling and decommissioning of such power stations or reactors" so an assessment specific to the Oskarshamn decommissioning project would be required to cover such environmental impacts such as pollution, noise, changes in traffic movements, effect on local flora and fauna etc.
- Preparation of Licensing Documents as required by the Swedish regulatory system (1998:905), e.g. (a) submission of the general report to SSM explaining the objectives, measures and time schedule for decommissioning and (b) the facility's plan, its incorporation into the facility safety report and its submission, with the completed EIAD (Environmental Impact Assessment for Decommissioning) attached, for the Swedish Environmental Court and SSM review and approval (as required by the Swedish Environmental Code "miljöbalken").
- Preparation of any local/regional permissions required for demolition and other modifications to the appearance of the site.
- Review of Essential Services and other relationships between systems and structures – this is to enable predecessor/successor activities to be correctly logic-linked in the preparation of the decommissioning plan. It also identifies relationships between buildings and systems that might require modification to allow decommissioning, or activities that assist decommissioning, to proceed at the earliest opportunity. For example, power cables for a system that would be required for some time during the decommissioning programme might be routed through or attached to a redundant building. The power supply can be diverted to allow the redundant building to be demolished. There is often work of this type which can be identified, and sometimes completed, before end of generation, thereby helping to reduce the decommissioning period. This activity typically leads to the development and installation of an alternative Decommissioning Power Supply for the site which feeds only those systems required beyond the end of generation and avoids buildings which will be demolished early. As a safety measure this power supply is installed using cables of a color not otherwise used at the site (bright yellow or orange are typically used) which enables the original power distribution to be isolated when redundant and makes it easy for decommissioning workers to identify those power cables which are still live.
- Production of detailed decommissioning programme and cost estimate, with supporting analysis of cost and programme risks.

- Identification of major work packages and contract strategies – this identifies which packages of work will be carried out by site staff and which will require bought in specialist contractors or labor. This then enables the required staff levels to be determined and a staff run-down/retention strategy to be developed. It also allows technical specifications and contracts to be prepared early.
- Development of a modified site organization to suit the roles and responsibilities needed for the decommissioning phase and identification of the personnel to populate the organization. Alongside this would be the development of processes and plans for management of staff no longer required or those wishing to leave/change roles at the end of generation. This might include retraining opportunities, redeployment at other sites or staff redundancy arrangements.
- Development of a plan to manage the inventory of high cost items – thereby making sure that the site does not purchase items during the final period of generation that will not be used.
- Preparation of plans and contracts for disposal of non-radiological hazardous wastes (bulk chemicals, asbestos etc) and non-hazardous wastes (e.g. bulk concrete/brick rubble).
- Design and licensing of any non-standard waste packages identified as being necessary for the decommissioning of the site (e.g. bespoke containers for intact shipment of large components).
- Preparing and approving (in advance) revisions as required to the following plans/procedures or their local equivalents:
  - Site Emergency Plan.
  - Radiation Protection Plan.
  - Environmental Health and Safety Management Plan.
  - Waste Management Plan.
- Place orders for any additional fuel and waste containers expected to be needed during the early phases of decommissioning.

3.1.4.2 On-site preparatory activities

As well as the planning activities above, the following activities (1–26) will be required for the reactor internal segmentation. In general they can be carried out during the defueling operation.

1. Review access/egress routes for personnel and equipment to ensure that they provide efficient movement of personnel to and from work areas and allow efficient movement of wastes from workface to the Waste Management and Monitor Release Facilities. Ideally movements of personnel and waste materials should be kept separate to reduce worker dose and improve general safety. Modify routes in line with any suitable improvements identified.
2. Design and construct a Waste Management Facility appropriate to the types, volume and rate of waste arising to be expected during the decommissioning programme.

   Typically this will be a refitting of a suitably sized existing facility, see Section 3.2. Ideally an existing facility would have:
   - Good connections to the various workfaces that will be producing radiological waste.
   - Sufficient space to allow the various processes of additional size reduction, and packing to be laid out efficiently.
   - A suitably rated active extract system (or good opportunities to allow an extension to the HVA system to service the area).
   - Easy access to the outside for dispatch of loaded waste containers.
   - A suitably rated overhead crane.
3. Design and equip a monitor/release facility appropriate to the types, volume and rate of non-radiological waste arising to be expected during the decommissioning programme. The aim of this facility is to efficiently monitor the materials produced by the dismantling programme that are expected to be suitable for unrestricted release. This facility would be equipped with automated scanning/monitor equipment and would be located in an area of low background radiation. The facility would not be required if applicable regulations prevented free release or if the radiological condition of the waste arising makes them unsuitable for release.

4. Establish a temporary contractor office/storage accommodation area if none already exists at the site. Typically, this will be a hardstanding area for contractors to bring temporary cabins to site. The area will be equipped with power, water and telephone lines as required. Alternatively make such accommodation available within existing buildings if space allows.

   It may also be necessary to relocate staff and offices from areas to be decommissioned early in the programme to other areas of the site, possibly in temporary accommodation. Establish IT and service connections to temporary accommodation.

5. Develop a programme of training for the plant operations workforce in the new duties/skills required during the decommissioning period. Complete the training required by the initial decommissioning activities.

6. Carry out a Post Operational Clean Out of the site. This will involve such works as:
   – Draining and disposal of operational fluids.
   – Disposal of operational wastes.
   – Disposal of any remaining stored chemicals.
   – Disposal of redundant spare components.
   – Carrying out a general house-keeping exercise on the plant to remove any redundant materials, spares etc that may be stored within the various plant buildings.

7. Carry out a radiological housekeeping of the plant, where possible, to reduce worker dose rates.

8. Install new independent decommissioning power supplies to the reactor and turbine building using non-standard cable color (orange/yellow) to replace operational power supplies. Identify essential installed power supplies, which cannot readily be replaced and should not be removed at this stage, with spray paint of the same color. This will allow the existing system to be de-energized and removed while the Decommissioning Power Supply continues to power items that need to remain in service.

9. Design and install a new independent ventilation system when the demolition project makes the ordinary ventilations system obsolescent.

3.1.4.3 Circuit decontamination

10. In most Light Water Reactor decommissioning projects completed to date, some form of chemical decontamination process has been applied to the more contaminated pipe work systems prior to dismantling (Primary Circuit Loops, Chemical Volume Control System and Residual Heat Removal systems in the case of PWR, and Recirculation, Reactor Water Clean Up and Shutdown Cooling systems in the case of BWR plants). Even the decontamination of Barsebäck 1 and 2 was executed in the same way. It is assumed that the potential reductions in dose uptake will be sufficient to warrant a similar activity during decommissioning of Oskarshamn 1, 2 and 3.

    Less aggressive decontaminations of these systems are also carried out periodically as part of an ongoing dose management programme or prior to maintenance activities. However, during decontaminations carried out as part of decommissioning, it is possible to use more aggressive techniques which remove some of the base metal of the system being decontaminated, thereby ensuring a more effective result.

    The reactor internals will be segmented underwater effectively shielded from personnel. So if the reactor vessel is included in any decontamination, the reactor internals will need to be removed first as the aggressive decontamination chemicals will remove material from the activated reactor internals, increasing the amount of radioactivity removed and the amount of waste generated but with negligible effect on the worker radiation dose uptake.

    The reactor internals should therefore be removed in accordance with normal plant operating procedures and placed in their normal storage locations within the internals storage pool. The reactor vessel lid would then be re-installed and decontamination carried out.

    Alternatively, the decontamination can take place after the reactor internals have been removed and segmented. With the internals gone and no ongoing need for water in the reactor pools, the decontamination project may be extended to include the Pool Water Cooling and Cleanup system (System 324).

The exact configuration of systems to be decontaminated, resulting flow paths and the required connections points to the systems will need to be determined in consultation with the system decontamination contractor.

3.1.4.4 Containment cupola

As discussed above, it is proposed that the Reactor Internals will be segmented underwater. Depending on the final radiological condition of the internals at the time, this may not be necessary for the components in the upper part of the Reactor Vessel, i.e. the Steam Dryer and the Steam Separator. In this case they can be segmented as required in a relatively simple Dry Cutting Area, such as the area that will be established for the Containment Cupola. However, in order to present the most conservative approach underwater cutting has been assumed.

11. At this point the Containment Cupola is likely to be removed to its normal storage location. If not it should be removed using normal plant operational procedures.
12. Using band saw, segment the Containment Cupola into pieces; load the pieces into transit containers for dispatch to the Waste Management Facility and subsequent release or packaging for disposal.
13. With the Containment Cupola removed and packaged, their stand assemblies can be removed for disposal along with any other miscellaneous redundant items such as tools, slings, grabs, stands etc stored around the reactor and fuel pools. This will make the maximum possible space available next to the reactor hall pools for the set up of equipment and storage areas for the reactor internals removal.

3.1.4.5 Reactor internals removal preparations

Install equipment in preparation for Reactor Internals segmentation:

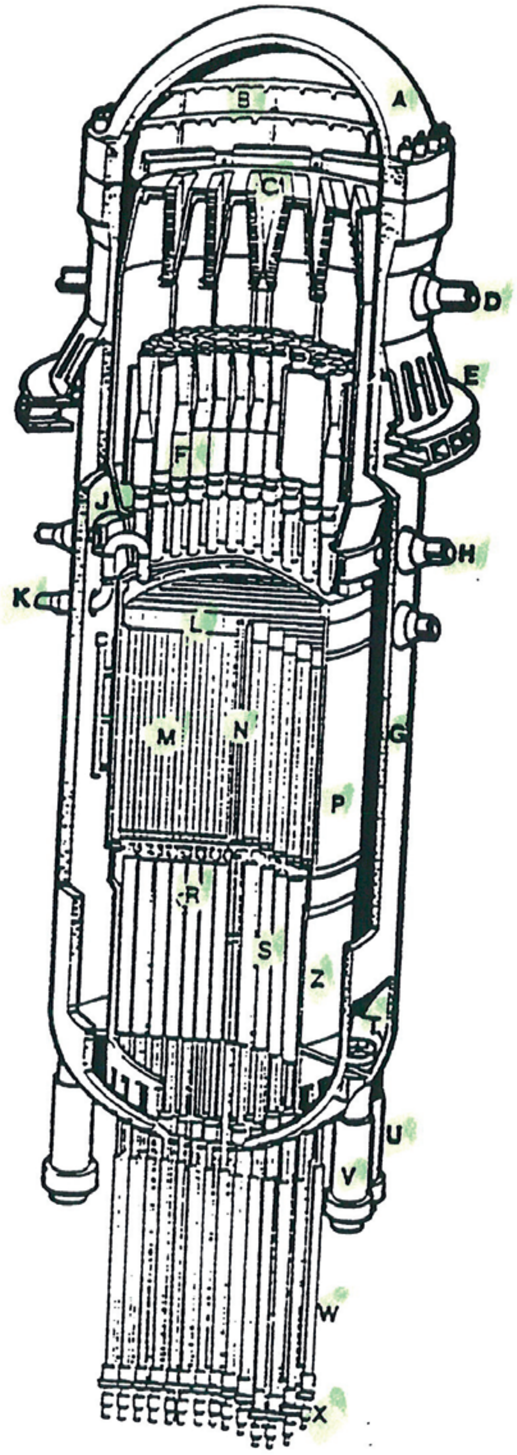
- Cover the Reactor pool and the Internal parts pool floors with stainless plates. The purpose of the plates is to make it possible to fasten equipment and material at the bottom of the pool without damaging the pool floor.
- Install remote cutting equipment (manipulator, working platform, tool deployment mast etc).
- Install or allocate storage for waste containers and racks for tooling storage.
- Install any temporary support stands required for correct positioning of components during cutting.
- Install any fixed position camera and lighting systems deemed to be useful to the project.
- Install equipment for decontaminate the pool linings using (vacuum equipment, water washing and mechanical methods as required).

3.1.4.6 Reactor internals removal

The following sections describe the removal and segmentation of the major components within the Reactor Vessel (System 211). Generally, these items will be removed using normal operational procedures where such procedures exist. Bolts normally untightened for removal of the various items are, as a preference, untightened during decommissioning to avoid unnecessary generation of secondary wastes. Any bolts not normally disassembled during operation that need to be removed will be removed using MDM machining.

Other lesser items (test specimens etc) will be removed using normal operational methods and, generally, disposed of without segmentation if their size allows.

Figure 3-1 shows the general layout of the Reactor Internals inside the Oskarshamn 3 Reactor Vessel. The general layouts for the Reactors Internals at O1 and O2 are similar.



A: Reactor Vessel Head
B: Flange Cooling System
C: Steam Dryer
D: Steam Outlet Nozzle
E: Reactor Vessel Flange
F: Steam Separators
G: Reactor Pressure Vessel
H: Feedwater Inlet Nozzle
J: Feedwater Spargers
K: Core Spray Inlet Nozzle
L: Core Grid
M: Fuel
N: Control Rods
P: Core Shroud
R: Core Instrumentation
S: Control Rod Guide Tubes
T: Pump Propeller
U: Forces Head Circulation Pump
V: Pump Motor Housing
W: Control Rod Drive
X: Control Rod Motor
Z: Core Shroud Support

Figure 3-1. *Section from plant drawing showing some of the components in the Reactor Pressure Vessel, at Oskarshamn 3.*

The following sequence refers to the use of mechanical cutting techniques for most tasks, as per Swedish segmentations experience to date.

14. Remove the Steam Dryer using normal plant operational procedures and move it to the Internal Parts Pool.

    The Steam Dryer (System 215) is a cylindrical device with a wall thickness of the steel casing, columns, beams etc of typically 5 mm.

The upper section of the Steam Dryer is a relatively complex arrangement of steel labyrinths. The lower section is a more simple steel cylindrical structure which, when installed in the Reactor Vessel, surrounds the Steam Separator assembly. The radiological condition of the Steam Dryer is expected to be such that it will not need to be packaged in BFA-tanks.

The steam dryer is cut with different kinds of disc saws. The rig saw is positioned on the pool floor and the mounted disc saw cuts either horizontally or vertically along the rig sledge. The discs used are based on the standard hard metal S13, mainly used for cutting in stainless steel. The cutting speed for a 10 mm plate is 1–200 mm/min and for a 50 mm plate, 1–40 mm/min.

The labyrinth section is separated from the lower cylinder with a full circumferential cut. The spokes inside the labyrinth is then cut out and put aside. The baffle plates and the casing will then be cut down and placed in an insert tray. After that the spokes will be cut into requisite pieces.

The lower section will then be segmented so that the pieces can fit into the large steel box.

15. The next item to be removed and segmented will be the CSH (System 212), see Figure 3-2, together with the Steam Separators (System 214). The Steam Separators (System 214) are geometrically complex items formed as tubes running from the CSH to just below the Steam Dryer labyrinth.

    The Steam Separators are attached to the CSH by being welded into position. The first step of dismantling the Steam Separators will be to cut them from the CSH by horizontal cuts. Each Steam Separator takes less than 60 minutes to cut from the CSH. The Steam Separators have to fit into the large steel box with a height of 2.4 m. Therefore they have to be cut into two lengths.

    Alternatively, there is a new technique in which the Steam Separators are compressed to reduce the size before disposal. SKB is conducting an investigation to see the outcome of this new technique.

16. The Steam Separator inlet tubes will be cut from the CSH with a tube cutter. The tube cutter is inserted into the tube and cuts from the inside and out at a specific level above the CSH spherical surface. The CSH tube in AISI 304 material and will be cut in about 20 min. The cutting wheel is normally replaced after 4–6 cuttings. The tubes will then be cut with a band saw into pieces that fit into the insert tray.

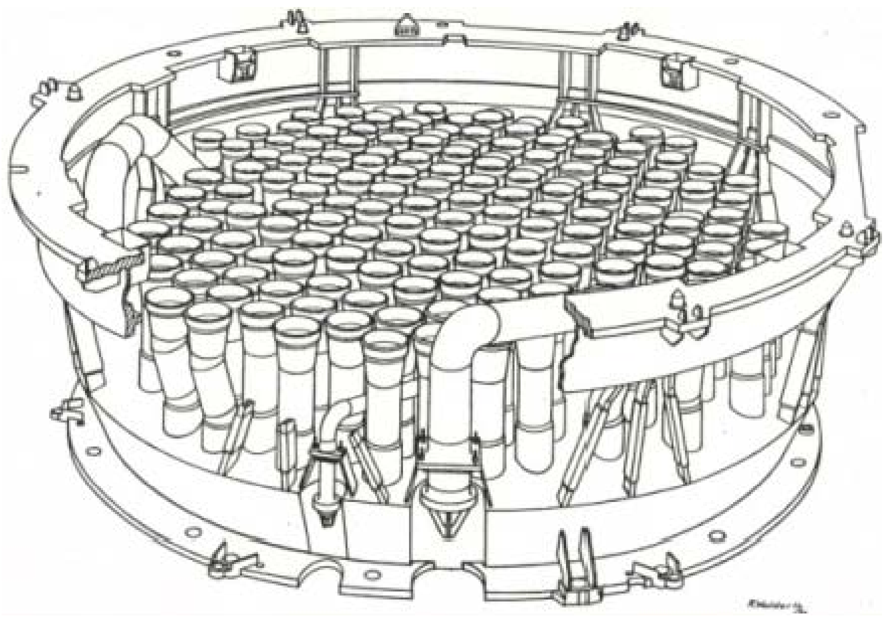


Figure 3-2. *Illustration showing the Core Shroud Head in principles.*

17. The outer ring that provides the support to the Steam Dryer will be separated from the CSH by shearing the support legs that hold it in place. This outer ring will then be lifted clear of the tube bundle and segmented. The close proximity of the CSH to the fuel during operation will mean that it will have become significantly more activated than the components that have been considered so far.
18. The CSH cover will be separated from the CSH and cut into pieces with a band saw and a disc saw.
19. The rest of the CSH is now the flange and will be cut with a band saw, a disc saw and a shear.
20. Remove the Feedwater Sparger pieces using normal operational procedures. Each Sparger will be too long to fit into the insert tray so they will need to be cut with a band saw into three pieces.
21. The next item to be removed is the Core Grid (System 212), see Figure 3-3. This item is a circular section surrounding a square grid structure with thick plates which locates the upper end of the fuel assemblies in their correct position within the core. The squares of the grid therefore correspond to the cross-sectional dimensions of the fuel assemblies. It is expected to be the most activated of the Reactor Internals pieces, and typically accounts for between one-third and half of the total activity inventory of the Internals. Because of that the Core Grid parts have to be loaded into a BFA-tank with a thickness of 150 mm. The Core Grid will be cut using hydraulic shears and band saws. Then the grid ring is cut into pieces with a band saw.
22. The Core Shroud will be removed next. This is effectively a cylinder, see Figure 3-4.

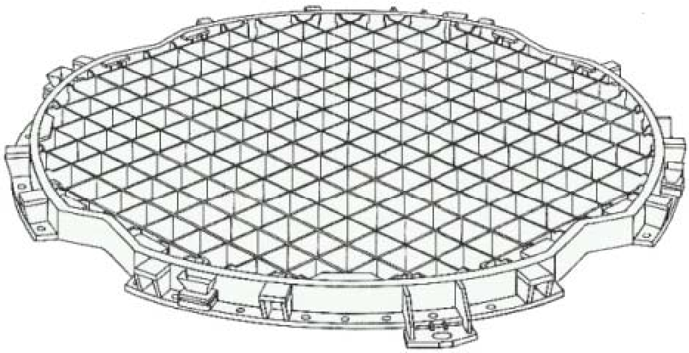


Figure 3-3. *Illustration showing a Core Grid.*

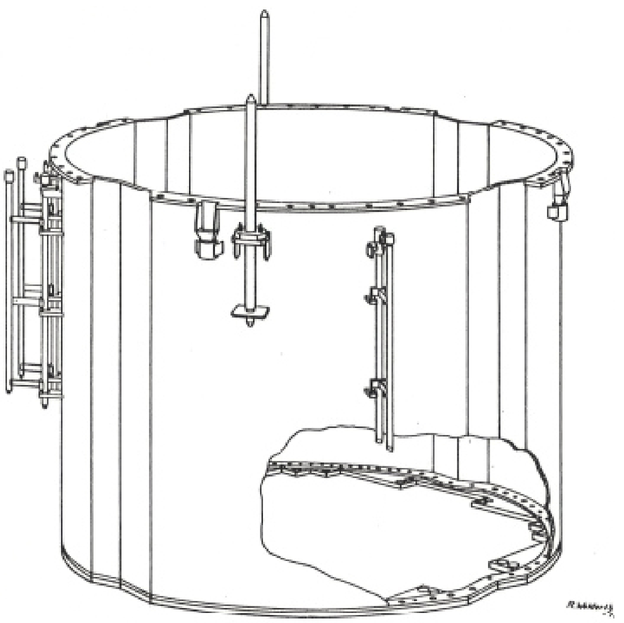


Figure 3-4. *Illustration showing configuration of a Core Shroud.*

Undo or remove the bolts holding the Core Shroud Support Baffle using MDM and lift it out to the pool. Segmentation of the Core Shroud will be carried out using a band saw. Before commencing segmentation of the Core Shroud itself, the Surveillance Test Equipment etc (System 218), mounted on the outside of the Core Shroud, will be removed to maximize packing efficiency. The Shroud will be cut by making parallel vertical cuts. All the pieces will then be cut in half.

23. Remove the Control Guide Tubes using normal operational procedures.
24. The Core Shroud Support is a cylindrical shell, where the bottom sits on and is welded to the bottom of the Reactor Pressure Vessel.

    A series of rectangular openings are provided in the upper end of the Core Shroud Support mantle to allow water in and up through the Reactor Core.

    The Core Shroud Support will be removed by first using MDM to make lifting holes in the shell. Then a full circumferential cut will be made from the inside of the support just above the point where the annular ring is welded to the support. The support is then lifted up from the reactor to the pool for segmentation into smaller pieces. Then the annular ring will be cut close to the inner wall of the reactor and lifted out for further segmentation.
25. Vacuum suction of debris from the bottom of the RPV.
26. Remove redundant Reactor Internals segmentation equipment. Empty water from the reactor pool. Remove all redundant equipment in the pool and clean up the steel lining of the pool walls using water jets and mechanical means for more persistent contamination.

3.1.4.7 One-piece reactor vessel removal

In the study (Farías et al. 2008) the method of removing a reactor vessel in one piece is described for the Swedish nuclear power plants. Before the removal of the RPV all of the internal parts and pipes connected to the RPV must be dismounted and the building has to be prepared.

The work would be carried out in following order (1–57):

1. Removal of internal parts as above, in Section 3.1.4.6.
2. Rig all RPV pipe work for lifting of a 2 m length immediately adjacent to the vessel. Using Clamshell cutters, cut all RPV penetration lines to remove the first 2 m length of each pipe. Weld end caps to RPV penetrations to provide a water tight seal. All inlet and outlet water/steam lines to and from the RPV, except the Forces circulations System (system 313), the bottom fill point and associated systems are now released for removal in parallel with work on the RPV. Decommissioning on some of these systems may start before this point. In addition all pipe work system connections between the reactor and the Turbines will have been severed at this point.
3. Remove the insulation from the RPV.
4. Demolish any buildings or structures that prevent access to the reactor building.
5. Preparation of the ground.
6. Assemble fastening device on the RPV.
7. Dismantle roof and beam.
8. Cut the annular support ring from the RPV.
9. Lift the RPV approx 8 m and mount an outer protection for radiation in the RPV.
10. Lift the tank out of the building down to a transport, Figure 3-5.
11. Mount the roof and beam.
12. Remove and package all wastes including contaminated tools, equipment, supports, racks etc. Remove all clean redundant tools and equipment from the work area.
13. Carryout a general housekeeping exercise.
14. Decontaminate the pool linings using vacuum equipment, water washing and mechanical methods as required.

Figure 3-5. *Views of Trojan Reactor Vessel with the radiation shield and impact reducers during transport.*

3.1.4.8 Reactor building equipment removal and clearance

27. In general, the remaining equipment in the reactor building will be removed on a floor by floor basis, starting at the top and working downward. This avoids the possibility of removing the lower sections of pipe systems that span more than one floor first. However, it may be possible to start at the floor level with the least contaminated systems first in order to practice use of the various tools in a real work environment.
28. Each floor level and work area will be surveyed first to identify radiological hot spots. Work on dismantling of systems will then proceed starting at the access/egress point and working away from it to open up space. In general large clean or easily decontaminable items will be removed first, followed by smaller clean items, large contaminated items and small contaminated items, though each work area will need to be assessed on a case by case basis to determine the optimum approach. In each area, useful systems that assist the task will naturally be left until last; these are expected to be limited to installed lifting equipment and possibly extract vent systems.
29. The Reactor Building Crane will be stripped of cables, winding gear etc, as any contamination in these items will be difficult to remove. The main beams will be lowered to floor level using jacks, though the option to drop it to floor level after explosive removal of the beam ends may be worth considering. The beams will then be segmented for disposal or recycling at ground level.
30. When all equipment has been removed, any wall/floor decontamination that may be necessary will be carried out. Given the floor finish used throughout the Oskarshamn plants, it is expected that much of the decontamination will be completed using the less aggressive methods available.
31. With all equipment removed and decontamination completed a radiological survey will be carried out to ensure that each room and floor level is of a radiological condition that permits demolition as a clean building using conventional techniques. Remedial decontamination will be carried out as required. Areas surveyed and declared clean will be closed off to avoid becoming recontaminated.

3.1.4.9 Turbine building preparations

Prior to operational working, a radiological and chemical hazard survey of the work area and surrounding area will be conducted to establish/confirm work area conditions.

Due to the age of the O1 and O2 plants there is expected to be some asbestos present in the lagging used in the Turbine Building. In plants where asbestos is expected, specialist contractors should be engaged to remove and dispose of it. Extensive air monitoring will be required immediately before and during these operations to ensure that a safe working environment is maintained and to check that asbestos is not being dispersed.

Work on dismantling of contaminated systems will generally take place in local tented containments. During lifting operations the tented enclosures will be penetrated. All equipment will be lifted to a minimum height required to allow all openings i.e. underside of turbine casing, to be sealed or equipment seal wrapped if possible, to ensure containment of any contamination, prior to lifting clear of the enclosure. The enclosure will be resealed after lifting.

Where extensive openings are expected to arise from the removal of equipment, a secure cordon will be positioned around the area prior to the removal.

32. Carry out radiological surveys of the work area.
33. Ensure that all redundant electrical systems are isolated and that the breakers are removed. Install temporary supplies for tools etc (in unusual colors). Spray color any remaining live supplies to required operational equipment (e.g. overhead cranes) or install new diverse supplies.
34. Carry out a hazard reduction exercise within the Turbine Building. This will include:
    - Ensuring that the hazardous material records are adequate via survey if necessary.
    - Removal of all hazardous materials from the Turbine Building using specialist contractors/ personnel as required, e.g. batteries, remaining working fluids, oils asbestos (if any), instruments bearing mercury etc. Dispose of hazardous materials as per applicable regulations.
    - Isolate and drain all system pipe work.
    - Flush through chemical and radiological contaminated pipe work systems with clean water.

3.1.4.10 Turbine building deplanting

35. Remove all small and easily removed non-contaminated items and equipment, e.g. control panels and cubicles etc, from all levels of the Turbine Building. Dispatch to the Waste Management Facility or Monitor Release facility as required.
36. Install scaffolding/access as required and remove all pipe work and system thermal insulation, including that on the High Pressure (HP) Turbine casing.
37. Install local containment and ventilation around the Superheaters (located either side of the HP Turbine).
38. With assistance from the overhead cranes, dismantle the Superheaters and elevated pipe work using plasma cutters. Cut them into large sections which are then moved to ground level for further segmentation with a reduced requirement for working at height. Resulting sections should be sized for packaging into selected waste container.

    In the upgrading project like PULS and PLEX the Steam Superheaters, Feedwater Pre-heaters, Low Pressure Turbine and other large components were removed intact from the Oskarshamn plant and sent for smelting. Consideration may be given to doing the same during the decommission project if logistical considerations allow it.
39. Make good floor space in the room vacated by the Superheaters using steel plates to give increased lay down space.
40. Establish waste handling routes within the Turbine Building and remove all remaining redundant pipe work, equipment etc from the various floor levels generally starting at the southern end of the Turbine Building and progressing northward. All pipe work will be cut using clam shell cutters, shears and other cold cutting techniques as a preference.
41. Separate the Generator from the supporting cable and pipe work system. Disconnect the Low Pressure (LP) Turbine to Generator coupling. The generator will be left in place until later in the Turbine Building removal as it is expected to be heavier than the installed lifting capacity.
42. Make available suitable support stands for the Turbine Blade assemblies (as used during overhaul). Maintenance procedures will be followed where possible during dismantling of the Turbines in order to ensure that the use of familiar methods is maximized.
43. Remove the LP Turbine enclosures in accordance with maintenance procedures and using specialist contractors to remove any remaining insulation from the exposed casings.
44. Segment the LP enclosures for disposal using plasma cutters and dispatch to the Waste Management Facility.

45. Remove any exposed ancillary equipment and package for disposal via the Waste Management Facility.

46. Disconnect HP to LP coupling in accordance with maintenance procedures.

47. Remove HP upper casing, monitor, decontaminate in situ, if possible, and transfer to the designated lay-down area.

48. Establish local containment and segment the casing using plasma cutters.

49. Radiologically survey the HP rotor and decontaminate where necessary prior to seal wrapping and removal/transfer to designated lay-down area. From here the HP rotor may be moved to the Waste Management Facility for appropriate disposal.

50. Repeat steps 46 to 49 for each of the LP Turbines in turn, though for these turbines size reduction will need to be carried out locally rather than at the Waste Management Facility. The turbine shafts will be cut using diamond wire saws or, if contamination levels are suitably low, thermal cutters.

51. Using access and supports from above and below as required and as safe, use thermal cutters to segment the turbine lower casings for removal. Connections to the condenser below should be temporarily sealed as the lower casings are removed. Transfer the removed segments to the Waste Management Facility. Fit floor plates to any floor penetrations.

52. The Condenser will generally be a geometrically complex item that, in the case of a BWR, will also present some radiological problems. For this reason the methodology for dismantling the condenser will need to be determined after a detailed review of its construction. However, it is expected to involve work in a tented contamination control area.

    In some conde,nser designs, the design allows for the withdrawal of individual condenser tubes out of the main condenser casing, following drilling or cutting out of the tube ends. The working fluid of the power transfer system runs external to these tubes so they are contaminated externally. They are therefore withdrawn individually into a polythene tube. The condenser tube is then cut to length for packaging once withdrawn, the cut being made through the polythene tubing. This is a laborious process but can be done in parallel with other tasks in the Turbine Building. Once emptied of tubing the Condenser casing is then cut using thermal cutters.

    If the design does not facilitate this method, the Condenser can be dismantled from a suitable starting workface at the top, with the shell and tubing being progressively removed together. The workface would need to be within a tented enclosure.

53. There may be a market for the intact turbo-generator if it has no significant contamination levels and has been rotated on a regular basis since end-of generation. If the generator is considered to be in saleable condition it can be removed intact, though as it is expected to be heavier than the installed lifting capacity, this may require the use of an external mobile crane working through a new opening in the northern wall of the Turbine Building. For conservatism, the following section outlines a proposed method for its removal as scrap.

    To make the Generator stator easier to manage the rotor will be removed. If the Stator is to be moved intact, perhaps for off-site segmentation by metal recyclers, this will lighten the main component lift and also eliminate the need to clamp the rotor in place while lifting the complete unit. If segmentation will take place in the Turbine Building, removal of the rotor should make the segmentation easier. Ideally rotor removal will be achieved using routine operational maintenance procedures.

    Firstly, any remaining ancillary equipment (exciter) and system connections will be removed from the Generator. The outer cladding sections will then be removed and lifted to a lay down area for segmentation into suitably sized sections for disposal or survey/release.

    Once the rotor shaft is accessible, the shaft will be jacked to allow removal of bearing liners, seals etc. Using a rotor removal sliding shoe or pad as a guide to the trailing end of the rotor, the rotor will be withdrawn. The leading end will be supported via the overhead crane. Once the Centre of Gravity of the rotor is outside the stator, the rotor will be supported on blocks and re-slung to allow the crane to move it out to a lay down area. The segmentation of the stator and rotor will then proceed in a tented enclosure using a combination of thermal cutters and shears.

Segmented pieces can be lowered to the Turbine Building ground level via one of the floor penetrations left by the removal of the LP Turbines and Condenser.

54. A final equipment removal and general housekeeping campaign will then take place leaving only the overhead cranes in place; lighting etc being provided by temporary supplies at this stage.
55. With all equipment removed a radiological and hazard survey will take place to verify clean areas and identify any remaining contamination on building/floor surfaces. Any identified contamination will be addressed using concrete / steel decontamination methods. Once the area is confirmed as clear of contamination, steel walkways and platforms etc will be removed.
56. The cranes can be removed in a number of ways depending on how they are to be disposed of. If they are to be reused, they can be run out of the Turbine Building on extensions to the crane rails through an opening in the northern wall of the Turbine Building. If they are to be scrapped, they can be lowered to the Turbine Building operating level using jacks for segmentation using thermal cutters. At Maine Yankee in the US the ends of the Containment Building crane beam were cut using explosive cord to allow the crane to drop from its rails to ground level for subsequent segmentation. A similar method could possibly be employed for the Turbine Building cranes.
57. With the cranes removed and the Turbine Building surveyed for contamination and decontaminated where necessary, the Turbine Building is ready for demolition using conventional techniques. However, given the design and layout of the site buildings it is suggested that a more efficient demolition contract would be possible if demolition of the various linked buildings takes place as a single activity near the end of the decommissioning project.

3.1.4.11 Other buildings and systems

The Reactor Building and Turbine Building represent the most significant buildings on site and a substantial proportion of the decommissioning work.

Other lesser buildings will be addressed on an "as-redundant" basis with buildings and rooms only being emptied of their contents when all systems within that area have become redundant, thereby avoiding the need to work in an area more than once.

Techniques to be used will generally be as above though there may be more scope for metals and material recycling from other areas of the plant than is the case for the Reactor Building and Turbine Building. In this case it may be acceptable to remove systems in larger sections knowing that they do not need to be packaged in the various disposal boxes available.

The sequence for dismantling of systems from these other buildings will follow the same basic pattern. Firstly, any surveys necessary to ensure a good understanding of the radiological condition of the systems and work area will be carried out. Surveys will also be required for asbestos and other hazardous materials where there is any uncertainty regarding whether such materials will be found during dismantling.

Next, all redundant loose items will be removed, e.g. tools and other stored equipment, spares etc. Hazardous materials such as asbestos, oil and chemicals will then be removed. This will lead into the "clean strip out" or removal of items known to be radiologically clean that can be removed without disturbing any contamination that might be found inside systems. This will include removal of electrical equipment and cabinets etc only connected to contaminated systems by cabling. This might also include removal of non-structural building features such as partition walled office enclosures.

Redundant systems will be removed in a manner that opens up access to the work area, generally working away from the waste route if space is limited. For larger work areas, the area will be broken down into smaller workfaces which can be scaffolded or prepared as required, equipment removed and then move on to the next area. Useful operational systems such as overhead cranes will be left operational until the end of equipment removal.

Where practical, equipment will be removed in pieces which will allow for packaging the selected disposal container without further segmentation. However, this may only be possible for dismantling when personnel are working comfortably on the local operational floor level. Where personnel will be required to work at height, in conditions of elevated temperature or other non-ideal working conditions, equipment will be removed in the largest pieces possible so that more comfortable, reduced risk working conditions can quickly be re-established. Removed items can then be size reduced locally or in the Waste Management Facility as appropriate.

With all redundant equipment removed, decontamination of any high level areas can proceed, i.e. those areas which may need existing cranes or overhead platforms to provide access. Any in-service cranes etc can be removed next along with any stairs/platforms and other remaining items. Building walls and floors can now be decontaminated using appropriate techniques. A final survey will be carried out to ensure the building is clean of radiological and other material hazards.

As with the Turbine Building and the Reactor Building, other lesser buildings will be cleared out of systems and equipment but left intact until such time as demolition of all site buildings can begin as a single, though extended, task with demolition contractors mobilizing on site once to complete the entire demolition workscope. Demolition in advance of this would only occur where necessary to provide improved access to other work areas.

3.2 Management of residual materials

3.2.1 Introduction

This chapter of the report considers the decommissioning of areas of the Oskarshamn site other than the reactor pressure vessel (RPV) and for the management of the associated wastes. The description has been done with regard to OKG's decommissioning plan for the Oskarshamn site (Olsson 2005) and OKG's instructions for the handling of radioactive waste (Ingemansson 2008), but at a conceptual level and the recommendations should therefore be considered as being indicative. Further engineering studies would be required to refine the management and to develop definitive recommendations.

The system that has been considered with respect to waste management a fit-for-purpose, modular waste screening facility constructed within the turbine building or similarly sized buildings, that makes use of re-usable modular containments and shielding, combined with the use of existing waste treatment buildings and their waste screening, size reduction, packaging and shipping systems as well as a new building for handling and screening of possible free release waste.

This chapter describes the above management system in the context of the anticipated waste arisings, waste monitoring and packaging requirements and relevant legal and regulatory considerations. An overview of potentially applicable size reduction equipments and methods are contained in Appendix 1.7. An overview of potential monitoring solutions is provided in Appendix 1.8.

The existing waste treatment facilities of the Oskarshamn site should be in operation as long as possible and will be a part of the waste route.

The RPV and internals are excluded from the scope of this section. However a discussion of the options for decommissioning of the RPV and of the overall waste inventory at Oskarshamn can be found in Appendix 1.9.

3.2.1.1 Decontamination

Consideration was given to the provision of decontamination facilities within the waste management system. The intention of these facilities would be to reduce levels of contamination to the next lower category. Therefore, LLW (Low Level Waste) items could potentially be disposed of as FRW (Free Release Waste) and ILW (Intermediate Level Waste) may attain LLW classification.

Given that it is assumed that decontamination will have been carried out on concrete surfaces, pipework interiors, etc, prior to dismantling, an effective process would have already been applied to those items of waste most likely to be of benefit from such a process.

Furthermore, any in situ decontamination process for the reactor steam supply system would likely make use of the reactor coolant pumps, leading to the application of decontamination chemicals at high force with the probability of considerable abrasion.

The limited incremental benefit, set against both the risk of cross-contamination and the secondary waste issues associated with the spent reagents and the mobilized contaminants, leads to the conclusion that further in situ decontamination would not be cost effective.

3.2.1.2 Compaction facilities

Low level waste management facilities are often suited to the application of compaction or super-compaction in order to reduce waste volumes. Consideration was given to the provision of such facilities at Oskarshamn with the intention of significantly reducing packaged low level waste volumes.

However, due to the space requirements and secondary waste volumes from a large industrial compactor, the cost benefit of including such a unit are diminished. (Even if all the secondary wastes were rerouted through the compactor, the total throughput may be insufficient to justify a large compactor on economic grounds alone.) As such, it has been decided that a large industrial compactor unit should not be included in the design concept for the waste management system. However, the use of a small-scale compactor may be appropriate for soft wastes arising from the plant dismantling operations, as well as the wastes from operating the facility itself, such as Personal Protective Equipment (PPE) and PVC sheeting.

3.2.1.3 Manual versus remote operation

A key question for the design of any waste management system relates to the source material that requires processing.

Consideration of the potential arisings of ILW across the Oskarshamn site favors the use of manual dismantling methods for most, if not all, structures apart from the reactor pressure vessel and core, with dedicated temporary, shielded, remotely-operated facilities for the small quantities of ILW that are anticipated to arise.

3.2.2 Design assumptions and exclusions

For the purpose of this study, the following assumptions and exclusions have been agreed as the basis of design. Should any of these assumptions change during the course of the decommissioning planning, the concept design for the waste management system should be reviewed for validity.

- The waste management system will be designed to handle only wastes arising from the Oskarshamn site.
- The design operating life time of the waste management system will be 18 years.
- The system will have the capability to process up to 4,600 tonnes per year. Throughput may be as high as 100 tonnes per week (assuming a 46 week working). This is based on a working time of 16 hours per day.
- The waste categories will be short-lived LILW and FRW.
- Based on the data in Chapter 4, the predominant part of the waste is anticipated to be FRW on arising. A major portion of this waste is accounted for by concrete in building structures. The demolition of building structures is however outside the scope of this chapter. The remaining radioactive waste is assumed to be short-lived ILW and LLW, although some may be found to be suitable, either on arising or after minimal decontamination, for free release.
- The Reactor Pressure Vessel coolant circuits will be chemically decontaminated prior to dismantling. The RPV itself and the core are discussed in Section 3.1 and are thus excluded from the scope of this chapter.
- The anticipated waste inventory requiring processing through the waste management system will be based on the data in Chapter 4.
- The waste will include concrete arisings from areas such as the fuel ponds (possibly contaminated following leaks) and the activated parts of the concrete bioshield.

- The wastes to be managed will be beta-gamma waste.
- There will be no alpha contamination hazard.
- There will be no activated metal wastes processed through the facility. This will be SFL waste.
- All waste will be dry; therefore no liquid effluents will be present.
- Most of the waste will undergo some size reduction at the workface in order to facilitate retrieval and loading into a transfer container.
- Categories of waste will be initially determined at source and will be confirmed during sentencing.
- Some processing of mixed waste may be required.
- The FRW transport and LLW disposal containers are assumed to be 20 ft half-height ISO-type freight containers.
- The short-lived ILW or mixed LILW final disposal package will be based on a 2.4×2.4×1.2 m, 5 mm thick steel container.

3.2.3 Sequence for dismantling and removal of decommissioning wastes

One of the key factors to success in the implementation of the physical decommissioning is to have a well thought-through, easy-to-use and accurate decommissioning database act as a management system for the documentation, planning and follow-up of the waste streams. The final design will be made at a later stage, but the idea is to have a database where every piece of the decommissioning waste is catalogued and marked for when it is supposed to be cleared out of the plant as well as its route in the waste management system and the final destination for disposal.

When the decommissioning commences, a worker gets a work order and goes to a pre-marked component. The component is removed, taken out of the plant and then scanned into the decommissioning database, thus marked as removed. The worker then gets instructions from the database about where the component is to be taken and what type of container to put it in.

Whatever approach is used for the processing and packaging of decommissioning wastes, broadly the same sequence will be used for dismantling and removal of waste materials. The sequence proposed is to deal as far as possible with the easier inactive wastes first, and steadily work through to the more difficult wastes higher up the ILW spectrum. This approach will allow operatives to learn from experience as they progress, and will also minimize any potential for active materials to cross-contaminate materials that might otherwise go for free release or LLW.

This sequence is based on actual experience in decommissioning operations in the UK[1], and follows the guidance of the relevant UK regulatory authority – the Health and Safety Executive Nuclear Installations Inspectorate (HSE-NII). The NII states in its guidance to inspectors on Decommissioning on Nuclear Licensed Sites:

"The processes associated with dismantling and decontamination will generally produce secondary radioactive waste, in the form of solid waste, or liquid and gaseous effluent. The strategy should avoid the unnecessary creation of radioactive waste and aim to minimize the quantities produced and discharged."

Similarly, in its guidance to inspectors on the Management of Radioactive Materials and Radioactive Waste on Nuclear Licensed Sites, the NII states:

"Radioactive waste is a product of many operations within the nuclear industry. Avoiding the creation of radioactive waste in the first instance and, secondly, minimizing the rate at which waste, which must be created, is produced is one of the foremost principles of good radioactive waste management which is embodied in international standards and Government Policy."

[1] As demonstrated in the decommissioning of the 500 MW Hinkley Point A and 242 MW Bradwell reactors in the UK.

"Number 7 of the principles of radioactive waste management set out by the IAEA (1995) relates to waste minimization. It states:

The generation of radioactive waste shall be kept to the minimum practicable, in terms of both its activity and volume, by appropriate design measures and operating and decommissioning practices. This includes the selection and control of materials, recycle and reuse of materials, and the implementation of appropriate operating procedures. Emphasis should be placed on the segregation of different types of waste and materials to reduce the volume of radioactive waste and facilitate its management."

"In general, measures to reduce radioactive waste production at source are more effective than measures taken after the waste has been created. Waste minimization is fundamental good practice, reduces hazards on site, reduces the potential impact on the environment, and in many cases is cost effective. NII's expectations for the application of waste minimization include the following practices (in some cases the practices reduce the accumulation of waste rather than its creation):

- Avoidance of the production of secondary wastes.
- Segregation of waste streams (by waste category, physical and chemical properties).
- Preventing spread of contamination.
- Recycling and reusing material.
- Waste clearance.
- Decontamination.
- Volume reduction.
- Disposal.

The primary objectives of the proposed decommissioning sequence are therefore to minimize dose to personnel and to minimize the volume of materials that need to be disposed of as radioactive waste.

Such a generic dismantling sequence will proceed as follows:

1. Removal of uncontaminated (FRW) items, but with three exceptions:
   – Retention of plant and equipment2 that can be employed in subsequent dismantling operations.
   – Retention of plant and equipment where the removal task would subject operators to a dose (from adjacent radiation sources) which is not ALARA.
   – Retention of concrete structures.
2. Removal of LLW, avoiding situations that would expose operators to an unacceptable dose uptake.
3. Removal of ILW.
4. Removal of uncontaminated plant and equipment that is either:
   – Inaccessible during stage 1.
   – Retained to support stages 2 and 3.
5. Removal of activated and contaminated concrete e.g. LLW scabbling wastes.
6. Removal of bulk concrete (FRW).

It is recognized that it will not be possible to adhere rigidly to this sequence, but in broad terms dismantling should be programmed as described above. If, as the result of a building survey, radiation hotspots are detected that can be readily removed without giving rise to cross-contamination or significant additional worker dose, then this should be done before the removal of FRW and LLW. Reducing the risk of contamination spread in this way will minimize any subsequent problems in the management and disposal of those wastes. If, however, hotspots cannot be readily removed, then

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[2] Equipment is here defined as that part of the installed plant that is relatively easy to install or remove (e.g. motors) as opposed to the major items of plant that are semi-permanently installed (e.g. vessels and pipework).

temporary modular shielding will be installed around the hotspots so as to allow removal of FRW and LLW in accordance with the above sequence. Consideration must also be taken to the possibility of presence of asbestos in the waste. If asbestos is found, the removal must be done in accordance with AFS 2006:1[3] regarding asbestos in connection with demolition work. The generic dismantling sequence will also need to provide for the management of secondary waste arisings.

3.2.4 Waste management system

There are a number of approaches that could be employed in developing waste management systems for the Oskarshamn site. The approach described in this chapter, consists of a modular fit-for-purpose screening facility built within an existing structure, split into segregated zones configured to meet the handling and screening requirements of different waste categories. This will be used in combination with the existing waste treatment facilities at Oskarshamn and a new building for screening of possible free release waste. This solution will place more emphasis on the logistics of the different waste streams, to avoid cross contamination and long and/or unnecessary transports between the different facilities.

3.2.4.1 Utilising existing waste treatment facilities

3.2.4.1.1 Waste transfer logistics

The purpose of this system is to maximize utilization of the existing waste treatment structures already in place at Oskarshamn. This waste management system begins with an initial screening of the waste at an appropriate building inside Oskarshamn to roughly sort possible FRW, LLW and ILW already at an early stage. From the initial screening, the respective type of waste is transferred to existing waste treatment facilities designated, and redesigned where necessary, to manage that particular type of waste. A rough schematic of the different waste treatment facilities and waste routes is shown in Figure 3-6. The logistics of these waste transfers will be crucial to the success of the project.

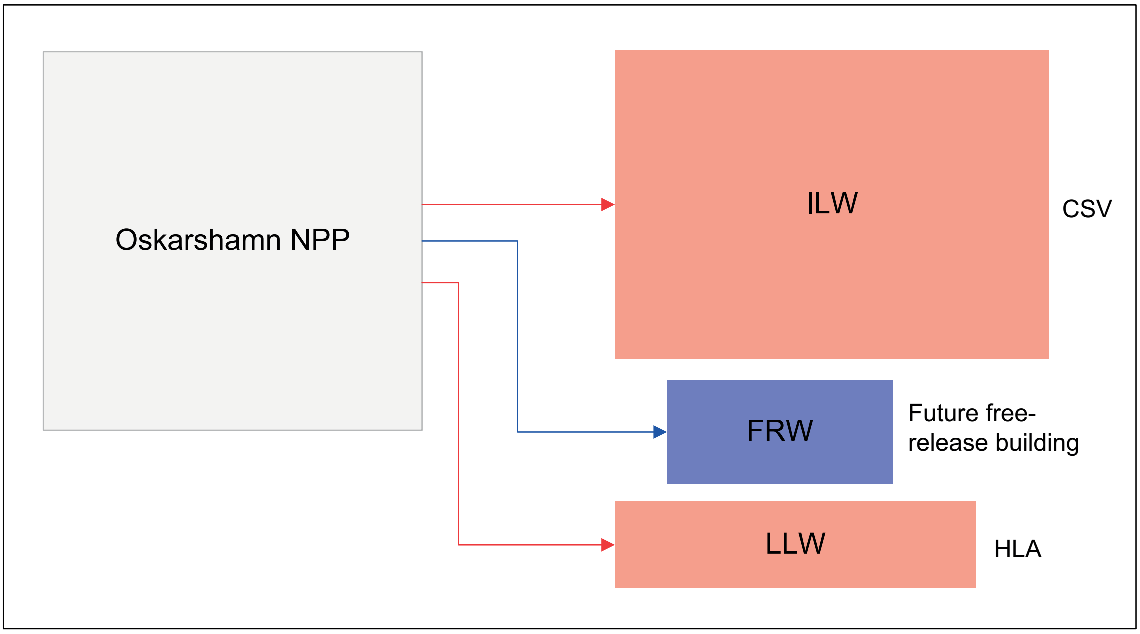

Figure 3-6. *Schematic of waste treatment facilities and waste transports at Oskarshamn.*

[3] Arbetsmiljöverkets författningssamling (Swedish Work Environment Authority) regarding asbestos.

3.2.4.1.2 Location of initial screening

With one of the primary objectives of this system being to maximize waste sorting operations as close as practicable to source, there is one location in this case that is far better suited than any other. With this option, all of the major waste sorting activities are likely to take place within the turbine building, as it is one of the largest facilities being addressed in this chapter.

With regard to the decommissioning of structures, plant and equipment distant from the waste management facilities, while some initial in situ decontamination may be required, the bulk of the material is expected to be categorized at no more than LLW so it should present no difficulties in terms of its removal and on-site transport (local tenting-out, monitoring etc). Once removed, and if necessary given a preliminary size reduction, the wastes will then be passed on to the proper waste management facility, where the waste will be processed.

3.2.4.1.3 Utilising existing facilities

The primary factor behind the suitability of this waste management solution stems from the fact that nearly all of the decommissioning waste arising from the Oskarshamn site will be categorized as free release or LLW. An approach that is designed for handling high volumes of ILW will therefore be inappropriate.

The fit-for-purpose design concept for the initial waste screening comprises three main areas, all within the confines of an existing building such as the turbine building, with the deployment where appropriate of re-usable modular containment and shielding. These three areas deal separately with FRW, LLW and ILW materials. A suitable enclosure might be in the form of a re-usable modular containment, (RMC) similar to that shown in Figure 3-7.

Free release material handling

As described in Section 3.2.4, free release materials will be dismantled and removed first. It will not be possible to remove all free release items during the first pass, but careful analysis of the location of various waste types, along with advanced sequence planning, will maximize the amount of FRW retrieved at this early stage.

There are plans today for the construction of an entirely new building for handling of free release material at Oskarshamn, as seen in Figure 3-8. This building will be used for screening, processing and packaging of possible FRW. With free release materials having no potential to generate contamination, it will not be necessary to construct any type of enclosure for the breakdown and packaging of these wastes.

Figure 3-7. *Manual dismantling operations utilizing Re-usable Modular Containment (RMC).*

The building will be divided broadly into four areas, an area for screening of the incoming material, a buffer area for wastes waiting processing, the main size reduction and packaging area and finally an area set aside to store both empty skips and a small number of filled skips awaiting transfer from the free release facility.

Waste will be transferred to the size reduction/packaging area by a variety of means: by hand, on trolleys, or via one of the installed overhead cranes. Size reduction will be carried out using a mixture of hand-held power tools and floor mounted equipment (see Appendix 1.7). As little size reduction as possible will be carried out on free release waste. Once size reduced, most waste will be loaded into transfer skips, if necessary by using one of the installed cranes.

Free release material export

With free release waste size reduced and ready to leave the free release building, the only operation remaining will be to transfer those wastes out of the facility for final export. Again this operation will be carried out using simple, fit for purpose means. Waste packages will be routed to an appropriate recycling or disposal facility. Metallic wastes could be dispatched to a metal recycling facility such as that currently operated by Studsvik (see Appendix 1.9).

Waste loaded into skips will be moved on powered trolleys, whilst other ‘oversized’ but lightweight waste will be moved by hand. Waste will leave the building through a simple airlock facility. Waste will pass through the airlock with only one set of doors open at any time, thus minimizing any migration of possible airborne contamination between the building and adjacent area. Waste will be given a final monitoring whilst inside the closed airlock to ensure that it meets acceptance criteria for free release material.

The outer airlock doors will be opened and waste moved (either by trolley or by hand) onto a concrete hard-standing outside. Waste that can safely be man-handled will be loaded by hand into skips parked on hard standing immediately outside the building. Waste held in transfer skips will be lifted by a small crane which will provide coverage of the concrete hard-standing area and tipped into an ISO-type transport container for export off-site.

LLW material handling

As described earlier in this chapter, low level waste material (LLW) will generally be removed following the bulk removal of free release waste. It will of course not be possible to remove all low level waste in a single campaign, but careful analysis of the location of various waste types, along with advanced sequence planning, will maximize the amount of LLW retrieved during this first phase. Even though it is envisaged that LLW will be retrieved in several campaigns, it can be assumed that buffering of LLW adjacent to the processing area will allow LLW breakdown and packaging to continue without interruption.

It is expected that LLW material will be transported to the building designated HLA – Handling building for Low Active waste. Some simpler methods for decontamination, such as high pressure water decontamination, already exist on site (Figure 3-8).

With low level waste having the potential to generate airborne contamination, it will be necessary to conduct processing operations using personal protective equipment (Figure 3-9 and Figure 3-10) and within a building which will provide radiological containment.

The building will be divided broadly into three main areas: the waste buffer area, the main size reduction and packaging area and finally an area set aside to store a small number of empty transfer skips (with further buffer capacity available outside of the facility). Filled skips will be buffered outside of the building to await transfer from the waste treatment facility.

Waste will be transferred inside the facility by a variety of means: by hand, on trolleys, or via one of the existing overhead cranes. Size reduction will be carried out using a mixture of hand-held power tools and floor-mounted equipment (see Appendix 1.7). Once size reduced, most waste will be loaded into transfer skips which will be lidded prior to exiting the building.

LLW will be loaded into ISO-type containers, similar to those shown in Figure 3-11.

Figure 3-8. *High pressure water decontamination facility at Oskarshamn.*

Figure 3-9. *Preparation work prior to plant dismantling operations.*

Figure 3-10. *Typical manual plant dismantling operations.*

Figure 3-11. *ISO-type containers for LLW packaging.*

LLW material export

With wastes size reduced and ready to leave the waste treatment facility, the only operation remaining will be to transfer those wastes out for final export. There are several ways in which waste can be transferred from inside the radiologically controlled confines of the facility to transport/disposal containers parked outside. The main problems associated with such export lie in ensuring that contamination does not migrate outside the facility and that operatives can load containers without risk of injury. Both problems are easily overcome using simple, fit for purpose means.

All packaged LLW, whether in lidded transfer skips or wrapped, will be swabbed and monitored before leaving the waste treatment facility. Waste loaded into skips will be moved on powered trolleys, whilst other 'oversized' but lightweight waste will be moved by hand.

If it is necessary to segregate the waste treatment facility's radiological zone from the adjacent waste transfer route, then a simple airlock will be constructed in the building perimeter wall. Waste will pass through the airlock with only one set of doors open at any one time, thus stopping any migration of airborne contamination between the waste treatment facility and the adjacent area. If necessary, waste packages will be monitored again for contamination whilst inside the closed airlock in order to confirm that they meet the necessary acceptance criteria for export from the facility. The outer airlock doors will be opened and the waste moved (either by trolley or by hand) onto a concrete hard-standing outside the facility.

The waste will be loaded into ISO-type containers. The ISO containers will then be exported off-site for either disposal in the SFR repository or further size reduction.

ILW material handling

As mentioned previously, it is believed that a few percent of the waste arising from decommissioning activities will be categorized as ILW. Even though sequencing of waste removal dictates that (broadly speaking) these wastes should be removed last, there will be many instances where it will be prudent to remove ILW in tandem with free release and LLW materials such as where operators removing FRW and LLW will be subject to excessive radiation shine. Removing ILW in such a progressive manner will deliver benefits in terms of scheduling all waste processing and packaging activities, and also in throughput demands on the ILW processing area. ILW processing will thereby be phased over a longer period, and will not require ILW management solutions that are artificially compressed into a tight timescale.

ILW will be removed using the most appropriate means for each situation, which will be determined during the detailed design stage and transferred to the appropriate waste treatment building, probably the building designated CSV – Central Service Workshop. The guiding principles are as follows:

- The majority of the waste will be packed into the half-height containers.
- Local / temporary shielding will be erected to protect decommissioning operatives. Any dose to operatives will be ALARA.
- The area will be tented-out with a temporary enclosure which will mitigate any spread of contamination.
- As far as possible, dismantling and removal of ILW will be carried out manually, with recourse to remote techniques only when demanded by activity levels. Note: Much of the ILW will be at the low end of the ILW spectrum.
- ILW is assumed to be loaded into large steel boxes and transported in shielded transport containers such as one shown in Figure 3-13.
- Existing cranes will be utilized as far as is realistically possible for container loading and for moving containers in the ILW waste treatment area.

ILW material processing

ILW processing will be conducted in one of the existing waste treatment area within a shielded containment which will be developed in detail during later design development. However, guiding principles in designing the containment will be as follows:

- ILW processing and packaging activities will take place within a housing which is of a modular construction.
- The module will be fabricated, tested and taken through preliminary commissioning off site.
- The module will comprise of three main areas:
  - Waste container receipt and opening.
  - Waste processing – assay, size reduction, decontamination (if required), etc.
  - Waste loading into containers suitable for final disposal.
- In order to maintain containment, the atmosphere within the ILW waste processing module will be maintained at a depression. Ventilation will be provided by a mobile HEPA filtration unit which will be attached to the processing module and will vent to atmosphere via the existing ventilation of the building.
- Ideally all operator viewing requirements will be satisfied by use of cameras rather than shielded windows.
- The module will be as lightweight as possible. Therefore shielding will be provided around the perimeter of the module using materials such as pre-cast concrete panels or water-filled blocks. Existing cranes will be used to move and assemble shielding.
- The module will be deployed within the waste treatment building as fully assembled as possible to maximize the benefits of off-site fabrication and testing. If necessary, a pathway will be made by the demolition of peripheral structures and a new opening will be formed in the exterior wall of the building.

ILW material export

In this last stage of ILW processing, waste is loaded into its final disposal container, and dispatched for export to the SFR repository. The final disposal container is assumed to be an enlarged version (2.4×2.4×1.2 m) of the 1.2 m cubed 5 mm thick steel container shown in Figure 3-12. The container is 'docked' to the processing module and waste loaded remotely.

The operation of a shielded hatch within the floor of the loading area will be integrated with removal of the container lid. This will ensure that the outside of the container remains radiologically clean at all times and is therefore free to travel between the Oskarshamn and the repository.

Prior to export, the disposal containers will be swabbed and monitored to ensure they meet acceptance criteria for off-site shipments. The containers will then be moved between the ILW processing building and the export bay by use of a bogie. At the export bay, a crane will be used to load the disposal containers into shielded transport containers (as shown in Figure 3-13) mounted on suitable transport equipment for transfer to the repository or further size reduction off-site.

3.2.5 Interim storage on site

all waste packages will not be able to leave the Oskarshamn area directly after processing and packaging since the containers are supposed to be transported by sea with only one ship available for transport. This requires that an interim storage will be available on site during the decommissioning. The buildings suited and recommended for parts of this interim storage are designated LLA (Storage building for low level waste) 1, 2, 3 and 4. LLA 1 has a volume of 30×15×3.6 m, LLA 2 is 35×15×3.6 m, LLA 3 is 29×42×4 m and LLA 4 is 29×24×4 m.

This storage volume is more than enough for interim storage even at the busiest time of the decommissioning project, although some of the LLA buildings should be reinforced with extra radiation shielding to be able to store intermediate level waste.

Figure 3-12. *Swedish standard 1.2 m×1.2 m×1.2 m steel container for ILW disposal (Photo: Bengt O Nordin, SKB).*

Figure 3-13. *Swedish shielded transport container (Photo: Bengt O Nordin, SKB).*

4 Material inventory, radioactivity inventory and resulting waste amounts

4.1 Material inventory

4.1.1 Introduction

The accurate estimate of the waste quantities and activities to be generated during the dismantling operations and of the associated radiological burden requires a thorough and comprehensive inventory of all the site system components and structures subject to potential radioactive contamination.

Besides, a reasonably accurate accounting of all conventional non-contaminable materials and structures of the site is a prerequisite for the performance of reasonable cost and schedule estimates for the whole site dismantling and demolition.

This chapter presents the results obtained in the evaluation of the overall inventories of systems, components and structures of the Oskarshamn NPP, performed using the plant operator databases, drawings and by use of the application of sound hypothesis and the results of informed engineering judgements.

The different sections of this chapter present, in tabular form, the results of these evaluations. The chapter is subdivided into two large parts, one dealing with metal components, which form most or all of the elements to be removed during dismantling, while the other is devoted to concrete, steel etc in building structures, subject to demolition.

The information presented in this chapter is then used to establish numerical values for the variables defining the different macro-components used in Chapter 5 and 6 by the model for estimating costs and schedule requirements.

4.1.2 Source of Information

The information listed in the following sections is mainly obtained from Dahlberg and Eriksson (2009) and Gustafsson et al. (2006) completed with data obtained from the site owner OKG, with affected changes made during the modernization project PULS, and with data derived in a GAP-analysis of the inventory made for Forsmark 3 and Oskarshamn 3 (Bergh 2010).

In those instances where the above inventory fails to include required data, e.g. equipment weights or piping length runs, the corresponding estimates are based on the application of duly justified criteria, assumptions and extrapolations.

Engineering judgement has also been used to fill the gaps encountered in the available information.

The estimated accuracy of the inventory is presumed as follows:

- ± 5% for the components closest to the core, i.e. components in the activity category red.
- ± 10% for the low contaminated components, i.e. in the activity categories yellow and green.
- ± 20% for the non-contaminated components, i.e. in the activity categories blue and white.

The accuracy of the building inventory is made with different priorities:

- Activated or contaminated concrete, reinforcement and embedded plates in the biological shield in the reactor containment have an accuracy of ± 5%.
- Possibly contaminated steel constructions (not reinforcement or embedded plates) in the reactor containment and surfaces in controlled areas have an accuracy of ± 10%.
- Non-contaminated concrete, reinforcement, embedded plates and steel constructions in controlled areas (not reactor containment) have an accuracy of ± 20%.
- Buildings in uncontrolled areas have an accuracy of ± 20%.

The ventilation inventory has an accuracy of ± 10% for contaminated areas and ± 20% for uncontaminated areas.

The accuracy of the electrical systems is at least ± 20%.

4.1.3 Site metal inventory

The following categories of elements have been used to estimate metal quantities in the Oskarshamn NPP:

- Mechanical and Piping Systems, including all site process fluid systems, with its associated equipment, piping, valves and accessories.
- Structural and Various Steel, including handling equipment, cranes, liners, supports and miscellaneous steel.
- Air Treatment Systems including its associated ducts, equipment, dampers and accessories.
- Electrical Equipment and Cabling, including cables, cable trays and conduits, as well as all electrical and I&C significant equipment.

These categories have been defined in this way to reflect the structure of the used databases and to facilitate the comparison with other similar studies. It also facilitates the extraction process required to fill the macro-components data fields.

4.1.3.1 Mechanical and piping systems inventory

The inventories presented in this subsection correspond to the Oskarshamn NPP fluid processing systems.

4.1.3.1.1 Reactor pressure vessel and internals

Table 4-1 presents the summary of the inventory for the reactor pressure vessel and its internals.

The reactor pressure vessels weigh in total 1,704 tonnes and consist of carbon steel with a stainless steel liner. The RPV insulation weighs 28 tonnes. The RPV internals weigh 619 tonnes in total.

4.1.3.1.2 Site metal summary

Table 4-2 presents the summary of all site metal for the Oskarshamn NPP.

Table 4-1. RPV Inventory and Internals.

Category/Tonne	Plant O1	Plant O2	Plant O3	NPP Oskarshamn
RPV	414	530	760	1,704
Insulation	5	3	20	28
Internals	126	124	368	618
Total	545	657	1,148	2,350

Table 4-2. Site metal inventory.

Category / Tonne	Plant O0	Plant O1	Plant O2	Plant O3	NPP Oskarshamn
RPV & Internals		545	658	1,148	2,351
Mech & Piping	892	4,753	4,221	9,959	19,825
Steel	997	1,463	3,491	4,414	10,365
Air Treatment	104	281	595	1,085	2,064
El. Equipm & Cabling	1,160	1,512	1,930	4,144	8,746
Total	3,153	8,554	10,896	20,748	43,350

The total metal inventory of the Oskarshamn NPP weighs 43,350 tonnes, excluding the reinforcement, which is presented in Table 4-3.

4.1.4 Site building data and concrete inventory

The estimate of costs and schedule associated with the decommissioning activities of the Oskarshamn NPP requires the knowledge of several overall building data, to be used in the application of productivity rates.

Besides, the estimate of the radioactive wastes, expected to be generated during building demolition activities, requires the knowledge of the internal exposed surface areas for each building. These are used to estimate, in conjunction with the information given in Section 4.2, the surface area for which actions (survey, scarification, scrabbling, etc) will be required prior to demolition, as well as the expected amount of radioactive waste resulting from those operations.

The following subsections present the results from these evaluations for the Oskarshamn NPP. The information is mainly obtained from Dahlberg and Eriksson (2009), Lundin (2009), Ericsson (2005), Gustafsson et al. (2005) and Bergh (2010).

4.1.4.1 Building data and concrete inventory

The data presented in this subsection correspond to the totality of the Oskarshamn NPP buildings. Total concrete weight and volume and weight of the reinforcement in each building are provided. The corresponding building data for each plant are presented in Table 4-3.

4.1.5 Site sand inventory

The sand beds of the off-gas treatment delay system, system 341, contains approximately 3,400 m^3 of sand, some of it contaminated with noble gas daughters. The sand bed is placed in delay tanks, one on each plant.

Table 4-4 presents the summary of the sand inventory for the Oskarshamn NPP.

Table 4-3. Plant building data and concrete inventory.

Category	Plant O0	Plant O1	Plant O2	Plant O3	Site Oskarshamn
Reinforcement tonne	2,588	2,482	5,352	17,048	27,470
Concrete tonne	76,819	82,291	135,445	303,084	597,640
Concrete volume m^3	32,008	34,288	56,436	126,285	249,017

Table 4-4. Site sand inventory.

Category	Plant O1	Plant O2	Plant O3	Site Oskarshamn
Sand volume, m^3	280	1,020	2,100	3,400
Sand weight, tonne	424	1,545	3,182	5,151

4.2 Radioactivity characterization

4.2.1 General

This chapter presents the radiological characteristics of the decommissioning waste for the Oskarshamn site. The activity inventory presented per process component is given in Section 4.3.

4.2.2 Process equipment contamination

The process equipment contamination has been determined using a calculation model in Excel and has been performed by ALARA Engineering (Jonasson 2012a, b, c), and includes both induced activity and surface contamination. The model emanates from a series of measurements and estimations, where future refinement of the basic data is possible. The model is considered to give a reasonably accurate result for the purpose of characterizing the contamination of the plants. A detailed description of the model is given in Lundgren (2012).

4.2.2.1 General prerequisites

The radioactivity data presented in this section originates from Jonasson (2012a, b, c), and is calculated assuming that the three reactors have a lifetime of 60 years i.e. the reactors are in operation until the beginning of year 2032 (O1), 2035 (O2) and 2045 (O3). The long-lived radionuclides in this study are assumed to be found, in considerable concentrations, solely in the reactor internals close to the core.

The decommissioning of each plant will start about one year after each plants final shutdown. The activity data available regarding process equipment is however assuming four years decay time for O1, i.e. the reference date for the activity calculations is 2036-01-01 and one year of decay time for O2. The reason for this is the shared waste handling facilities between O1 and O2. For O3 the reference date is set to 2046-01-01 i.e. one year after shutdown.

When each plant is shut down all operational waste (fuel, detection probes, control rods, ion exchange resins, filters, catalysts) is removed and not included in the dismantling of the process equipment. Before the dismantling, thorough system decontamination is carried out, see Section 4.2.2.4. The waste systems are assumed to be in operation during the entire decommissioning phase and will be dismantled last.

4.2.2.2 Activated corrosion products

The activated corrosion products, especially Co-60, dominate the radiation levels around most of the process systems after shutdown. System 321, the shutdown cooling system, is one of the systems that contribute the most to the radiation levels to personnel during operation of the plants. The amount of activated corrosion products at the time of decommissioning has been estimated with BWR-CRUD (Jonasson 2012a, b, c).

The following assumption has been stated in Jonasson (2012a, b, c):

Reference value for Co-60 at shutdown of O1 in January 2032: 2.6×10^9 Bq/m^2

Reference value for Co-60 at shutdown of O2 in January 2035: 2.6×10^9 Bq/m^2

Reference value for Co-60 at shutdown of O3 in January 2045: 3.6×10^9 Bq/m^2

4.2.2.3 Fission products and actinides

The O1, O2 and O3 plants have at a number of occasions been subject to fuel leakages. The amount of fission products and actinides in the waste in relation to the activated corrosion products is thus estimated to be significant. A model to predict the fuel leakage history for each plant has recently been developed (Jonasson 2012a, b, c). Experience from system decontamination in Barsebäck 1 and 2 gives that about 10% of the actinides and insoluble fission products from the dissolved fuel stay in the crud. The estimated amount of uranium from fuel leakages from each plant at the Oskarshamn site is shown in Table 4-5. The nuclide spectra for the reactor system surfaces are presented in Table 4-6.

Table 4-5. Estimated mass of dissolved Uranium (Jonasson 2012a, b, c).

Unit	Estimated mass of dissolved Uranium at shutdown* [g]	Estimated mass of dissolved Uranium in the CRUD at shutdown* [g]
O1	425	42.5
O2	641	64.1
O3	542	54.2

* Before decontamination

4.2.2.4 Decontamination

Thorough system decontamination is assumed to be carried out before the dismantling of the systems 312, 313, 321, 326, 327, 331, 352 and 354 in each plant. One third of the reactor pressure vessels (without internals) are also assumed to be decontaminated. Regarding Unit 0, system 342 in the waste management building and system 344 in the central service workshop is assumed to be decontaminated. The decontamination factor (DF) is set to 10. The decontamination conditions are very different for various systems. For the primary systems chemical system decontamination is assumed. For larger open surfaces like the pool liner, mechanical or electrochemical methods are suitable.

4.2.2.5 Reactor systems

Among all the process systems the reactor systems are the most radioactive. The activity is dominated by surface contamination of activated corrosion products (i.e. crud) except for parts of the RPV and some internals where induced activity is dominating. Among the most radioactive systems are the reactor water circuits (system 321 and system 331). Based on the data of the primary system surfaces and the measured activity relationships between the different reactor process systems (311, 313, 324, 331 and 354), nuclide spectra for contaminated reactor systems have been compiled, see Table 4-6.

4.2.2.6 Reactor pressure vessel and internal parts

The activity for the reactor pressure vessel and internal parts is presented in Table 4-7, Table 4-8 and Table 4-9. Observe that the weights are the estimated radioactive weights and do not necessarily include the weight of the whole component.

Table 4-6. Nuclide spectra for some reactor systems surfaces, at respective decay time (Jonasson 2012a, b, c).

	O1					O2					O3				
Ident	**311**	**321**	**324**	**331**	**354**	**311**	**321**	**324**	**331**	**354**	**311**	**321**	**324**	**331**	**354**
Unit			Bq/m²					Bq/m²					Bq/m²		
Fe-55	7.0E+06	7.0E+08	7.0E+07	7.0E+07	2.1E+06	1.5E+07	1.5E+09	1.5E+08	1.5E+08	4.5E+06	2.0E+07	2.0E+09	2.0E+08	2.0E+08	5.9E+06
Co-60	1.5E+07	1.5E+09	1.5E+08	1.5E+08	4.6E+06	2.3E+07	2.3E+09	2.3E+08	2.3E+08	6.8E+06	3.2E+07	3.2E+09	3.2E+08	3.2E+08	9.6E+06
Ni-59	2.9E+05	2.9E+07	2.9E+06	2.9E+06	8.7E+04	2.9E+05	2.9E+07	2.9E+06	2.9E+06	8.7E+04	1.9E+05	1.9E+07	1.9E+06	1.9E+06	5.7E+04
Ni-63	3.7E+07	3.7E+09	3.7E+08	3.7E+08	1.1E+07	3.8E+07	3.8E+09	3.8E+08	3.8E+08	1.1E+07	2.5E+07	2.5E+09	2.5E+08	2.5E+08	7.6E+06
Sr-90	1.0E+05	1.0E+07	1.0E+06	1.0E+06	3.0E+04	1.7E+05	1.7E+07	1.7E+06	1.7E+06	5.0E+04	1.2E+05	1.2E+07	1.2E+06	1.2E+06	3.6E+04
Zr-93	2.0E+02	2.0E+04	2.0E+03	2.0E+03	5.9E+01	2.0E+02	2.0E+04	2.0E+03	2.0E+03	5.9E+01	8.7E+01	8.7E+03	8.7E+02	8.7E+02	2.6E+01
Nb-93m	6.6E+06	6.6E+08	6.6E+07	6.6E+07	2.0E+06	7.5E+06	7.5E+08	7.5E+07	7.5E+07	2.2E+06	6.4E+06	6.4E+08	6.4E+07	6.4E+07	1.9E+06
Nb-94	1.1E+04	1.1E+06	1.1E+05	1.1E+05	3.2E+03	1.1E+04	1.1E+06	1.1E+05	1.1E+05	3.2E+03	7.1E+03	7.1E+05	7.1E+04	7.1E+04	2.1E+03
Mo-93	6.5E+01	6.5E+03	6.5E+02	6.5E+02	1.9E+01	6.5E+01	6.5E+03	6.5E+02	6.5E+02	1.9E+01	5.5E+01	5.5E+03	5.5E+02	5.5E+02	1.6E+01
Tc-99	5.2E+01	5.2E+03	5.2E+02	5.2E+02	1.6E+01	7.2E+01	7.2E+03	7.2E+02	7.2E+02	2.2E+01	5.0E+01	5.0E+03	5.0E+02	5.0E+02	1.5E+01
Ag-108m	7.1E+02	7.1E+04	7.1E+03	7.1E+03	2.1E+02	7.2E+02	7.2E+04	7.2E+03	7.2E+03	2.1E+02	8.7E+02	8.7E+04	8.7E+03	8.7E+03	2.6E+02
Sn-126	1.4E+00	1.4E+02	1.4E+01	1.4E+01	4.3E–01	2.2E+00	2.2E+02	2.2E+01	2.2E+01	6.5E–01	1.6E+00	1.6E+02	1.6E+01	1.6E+01	4.8E–01
Sb-125	1.1E+05	1.1E+07	1.1E+06	1.1E+06	3.2E+04	2.2E+05	2.2E+07	2.2E+06	2.2E+06	6.7E+04	1.4E+05	1.4E+07	1.4E+06	1.4E+06	4.3E+04
Pm-147	7.0E+03	7.0E+05	7.0E+04	7.0E+04	2.1E+03	3.1E+04	3.1E+06	3.1E+05	3.1E+05	9.4E+03	2.2E+04	2.2E+06	2.2E+05	2.2E+05	6.5E+03
Sm-151	1.2E+03	1.2E+05	1.2E+04	1.2E+04	3.5E+02	1.1E+03	1.1E+05	1.1E+04	1.1E+04	3.4E+02	1.0E+03	1.0E+05	1.0E+04	1.0E+04	3.0E+02
Eu-152	5.3E+00	5.3E+02	5.3E+01	5.3E+01	1.6E+00	9.3E+00	9.3E+02	9.3E+01	9.3E+01	2.8E+00	6.7E+00	6.7E+02	6.7E+01	6.7E+01	2.0E+00
Eu-154	4.4E+03	4.4E+05	4.4E+04	4.4E+04	1.3E+03	4.1E+03	4.1E+05	4.1E+04	4.1E+04	1.2E+03	3.6E+03	3.6E+05	3.6E+04	3.6E+04	1.1E+03
Eu-155	1.4E+03	1.4E+05	1.4E+04	1.4E+04	4.2E+02	1.1E+03	1.1E+05	1.1E+04	1.1E+04	3.2E+02	7.9E+02	7.9E+04	7.9E+03	7.9E+03	2.4E+02
Ho-166m	9.1E–03	9.1E–01	9.1E–02	9.1E–02	2.7E–03	1.4E–02	1.4E+00	1.4E–01	1.4E–01	4.2E–03	2.9E–02	2.9E+00	2.9E–01	2.9E–01	8.8E–03
U-232	1.7E–02	1.7E+00	1.7E–01	1.7E–01	5.0E–03	2.8E–02	2.8E+00	2.8E–01	2.8E–01	8.3E–03	2.0E–02	2.0E+00	2.0E–01	2.0E–01	6.1E–03
U-236	7.3E–01	7.3E+01	7.3E+00	7.3E+00	2.2E–01	1.2E+00	1.2E+02	1.2E+01	1.2E+01	3.5E–01	8.3E–01	8.3E+01	8.3E+00	8.3E+00	2.5E–01
Np-237	1.1E+00	1.1E+02	1.1E+01	1.1E+01	3.2E–01	1.1E+00	1.1E+02	1.1E+01	1.1E+01	3.3E–01	9.7E–01	9.7E+01	9.7E+00	9.7E+00	2.9E–01
Pu-238	8.2E+03	8.2E+05	8.2E+04	8.2E+04	2.5E+03	8.1E+03	8.1E+05	8.1E+04	8.1E+04	2.4E+03	7.7E+03	7.7E+05	7.7E+04	7.7E+04	2.3E+03
Pu-239	1.1E+03	1.1E+05	1.1E+04	1.1E+04	3.2E+02	1.2E+03	1.2E+05	1.2E+04	1.2E+04	3.5E+02	8.5E+02	8.5E+04	8.5E+03	8.5E+03	2.5E+02
Pu-240	1.4E+03	1.4E+05	1.4E+04	1.4E+04	4.1E+02	2.0E+03	2.0E+05	2.0E+04	2.0E+04	6.1E+02	1.1E+03	1.1E+05	1.1E+04	1.1E+04	3.3E+02
Pu-241	1.2E+05	1.2E+07	1.2E+06	1.2E+06	3.5E+04	1.2E+05	1.2E+07	1.2E+06	1.2E+06	3.7E+04	1.1E+05	1.1E+07	1.1E+06	1.1E+06	3.4E+04
Pu-242	5.7E+00	5.7E+02	5.7E+01	5.7E+01	1.7E+00	8.3E+00	8.3E+02	8.3E+01	8.3E+01	2.5E+00	6.7E+00	6.7E+02	6.7E+01	6.7E+01	2.0E+00
Am-241	2.2E+03	2.2E+05	2.2E+04	2.2E+04	6.5E+02	1.4E+03	1.4E+05	1.4E+04	1.4E+04	4.2E+02	1.2E+03	1.2E+05	1.2E+04	1.2E+04	3.5E+02
Am-242m	7.9E+01	7.9E+03	7.9E+02	7.9E+02	2.4E+01	2.8E+01	2.8E+03	2.8E+02	2.8E+02	8.5E+00	2.4E+01	2.4E+03	2.4E+02	2.4E+02	7.2E+00
Am-243	5.8E+01	5.8E+03	5.8E+02	5.8E+02	1.7E+01	9.2E+01	9.2E+03	9.2E+02	9.2E+02	2.8E+01	9.7E+01	9.7E+03	9.7E+02	9.7E+02	2.9E+01
Cm-243	4.2E+01	4.2E+03	4.2E+02	4.2E+02	1.3E+01	3.3E+01	3.3E+03	3.3E+02	3.3E+02	9.9E+00	3.2E+01	3.2E+03	3.2E+02	3.2E+02	9.6E+00
Cm-244	5.0E+03	5.0E+05	5.0E+04	5.0E+04	1.5E+03	5.0E+03	5.0E+05	5.0E+04	5.0E+04	1.5E+03	6.5E+03	6.5E+05	6.5E+04	6.5E+04	2.0E+03
Cm-245	1.1E+00	1.1E+02	1.1E+01	1.1E+01	3.4E–01	1.0E+00	1.0E+02	1.0E+01	1.0E+01	3.0E–01	1.5E+00	1.5E+02	1.5E+01	1.5E+01	4.4E–01
Cm-246	3.5E–01	3.5E+01	3.5E+00	3.5E+00	1.0E–01	3.1E–01	3.1E+01	3.1E+00	3.1E+00	9.3E–02	6.2E–01	6.2E+01	6.2E+00	6.2E+00	1.8E–01

4.2.2.6.1 Oskarshamn 1

It should be mentioned that the core shroud, core shroud head and core spray were exchanged after nineteen years of operation. The new components have been assigned an operation time of 41 years. The core grid has also been exchanged and the new one has been assigned an operation time of 50 years.

Table 4-7. Neutron induced activity in the Reactor Pressure Vessel and in the internal parts of O1 (four years decay time) (Jonasson 2012a).

				O1				
Part	**Reactor Containment – Contaminated Concrete**	**Reactor Containment – Reinforcement**	**RPV**	**RPV Insulation**	**Core Frame**	**Core Spray**	**Instru-mentation**	**TIP-detector**
Active Weight [tonne]	**546,8**	**167,9**	**417,0**	**5,0**	**0,1**	**8,0**	**0,1**	**0,0**
Nuclide	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**
H-3	3.0E+12						4.9E+07	9.5E+02
Be-10	8.3E+02							
C-14	1.1E+09	1.4E+08	3.5E+08	5.5E+06	1.2E+12	1.2E+12	9.1E+10	1.7E+05
Cl-36	3.6E+07	1.9E+05	2.2E+05		6.3E+08	6.0E+08	2.9E+07	1.8E+02
Ca-41	3.6E+09			5.1E+08				
Fe-55	1.8E+11	1.4E+12	6.5E+12		2.2E+15	2.1E+15	1.2E+15	7.6E+09
Co-60	7.7E+10	1.2E+11	9.5E+11		4.4E+14	4.0E+14	5.2E+14	7.6E+08
Ni-59	8.4E+06	2.6E+08	4.4E+09		1.2E+13	1.2E+13	5.3E+11	3.6E+05
Ni-63	8.2E+08	2.6E+10	5.0E+11		1.9E+15	8.8E+14	8.1E+13	5.1E+07
Se-79	1.2E+03						2.8E+03	5.5E–02
Sr-90	1.3E+07						1.0E+10	1.9E+05
Zr-93	2.5E+04						2.3E+05	4.5E+00
Nb-93m	7.9E+08	6.8E+08	2.4E+10		7.2E+11	1.3E+12	1.1E+12	6.5E+06
Nb-94	7.0E+06	5.6E+06	2.5E+08		1.5E+10	3.2E+10	1.4E+09	8.9E+03
Mo-93	1.3E+04	1.2E+07	3.1E+08		2.1E+11	1.5E+11	8.0E+09	3.3E+04
Tc-99	2.5E+03	2.4E+06	4.9E+07		3.3E+10	2.3E+10	1.0E+09	5.0E+03
Ru-106							5.3E+08	1.0E+04
Ag-108m	7.0E+08						5.9E+00	1.1E–04
Pd-107							1.9E+03	3.8E–02
Cd-113m	2.5E+06						1.5E+04	2.9E–01
Sn-126							2.5E+04	4.8E–01
Sb-125	1.9E+06	1.6E+07			9.6E+10	8.0E+09	5.3E+10	2.4E+05
I-129							3.2E+03	6.2E–02
Cs-134	4.0E+09						5.5E+09	1.1E+05
Cs-135							3.8E+04	7.4E–01
Cs-137	1.4E+07						1.0E+10	2.0E+05
Ba-133	2.8E+08						2.7E+03	5.2E–02
Pm-147	2.4E+08						4.2E+09	8.1E+04
Sm-151	8.2E+09						1.7E+07	3.2E+02
Eu-152	2.1E+11						6.5E+04	1.3E+00
Eu-154	8.8E+09						3.4E+08	6.5E+03
Eu-155	3.2E+09						1.8E+08	3.6E+03
Ho-166m	8.8E+07						8.6E+00	1.7E–04
U-232							2.4E+05	4.7E+00
U-236							4.6E+04	9.0E–01
Np-237							6.2E+04	1.2E+00
Pu-238							4.9E+08	9.5E+03
Pu-239	2.6E+06						7.0E+05	1.4E+01
Pu-240							6.3E+05	1.2E+01
Pu-241							2.5E+08	4.8E+03
Pu-242							8.0E+03	1.6E–01
Am-241							2.1E+06	4.2E+01
Am-242m							1.1E+04	2.1E–01
Am-243							1.0E+05	2.0E+00
Cm-243							5.5E+04	1.1E+00
Cm-244							1.7E+07	3.2E+02
Cm-245							2.3E+03	4.5E–02
Cm-246							9.1E+02	1.8E–02
Total	3.5E+12	1.5E+12	8.0E+12	5.1E+08	4.6E+15	3.4E+15	1.8E+15	8.4E+09

4.2.2.6.2 Oskarshamn 2

It should be mentioned that the core shroud head, core grid and core spray in O2 have been exchanged after twelve years of operation. The new components have been assigned an operation time of 48 years.

Table 4-8. Neutron induced activity in the Reactor Pressure Vessel and in the internal parts of O2 (one year decay time) (Jonasson 2012b).

	O2							
Part	**Reactor Containment – Contaminated Concrete**	**Reactor Containment – Reinforcement**	**RPV**	**RPV Insulation**	**Core Frame**	**Core Spray**	**Instrumentation**	**TIP-detector**
Active Weight [tonne]	**546.8**	**167.9**	**620.0**	**5.0**	**5.0**	**3.2**	**0.1**	**0.0**
Nuclide	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**
H-3	3.5E+12			2.9E+05			5.8E+07	1.1E+03
Be-10	8.3E+02							
C-14	1.1E+09	1.4E+08	2.0E+09	1.5E+07	1.9E+12	7.2E+11	9.1E+10	1.7E+05
Cl-36	3.6E+07	1.9E+05	1.5E+06	1.1E+07	6.3E+08	2.4E+08	2.9E+07	1.8E+02
Ca-41	3.6E+09			3.0E+08				
Fe-55	4.0E+11	3.0E+12	2.3E+13	5.4E+09	7.8E+15	3.0E+15	2.6E+15	1.6E+10
Co-60	1.1E+11	1.8E+11	1.8E+12	4.2E+08	9.9E+14	3.5E+14	7.7E+14	1.1E+09
Ni-59	8.4E+06	2.6E+08	9.9E+09	1.8E+04	1.5E+13	4.7E+12	5.3E+11	3.6E+05
Ni-63	8.4E+08	2.6E+10	9.8E+11	1.8E+06	1.6E+15	5.5E+14	8.2E+13	5.2E+07
Se-79	1.2E+03						2.8E+03	5.5E–02
Sr-90	1.4E+07						1.1E+10	2.1E+05
Zr-93	2.5E+04						2.3E+05	4.5E+00
Nb-93m	9.0E+08	7.7E+08	6.7E+10		4.0E+12	9.8E+11	1.3E+12	7.4E+06
Nb-94	7.0E+06	5.6E+06	6.6E+07		1.7E+10	5.5E+09	1.4E+09	8.9E+03
Mo-93	1.3E+04	1.2E+07	2.8E+08		1.5E+10	3.2E+09	8.0E+09	3.3E+04
Tc-99	2.5E+03	2.4E+06	3.7E+07		2.6E+09	5.2E+08	1.0E+09	5.0E+03
Ru-106							4.1E+09	7.9E+04
Ag-108m	7.0E+08						5.9E+00	1.1E–04
Pd-107							1.9E+03	3.8E–02
Cd-113m	2.9E+06						1.7E+04	3.3E–01
Sn-126							2.5E+04	4.8E–01
Sb-125	4.1E+06	3.5E+07	5.5E+08		1.1E+11	2.4E+10	1.1E+11	5.0E+05
I-129							3.2E+03	6.2E–02
Cs-134	1.1E+10			7.8E+07			1.5E+10	2.9E+05
Cs-135							3.8E+04	7.4E–01
Cs-137	1.5E+07						1.1E+10	2.1E+05
Ba-133	3.5E+08						3.3E+03	6.4E–02
Pm-147	5.3E+08						9.2E+09	1.8E+05
Sm-151	8.3E+09						1.7E+07	3.3E+02
Eu-152	2.5E+11						7.5E+04	1.5E+00
Eu-154	1.1E+10						4.3E+08	8.3E+03
Eu-155	5.0E+09						2.9E+08	5.6E+03
Ho-166m	8.8E+07						8.6E+00	1.7E–04
U-232							2.5E+05	4.8E+00
U-236							4.6E+04	9.0E–01
Np-237							6.2E+04	1.2E+00
Pu-238							5.0E+08	9.7E+03
Pu-239	2.6E+06						7.0E+05	1.4E+01
Pu-240							6.3E+05	1.2E+01
Pu-241							2.8E+08	5.5E+03
Pu-242							8.0E+03	1.6E–01
Am-241							8.8E+05	1.7E+01
Am-242m							1.1E+04	2.1E–01
Am-243							1.0E+05	2.0E+00
Cm-243							5.9E+04	1.1E+00
Cm-244							1.9E+07	3.6E+02
Cm-245							2.3E+03	4.5E–02
Cm-246							9.1E+02	1.8E–02
Total	4.3E+12	3.2E+12	2.6E+13	6.2E+09	1.0E+16	3.9E+15	3.5E+15	1.7E+10

4.2.2.6.3 Oskarshamn 3

In O3 the neutron induced activity in the core spray is not presented since it was removed after 24 years of operation.

Table 4-9. Neutron induced activity in the Reactor Pressure Vessel and in the internal parts of O3 (one year decay time) (Jonasson 2012c).

	O3						
Part	**Reactor Containment – Contaminated Concrete**	**Reactor Containment – Reinforcement**	**RPV**	**RPV Insulation**	**Core Frame**	**SRM/WRNM detectors**	**TIP-detector**
Active Weight [tonne]	**600.0**	**56.2**	**760.0**	**6.0**	**82.0**	**2.4**	**0.0**
Nuclide	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**	**[Bq]**
H-3	6.9E+11					5.4E+07	1.0E+03
Be-10	1.6E+02						
C-14	2.1E+08	2.7E+07	4.6E+08	2.2E+07	9.9E+12	1.2E+11	1.7E+05
Cl-36	7.1E+06	3.7E+04	3.4E+05	7.2E+03	3.3E+09	3.7E+07	1.8E+02
Ca-41	7.0E+08						
Fe-55	7.8E+10	5.9E+11	5.2E+12	8.3E+10	3.7E+16	4.0E+15	2.9E+10
Co-60	2.3E+10	3.6E+10	4.1E+11	8.1E+10	4.8E+15	1.1E+15	1.7E+09
Ni-59	1.7E+06	5.2E+07	2.2E+09	1.7E+08	7.1E+13	7.2E+11	4.2E+05
Ni-63	1.7E+08	5.2E+09	2.2E+11	1.7E+10	8.1E+15	1.1E+14	5.6E+07
Se-79	2.4E+02					2.6E+03	5.1E–02
Sr-90	2.8E+06					1.0E+10	1.9E+05
Zr-93	4.9E+03					2.2E+05	4.2E+00
Nb-93m	1.5E+08	1.3E+08	2.0E+10	1.3E+08	2.2E+13	1.9E+12	9.7E+06
Nb-94	1.4E+06	1.1E+06	1.6E+07	3.5E+05	9.5E+10	1.9E+09	1.0E+04
Mo-93	2.6E+03	2.5E+06	7.8E+07	4.5E+05	9.2E+10	1.6E+10	3.8E+04
Tc-99	5.1E+02	4.7E+05	9.8E+06	8.0E+04	1.5E+10	2.1E+09	6.2E+03
Ru-106						3.8E+09	7.3E+04
Ag-108m	1.4E+08					5.4E+00	1.1E–04
Pd-107						1.8E+03	3.5E–02
Cd-113m	5.6E+05					1.6E+04	3.1E–01
Sn-126						2.3E+04	4.4E–01
Sb-125	8.2E+05	6.9E+06	1.5E+08	3.2E+06	6.0E+11	1.9E+11	9.9E+05
I-129						3.0E+03	5.8E–02
Cs-134	2.2E+09					1.4E+10	2.7E+05
Cs-135						3.5E+04	6.8E–01
Cs-137	3.0E+06					1.0E+10	2.0E+05
Ba-133	6.8E+07					3.1E+03	5.9E–02
Pm-147	1.0E+08					8.5E+09	1.7E+05
Sm-151	1.7E+09					1.6E+07	3.1E+02
Eu-152	4.8E+10					7.0E+04	1.4E+00
Eu-154	2.2E+09					4.0E+08	7.7E+03
Eu-155	9.9E+08					2.6E+08	5.1E+03
Ho-166m	1.7E+07					8.0E+00	1.5E–04
U-232						2.3E+05	4.5E+00
U-236						4.3E+04	8.3E–01
Np-237						5.7E+04	1.1E+00
Pu-238						4.7E+08	9.0E+03
Pu-239	5.2E+05					6.5E+05	1.3E+01
Pu-240						5.8E+05	1.1E+01
Pu-241						2.6E+08	5.1E+03
Pu-242						7.4E+03	1.4E–01
Am-241						8.1E+05	1.6E+01
Am-242m						1.0E+04	2.0E–01
Am-243						9.7E+04	1.9E+00
Cm-243						5.5E+04	1.1E+00
Cm-244						1.7E+07	3.4E+02
Cm-245						2.1E+03	4.2E–02
Cm-246						8.4E+02	1.6E–02
Total	8.5E+11	6.3E+11	5.9E+12	1.8E+11	5.0E+16	5.2E+15	3.1E+10

4.2.2.7 Reactor pressure vessel insulation

The reactor pressure vessel insulation in O1 and O2 and consists of 18 cm asbestos insulation in the form of blocks of Caposil as well as a 1.5 mm outer plate in aluminium. The insulation of the reactor pressure vessel in O3 consists of a metallic reflection insulation of stainless steel. The neutron induced activity in the insulation is presented in Jonasson (2012a, b, c).

4.2.2.8 Turbine systems

The turbine systems have a lower degree of contamination in comparison to the reactor systems. The dominating contamination source is, as for the reactor systems, activated corrosion products. The activity in the turbine systems is caused by carry-over of the moisture in the reactor steam. From experience the most active systems are the systems containing high pressure steam before the moisture separators and systems transporting high pressure drainage. Systems located downstream the moisture separators, i.e. downstream the reheaters, are considered to have low activity. Free release would be possible after appropriate decontamination and cleaning. The degree of contamination of the different turbine systems (4xx) is supposed to be related to the source strength in the main steam lines and the moisture content in the reactor steam. The nuclide spectra for some representative turbine systems are presented in Table 4-10, Table 4-11 and Table 4-12. Observe that system 441 in O1 is divided into two parts with different surface activity (441.1 – the condenser pre-heater and 441.2 – the drainage system).

Table 4-10. Nuclide spectra for some turbine systems of O1 (four year decay time) (Jonasson 2012a).

System: Nuclide:	311.1 [Bq/m^2]	411.1 [Bq/m^2]	411.2 [Bq/m^2]	413.1 [Bq/m^2]	431.1 [Bq/m^2]	433.1 [Bq/m^2]	441.1 [Bq/m^2]	441.2 [Bq/m^2]
Fe-55	7.0E+06	7.0E+05	7.0E+05	7.0E+06	7.0E+03	7.0E+04	7.0E+05	6.3E+06
Co-60	1.5E+07	1.5E+06	1.5E+06	1.5E+07	1.5E+04	1.5E+05	1.5E+06	1.4E+07
Ni-59	2.9E+05	2.9E+04	2.9E+04	2.9E+05	2.9E+02	2.9E+03	2.9E+04	2.6E+05
Ni-63	3.7E+07	3.7E+06	3.7E+06	3.7E+07	3.7E+04	3.7E+05	3.7E+06	3.3E+07
Sr-90	1.0E+05	1.0E+04	1.0E+04	1.0E+05	1.0E+02	1.0E+03	1.0E+04	9.0E+04
Zr-93	2.0E+02	2.0E+01	2.0E+01	2.0E+02	2.0E–01	2.0E+00	2.0E+01	1.8E+02
Nb-93m	6.6E+06	6.6E+05	6.6E+05	6.6E+06	6.6E+03	6.6E+04	6.6E+05	5.9E+06
Nb-94	1.1E+04	1.1E+03	1.1E+03	1.1E+04	1.1E+01	1.1E+02	1.1E+03	9.5E+03
Mo-93	6.5E+01	6.5E+00	6.5E+00	6.5E+01	6.5E–02	6.5E–01	6.5E+00	5.8E+01
Tc-99	5.2E+01	5.2E+00	5.2E+00	5.2E+01	5.2E–02	5.2E–01	5.2E+00	4.7E+01
Ag-108m	7.1E+02	7.1E+01	7.1E+01	7.1E+02	7.1E–01	7.1E+00	7.1E+01	6.4E+02
Sn-126	1.4E+00	1.4E–01	1.4E–01	1.4E+00	1.4E–03	1.4E–02	1.4E–01	1.3E+00
Sb-125	1.1E+05	1.1E+04	1.1E+04	1.1E+05	1.1E+02	1.1E+03	1.1E+04	9.5E+04
Pm-147	7.0E+03	7.0E+02	7.0E+02	7.0E+03	7.0E+00	7.0E+01	7.0E+02	6.3E+03
Sm-151	1.2E+03	1.2E+02	1.2E+02	1.2E+03	1.2E+00	1.2E+01	1.2E+02	1.0E+03
Eu-152	5.3E+00	5.3E–01	5.3E–01	5.3E+00	5.3E–03	5.3E–02	5.3E–01	4.7E+00
Eu-154	4.4E+03	4.4E+02	4.4E+02	4.4E+03	4.4E+00	4.4E+01	4.4E+02	4.0E+03
Eu-155	1.4E+03	1.4E+02	1.4E+02	1.4E+03	1.4E+00	1.4E+01	1.4E+02	1.2E+03
Ho-166m	9.1E–03	9.1E–04	9.1E–04	9.1E–03	9.1E–06	9.1E–05	9.1E–04	8.2E–03
U-232	1.7E–02	1.7E–03	1.7E–03	1.7E–02	1.7E–05	1.7E–04	1.7E–03	1.5E–02
U-236	7.3E–01	7.3E–02	7.3E–02	7.3E–01	7.3E–04	7.3E–03	7.3E–02	6.6E–01
Np-237	1.1E+00	1.1E–01	1.1E–01	1.1E+00	1.1E–03	1.1E–02	1.1E–01	9.6E–01
Pu-238	8.2E+03	8.2E+02	8.2E+02	8.2E+03	8.2E+00	8.2E+01	8.2E+02	7.4E+03
Pu-239	1.1E+03	1.1E+02	1.1E+02	1.1E+03	1.1E+00	1.1E+01	1.1E+02	9.6E+02
Pu-240	1.4E+03	1.4E+02	1.4E+02	1.4E+03	1.4E+00	1.4E+01	1.4E+02	1.2E+03
Pu-241	1.2E+05	1.2E+04	1.2E+04	1.2E+05	1.2E+02	1.2E+03	1.2E+04	1.1E+05
Pu-242	5.7E+00	5.7E–01	5.7E–01	5.7E+00	5.7E–03	5.7E–02	5.7E–01	5.2E+00
Am-241	2.2E+03	2.2E+02	2.2E+02	2.2E+03	2.2E+00	2.2E+01	2.2E+02	2.0E+03
Am-242m	7.9E+01	7.9E+00	7.9E+00	7.9E+01	7.9E–02	7.9E–01	7.9E+00	7.1E+01
Am-243	5.8E+01	5.8E+00	5.8E+00	5.8E+01	5.8E–02	5.8E–01	5.8E+00	5.2E+01
Cm-243	4.2E+01	4.2E+00	4.2E+00	4.2E+01	4.2E–02	4.2E–01	4.2E+00	3.8E+01
Cm-244	5.0E+03	5.0E+02	5.0E+02	5.0E+03	5.0E+00	5.0E+01	5.0E+02	4.5E+03
Cm-245	1.1E+00	1.1E–01	1.1E–01	1.1E+00	1.1E–03	1.1E–02	1.1E–01	1.0E+00
Cm-246	3.5E–01	3.5E–02	3.5E–02	3.5E–01	3.5E–04	3.5E–03	3.5E–02	3.1E–01

Table 4-11. Nuclide spectra for some turbine systems of O2 (one year decay time) (Jonasson 2012b).

System Nuclide:	311.1 [Bq/m²]	413.1 [Bq/m²]	414.1 [Bq/m²]	412.1 [Bq/m²]	431.1 [Bq/m²]	441.1 [Bq/m²]	441.2 [Bq/m²]	455.1 [Bq/m²]
Fe-55	1.5E+07	1.5E+09	4.5E+06	1.5E+06	1.5E+04	1.5E+06	1.4E+07	1.5E+05
Co-60	2.3E+07	2.3E+09	6.8E+06	2.3E+06	2.3E+04	2.3E+06	2.0E+07	2.3E+05
Ni-59	2.9E+05	2.9E+07	8.7E+04	2.9E+04	2.9E+02	2.9E+04	2.6E+05	2.9E+03
Ni-63	3.8E+07	3.8E+09	1.1E+07	3.8E+06	3.8E+04	3.8E+06	3.4E+07	3.8E+05
Sr-90	1.7E+05	1.7E+07	5.0E+04	1.7E+04	1.7E+02	1.7E+04	1.5E+05	1.7E+03
Zr-93	2.0E+02	2.0E+04	5.9E+01	2.0E+01	2.0E–01	2.0E+01	1.8E+02	2.0E+00
Nb-93m	7.5E+06	7.5E+08	2.2E+06	7.5E+05	7.5E+03	7.5E+05	6.7E+06	7.5E+04
Nb-94	1.1E+04	1.1E+06	3.2E+03	1.1E+03	1.1E+01	1.1E+03	9.5E+03	1.1E+02
Mo-93	6.5E+01	6.5E+03	1.9E+01	6.5E+00	6.5E–02	6.5E+00	5.8E+01	6.5E–01
Tc-99	7.2E+01	7.2E+03	2.2E+01	7.2E+00	7.2E–02	7.2E+00	6.5E+01	7.2E–01
Ag-108m	7.2E+02	7.2E+04	2.1E+02	7.2E+01	7.2E–01	7.2E+01	6.4E+02	7.2E+00
Sn-126	2.2E+00	2.2E+02	6.5E–01	2.2E–01	2.2E–03	2.2E–01	2.0E+00	2.2E–02
Sb-125	2.2E+05	2.2E+07	6.7E+04	2.2E+04	2.2E+02	2.2E+04	2.0E+05	2.2E+03
Pm-147	3.1E+04	3.1E+06	9.4E+03	3.1E+03	3.1E+01	3.1E+03	2.8E+04	3.1E+02
Sm-151	1.1E+03	1.1E+05	3.4E+02	1.1E+02	1.1E+00	1.1E+02	1.0E+03	1.1E+01
Eu-152	9.3E+00	9.3E+02	2.8E+00	9.3E–01	9.3E–03	9.3E–01	8.4E+00	9.3E–02
Eu-154	4.1E+03	4.1E+05	1.2E+03	4.1E+02	4.1E+00	4.1E+02	3.7E+03	4.1E+01
Eu-155	1.1E+03	1.1E+05	3.2E+02	1.1E+02	1.1E+00	1.1E+02	9.7E+02	1.1E+01
Ho-166m	1.4E–02	1.4E+00	4.2E–03	1.4E–03	1.4E–05	1.4E–03	1.3E–02	1.4E–04
U-232	2.8E–02	2.8E+00	8.3E–03	2.8E–03	2.8E–05	2.8E–03	2.5E–02	2.8E–04
U-236	1.2E+00	1.2E+02	3.5E–01	1.2E–01	1.2E–03	1.2E–01	1.1E+00	1.2E–02
Np-237	1.1E+00	1.1E+02	3.3E–01	1.1E–01	1.1E–03	1.1E–01	1.0E+00	1.1E–02
Pu-238	8.1E+03	8.1E+05	2.4E+03	8.1E+02	8.1E+00	8.1E+02	7.3E+03	8.1E+01
Pu-239	1.2E+03	1.2E+05	3.5E+02	1.2E+02	1.2E+00	1.2E+02	1.1E+03	1.2E+01
Pu-240	2.0E+03	2.0E+05	6.1E+02	2.0E+02	2.0E+00	2.0E+02	1.8E+03	2.0E+01
Pu-241	1.2E+05	1.2E+07	3.7E+04	1.2E+04	1.2E+02	1.2E+04	1.1E+05	1.2E+03
Pu-242	8.3E+00	8.3E+02	2.5E+00	8.3E–01	8.3E–03	8.3E–01	7.5E+00	8.3E–02
Am-241	1.4E+03	1.4E+05	4.2E+02	1.4E+02	1.4E+00	1.4E+02	1.2E+03	1.4E+01
Am-242m	2.8E+01	2.8E+03	8.5E+00	2.8E+00	2.8E–02	2.8E+00	2.6E+01	2.8E–01
Am-243	9.2E+01	9.2E+03	2.8E+01	9.2E+00	9.2E–02	9.2E+00	8.3E+01	9.2E–01
Cm-243	3.3E+01	3.3E+03	9.9E+00	3.3E+00	3.3E–02	3.3E+00	3.0E+01	3.3E–01
Cm-244	5.0E+03	5.0E+05	1.5E+03	5.0E+02	5.0E+00	5.0E+02	4.5E+03	5.0E+01
Cm-245	1.0E+00	1.0E+02	3.0E–01	1.0E–01	1.0E–03	1.0E–01	9.1E–01	1.0E–02
Cm-246	3.1E–01	3.1E+01	9.3E–02	3.1E–02	3.1E–04	3.1E–02	2.8E–01	3.1E–03

Table 4-12. Nuclide spectra for some turbine systems of O3 (one year decay time) (Jonasson 2012c).

System Nuclide	311.1 [Bq/m^2]	403.1 [Bq/m^2]	421.1 [Bq/m^2]	422.1 [Bq/m^2]	423.1 [Bq/m^2]	424.1 [Bq/m^2]	461.1 [Bq/m^2]	463.1 [Bq/m^2]
Fe-55	2.0E+07	9.8E+06	9.8E+06	2.0E+06	2.0E+06	2.0E+06	2.0E+06	2.0E+06
Co-60	3.2E+07	1.6E+07	1.6E+07	3.2E+06	3.2E+06	3.2E+06	3.2E+06	3.2E+06
Ni-59	1.9E+05	9.6E+04	9.6E+04	1.9E+04	1.9E+04	1.9E+04	1.9E+04	1.9E+04
Ni-63	2.5E+07	1.3E+07	1.3E+07	2.5E+06	2.5E+06	2.5E+06	2.5E+06	2.5E+06
Sr-90	1.2E+05	6.0E+04	6.0E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04
Zr-93	8.7E+01	4.3E+01	4.3E+01	8.7E+00	8.7E+00	8.7E+00	8.7E+00	8.7E+00
Nb-93m	6.4E+06	3.2E+06	3.2E+06	6.4E+05	6.4E+05	6.4E+05	6.4E+05	6.4E+05
Nb-94	7.1E+03	3.6E+03	3.6E+03	7.1E+02	7.1E+02	7.1E+02	7.1E+02	7.1E+02
Mo-93	5.5E+01	2.7E+01	2.7E+01	5.5E+00	5.5E+00	5.5E+00	5.5E+00	5.5E+00
Tc-99	5.0E+01	2.5E+01	2.5E+01	5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.0E+00
Ag-108m	8.7E+02	4.4E+02	4.4E+02	8.7E+01	8.7E+01	8.7E+01	8.7E+01	8.7E+01
Sn-126	1.6E+00	7.9E–01	7.9E–01	1.6E–01	1.6E–01	1.6E–01	1.6E–01	1.6E–01
Sb-125	1.4E+05	7.1E+04	7.1E+04	1.4E+04	1.4E+04	1.4E+04	1.4E+04	1.4E+04
Pm-147	2.2E+04	1.1E+04	1.1E+04	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03
Sm-151	1.0E+03	5.0E+02	5.0E+02	1.0E+02	1.0E+02	1.0E+02	1.0E+02	1.0E+02
Eu-152	6.7E+00	3.4E+00	3.4E+00	6.7E–01	6.7E–01	6.7E–01	6.7E–01	6.7E–01
Eu-154	3.6E+03	1.8E+03	1.8E+03	3.6E+02	3.6E+02	3.6E+02	3.6E+02	3.6E+02
Eu-155	7.9E+02	4.0E+02	4.0E+02	7.9E+01	7.9E+01	7.9E+01	7.9E+01	7.9E+01
Ho-166m	2.9E–02	1.5E–02	1.5E–02	2.9E–03	2.9E–03	2.9E–03	2.9E–03	2.9E–03
U-232	2.0E–02	1.0E–02	1.0E–02	2.0E–03	2.0E–03	2.0E–03	2.0E–03	2.0E–03
U-236	8.3E–01	4.1E–01	4.1E–01	8.3E–02	8.3E–02	8.3E–02	8.3E–02	8.3E–02
Np-237	9.7E–01	4.9E–01	4.9E–01	9.7E–02	9.7E–02	9.7E–02	9.7E–02	9.7E–02
Pu-238	7.7E+03	3.9E+03	3.9E+03	7.7E+02	7.7E+02	7.7E+02	7.7E+02	7.7E+02
Pu-239	8.5E+02	4.2E+02	4.2E+02	8.5E+01	8.5E+01	8.5E+01	8.5E+01	8.5E+01
Pu-240	1.1E+03	5.5E+02	5.5E+02	1.1E+02	1.1E+02	1.1E+02	1.1E+02	1.1E+02
Pu-241	1.1E+05	5.6E+04	5.6E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04
Pu-242	6.7E+00	3.3E+00	3.3E+00	6.7E–01	6.7E–01	6.7E–01	6.7E–01	6.7E–01
Am-241	1.2E+03	5.8E+02	5.8E+02	1.2E+02	1.2E+02	1.2E+02	1.2E+02	1.2E+02
Am-242m	2.4E+01	1.2E+01	1.2E+01	2.4E+00	2.4E+00	2.4E+00	2.4E+00	2.4E+00
Am-243	9.7E+01	4.9E+01	4.9E+01	9.7E+00	9.7E+00	9.7E+00	9.7E+00	9.7E+00
Cm-243	3.2E+01	1.6E+01	1.6E+01	3.2E+00	3.2E+00	3.2E+00	3.2E+00	3.2E+00
Cm-244	6.5E+03	3.3E+03	3.3E+03	6.5E+02	6.5E+02	6.5E+02	6.5E+02	6.5E+02
Cm-245	1.5E+00	7.3E–01	7.3E–01	1.5E–01	1.5E–01	1.5E–01	1.5E–01	1.5E–01
Cm-246	6.2E–01	3.1E–01	3.1E–01	6.2E–02	6.2E–02	6.2E–02	6.2E–02	6.2E–02

4.2.2.9 Waste system

Source strength in the form of waste from different cleanup systems is displayed in Table 4-13, Table 4-14 and Table 4-15. These source strengths are used in the estimation of the activity in the waste systems assuming a small amount of ion exchange resin in the systems. Observe that system 342 is shared between O1 and O2, and the waste building belongs to O1. Observe that the long-lived nuclides C-14 and Cl-36 are included in the estimation of the waste activity. Noticeable is that the ion exchange resins in system 332 accumulate 50% more C-14 than the ion exchange resins in system 331 due to different types of ion exchange resins in the different systems and that carbon dioxide has a higher solubility in the condensate than in the reactor water. The used activity concentrations in the ion exchange resins imply that approximately 0.14% of the total production of C-14 in the reactor coolant end up in the 331-ion exchange mass and 0.21% end up in the 332-ion exchange mass.

Table 4-13. Activity in the waste system at the O1 reactor shutdown (four year decay time) (Jonasson 2012a).

Ident Nuclide	324.1 [Bq/m²]	331.1 [Bq/m²]	332.1 [Bq/m²]	342.11 [Bq/m²]	342.21 [Bq/m²]
Be-10			3.4E–06	1.5E–05	4.9E–07
C-14			8.7E+02	2.1E+02	7.0E+00
Cl-36			1.0E–02	4.6E–02	1.5E–03
Fe-55	7.0E+07	7.0E+08	5.7E+03	9.8E+04	3.3E+03
Co-60	1.5E+08	1.5E+09	5.3E+04	4.4E+05	1.5E+04
Ni-59	2.9E+06	2.9E+07	1.2E+02	6.8E+02	2.3E+01
Ni-63	3.7E+08	3.7E+09	1.6E+04	9.2E+04	3.1E+03
Se-79			1.1E–03	5.0E–03	1.7E–04
Sr-90	1.0E+06	1.0E+07	1.0E+03	5.1E+03	1.7E+02
Zr-93	2.0E+03	2.0E+04	8.1E–02	4.5E–01	1.5E–02
Nb-93m	6.6E+07	6.6E+08	2.7E+03	1.7E+04	5.8E+02
Nb-94	1.1E+05	1.1E+06	4.5E+00	2.5E+01	8.3E–01
Mo-93	6.5E+02	6.5E+03	2.7E–02	1.5E–01	5.1E–03
Tc-99	5.2E+02	5.2E+03	1.3E+01	1.0E+02	3.5E+00
Ru-106			2.8E+02	2.4E+05	8.0E+03
Ag-108m	7.1E+03	7.1E+04	3.0E–01	1.7E+00	5.6E–02
Pd-107			1.6E+03	8.8E+03	2.9E+02
Cd-113m			4.9E+03	3.1E+04	1.0E+03
Sn-126	1.4E+01	1.4E+02	7.6E+03	4.2E+04	1.4E+03
Sb-125	1.1E+06	1.1E+07	3.9E+01	4.6E+02	1.5E+01
I-129			4.1E–01	3.7E–01	1.2E–02
Cs-134			3.8E+02	1.5E+05	5.0E+03
Cs-135			4.9E–01	3.7E+00	1.2E–01
Cs-137			2.4E+03	2.6E+05	8.5E+03
Ba-133			8.4E–04	1.0E–01	3.5E–03
Pm-147	7.0E+04	7.0E+05	8.7E+02	2.6E+05	8.6E+03
Sm-151	1.2E+04	1.2E+05	1.3E+01	8.4E+02	2.8E+01
Eu-152	5.3E+01	5.3E+02	1.5E–01	1.7E+01	5.8E–01
Eu-154	4.4E+04	4.4E+05	1.8E+02	1.1E+04	3.8E+02
Eu-155	1.4E+04	1.4E+05	1.0E+02	5.2E+03	1.7E+02
Ho-166m	9.1E–02	9.1E–01	8.2E–05	8.4E–03	2.8E–04
U-232	1.7E–01	1.7E+00	2.0E–04	2.2E–02	7.2E–04
U-236	7.3E+00	7.3E+01	6.5E–03	7.0E–01	2.3E–02
Np-237	1.1E+01	1.1E+02	9.4E–03	6.6E–01	2.2E–02
Pu-238	8.2E+04	8.2E+05	2.3E+01	1.0E+02	3.4E+00
Pu-239	1.1E+04	1.1E+05	3.1E+00	1.7E+01	5.6E–01
Pu-240	1.4E+04	1.4E+05	4.9E+00	2.6E+01	8.6E–01
Pu-241	1.2E+06	1.2E+07	4.1E+02	2.5E+03	8.3E+01
Pu-242	5.7E+01	5.7E+02	6.8E–03	5.6E–02	1.9E–03
Am-241	2.2E+04	2.2E+05	4.3E+00	1.3E+01	4.4E–01
Am-242m	7.9E+02	7.9E+03	1.7E–01	4.9E–01	1.6E–02
Am-243	5.8E+02	5.8E+03	1.1E–01	1.4E+00	4.6E–02
Cm-243	4.2E+02	4.2E+03	1.5E–01	9.0E–01	3.0E–02
Cm-244	5.0E+04	5.0E+05	1.5E+01	8.8E+01	2.9E+00
Cm-245	1.1E+01	1.1E+02	1.4E–03	7.1E–03	2.4E–04
Cm-246	3.5E+00	3.5E+01	4.2E–04	2.2E–03	7.3E–05

[1)] System 342 is shared by O1 and O2.

Table 4-14. Activity in the waste system at the O2 reactor shutdown (one year decay time) (Jonasson 2012b).

Ident Nuclide	324.1 [Bq/m²]	331.1 [Bq/m²]	332.1 [Bq/m²]
Be-10			3.2E–04
C-14			8.7E+04
Cl-36			1.0E+00
Fe-55	1.5E+08	1.5E+09	1.2E+06
Co-60	2.3E+08	2.3E+09	7.8E+06
Ni-59	2.9E+06	2.9E+07	1.2E+04
Ni-63	3.8E+08	3.8E+09	1.7E+06
Se-79			1.1E–01
Sr-90	1.7E+06	1.7E+07	1.1E+05
Zr-93	2.0E+03	2.0E+04	8.1E+00
Nb-93m	7.5E+07	7.5E+08	3.1E+05
Nb-94	1.1E+05	1.1E+06	4.5E+02
Mo-93	6.5E+02	6.5E+03	2.7E+00
Tc-99	7.2E+02	7.2E+03	1.3E+03
Ru-106			2.2E+05
Ag-108m	7.2E+03	7.2E+04	3.0E+01
Pd-107			1.6E+05
Cd-113m			5.6E+05
Sn-126	2.2E+01	2.2E+02	7.6E+05
Sb-125	2.2E+06	2.2E+07	8.3E+03
I-129			4.1E+01
Cs-134			1.0E+05
Cs-135			4.9E+01
Cs-137			2.6E+05
Ba-133			1.0E–01
Pm-147	3.1E+05	3.1E+06	2.6E+05
Sm-151	1.1E+04	1.1E+05	8.3E+02
Eu-152	9.3E+01	9.3E+02	1.7E+01
Eu-154	4.1E+04	4.1E+05	1.1E+04
Eu-155	1.1E+04	1.1E+05	5.2E+03
Ho-166m	1.4E–01	1.4E+00	8.4E–03
U-232	2.8E–01	2.8E+00	2.2E–02
U-236	1.2E+01	1.2E+02	7.0E–01
Np-237	1.1E+01	1.1E+02	6.6E–01
Pu-238	8.1E+04	8.1E+05	2.4E+03
Pu-239	1.2E+04	1.2E+05	3.1E+02
Pu-240	2.0E+04	2.0E+05	4.9E+02
Pu-241	1.2E+06	1.2E+07	4.8E+04
Pu-242	8.3E+01	8.3E+02	1.1E+00
Am-241	1.4E+04	1.4E+05	2.2E+02
Am-242m	2.8E+02	2.8E+03	7.5E+00
Am-243	9.2E+02	9.2E+03	2.1E+01
Cm-243	3.3E+02	3.3E+03	1.4E+01
Cm-244	5.0E+04	5.0E+05	1.7E+03
Cm-245	1.0E+01	1.0E+02	1.4E–01
Cm-246	3.1E+00	3.1E+01	4.2E–02

Table 4-15. Activity in the waste system at the O3 reactor shutdown (one year decay time) (Jonasson 2012c).

Ident Nuclide	324.1 [Bq/m²]	331.1 [Bq/m²]	332.1 [Bq/m²]	342.1 [Bq/m²]	342.7 [Bq/m²]
Be-10			2.9E–07	4.8E–06	
C-14			4.6E+04	8.8E+03	
Cl-36			3.1E–02	9.5E–01	
Fe-55	2.0E+08	2.0E+09	1.2E+06	9.0E+06	5.9E+05
Co-60	3.2E+08	3.2E+09	7.0E+05	1.6E+07	9.6E+05
Ni-59	1.9E+06	1.9E+07	1.1E+03	1.9E+04	5.7E+03
Ni-63	2.5E+08	2.5E+09	1.5E+05	2.6E+06	7.6E+05
Se-79			6.6E–03	1.1E–01	
Sr-90	1.2E+06	1.2E+07	7.4E+03	1.2E+05	3.6E+03
Zr-93	8.7E+02	8.7E+03	4.7E–01	8.3E+00	2.6E+00
Nb-93m	6.4E+07	6.4E+08	3.6E+04	6.3E+05	1.9E+05
Nb-94	7.1E+04	7.1E+05	4.1E+01	7.1E+02	2.1E+02
Mo-93	5.5E+02	5.5E+03	3.1E–01	5.4E+00	1.6E+00
Tc-99	5.0E+02	5.0E+03	1.4E+02	3.1E+03	1.5E+00
Ru-106			2.1E+04	7.6E+06	
Ag-108m	8.7E+03	8.7E+04	5.0E+00	8.7E+01	2.6E+01
Pd-107			1.0E+02	1.8E+03	
Cd-113m			2.5E+04	4.5E+05	
Sn-126	1.6E+01	1.6E+02	4.8E+02	8.5E+03	4.8E–02
Sb-125	1.4E+06	1.4E+07	7.1E+02	1.2E+04	4.3E+03
I-129			1.3E+01	1.4E+01	
Cs-134			1.1E+04	5.1E+06	
Cs-135			5.0E+00	1.1E+02	
Cs-137			2.4E+04	7.4E+06	
Ba-133			5.3E–06	1.6E–03	
Pm-147	2.2E+05	2.2E+06	2.4E+04	7.2E+06	6.5E+02
Sm-151	1.0E+04	1.0E+05	9.8E+01	3.0E+04	3.0E+01
Eu-152	6.7E+01	6.7E+02	1.7E+00	5.0E+02	2.0E–01
Eu-154	3.6E+04	3.6E+05	1.3E+03	4.0E+05	1.1E+02
Eu-155	7.9E+03	7.9E+04	5.1E+02	1.5E+05	2.4E+01
Ho-166m	2.9E–01	2.9E+00	2.3E–03	7.0E–01	8.8E–04
U-232	2.0E–01	2.0E+00	2.1E–03	6.3E–01	6.1E–04
U-236	8.3E+00	8.3E+01	6.5E–02	2.0E+01	2.5E–02
Np-237	9.7E+00	9.7E+01	7.6E–02	2.3E+01	2.9E–02
Pu-238	7.7E+04	7.7E+05	2.2E+02	3.4E+03	2.3E+02
Pu-239	8.5E+03	8.5E+04	2.7E+01	4.1E+02	2.5E+01
Pu-240	1.1E+04	1.1E+05	3.0E+01	4.7E+02	3.3E+01
Pu-241	1.1E+06	1.1E+07	5.4E+03	8.4E+04	3.4E+03
Pu-242	6.7E+01	6.7E+02	1.1E–01	1.7E+00	2.0E–01
Am-241	1.2E+04	1.2E+05	2.1E+01	3.6E+02	3.5E+01
Am-242m	2.4E+02	2.4E+03	7.6E–01	1.3E+01	7.2E–01
Am-243	9.7E+02	9.7E+03	2.7E+00	4.7E+01	2.9E+00
Cm-243	3.2E+02	3.2E+03	1.6E+00	2.8E+01	9.6E–01
Cm-244	6.5E+04	6.5E+05	2.7E+02	4.3E+03	2.0E+02
Cm-245	1.5E+01	1.5E+02	2.4E–02	3.8E–01	4.4E–02
Cm-246	6.2E+00	6.2E+01	1.0E–02	1.6E–01	1.8E–02

4.2.2.10 Gas treatment and ventilation systems

The radioactivity in the off-gas system 341 of each plant is dominated by the noble gas daughters Sr-90, Cs-135 and Cs-137 (at short decay times Ba-140/La-140 dominates).

The activity inventory in the off-gas system caused by deposited noble gas daughters is presented in Table 4-16. The predominating part of the inventory is in the sand bed in the off-gas delay tank of system 341. The ventilation systems 74x are considered to be free released and have therefore been excluded.

Table 4-16. Activity inventory of noble gas daughters in different off-gas systems for O1 (four year decay time), O2 (one year decay time) and O3 (one year decay time) (Jonasson 2012a, b, c).

Ident Nuclide/ Unit	341, before TX, distribution lines in TX and the bottom of TX [Bq]	341 TX (sand) [Bq]
	O1 (X=2)	
Sr-90	5.9E+06	1.4E+10
I-129	3.8E+01	8.9E+04
Cs-135	6.2E+03	1.4E+07
Cs-137	5.0E+07	1.2E+11
	O2 (X=1)	
Sr-90	6.3E+06	1.5E+10
I-129	3.8E+01	8.9E+04
Cs-135	6.2E+03	1.4E+07
Cs-137	5.3E+07	1.2E+11
	O3 (X=1)	
Sr-90	4.9E+07	9.4E+08
I-129	1.3E+04	2.4E+05
Cs-135	1.0E+06	2.0E+07
Cs-137	6.2E+09	1.2E+11

4.2.3 Building contamination

In the study of building demolition of Swedish BWRs (Ericsson 2005), contamination levels for the different concrete structures of the plant have been presented. The contamination exists in both the activated biological shield and on surfaces due to spillage of contaminated media. The data were gathered at Barsebäck but is considered to be generic and thus also applicable to the plants within the Oskarshamn site.

4.2.3.1 Concrete surfaces

An inventory of the building contamination of concrete structures in Barsebäck 1 has been done in Ericsson (2005). That inventory would also apply to the utilities at the Oskarshamn site after modifications to the existing plant areas of the site. The areas have been categorized in three levels:

Level 1 Partly contaminated

It is mainly in the reactor building where spreading of activity can occur in areas where active systems are located. Other areas are, for example, the stack for release of process off-gases and ventilation areas.

Level 2 Contamination can occur

Turbine building, waste building, active workshop, waste management building of low active waste and ventilation areas.

Level 3 Possible areas for free release without particular actions

Central service building, electrical buildings and office building.

For estimation of the amount of contaminated concrete surfaces, the following assumptions are used regarding penetration and spreading of activity (Ericsson 2005):

- *Containment contamination depths*

On wet-well walls	1 cm on 100% of the surface
On wet-well bottom	2 cm on 100% of the surface
In dry-well	2 cm on 5% of the surface
The Biological Shield	The entire structure

- *Fuel and Handling Pools*
  Bottom — 2 cm on 100% of the surface
  Wall surfaces — 1 cm on 100% of the surface
- *In pump pits the concrete contamination depth is estimated to 5 cm.*
- *Rooms with process equipment.*
  Rooms with limited amounts of process equipment. — 1 cm on 0.5% of the floor surface
  Rooms with higher leakage risk. E.g. rooms containing filter banks, waste water tanks, pumps etc. — 2 cm on 5% of the floor surface

4.2.3.2 The biological shield

The activity distribution through the biological shield follows the principal distribution according to drill samples taken from Barsebäck 1 and 2. The nuclide inventory is however calculated for each of the plant of Oskarshamn site (Jonasson 2012a, b, c).

In Table 4-17 specific nuclide inventories for the biological shield is presented (Jonasson 2012a, b, c). The data presented are based on calculations adjusted with empirical data.

Table 4-17. Neutron induced activity in the biological shield (Jonasson 2012a, b, c).

	O1			O2			O3		
	Concrete	Rein-forecement	Total	Concrete	Rein-forecement	Total	Concrete	Rein-forecement	Total
	[Bq]	[Bq]	[Bq]	[Bq]	[Bq]	[Bq]	[Bq]	[Bq]	[Bq]
H-3	3.0E+12		3.0E+12	3.5E+12		3.5E+12	6.9E+11		6.9E+11
Be-10	8.3E+02		8.3E+02	8.3E+02		8.3E+02	1.6E+02		1.6E+02
C-14	1.1E+09	1.4E+08	1.2E+09	1.1E+09	1.4E+08	1.2E+09	2.1E+08	2.7E+07	2.4E+08
Cl-36	3.6E+07	1.9E+05	3.6E+07	3.6E+07	1.9E+05	3.6E+07	7.1E+06	3.7E+04	7.2E+06
Ca-41	3.6E+09		3.6E+09	3.6E+09		3.6E+09	7.0E+08		7.0E+08
Fe-55	1.8E+11	1.4E+12	1.6E+12	4.0E+11	3.0E+12	3.4E+12	7.8E+10	5.9E+11	6.7E+11
Co-60	7.7E+10	1.2E+11	2.0E+11	1.1E+11	1.8E+11	2.9E+11	2.3E+10	3.6E+10	5.8E+10
Ni-59	8.4E+06	2.6E+08	2.7E+08	8.4E+06	2.6E+08	2.7E+08	1.7E+06	5.2E+07	5.4E+07
Ni-63	8.2E+08	2.6E+10	2.6E+10	8.4E+08	2.6E+10	2.7E+10	1.7E+08	5.2E+09	5.4E+09
Se-79	1.2E+03		1.2E+03	1.2E+03		1.2E+03	2.4E+02		2.4E+02
Sr-90	1.3E+07		1.3E+07	1.4E+07		1.4E+07	2.8E+06		2.8E+06
Zr-93	2.5E+04		2.5E+04	2.5E+04		2.5E+04	4.9E+03		4.9E+03
Nb-93m	7.9E+08	6.8E+08	1.5E+09	9.0E+08	7.7E+08	1.7E+09	1.5E+08	1.3E+08	2.8E+08
Nb-94	7.0E+06	5.6E+06	1.3E+07	7.0E+06	5.6E+06	1.3E+07	1.4E+06	1.1E+06	2.5E+06
Mo-93	1.3E+04	1.2E+07	1.2E+07	1.3E+04	1.2E+07	1.2E+07	2.6E+03	2.5E+06	2.5E+06
Tc-99	2.5E+03	2.4E+06	2.4E+06	2.5E+03	2.4E+06	2.4E+06	5.1E+02	4.7E+05	4.8E+05
Ag-108m	7.0E+08		7.0E+08	7.0E+08		7.0E+08	1.4E+08		1.4E+08
Cd-113m	2.5E+06		2.5E+06	2.9E+06		2.9E+06	5.6E+05		5.6E+05
Sb-125	1.9E+06	1.6E+07	1.8E+07	4.1E+06	3.5E+07	3.9E+07	8.2E+05	6.9E+06	7.8E+06
Cs-134	4.0E+09		4.0E+09	1.1E+10		1.1E+10	2.2E+09		2.2E+09
Cs-137	1.4E+07		1.4E+07	1.5E+07		1.5E+07	3.0E+06		3.0E+06
Ba-133	2.8E+08		2.8E+08	3.5E+08		3.5E+08	6.8E+07		6.8E+07
Pm-147	2.4E+08		2.4E+08	5.3E+08		5.3E+08	1.0E+08		1.0E+08
Sm-151	8.2E+09		8.2E+09	8.3E+09		8.3E+09	1.7E+09		1.7E+09
Eu-152	2.1E+11		2.1E+11	2.5E+11		2.5E+11	4.8E+10		4.8E+10
Eu-154	8.8E+09		8.8E+09	1.1E+10		1.1E+10	2.2E+09		2.2E+09
Eu-155	3.2E+09		3.2E+09	5.0E+09		5.0E+09	9.9E+08		9.9E+08
Ho-166m	8.8E+07		8.8E+07	8.8E+07		8.8E+07	1.7E+07		1.7E+07
Pu-239	2.6E+06		2.6E+06	2.6E+06		2.6E+06	5.2E+05		5.2E+05

4.3 Radioactivity inventory

4.3.1 Introduction

In this chapter a classification of the dismantling and demolition waste material quantities of the Oskarshamn site introduced in Section 4.1 is presented. The chapter is divided into three subchapters: Plant Metal Activity Inventory, Concrete Activity Inventory and Sand Activity Inventory. The activity categorization is based on specific activity data. The reference date for the activity estimations is one year after shutdown. This means 2036-01-01 for O1 (Jonasson 2012a), 2036-01-01 for O2 (Jonasson 2012b) and 2046-01-01 for O3 (Jonasson 2012c). Information regarding nuclide spectra of process and structural materials is presented in previous section.

According to IAEA, the radioactive waste can be divided into the typical waste categories (IAEA 1994): High level waste (HLW), Low and Intermediate level waste (LLW, ILW and in combination LILW) and Free Released waste (FRW). HLW is defined as waste which has a thermal power above 2 kW/m^3 and is in practice not applicable for decommissioning waste. ILW is defined as radioactive waste which requires shielding but needs little or no provision for heat dissipation. LLW has been defined in the past to mean radioactive waste that does not require shielding during normal handling and transportation. A surface dose rate of below 2 mSv/h of the waste package is generally called LLW and a surface dose rate of above 2 mSv/h is classified as ILW.

LILW is according to IAEA divided into short-lived (LILW-SL) and long-lived (LILW-LL) waste. Short-lived low and intermediate level waste contain low concentrations of long-lived radionuclides. Although the waste may contain high concentrations of short-lived radionuclides, significant radioactive decay occurs during the period of institutional control. Long-lived low and intermediate level waste contain long-lived radionuclides (half-lives in excess of 30 years) in quantities that need a high degree of isolation from the biosphere.

Free Released waste (FRW) has activity levels below the clearance level and thereby contains so little radioactive material that it cannot be considered "radioactive" and might be free released from nuclear regulatory control. That is to say, although it still can be radioactive from a physical point of view, this waste may be safely disposed of, applying conventional techniques and systems, without specifically considering its radioactive properties.

Free release of radioactive material from controlled area is regulated by SSM (SSMFS 2011:2) and described in SKB handbook (R-11-15).The free release level of material from decommissioning waste and controlled areas is nuclide specific with a general specific activity of 100 Bq/kg. But in this study the following assumption has been used for the decommissioning waste:

- Limit for free release: 500 Bq/kg

To be able to include the waste that origins from uncontrolled area, the activity category Non-Active material with color code white, has been added to the specific activity levels presented in Table 4-18. The waste in this category is by origin non-active and does not need to be monitored.

All waste in the categories blue and white is assumed to be recycled or disposed of at a municipal deposit.

Table 4-18. Activity Categorization.

Waste Category	Specific activity Category [Bq/kg]	Description
Red	> 10^6	Radioactive material requiring radiation shielding
Yellow	10^4–10^6	Radioactive material not requiring radiation shielding.
Green	500–10^4	Potentially free-release material after treatment
Blue	< 500	Non-active material, controlled area
White	–	Non-active material, uncontrolled area

4.3.2 Source of information

Component data for O1, O2 and O0, e.g.weight, is mainly based on material supplied from OKG (Dahlberg and Eriksson 2009). For O3 the component data information is compiled from Bergh (2010), Gustafsson et al. 2006) and Lönnerberg (1994).

The inventory data presented in Section 4.1 has been complemented with specific system area codes for different sections of the radioactive systems. The reference date for the activity calculations is 2036-01-01 for O1 and O2, 2046-01-01 for O3. ALARA Engineering has calculated total radioactivity for each system ident based on those components in each system that contain neutron induced activity or have been in contact with active water or steam and thus are considered to be active.

4.3.3 Accuracy and uncertainties in the study

The estimated accuracy of the activity inventory is discussed in Jonasson (2012a, b, c). To conclude, the estimated total activity has relatively good accuracy as it depends to a great extent on the neutron induced activity in the internals. The accuracy of the total activity is approximately ± 50%.

If the applied limit for free release will differ from 500 Bq/kg which is the assumed limit in this study, the amount of free releasable waste might change from the quantities presented in this chapter. The experience from Oskarshamn is however that the amount of free-released waste will not significantly change with the new limits for free-released waste. The total amount of active waste depends strongly on which components that can be free released, e.g, components in the turbine building, where surface contamination is relevant only for surfaces that have been in contact with radioactive media. This amount will also be affected by the decay time between shutdown and the start of the decommissioning and of the grade of cleaning of the actual systems. Therefore the total amount of active waste estimated in this study contains some uncertainty.

Other uncertainties are those instances where estimates, assumptions and extrapolations have been used, as described in Section 4.3.2. Possible future fuel damages or malfunctions are scenarios not taken into account and have to be considered as uncertainties.

4.3.4 Radioactivity levels

The most radioactive systems are the reactor systems while most parts of the turbine systems can be free released. For example regarding the surface condenser (system 431) only the dump equipment and lines to the off-gas system are considered as active and the rest is free released.

The majority of the systems at controlled areas in Unit 0 are considered to be below free release level except system 342 in the waste management building and system 344 (the decontamination system) in the central service workshop.

4.3.5 Plant metal activity inventory

The following categories of elements have been used to estimate metal quantities in each activity category for the Oskarshamn site:

- Mechanical and Piping Systems, that includes all plant process fluid systems, with its associated equipment, piping, valves and accessories.
- Structural and Various Steel, including handling equipment, cranes, liners, supports and miscellaneous steel.
- Air Treatment Systems including its associated ducts, equipment, dampers and accessories.
- Electrical Equipment and Cabling, including cables, cable trays and conduits, as well as all electrical and I&C significant equipment.

These categories have been defined in this way to reflect the structure of the used databases and to facilitate the comparison with other similar studies.

Plant areas

In this section the plant buildings are divided into different areas[4].

Oskarshamn 1:
Area RI – Reactor Containment.

Area R – Reactor Building.

Area B – Turbine Building.

Area OK – Buildings in uncontrolled area (E – auxiliary control building, M – office building and electric control building, R. – sea water cleaning building and T – new electric control building).

Note that building V – active workshop is included under area R.

Oskarshamn 0:
Area K[5] – buildings in controlled area (AVF – waste management building, CSV – central service workshop and HLA – waste management building for low active waste).

Area OK – For buildings included in this area, see Section 4.1.

Oskarshamn 2:
Area RI Reactor Containment.

Area R Reactor Building.

Area D Turbine Building.

Area K[2] Remaining rooms in controlled area (mainly in building Y and V).

Area OK Rooms in uncontrolled area incl. Yard (mainly in building E, F and N).

Oskarshamn 3:
Area A – Reactor containment.

Area B – Reactor building.

Area D – Turbine building.

Area K[2] – Remaining rooms in controlled area (mainly in buildings F, L, N, Q and Z).

Area OK – Rooms in uncontrolled area incl. yard (mainly in buildings E, H, J, K, M, P, R, S, T, U, X and yard).

4.3.5.1 Mechanical and piping systems activity inventory

The activity inventories presented in this subsection correspond to the fluid processing systems of the three units in Oskarshamn.

4.3.5.2 Reactor pressure vessels and internals

Table 4-19, Table 4-20 and Table 4-21 presents the summary of the activity inventory for the Reactor Pressure Vessels (RPV); RPV Insulation and the internals for each unit. The weight of the active reactor pressure vessel insulation in the containment as well as specific and total activity is obtained from Jonasson (2012a, b, c) respectively.

The internals are the most radioactive components of the plant and have a significantly higher radioactivity by comparison with the reactor pressure vessel. The activity of the internals close to the core, e.g. the core grid and the core shroud mainly originates from neutron induced activity. Further away from the core, the activity of the internals predominantly originates from surface contamination.

[4] The areas used here are defined specific for this study. The area designations should not be mixed up with building designation letters.

[5] Area K should not be mixed up with the diesel buildings.

Table 4-19. O1 – RPV insulation and internals activity inventory.

Activity Category Bq/kg		O1 RPV	RPV Insulation	Internals	Total
> 10^6	Weight, tonne	414		126	540
	Total activity, Bq	9.2E+12		8.0E+15	8.0E+15
10^4–10^6	Weight, tonne		5		5
	Total activity, Bq		5.1E+08		5.1E+08
500–10^4	Weight, tonne				
	Total activity, Bq				
< 500	Weight, tonne				
	Total activity, Bq				
–	Weight, tonne				
	Total activity, Bq				
Total	Weight, tonne	414	5	126	545
	Total activity, Bq	9.2E+12	5.1E+08	8.0E+15	8.0E+15

Table 4-20. O2 – RPV insulation and internals activity inventory.

Activity Category Bq/kg		O2 RPV	RPV Insulation	Internals	Total
> 10^6	Weight, tonne	530	3	124	657
	Total activity, Bq	2.5E+13	6.2E+09	1.4E+16	1.4E+16
10^4–10^6	Weight, tonne				
	Total activity, Bq				
500–10^4	Weight, tonne				
	Total activity, Bq				
< 500	Weight, tonne				
	Total activity, Bq				
–	Weight, tonne				
	Total activity, Bq				
Total	Weight, tonne	530	3	124	657
	Total activity, Bq	2.5E+13	6.2E+09	1.4E+16	1.4E+16

Table 4-21. O3 – RPV insulation and internals activity inventory.

Activity Category Bq/kg		O3 RPV	RPV Insulation	Internals	Total
> 10^6	Weight, tonne	760	6	368	1,134
	Total activity, Bq	9.0E+12	1.8E+11	5.5E+16	5.5E+16
10^4–10^6	Weight, tonne				
	Total activity, Bq				
500–10^4	Weight, tonne				
	Total activity, Bq				
< 500	Weight, tonne		14		14
	Total activity, Bq				
–	Weight, tonne				
	Total activity, Bq				
Total	Weight, tonne	760	20	368	1,148
	Total activity, Bq	9.0E+12	1.8E+11	5.5E+16	5.5E+16

4.3.5.3 Plant metal activity summary

The following categories have been included in the plant metal activity summary: mechanical and piping systems, structural and various steel, air treatment systems, electrical equipment and cabling. A summary of the plant metal activity inventory for O1, O2 and O3 respectively is presented in Table 4-22, Table 4-23 and Table 4-24.

Table 4-22. O0 and O1 – Metal activity inventory.

Activity Category		O0			O1				
Bq/kg		K	OK	Total	RI	R	B	OK	Total
> 10^6	Weight, tonne				729	59	13		802
	Total activity, Bq				8.0E+15	9.2E+11	4.5E+10		8.0E+15
10^4–10^6	Weight, tonne	7		7	106	178	198		482
	Total activity, Bq	4.9E+08		4.9E+08	2.7E+10	4.6E+10	5.2E+10		1.2E+11
500–10^4	Weight, tonne	187		187	2	5	752		759
	Total activity, Bq	3.7E+08		3.7E+08	1.5E+07	2.1E+07	1.6E+09		1.6E+09
< 500	Weight, tonne	752		752	298	1,055	3,345		4,698
	Total activity, Bq								
–	Weight, tonne		2,206	2,206				1,863	1,863
	Total activity, Bq								
Total	Weight, tonne	947	2,206	3,153	1,135	1,297	4,308	1,863	8,603
	Total activity, Bq	8.6E+08		8.6E+08	8.0E+15	9.7E+11	9.8E+10		8.0E+15

Table 4-23. O2 – Metal activity inventory.

Activity Category		O2					
Bq/kg		RI	R	D	K	OK	Total
> 10^6	Weight, tonne	788	165	88	2		1,043
	Total activity, Bq	1.9E+16	2.2E+13	9.7E+10	6.0E+10		1.9E+16
10^4–10^6	Weight, tonne	60	155	1,031	2		1,248
	Total activity, Bq	2.7E+10	6.7E+10	1.9E+11	5.8E+08		2.8E+11
500–10^4	Weight, tonne	51	58	60			170
	Total activity, Bq	4.4E+08	3.8E+08	5.1E+07			8.7E+08
< 500	Weight, tonne	797	4,769	5,108	771		11,446
	Total activity, Bq						
–	Weight, tonne					2,338	2,338
	Total activity, Bq						
Total	Weight, tonne	1,697	5,148	6,287	775	2,338	16,244
	Total activity, Bq	1.9E+16	2.2E+13	2.9E+11	6.0E+10		1.9E+16

Table 4-24. O3 – Metal activity inventory.

Activity Category		O3					
Bq/kg		A	B	D	K	OK	Total
> 10^6	Weight, tonne	1,226	349	279	13		1,867
	Total activity, Bq	5.5E+16	1.3E+13	5.9E+12	7.7E+12		5.5E+16
10^4–10^6	Weight, tonne	113	154	2,400	99		2,756
	Total activity, Bq	1.1E+02	5.7E+10	1.2E+12	2.3E+10		1.3E+12
500–10^4	Weight, tonne	2	2		244		248
	Total activity, Bq	9.49E+06	9.49E+06		8.54E+08		8.73E+08
< 500	Weight, tonne	1,380	1,589	6,339	906		1.02E+04
	Total activity, Bq						
–	Weight, tonne					5,657	5,657
	Total activity, Bq						
Total	Weight, tonne	2,721	2,094	9,017	1,263	5,657	20,752
	Total activity, Bq	5.5E+16	1.3E+13	7.2E+12	7.7E+12		5.5E+16

4.3.6 Concrete activity inventory

The buildings of the O1, O2 and O3 plants and O0 will be demolished down to one meter below ground level and consequently this subsection will present the concrete activity inventory above this level.

The following description of the treatment of concrete structures is an assumed scenario which forms the basis of the concrete waste handling in this study. The majority of concrete building structures of the three plants are assumed to be monitored and free released before being demolished. Some of the crushed free released concrete will be used to backfill the cavities up to one meter below ground level, and the rest will be shipped off-site to landfills. The total activity is however calculated for the three plants in Jonasson (2012a, b, c).

In area RI (for O3 area A), the reactor containment, the concrete from the biological shield is distributed in different activity categories based on activity data from a drill sampling test made at Barsebäck 1.

The active concrete is concentrated to parts of the biological shield and concrete in the reactor building. As can be seen in Table 4-25, the total concrete activity for the OKG site is dominated by the activity contribution from the biological shield located in area RI/A. All concrete in the turbine building is assumed to be below the free release level.

In Table 4-26 the summary of the reinforcement activity for O0, O1, O2 and O3 is presented. The active reinforcement is located in the containment and originates from the biological shield.

4.3.7 Sand activity inventory

The sand bed of the off-gas treatment delay systems, the system 341's, contains approximately 5,151 tonnes of sand of which 757 tonnes are contaminated with noble gas daughters. The total activity inventory of the sand is approx $2.0 \cdot 10^{11}$ Bq. A summary of the sand activity is presented in Table 4-27.

Table 4-25. Concrete activity inventory for the oskarshamn site.

Activity Category Bq/kg		O0 Total	O1 Total	O2 Total	O3 Total
> 10^6	Weight, tonne	114	267	306	592
	Total activity, Bq	2.3E+10	5.1E+12	5.8E+12	7.7E+11
10^4–10^6	Weight, tonne		435	585	661
	Total activity, Bq		2.0E+11	2.5E+11	1.6E+11
500–10^4	Weight, tonne		238	238	219
	Total activity, Bq		1.2E+09	1.2E+09	6.9E+08
< 500	Weight, tonne	35,418	43,460	99,483	174,270
	Total activity, Bq				
–	Weight, tonne	41,287	37,891	34,834	127,341
	Total activity, Bq				
Total	Weight, tonne	76,819	82,291	135,445	303,084
	Total activity, Bq	2.3E+10	5.3E+12	6.1E+12	9.3E+11

Table 4-26. Reinforcement in concrete activity inventory.

Activity Category Bq/kg		O0 Total	O1 Total	O2 Total	O3 Total
> 10^6	Weight, tonne		47	47	56
	Total activity, Bq		1.5E+12	3.2E+12	6.3E+11
10^4–10^6	Weight, tonne				
	Total activity, Bq				
500–10^4	Weight, tonne				
	Total activity, Bq				
< 500	Weight, tonne	1,036	1,279	5,092	11,612
	Total activity, Bq				
–	Weight, tonne	371	1,156	392	5,380
	Total activity, Bq				
Total	Weight, tonne	1,407	2,482	5,531	17,048
	Total activity, Bq		1.5E+12	3.2E+12	6.3E+11

Table 4-27. Sand activity inventory.

Activity Category Bq/kg		O1	O2	O3
> 10^6	Weight, tonne	106	386	265
	Total activity, Bq	1.3E+11	1.4E+11	1.2E+11
10^4–10^6	Weight, tonne			
	Total activity, Bq			
500–10^4	Weight, tonne	318	1,159	2,916
	Total activity, Bq			
< 500	Weight, tonne			
	Total activity, Bq			
Total	Weight, tonne	424	1,545	3,182
	Total activity, Bq	1.3E+11	1.4E+11	1.2E+11

4.4 Waste amounts and activity categories

4.4.1 Waste containers

This chapter contains the waste volumes of metals, concrete, sand and ion exchange resins from the system decontaminations of the three reactors in Oskarshamn. No soft waste, contaminated or free release, in the form of PPE, decontamination liquids or abrasives from the decontamination of LILW is included. This is treated as an uncertainty.

As described in Section 4.3 the process equipment, concrete, sand and decontamination waste are divided into waste categories. The categorization is based on specific activity of the waste and is shown in Table 4-18.

All waste in the categories blue and white is assumed to be recycled or disposed of at a municipal deposit. In Table 4-28 the number of waste containers and their net storage volume at the repository required for all the waste from the Oskarshamn site is presented.

4.4.1.1 Process equipment waste

The process equipment waste in the red activity category (> 10^6 Bq/kg) consists of long-lived (LL) and short-lived (SL) waste. The long-lived waste mainly consists of the internals close to the core. In this study it is assumed that the long lived waste consists of the core shroud and core shroud cover including internals inside it, i.e. the core grid, parts of the control rod guide tubes, the core spray and in-core instrumentation piping. The long-lived waste is assumed to be transported and stored in 0.1 m thick steel containers (BFA-tanks) with the outer dimensions 3.30×1.30×2.30 m. The inner volume is approx. 7 m^3 and the maximum weight, including 12 tonnes of waste, is 34 tonnes. The long-lived waste is assumed to be deposited at the future final repository for long-lived LILW; SFL. The SFL repository is planned to be commissioned in 2045.

Table 4-28. Waste container data: All waste for the Oskarshamn site.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFL	335	34	BFA-tank	Red (LL)	3.30×2.30×1.30
SFR	2,356	341	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	36	21	Steel Box	Red (SL)	1.20×1.20×1.20
SFR	12	7	Steel Box	Yellow & Green	1.20×1.20×1.20
SFR	11,423	580	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Recycling	197,757	10,041	ISO-type Container	Blue & White	6.06×2.50×1.30

The short-lived waste in the red activity category (> 10^6 Bq/kg) is assumed to be transported and stored in 5 mm thick steel containers (large steel boxes) with the outer dimensions 2.40×2.40×1.20 m and the maximum total weight 20 tonnes. This is an enlarged version of the 1.20×1.20×1.20 m steel container, and the maximum total weight is assumed to be 20 tonnes based on the limitation of today's lifting devices at the final repository. The short-lived waste is assumed to be transported in shielded transport containers and stored at the final repository for short-lived LILW; SFR.

When calculating the number of waste containers needed for process equipment waste in the red activity category, not including the internals, a packing degree of 1.1 tonne/m^3 is used. This packing degree estimation is based on amongst others Spanish experiences, e.g. ENRESA assumed a packing degree of 1.1 tonne/m^3 for metal scrap waste in steel containers with the outer dimensions 1.74×0.87×0.87 m.

Experience from internals replacement at Oskarshamn indicates that the packing degree of internals in 3.30×2.30×1.30 m steel containers is lower than 1.1 tonne/m^3. For the packing of internals, experience data and calculations from previous Westinghouse segmentation projects have been used. A packing degree of 0.4–1.1 tonne/m^3 is assumed depending on which internal is being segmented.

The largest quantity of the process equipment waste can be found in the less radioactive categories: yellow (10^4–10^6 Bq/kg), green (500–10^4 Bq/kg), blue (< 500 Bq/kg) and white (non-active). The process equipment waste in the yellow and green categories is assumed to be transported and deposited at the SFR repository whilst the waste in the blue and white category is assumed to be transported to an appropriate disposal or recycling facility. The waste containers to be used for this kind of waste are assumed to be 20 ft half height ISO-type containers with top opening and outside measurements 6.06×2.50×1.30 m. The inner volume of these containers is approx. 15 m^3 and the total weight is limited to 20 tonnes. When calculating the number of waste containers needed for this low activity process equipment waste, the packing degree 1.1 tonne/m^3 is used. Assuming a packing degree of 1.1 tonne/m^3 and the use of 20 ft half height containers results in better volume utilization than if 20 ft full height containers are used. This is due to the limitation in total weight. Even though the use of 10 ft full height ISO containers would result in the same volume utilization as the 20 ft half height containers, the 20 ft half height versions are preferred. Most of the 10 ft full height containers are constructed for single storage purposes and do not have the same strength as 20 ft containers. Most of the low activity waste at the existing final repository for radioactive operational waste, SFR, is stored in 20 ft half height ISO-type containers. The supply of used 20 ft half height ISO containers is today rather limited and will be even more limited in the future. The cost estimate in Chapter 6 will therefore presuppose that brand new 20 ft half height containers with top opening will be used.

The waste which is free released is assumed to preferably be taken care of by a metal recycling company and the container to be used depends on what that company finds most appropriate. To get a clear overview of the FRW quantity it is here assumed that the 20 ft half height container is used for FRW as well. When calculating the number of waste containers needed for FRW process equipment the packing degree 1.1 tonne/m^3 is used.

In Table 4-29 the number of waste containers and their net storage volume at the repository required for process equipment waste is presented.

Table 4-29. Waste container data: Process equipment waste for the OKG site.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFL	335	34	BFA-tank	Red (LL)	3.30×2.30×1.30
SFR	1,687	244	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	7,543	383	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Recycling	73,718	3,743	ISO-type Container	Blue & White	6.06×2.50×1.30

The plant systems are divided into identities according to Jonasson (2012a, b, c). Each identity is connected to a nuclide vector, presented in Appendix 2.4. The vectors are normalized against a reference nuclide, specified for each vector. The vectors do therefore not correspond to the activity of each nuclide. To get the activity of each specific nuclide for an identity, the vector should be multiplied with the activity of the normalised nuclide. The normalisation of the nuclide vectors is done so that the information can be presented in a neat and manageable way, without the need to present different vectors for each identity.

The activity has been calculated presuming the operational time of the three units in OKG to be 60 years, with a decay time of four years for O1 and one year for O2 and O3 from shutdown. The reference date for the activity calculations is 2036-01-01 for O1 and O2 (Jonasson 2012a, b), and 2046-01-01 for O3 (Jonasson 2012c).

The mean specific activity of the waste from each identity is presented in Appendix 2.1.

4.4.1.2 Concrete waste

The concrete waste in the red activity category (> 10^6 Bq/kg) originates from parts of the biological shield close to the core (Ericsson 2005). This waste is considered to be short-lived and presumed to be transported and stored in a 5 mm thick steel container with the outer dimensions 2.40×2.40×1.20 m. The biological shield is assumed to be sawed in blocks to be fitted into the waste containers. The fit will not be perfect and the total packing degree of the concrete waste from the biological shield is assumed to be the same as for crushed concrete i.e. approx. 1.5 tonne/m^3 (Ericsson 2005). The 2.40×2.40×1.20 m waste containers will be transported to the final repository in shielded transport containers.

The concrete waste in the yellow (10^4–10^6 Bq/kg) and green (500–10^4 Bq/kg) activity categories consists of material from the outer parts of the biological shield and of contaminated concrete from the controlled areas of the plant. The container for this kind of waste is assumed to be 20 ft half height ISO-type containers with top opening and an inner volume of 15 m^3. The waste material will most likely be in the form of crushed concrete and a packing degree of approx. 1.5 tonne/m^3 is assumed (Ericsson 2005). When calculating the number of containers the maximum load constraint of 18 tonne/container results in a utilization of 80% of the volume in the ISO-type containers.

The number of concrete waste containers and their net storage volume at the repository is presented in Table 4-30 and Table 4-31, Table 4-32, Table 4-33 and Table 4-34.

The most part of the concrete waste is non-active concrete originating from building structures found both at controlled and at uncontrolled areas. The total amount of this free released waste from the OKG site is approx. 594,000 tonnes of which approx. 485,000 tonnes is supposed to be used for landfill on site, i.e. filling of building levels one meter below ground, and culverts (Ericsson 2005). The resulting amount to be transported from the site is therefore approx. 109,000 tonnes. In O0 there is room for about 185,000 tonnes of more concrete, which could be used for all concrete if there is a possibility for interim storage of the concrete from O1, O2 and O3. In Table 4-31, Table 4-32, Table 4-33 and Table 4-34 the waste activity, category and weight data for each identity is given for the concrete waste.

Table 4-30. Waste container data: Concrete waste for the OKG site.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	567	82	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	3,151	160	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	119,194	6,052	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 4-31. Waste activity data: Concrete waste for O1.

Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
R.1	1	Co-60	1.1E+11	267.2	1.9E+07	Large Steel Box	26,7	Red (SL)
R.1	1	Co-60	4.2E+09	504.7	3.7E+05	ISO-type Container	28,0	Yellow & Green
R.2	2	Co-60	4.3E+09	167.9	4.8E+04	ISO-type Container	9,3	Yellow & Green

Table 4-32. Waste activity data: Concrete waste for O0.

Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
D.1	3	Co-60	1.2E+10	101.2	2.2E+05	ISO-type Container	5,6	Yellow & Green
V.1	3	Co-60	4.8E+08	12.7	7.3E+04	ISO-type Container	0,7	Yellow & Green

Table 4-33. Waste activity data: Concrete waste for O2.

Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
R.1	1	Co-60	1.5E+11	305.7	1.9E+07	Large Steel Box	30,5	Red(SL)
R.1	1	Co-60	6.3E+09	577.4	4.1E+05	ISO-type Container	32,1	Yellow & Green
R.2	2	Co-60	6.4E+09	245.0	5.0E+04	ISO-type Container	13,6	Yellow & Green

Table 4-34. Waste activity data: Concrete waste for O3.

No	Identity	Nuclide Vector	Normalized Against	Activity of Normalized Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	R.1	1	Co-60	2.0E+10	240.3	3.1E+06	Large Steel Box	24,0	Red (SL)
3	R.3	3	Co-60	1.3E+10	352.1	8.4E+04	ISO-type Container	19,6	Yellow & Green
2	R.1	1	Co-60	2.9E+09	641.7	1.7E+05	ISO-type Container	35,6	Yellow & Green
4	D.1	4	Co-60	2.4E+10	212.2	2.5E+05	ISO-type Container	11,8	Yellow & Green
5	V.1	4	Co-60	1,0E+09	26,5	8,4E+04	ISO-type Container	1,5	Yellow & Green

4.4.1.3 Sand waste

The sand bed of the off-gas treatment delay systems, contains approx. 5,150 tonnes of sand, out of which 757 tonnes is contaminated with noble gas daughters. The sand waste has an estimated average specific activity of $1.2 \cdot 10^6$ Bq/kg in O1 and therefore belongs to the red category (>10^6 Bq/kg) for O2 the average specific activity is $3.6 \cdot 10^5$ Bq/kg and for O3 the average specific activity is $4.5 \cdot 10^5$ Bq/kg ,thus they belong to the yellow activity category (10^4–10^6 Bq/kg). The activity predominantly originates from short-lived nuclides (Lundgren 2012), and it is assumed that the waste containers to be used are the 6.06×2.50×1.30 m 20 ft half height ISO-type containers. The containers will only be filled to approx. 70% due to the high density of sand and not to exceed the maximum weight capacity of the container. The active sand waste will be deposited at SFR. Each container is assumed to be loaded with 18 tonnes of sand, and the number of waste containers and their net storage volume for the sand waste are presented in Table 4-35.

Table 4-35. Waste container data: Sand waste from the off-gas treatment delay systems.

Suggested disposal facility	Net storage volume (m3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	102	15	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	729	37	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	4,845	246	ISO-type Container	Blue & White	6.06×2.50×1.30

In Table 4-36, Table 4-37 and Table 4-38 the waste activity, category and weight data for each specific identity is given for the sand waste.

Table 4-36. Waste activity data: Sand waste from the off-gas treatment delay system in O1.

Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
341.2	14	Cs-137	1.2E+11	106.1	1.2E+06	Large Steel Box	14.8	Red (SL)

Table 4-37. Waste activity data: Sand waste from the off-gas treatment delay system in O2.

Identity	Nuclide Vector	Normalized Against	Activity of Normalized Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
341.2	13	Co-60	1.2E+11	386.3	3.6E+05	ISO-type Container	22.0	Yellow & Green

Table 4-38. Waste activity data: Sand waste from the off-gas treatment delay system in O3.

Identity	Nuclide Vector	Normalized Against	Activity of Normalized Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
341.2	12	Cs-137	1.2E+11	265.1	4.5E+05	ISO-type Container	14.7	Yellow & Green

4.4.1.4 Decontamination waste

As described in previous sections, some systems will be decontaminated prior to decommissioning. A decontamination factor of 10 has been used in this study, which most likely is conservatively assumed. Based on experience from Oskarshamn and Barsebäck decontamination campaigns regarding the spent volume of ion exchange resins, the number of waste containers is set to 7. The waste that will have to be sent to final storage from the decontamination process will be in the form of ion exchange resins.

The decontamination waste will be in the red activity category except for in O0 where it will fall in the yellow category and is considered to be short-lived. It is presumed to be transported in 5 mm thick steel containers with the outer dimensions 1.20×1.20×1.20 m. The ion exchange resins will be mixed with liquid concrete in the steel containers. The mix will have equal parts of concrete and ion exchange resins, and the density of the concrete is assumed to be 2.4 tonne/m^3.

The number of decontamination waste containers and their net storage volume at the repository is presented in Table 4-39.

In Appendix 2.2 the waste activity, category and weight data for each specific identity is given for the decontamination waste.

Table 4-39. Waste container data: Decontamination waste for the OKG site.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	36	21	Steel Box	Red (SL)	1.20×1.20×1.20
SFR	12	7	Steel Box	Yellow & Green	1.20×1.20×1.20

4.4.2 Optional treatments

4.4.2.1 Waste containers at maximum weight load capacity

For the process equipment waste, a packing degree of 1.1 tonne/m^3 has been assumed. If the packing degrees would be disregarded and the maximum weight load capacities for the different waste containers would be used, the number of waste containers would decrease significantly. This could be achieved through e.g. better size reduction on site and better packing of the waste. The maximum weight load capacities for the different waste containers are:

- BFA-tank: 12 tonne/container
- Large Steel Box: 19 tonne/container
- ISO-type Container: 18 tonne/container

This does not concern the sand waste, the decontamination waste or the concrete waste stored in ISO-type containers since that waste is already packed at the maximum weight load capacity.

The number of waste containers and their net storage volume at the repository required for process equipment waste at the maximum container weight load capacity is presented in Table 4-40.

The process equipment waste activity, category and weight data for each identity at a maximum container load capacity is given in Appendix 2.3.

The number of waste containers and their net storage volume at the repository required for concrete waste at the maximum container weight load capacity is presented in Table 4-41.

The concrete waste activity, category and weight data for each identity at maximum container load capacity is given in Table 4-42, Table 4-43, Table 4-44 and Table 4-45.

Table 4-40. Waste container data: Process equipment waste for the OKG site at maximum load capacity.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFL	178	18	BFA-tank	Red (LL)	3.30×2.30×1.30
SFR	484	70	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	6,933	352	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Recycling	73,837	3,431	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 4-41. Waste container data: Concrete waste for the OKG site at maximum load capacity.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	449	65	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	2,757	140	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	119,194	6,052	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 4-42. Waste container data: Concrete waste for O1 at maximum load capacity.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	104	15	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	748	38	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	26,569	1,349	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 4-43. Waste container data: Concrete waste for O0 at maximum load capacity.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	0	0	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	138	7	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	0	0	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 4-44. Waste container data: Concrete waste for O2 at maximum load capacity.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	"Waste category"	Outside measurements (m)
SFR	118	17	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	906	46	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	71,631	3,637	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 4-45. Waste container data: Concrete waste for O3 at maximum load capacity.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	228	33	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	965	49	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	20,995	1,066	ISO-type Container	Blue & White	6.06×2.50×1.30

4.4.2.2 Process Equipment Size Reduction Off-Site

As described in Chapter 3, process equipment waste may be size reduced off-site through e.g. melting. The alternative of size reduction off-site is throughout the study taken as an example of an alternative treatment of some of the process waste. In the cost calculations of Chapter 6 this alternative is presented in parenthesis, and not as the main alternative.

Studsvik is taken as an example of a certified company that performs melting of radioactive waste. For Studsvik to be able to handle scrap or components for direct treatment there is a surface dose rate limit of < 0.2 mSv/h and a specific activity limit of approximately $< 5\times10^5$ Bq/kg.

The process equipment waste from the OKG site in the yellow and green category that fulfills these criteria weighs 4,637 tonnes and equals 282 ISO-type containers. The total activity in the waste is 5.8×10^{11} Bq.

Assuming a 75% weight reduction, 25% of the melt will contain all the activity and will need to be sent to SFR. The density of the melt metal is so high that it is assumed that the maximum weight capacity of the container, 18 tonnes, is reached. This equals 1,159 tonnes of waste, or 65 ISO-type containers, with a specific activity of 5.0×10^5 Bq/kg.

5 Decommissioning programme for the Oskarshamn site

5.1 Introduction

This chapter presents a general decommissioning programme for the Oskarshamn site. The aim has been to cover all of the important phases of the decommissioning programme, from planning to site restoration. This has been done with input from the OKG decommissioning strategies (Olsson 2005). The entire nuclear site has been studied, but with a stronger emphasis on the structures on the site that contain radioactive parts.

The decommissioning programme has been developed in sufficient detail to give a good understanding of the varying activities that need to be performed and provides a good basis for a more detailed planning for site-specific decommissioning project. Also, the level of detail has been set in order to give a sufficient basis for the cost estimation, presented in Chapter 6.

The programme will cover the whole decommissioning time span from shutdown of power production (including the initial planning that is done the last five years of power operation) to hand-over of the cleared and decontaminated site for other industrial purposes. The programme will be limited to activities that the plant owner is responsible for and that are related to the decommissioning. Consequently, activities related to plant operation and maintenance before start of the dismantling (i.e. during the defueling period) are excluded. These activities are presented in detail in a separate study (Pålsson et al. 2003).

Activities after the radiological declassification of the plants, i.e. non-radioactive building demolition and restoration of the ground to a state adapted to the further use of the site, can be regarded as a sole interest of the site owner, not necessarily to be covered by mutual funds, and are therefore included but presented separately.

The project organization is formed during the last 1.5 years of power production for O1. The defueling periods starts after shutdown of each power plant and this phase proceeds for about one year. All preparatory work is assumed to take place during the defueling period.

5.2 Conditions and assumptions

A number of conditions and assumptions have influence on the decommissioning programme. These are as follows:

- The O1, O2 and O3 power plant will be shut down year 2032, 2035 and 2045 (after 60 years of operation).
- The site will be operated by the owner (licensee) with a staff adapted to the prevailing activities.
- Decommissioning work will be executed as one project with project management and administration.
- The site owner has the overall responsibility for the relations with the authorities and the public.
- Planning, EIA work[6] etc for the decommissioning of the site commences 5 years before the planned shutdown date of O1. This is part of a refined plan of the decommissioning plan that all power plants in Sweden are required to be in possession of.
- The administration building will be used for office spaces for the project as long as possible during the decommissioning period.

[6] Environmental Impact Assessment

- An adaptation of the buildings will take place in order to house waste and packaging facilities.
- There will be a building for free releasing of waste.
- The site shall be restored to a level suitable for other industrial enterprises i.e. the buildings shall be demolished to 1 meter below ground level and all buildings below ground shall be filled with crushed non-active concrete.
- Sufficient manpower, commercial equipment and materials are assumed to be available on demand.
- Landfill for very low-level radioactive waste is assumed to be available.

5.3 General basis of the decommissioning programme

The construction of the decommissioning programme has been based on a high-level optimization of the time schedule. The objective of this optimization was to create a time schedule that is reasonably short without the need for extraordinary measures during the decommissioning work. The time schedule is based on the amount of work that has to be executed and the number of teams that can be in a building at the same time. The decommissioning sequences have been planned in a way that is logical.

With the above principle and the prerequisites according to Section 5.2, a high-level sequence has been structured for the decommissioning programme; see Figure 5-1 for a schematic outline. For the detailed planning of the decommissioning sequence, other factors like ALARA considerations, for example removal of the radioactive parts first in order to lower the dose or the opposite in order not to contaminate non-radioactive installations, will also matter. This issue has been considered for the removal of large components but would also need to be considered at a much lower level during detailed planning.

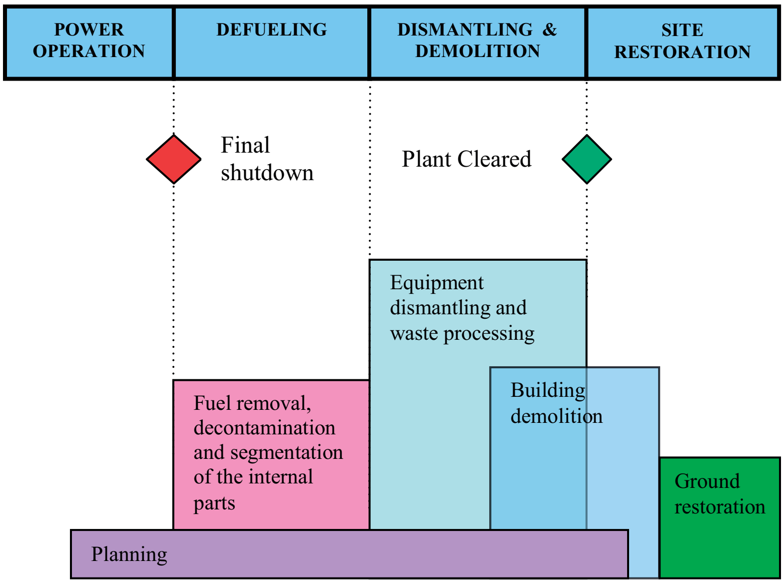

***Figure 5-1.** Schematic outline of the decommissioning phases.*

The high-level sequence is defined by four time periods describing the plant's operational mode over time:

- **Power operation**
  The normal operating cycle, generation of electricity together with regular outages, which continues until the final shutdown of the plant.
- **Defueling**
  The period between final shutdown of the plant until the last fuel element has been removed from site. All preparatory work is assumed to take place during this period. Dismantling and segmentation of reactor internals, decontamination of the reactor vessel and some systems start during this phase.
- **Dismantling**
  The period from when the dismantling has started in a greater extent until the site is "cleared". The following conditions would define the interface between the defueling operation and dismantling operation periods. In this study some of the dismantling activities have been optimized:
  – The project organization for managing dismantling activities is established.
  – The most significant dismantling packages are purchased.
  – Investments in equipment for treatment and measuring of dismantling waste are prepared.
  – Necessary plant documentation is identified and arranged in a specific decommissioning archive.
  – A computer system that handles the outage labeling and flows of the decommissioning waste is put in place. This database reports directly to the time schedule.
  – The decommissioning plan and the environmental impact assessment are approved.
  – The radiological survey has been completed.
  – Decontamination of the reactor pressure vessels and the primary process systems has been carried out and the decontamination waste has been taken care of.
  – Individual decontamination has been carried out for selected components.
  – Operational waste from the units has been removed.
  – Nuclear fuel, control rods, neutron flux detectors and scrapped components from the pools are transported away.
  – Systems not to be utilized during the dismantling phase are drained of its medium, if necessary dried, and the waste has been taken care of.
  – Electrical equipment that is no longer needed is disconnected.
  – Equipment that are no longer needed and that can be sold are dismantled.
  – The generators are dismantled and the turbines are drained.
  – Existing systems, lifting devices etc that are needed during the dismantling phase are in proper condition and if needed rebuilt to suit the need from the dismantling operations.
  – Staff with proper competence for operation and maintenance of the plants are available.
  – Necessary permissions and approvals from the authorities have been obtained.
  – Adaptation of buildings for waste handling and storage has been completed.
  – Adaptation of air, water and electrical systems has been carried out.
  – Adaptation of transport systems and communication facilities has been performed.
  – Other service facilities are installed on site.
- **Building demolition and site remediation**
  Demolition of non-contaminated buildings and site restoration.

In order to limit the total project time there has been an ambition to put several activities in parallel. An estimation of the number of dismantling teams is based on the maximum of people that can work in the same building at the same time. Based on number of teams and the amount of work hours that will be executed, the calendar time is calculated. This means that the numbers of dismantling teams will vary during the dismantling project.

The dismantling teams will move from one building to another and the same is valid for the demolition teams, so that dismantling and demolition sequences proceed in parallel in different buildings.

The milestones in the project plan presented in this chapter are mainly identified in Pålsson and Hedin (2005). However, information in plans presented in Ericsson (2005), Enekull (2000), Farías et al. (2008) and Olsson (2005) has contributed to the specifics in the decommissioning time schedule.

5.4 Scope of decommissioning activities (WBS)

Many different criteria could be applied when establishing a Work Breakdown Structure (WBS) for a large project. The following have been considered here:

- The top level items are divided by time-depending milestones and this leads to the division into the main phases: power operation, defueling, nuclear dismantling and conventional demolition. For all phases only activities related to dismantling and demolition activities are included. This means that activities related to plant operation and maintenance before start of the dismantling (i.e. during the defueling period) are not included.
- The classification of activities that has been used in the study of dismantling operation (Pålsson and Hedin 2005) and information in the study of personnel during decommissioning operation (SKBdoc 1359832) should also be used here, as far as reasonable. This implies that the classification of costs into own personnel, operational costs, fixed costs, organizational costs and project costs will be used.
- WBS items, whose size is dependent on time, are separated from items whose size are dependent on the actual work or activities that are carried out.
- WBS items related to so-called conventional dismantling and demolition are separated. With conventional dismantling is understood all dismantling/demolition that is executed after that the particular building has been classified as non-radioactive.
- A WBS item, after break-down to the most detailed level, should be able to be clearly linked to a single item in the OECD/NEA structure.
- Similar WBS structure as for earlier studies is a benefit as it enables comparisons.
- Break-down should be done to a level that enables existing data in the form of inventory lists etc to be used with reasonable additional efforts for data separation per building or similar.
- The basis for each item should be traceable.

It is assumed that the plant owner has their own staff for operation of the site during the dismantling phase. The project organization is established early in the process. This organization will purchase all services needed, mainly through larger contractors.

Items connected to transport and disposal of radioactive waste, until the waste is packed and transported outside the waste facility, are included in the WBS. However, these WBS elements are covered by this study's time schedule on a very general level.

Based on the above mentioned criteria, a WBS has been established, see Appendix 3.1. The time schedule presented in Appendix 3.2 is structured according to this WBS.

5.5 Duration of the decommissioning activities

The WBS is presented in detail in the programme attached in Appendix 3.2.

The detailed dismantling sequence, along with some preparatory activities, for mainly the reactor and turbine buildings, is described in Chapter 3.

An important aspect of the time schedule preparation is to define a proper duration for each activity. As mentioned in Chapter 3, the critical path of the project is concentrated along the segmentation and dismantling activities in the reactor building and containment. Thus, it is most important to find realistic values for how long these activities need to be.

The duration for the reactor internals segmentation have mainly been based on experience from the Westinghouse Group decommissioning projects. For less critical dismantling activities, like removal of ordinary sized process equipment (pumps, tanks, valves, pipes etc), a specific model has been used. This model was established during the process system dismantling study (Lönnerberg 1994) and is mainly based on a combination of theoretical analysis and field experience, mostly from dismantling of equipment during repair work. The model relates the activity duration to a specific feature of the particular equipment, like length and diameter for pipe systems, number of units for small pumps etc. This is a fairly reliable and very practical way of dealing with the voluminous but less complex parts of the dismantling sequences. In addition, the model is used to calculate the corresponding work and, in that connection, the cost. More details about the model are given in Chapter 6.

An important factor is that only a certain number of people can work at the same time in a specific building and that more people means more administration and co-ordination effort in order to maintain the efficiency for the site work. Increased number of people working in the controlled area could also result in increased cross-contamination. Another factor to be considered is the limited capacity of lifts and overhead cranes which could result in increased waiting time.

The duration for demolition of the buildings is based on experiences from large scale demolition of conventional (non-nuclear) concrete buildings, e.g. grain silo complex. This is described in Ericsson (2005).

A normal working time of 8 hours per day, 5 days a week, has been foreseen. In addition, four weeks in July and two weeks in connection with Christmas are designated as non-working time for most activities and resources. The exceptions are segmentation of the internals as well as the removal of the reactor pressure vessel as a whole piece, where 5 working days a week year-round has been expected. Furthermore, a working time of 16 hours a day has been assumed during the segmentation activities of the internals and during the operation of the waste system. The waste system is however operated with 6 weeks of non-working time per year as described above.

5.6 Characteristics of the time schedule for Oskarshamn site

The time schedule for the decommissioning of O1, O2, O3 and Unit 0 is presented in Appendix 3.2. This section gives a broad description of its content, see Figure 5-2 for the decommissioning phases for the Oskarshamn site. The bars in the schedule indicate the time periods when the main parts of the activities are carried out.

In this study, the buildings belonging to Unit 0 have been divided into three groups to optimize the time schedule. Group 1 consists of buildings that have no function after the shutdown of the last power plant. This group will be dismantled after the shutdown of O3 and therefore the first milestone in the time schedule is O3 plant shutdown, which is planned to occur in year 2045 (Olsson 2005). Group 2 consists of buildings having high importance during the dismantling and demolishing of the power plants (Olsson 2005). This group will be dismantled after the nuclear dismantling and demolition of O3, which occurs in the year 2049. The last group, Group 3, contains buildings that will not be demolished according to OKG. The grouping is presented in Table 5-1.

The power operations in the schedule for Group 1 and Group 2 refer to the periods when the buildings are in use. No preparatory activities are needed in Group 1 since the group does not consist of any active buildings.

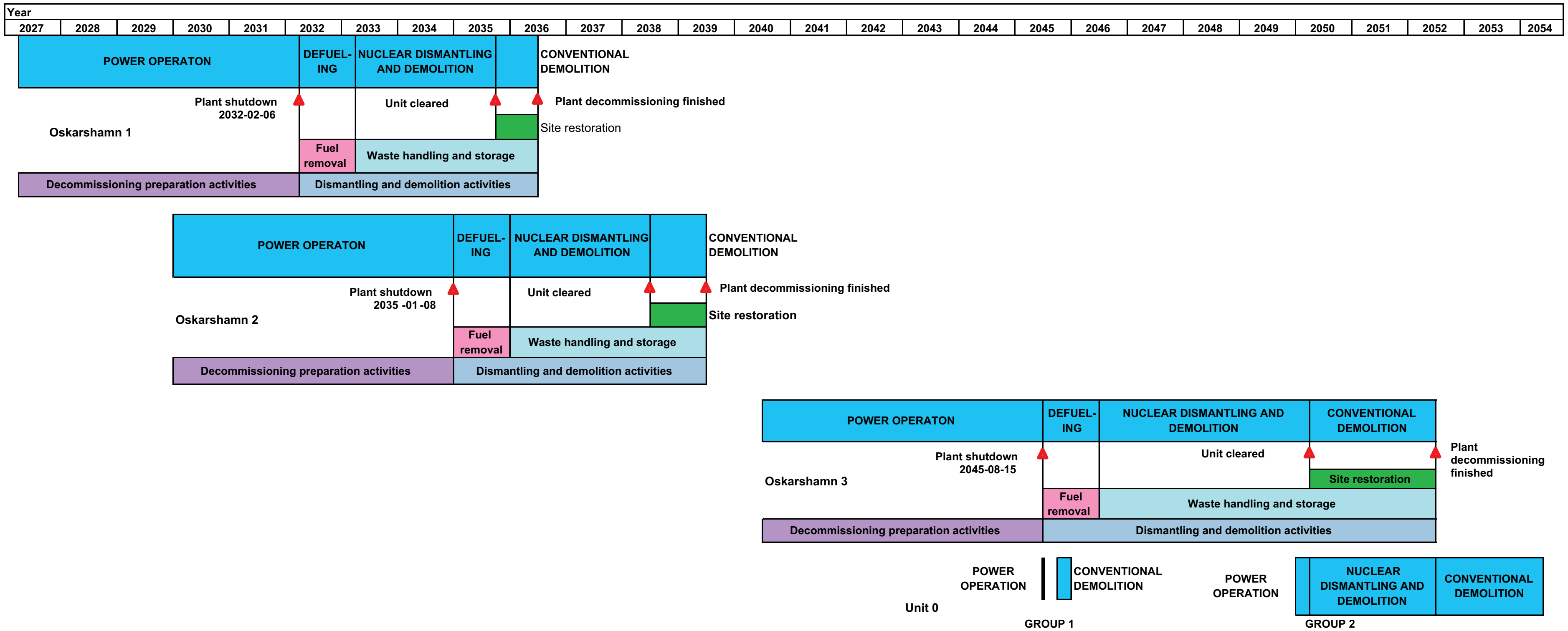

Figure 5-2. *The decommissioning phases for O1, O2, O3 and Unit 0.*

Table 5-1. Grouping of the buildings belonging to Unit 0.

Group 1	Group 3
KYL – Cooling Water Inlet Building	**MLA** – Landfill for Low Active Waste
OLJ – Oil Storage and Distribution Plant	**VVK** – Distribution Plant for Tap Water and Demineralized Water
VGB – Hydrogen Gas Building	**ÖVB8** – Petersburg
SIM – Simulator Building	**ÖVB9** – Hamburg
SKY – Shelter (O1/O2 and O3)	
ÖVB3 – Service Building	
Group 2	
AVF – Waste Management Building	**BLM** – Blasting Station
HLA – Waste Management Building for Low Active Waste	**KST** – Distributing Sub-station
CSV – Central Service Workshop	**MET** – Meteorology Mast and House
CMV– Central Mechanical Workshop	**KLV** – Culvert between CLAB -O1/O2 -O3 (the part between CLAB and VVK is not demolished)
BFA – Rock Cavern for Active Waste	**KYB** – Power Outer Load
FVB – Storage Buildings	**SÖR** – Staff Accommodation
NVO – Tap Water Plant	**SVP** – Simpevarp's Main Switchgear
RES – Restaurant	**TX** – Transformer Booth
SAN – Sanitary Sewage Treatment Plant	**ÖVB1** – Fire Drill Plant
UBH – Education Buildings	**ÖVB2** – Winter Sand Box
BYN –Staff Accommodation, etc	**ÖVB4** – Inactive Scrap Yard at MLA
GRD – Fire Station etc	**ÖVB10** – Environment Station
BVB – Security Central	**ÖVB11** – Fishing Laboratory

The first milestone in the time schedule is plant shutdown, which is planned to occur in 2032 for O1 (Olsson 2005), assuming in total 60 years of plant operation. The bars in the time schedule indicate the time periods when the main parts of the activities, respectively, are carried out.

During the power operation the decommissioning activities are mainly limited to information gathering, planning, preliminary EIA work and some preparatory activities.

The expected total duration of the decommissioning programme, from O1 plant shutdown to finalized landscaping of the Oskarshamn site, is about 21 years.

6 Decommissioning cost estimate

6.1 Introduction

This chapter presents a cost estimate for decommissioning of the Oskarshamn site. The cost estimate has been done for the decommissioning program described in Chapter 5.

With the frame defined and all information generated previously, the objective of this particular task is to estimate the total dismantling costs, with the use of information from previous studies (Pålsson et al. 2003, Pålsson and Hedin 2005, Ericsson 2005, Gustafsson et al. 2006, Farías et al. 2008, Lönnerberg 1994, SKBdoc 1359832) and the Westinghouse experience from both national and international projects.

The cost estimate will cover the whole decommissioning phase from shutdown of power production (including the initial planning that starts 5 years prior to shutdown) of Oskarshamn 1 to hand-over of the cleared and decontaminated site for other industrial purposes. However, it is limited to activities the plant owner is responsible for, which are to be covered by the national decommissioning fund under the headline "Dismantling & Demolition Costs". Consequently, activities during the defueling and shutdown operation periods which are primarily aimed to keep the plant in the intended state (i.e. activities not associated to the decommissioning) and will be covered by the national decommissioning fund under the headline "Operation of Nuclear Power Plant Units after Final Shutdown", are excluded. The costs of these activities are presented in detail in a separate study (Pålsson et al. 2003).

The costs of activities after the radiological declassification of the plant, i.e. non-radioactive building demolition and restoration of the ground, can be regarded as a sole interest of the site owner, not necessarily to be covered by mutual funds, and are thus included but presented separately.

The cost estimates are presented both according to the WBS presented in Chapter 5, and according to the internationally accepted structure developed jointly between the EC, IAEA and OECD/NEA (OECD/NEA 2012). The cost estimates also include EEFs (External Economic Factors), see 6.4.2.

6.2 Conditions and assupmtions

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

- All conditions and assumptions in Chapter 3 and 5 are also valid for the cost estimation.
- The cost estimates have been based on typical Swedish rates for different staff categories.
- All equipment costs are presented on the basis of the purchase price in the country of origin converted into SEK at the prevailing rate.
- Costs have been calculated as cash costs at the cost level of 2009. No discounting of costs of future work has been done.
- The programme of work and the resulting cash flows have been compiled on the basis that cash is available on demand. No attempt has been made to smooth cash flows throughout the project.
- The potential commercial or industrial benefits obtained by future use of the site, equipment or materials and the financial benefits of the decommissioning funds are not considered.
- The costs associated with spent fuel management, and transportation and final disposal of radioactive wastes from dismantling and demolition are not included.
- Costs for fees to authorities, SSM, are not part of the study, as these are not normally covered in SKB's annual Plan reports. Instead, these are discussed separately.
- No risk element has been added to any costs identified.

6.3 Cost elements

6.3.1 General

The main cost elements in the WBS cost structure are explained in more detail in the following subsections. The utility costs presented in Pålsson et al. (2003) and Pålsson and Hedin (2005) are based on experience from defueling and shutdown operation in Barsebäck 1. The staff number in the project organisation and the plant operation organisation is based on SKBdoc 1359832.

Cost figures calculated in this study are presented without associated contingency factors. Thus, in a further analysis it is possible to apply different contingencies depending on the particular case that is being studied. There is otherwise an uncertainty that factors are applied on each other in several steps, reflecting an unjustified level of uncertainties. Suitable contingencies are however suggested in Section 6.5. Estimated (i.e. not calculated) cost figures, in particular figures based on experience, naturally include contingencies. Suitable extra contingencies are however suggested in Section 6.5.

6.3.2 Personnel rates

Each category of labour is classified according to Table 6-1. A typical Swedish rate for each category is used. While the personnel in Category M, E and P are employed by the Utility, P as a consultant, the other categories are employed by Contractors. The rates for category M and E correspond to wages including payroll tax only while the rate for the other categories should cover all costs, markups and profits associated to the work performed by the personnel employed by the Contractors.

The labour costs associated with RPV and internals removal and segmentation and the demolition of the buildings are based on special labour rates. This is described in more detail in Section 6.3.8.1 for labour costs associated with RPV and internals and in Section 6.3.10 for labour costs associated with building demolition.

6.3.3 Personnel and project costs

The final planning for decommissioning, starts 1.5 years before the shutdown of O1. The organization is presented in Figure 6-1. The personnel are adapted to keep the plant in a safe and good condition and to prepare the plant for the decommissioning.

The organization comprises the Site Manager, a Project Manager and below a subdivision in two main branches; one including the project organization and the other including the operation and maintenance personnel. The project subdivision is fully concentrated on preparing the future decommissioning work while the other has a dual role, one to operate and perform maintenance to the plant and the other to assist the Project Managers with various technical services.

The Project Manager Organization is responsible for the operating personnel and other personnel and reports directly to the Site Manager.

Table 6-1. Personnel rates.

Typical kind of labour	Rate (SEK/hr)
Utility Manager	650
Utility Engineer	350
Project Manager	1,300
Engineer	1,000
Foreman	750
HP Technician	600
Craftsman	600
Labourer	450

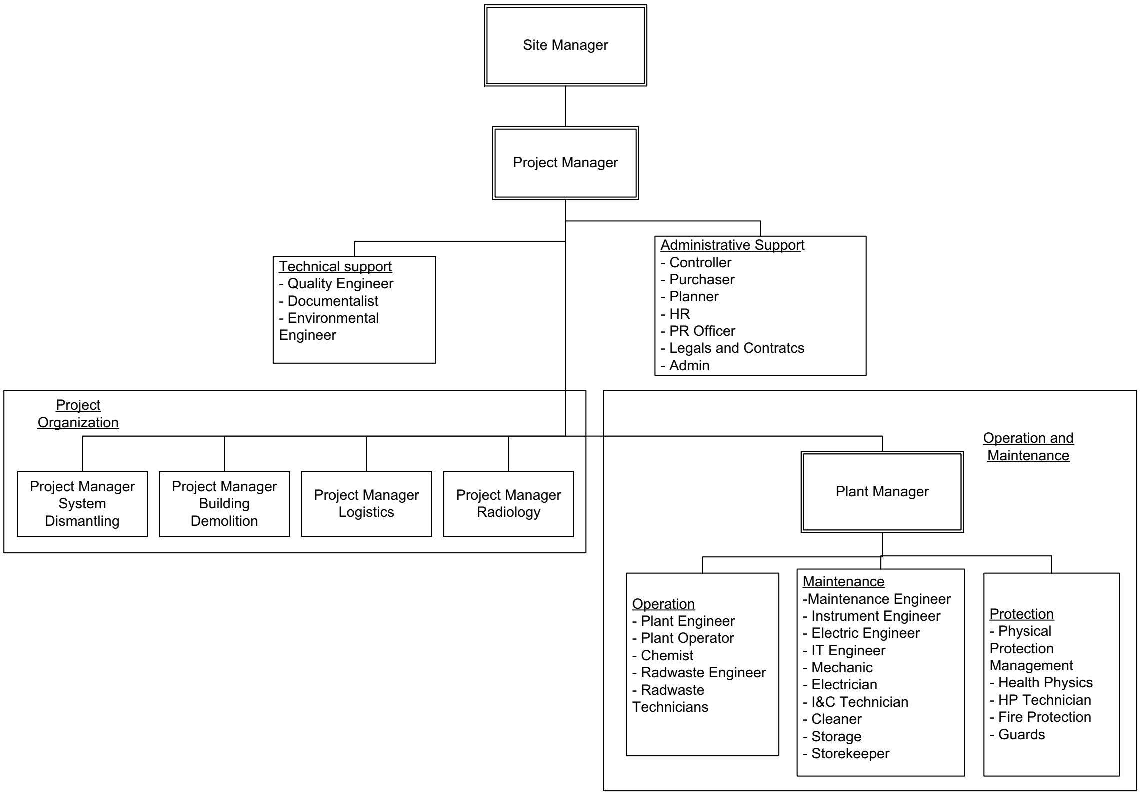

Figure 6-1. *Site Organization.*

As previously mentioned, costs which will be covered by the national decommissioning fund under the headline "Operation of Nuclear Power Plant Units after Final Shutdown" are excluded. This means that the personnel cost the defueling period, which is for the 50 positions described above, is only a part of the total utility personnel costs during this specific period.

As in the case with utility personnel costs during the defueling period, the costs during the shutdown operation period only includes a part of the total utility personnel costs.

During the nuclear dismantling period and the conventional demolition period, all utility personnel costs are to be covered by the national decommissioning fund under the headline "Dismantling & Demolition Costs".

6.3.4 Operational costs

The operational costs for the site during the power operation periods of O1, O2 and O3 respectively, the defueling periods and the shutdown operation periods, which are covered for in the present study, are limited to the costs which in Pålsson et al. (2003) are classified as decommissioning costs, i.e. decommissioning preparation work. The costs are due to operational utility personnel costs and purchase of goods, services etc.

The operational costs for the dismantling and demolition periods include utility personnel costs and all purchase of goods, services, energy etc necessary for the operation and maintenance of the plant (Pålsson and Hedin 2005).

6.3.5 Fixed costs

The fixed costs for the Oskarshamn site include fees, taxes and insurances. It is assumed that the annual fees to SSM are the same as during the shutdown operation period in Barsebäck, typically 10,500 kSEK per year. However, costs for fees to authorities are not part of the study, as these are not normally covered in the Plan reports. The costs are given in brackets and are not included in the total cost

Other fees, inspection cost or taxes are not shown in Pålsson and Hedin (2005). It is presumed that these costs are included in plant operation costs.

6.3.6 Organizational costs

Organizational costs include costs for administration (personnel administration, legal and contracts, office equipment and supplies) and data processing hardware and software (Pålsson et al. 2003, Pålsson and Hedin 2005, SKBdoc 1359832).

6.3.7 Project costs during defueling operations

During the defueling of the Oskarshamn site, the following subprojects are carried out; primary circuit decontamination including radiological inventory characterization, process auxiliary system adaptation (Pålsson et al. 2003, Pålsson and Hedin 2005) and the segmentation of internals. In addition, preparation of the EIA will continue and a number of objects will be decontaminated.

6.3.8 Nuclear dismantling and demolition

6.3.8.1 Reactor vessel and internals

The Reactor Vessel and Internals work is subdivided as shown in Table 6-2.

As described in Chapter 3 there are two ways to remove the reactor pressure vessel; by segmentation or by one-piece removal. This study only presents the cost for one-piece removal of the RPV. Finally, personnel resources and allowances have been added, based on quoted rates from a contractor specialist in the segmentation area.

In Table 6-3 the costs of personnel and services that the contractor would expect the site to provide are excluded. These costs are found in Personnel Costs (WBS 4.1.1), Operational Costs (WBS 4.1.2) and Container Costs (WBS 4.4.3). These are mainly:

- The operator for the reactor building crane.
- Personnel to handle waste containers.
- Operators for other installed plant systems such as building HVAC systems.
- Provision of the waste containers.
- Disposal of all wastes including plant items that cannot be decontaminated for release off-site.
- Decontamination of contractors equipment (where possible).
- Provision of temporary office space with normal office furniture, power, phone lines etc, and rest areas/on site "accommodation".

The corresponding costs are included in other WBS elements.

Table 6-2. WBS structure for reactor pressure vessel and internals.

4.3.1	**Reactor Vessel and Internals**
4.3.1.1	**Reactor Vessel segmentation**
4.3.1.1.1	Reactor Vessel Head removal
4.3.1.1.2	Reactor Vessel segmentation preparations
4.3.1.1.3	Reactor Vessel segmentation
4.3.1.1.4	Clean up
4.3.1.3.1	Preparation buildings
4.3.1.3.2	Reactor Vessel removal
4.3.1.3.3	Reactor Vessel removal
4.3.1.3.4	Clean up

Table 6-3. Cost of removal of the RPV and the segmentation of the internals.

WBS	Work	Cost, MSEK
4.3.1.1	**Reactor Internals**	**339**
	O1	109
	O2	107
	O3	123
4.3.1.3	**Reactor Vessel One-piece Removal**	**461**
	O1	110
	O2	147
	O3	204
Total sum		**800**

6.3.8.2 Process equipment apart from reactor pressure vessel and internals

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

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

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

To use the formulas it is necessary to have detailed information about all components and piping. From the inventory presented in Chapter 4, so-called macro-components have been defined according to Gustafsson et al. (2006). This implies that components, piping etc have been subdivided into intervals with respect to size and for each interval a characteristic quantity like length or weight is calculated. This way of dealing with data facilitates future revisions.

The work procedures, WP, used in the present study are presented in Table 6-4 and, including the composition of the corresponding work teams, in Appendix 4.1. The subdivision into macro-components and the corresponding productivity rates[7] are shown in Appendix 4.2.

The Site Factor is in the present study generally set to 3.3 for Oskarshamn 1, 3.0 for Oskarshamn 2 and 2.75 for Oskarshamn 3. This means that the duration for a certain work in the plant with a site factor of 3.0, is 3.0 times longer than if it is carried out under ideal conditions. It is an obvious fact that the Site Factor cannot be the same in all areas of the plant, hence different Site Factors have been calculated for each plant area (A, B, D, K and OK as defined in Chapter 4.3). Also within a single area the Site Factor might differ between different types of equipment. The Site Factors in this study have been differentiated based on engineering judgements made by individuals with extensive experiences from installation and dismantling work in nuclear power plants. The Site Factors are presented in Appendix 4.2**.**

The calculation of the amount of work for the Oskarshamn site has been carried out separately for each of the different plant areas (A, B, D, K and OK) at the three plants. Quantity values are collected from Chapter 4. The work has been summarized for each area. With the amount of work and the labour cost per hour, see Table 6-1, the resulting costs are calculated. In addition the average number of workers in each personnel category during the corresponding duration, which is collected from the time schedule in Chapter 5, is calculated.

[7] A productivity rate defines the number of hours a work team needs for dismantling etc one unit of equipment, piping etc. The unit could be meter, kg, number etc.

Table 6-4. Work procedures.

WP No	WP Description
1a	Preparations of work area – radiological areas
1b	Preparations of work area – non-radiological areas
2	Removal of insulation from pipes and components
3a	Dismantling of intermediate level active pipes >DN50
3b	Dismantling of low level active pipes >DN50
3c	Dismantling of pipes up to and including DN50
3d	Dismantling of valves and actuators
4	Internal transports of waste
7	Dismantling and internal transportation of large components and tanks
8	Dismantling of steel (pipe supports, gratings, ladders, beams etc)
10	Dismantling of cables and cable trays etc
11a	Dismantling of HVAC ducts
11b	Dismantling of HVAC components
13a	Pool Liner – preparations, scaffolding and lifting preparations
13b	Pool Liner – decontamination by HP-cleaning
13c	Pool Liner – cutting, dismantling and removal
14	Dismantling and transportation of cranes
15a	Dismantling and transportation of cabinets
15b	Dismantling and transportation of electrical components
16	Dismantling of turbine & generator

The project management and administration work within the process dismantling contractor's organisation has been collected from Lönnerberg (1994).

The contractor's costs for the procurement and consumption of tools during the nuclear dismantling and demolition period are based on an analysis made in Lönnerberg (1994), but in the present study the tools are conservatively assumed to have no surplus value.

6.3.8.3 Cleaning and clearance of controlled area buildings

An estimation of the work associated to the clearance survey of the buildings is made in Ericsson (2005). The estimate is based on the total internal surface area given in Chapter 4.1.4 and with the following assumptions:

- Controlled area (A, B, D, K), 100% survey for β/γ-nuclides and random check for α-nuclides. Duration 20 min/m^2.
- Uncontrolled area, equipment rooms: random (appr. 20%) survey for β/γ -nuclides. Duration 15 min/m^2.
- Uncontrolled area, offices etc: no survey.

The duration includes wipe tests and documentation of the results and with the assumptions given above the total work will be for 42,000 man-hours for O1, 84,000 man-hours for O2 and 152,500 man-hours for O3.

It is also estimated in Ericsson (2005) that ten persons will be needed per plant for other measurement and radiation protection activities during the active building demolition. In O1 and O2 this will take just over one year. For O3 it is estimated to take approximately 1.5 years. In addition, five persons will be needed for half a year (O1), one year (O2) and almost 2 years (O3), for random check of the building rubble.

As it is not separated in Ericsson (2005), the costs for the cleaning of building surfaces are included in "Demolition of Other Contaminated Concrete".

6.3.9 Waste handling and storage

The waste handling and storage costs include the following:

- Waste Management System, as described in Chapter 3.2.4.
- Off-site waste processing.
- Disposal containers suitable for SFR and SFL.
- Transport to repository and landfill.
- Repository and landfill fees.

Neither the transports to SFR or SFL, nor disposal fees for radioactive waste are part of this study, as they are presented in another position in the SKB Funding, and the corresponding costs have been set to zero.

6.3.9.1 Waste management system

It is assumed that the waste management system will not be a purpose-built building or a purpose built facility in an existing building (that means that it will not be a room or building cleared out and specifically re-equipped for waste processing before waste production starts). Instead the waste management system will make use of the existing waste treatment facilities on site, with an initial screening facility in the Turbine Building.

It will not be required to manage the most active/contaminated wastes from removal of the reactor. Neither will it be required to survey large quantities of wastes for free release (the idea being that buildings and rooms are deplanted and decontaminated of all contaminated wastes so the remaining structural material of a building plus possibly some equipment will be surveyed as clean in situ and never need to go to the facility). The waste management system will be required to stack waste material into steel boxes, but this is already an established process at the site.

All of these factors tend to work towards making the waste management system relatively cheap, and in some ways more flexible as it will consist of individual facilities working together as a complement to the existing equipment being permanently linked together as an integrated process line. According to US experience at places such as Oak Ridge, this is the best way to manage the processing of wastes that may be highly variable in size and type of material.

Based on these assumptions, the costs for purchased equipment are estimated to 19,300 kSEK and the corresponding erection costs 2,150 kSEK, for the site. The facility is conservatively assumed to have no surplus value.

As for labour requirements, it is estimated each shift will require:

- 1 × Shift Supervisor/Waste Engineer (to look after QA records, package consignment paperwork etc).
- 1–2 × Health Physics Monitor (may vary with workload).
- 2 × Technicians (operate equipment and general maintenance).
- 3–6 × General Labourers (to move raw and processed material, operate equipment as required – may vary with workload).
- 0.1 × Electrical and Mechanical Technicians for maintenance.

It is assumed in this study, as well as in Gustafsson et al. (2006), that the average capacity for the waste management system is about 10 tons per 8 hour shift, based on experience, and that two shifts per day are handling the waste. These assumptions result in a total work of approximately 114,000 man-hours during operation of the waste systems for the Oskarshamn site.

6.3.9.2 Waste containers

The costs for the waste containers are calculated from the number of containers of each category, given in Chapter 4.4, and the unit costs as specified in Table 6-5.

Table 6-5. Cost for waste containers.

Cost per Waste Container	Value	Unit
ISO-type container (6×2,5×1,3)	30	kSEK
Cubical steel box (1,2×1,2×1,2)	30	kSEK
Large steel box (2,4×2,4×1,2)	150	kSEK
BFA-tank for SFL (3,3×2,3×1,3)	700	kSEK

6.3.9.3 Transport to landfill and landfill fees

The costs for the transport to landfill and landfill fees are calculated from the amount of waste, given in Chapter 4.3, and the unit costs as specified in Table 6-6.

Table 6-6. Cost for landfill.

Cost for Landfill	Value	Unit
Landfill cost	0,75	kSEK/tonne
Transport to landfill	0,16	kSEK/tonne

The unit costs used in Ericsson (2005) are also used in the present study, presented in the cost-index of 2009, as the actual amount of waste is dominated by the building rubbles.

6.3.9.4 Off-site processing and recycling

Instead of sending all the process components and pipes to SFR, a part of the waste can be sent to a plant for size-reduction (melting), see Chapter 3.2 and 4.3. The free-released waste will be sent off-site for recycling. There are no additional costs for treatment or disposal of non-radioactive hazardous waste included. It is estimated that the costs, if any, would be covered by the value of the metal scrap. The unit costs are specified in Table 6-7.

Table 6-7. Cost of off-site processing and recycling.

Off-site processing and Recycling	Value	Unit
Recycling cost	0	kSEK/tonne
Melting cost	30	kSEK/tonne

6.3.10 Building demolition

The costs for building demolition have been investigated and reported in Ericsson (2005).

The cost calculation method is based on using simple measuring criteria, construction types and choice of demolition method with respect to, among other thing, concrete thickness, reinforcement, embedded steel and contamination penetration to calculate the demolition cost for various building elements. The calculation method is determined by the complexity of the building object. In case of thick contaminated concrete elements with strong reinforcement, the surface method[8] is used. For conventional building objects the building volume[9] is used as base for the calculation.

For buildings where both methods are used the building volume of the parts calculated with the surface method has to be subtracted from the building volume obtained from the volume method.

[8] Can also be expressed as cost per compact concrete volume.

[9] According to SS 02 10 53, based on outer building volumes.

The costs for the building demolition are (as well as in Ericsson 2005) made up from the following components:

A. Basic costs.

B. Treatment, transport and final disposal of radioactive waste. Called "Waste handling and storage".

C. Treatment, transport and final disposal of non-radioactive waste. Called "Waste handling and storage".

D. General site expenses, contractor fees.

E. Proprietor costs.

The basic costs have been derived by means of a so called production cost estimate, which implies that the costs are determined at activity level. The need for material, work and equipment is assessed for each activity and then the cost is estimated. However, relevant experience values from a project of this nature are not available. Instead, information from large conventional (non-nuclear) demolition projects has been used after appropriate adaptation. Finally, the costs related to the waste management and site expenses have not been added.

The cost category "basic costs" includes costs for the resources necessary for the primary demolition work such as:

- Equipment, such as breaking jaws, floor shavers, impact hammers and diamond wire saws. The costs include depreciation, fuel, consumables, maintenance and repairs.
- Personnel resources for operation of the demolition equipment and other work directly related to the demolition.
- Equipment for handling and transport of radioactive building rubbles to containers. The container cost is included in the category "Treatment, transport and final disposal of radioactive waste".
- Equipment for separation and decontamination of embedded steel such as cutters and high pressure cleaners.
- Equipment for handling and transport of non-radioactive building rubbles to transport vehicles. The vehicle cost is included in the category "Treatment, transport and final disposal of non-radioactive waste".

The cost category "General site expenses, contractor fees" includes costs for the resources necessary for the general work and facilities necessary for the primary demolition work such as:

- Establishing on site.
- Machinery such as mobile cranes, lifts and general tools.
- Weather related costs.
- General operation and maintenance.
- Supervision and administration.
- Investigations, working preparations.
- Training.
- Adaptation of equipment and methods.
- Special auxiliary arrangements.
- Central administration, risks and profit.

The cost category "Proprietor costs" includes costs for the resources necessary to realize the project but not included in the contractors undertaking. This cost category is included in the organizational costs.

The cost figures used to calculate the basic costs for the reactor containment are presented in Table 6-8.

The cost figures used to calculate the basic costs for the remaining buildings are presented in Table 6-9.

The cost figures used to calculate the basic costs for ground restoration work are presented in Table 6-10.

The costs in the category "General site expenses, contractor fees" were in Ericsson (2005) calculated as a percentage of the basic cost varying from 30 to 45% depending on the complexity of the building. The same figures are used in this study.

The resulting demolition costs are, as well as the WBS elements to which the costs are assigned, summarized in Table 6-11, Table 6-12, Table 6-13 and Table 6-14.

Table 6-8. Specific costs for reactor containment demolition.

Element	Specific cost	Unit
Demolition large size embedded steel	33,000	SEK/tonne
Demolition steel structures	17,500	SEK/tonne
Demolition contaminated concrete	30,000–45,000	SEK/m^3
Demolition non-radioactive concrete	5,000–10,000	SEK/m^3
Demolition containment liner	32,000	SEK/tonne
Internal handling of building rubbles	200–300	SEK/m^3

Table 6-9. Specific costs for demolition of the remaining buildings.

Element	Specific cost	Unit
Demolition of concrete estimated according to SS 10 02 53	100–200	SEK/m^3
Demolition contaminated concrete	39,000	SEK/m^3
Demolition non-radioactive concrete	6,500	SEK/m^3
Internal handling of building rubbles	200–300	SEK/m^3

Table 6-10. Specific costs for ground restoration.

Element	Specific cost	Unit
Demolition remaining building parts	3,300	SEK/m^2
Ground restoration, building with deep foundations	320	SEK/m^2
Ground restoration, buildings with surface foundations	230	SEK/m^2
Ground restoration, hard surfaces	270	SEK/m^2
Ground restoration, remaining areas	170	SEK/m^2

Table 6-11. O1 – Resulting building demolition costs.

WBS	Object	O1 Basic cost kSEK	Gen. Site Expenses kSEK
4.3.6.1	Reactor Containment radioactive parts	16,000	7,200
5.3.1	Reactor Containment nonradioactive parts	18,400	8,300
4.3.6.2	Reactor Building radioactive parts	2,800	900
5.3.2	Reactor Building nonradioactive parts	18,900	5,700
4.3.6.2	Turbine Building radioactive parts	0	0
5.3.3	Turbine Building nonradioactive parts	9,100	3,200
4.3.6.2	Other Controlled buildings radioactive parts	0	0
5.3.4	Other Controlled buildings nonradioactive parts	0	0
5.3.4	Remaining buildings	32,300	13,000
5.5.2	Ground restoration	6,500	2,600
Total:		**104,000**	**40,900**

Table 6-12. O2 – Resulting building demolition costs.

WBS	Object	O2	
		Basic cost kSEK	Gen. Site Expenses kSEK
4.3.6.1	Reactor Containment radioactive parts	19,900	9,000
5.3.1	Reactor Containment nonradioactive parts	3,800	1,700
4.3.6.2	Reactor Building radioactive parts	4,100	1,300
5.3.2	Reactor Building nonradioactive parts	8,000	2,400
4.3.6.2	Turbine Building radioactive parts	0	0
5.3.3	Turbine Building nonradioactive parts	34,800	12,200
4.3.6.2	Other Controlled buildings radioactive parts	0	0
5.3.4	Other Controlled buildings nonradioactive parts	4,000	1,600
5.3.4	Remaining buildings	10,500	4,200
5.5.2	Ground restoration	6,500	2,600
Total:		**91,600**	**35,000**

Table 6-13. O3 – Resulting building demolition costs.

WBS	Object	O3	
		Basic cost kSEK	Gen. Site Expenses kSEK
4.3.6.1	Reactor Containment radioactive parts	14,600	6,600
5.3.1	Reactor Containment nonradioactive parts	80,700	36,300
4.3.6.2	Reactor Building radioactive parts	5,800	1,800
5.3.2	Reactor Building nonradioactive parts	3,100	1,000
4.3.6.2	Turbine Building radioactive parts	0	0
5.3.3	Turbine Building nonradioactive parts	44,700	15,700
4.3.6.2	Other Controlled buildings radioactive parts	4,000	1,600
5.3.4	Other Controlled buildings nonradioactive parts	13,700	400
5.3.4	Remaining buildings	13,700	5,500
5.5.2	Ground restoration	28,600	11,500
Total:		**208,900**	**80,400**

Table 6-14. O0 – Resulting building demolition costs.

WBS	Object	O0	
		Basic cost kSEK	Gen. Site Expenses kSEK
3.3.1	Group 1 nonradioactive parts	600	300
5.3.2.1	Group 2 radioactive parts	103,000	41,200
6.3.1	Group 2 nonradioactive parts	5,400	2,200
6.5.2	Ground restoration	43,300	17,300
Total:		**152,300**	**61,000**

6.4 Cost estimation results

6.4.1 WBS Structure

The total cost amounts to about 5.3 billion SEK for the Oskarshamn site. The costs on a higher level of the WBS structure for each unit are shown in Table 6-15, Table 6-16, Table 6-17 and Table 6-18.

Table 6-15. O1 – Total costs (WBS structure).

WBS		Cost kSEK	%
1	Power Operation	18,492	2%
2	Defueling	86,643	8%
3	Shutdown Operation	0	0%
4	Nuclear Dismantling and Demolition	786,536	73%
4.1	Plant Operation Costs	91,953	
4.2	Purchaser's Projcet Management, Administration and Technical Support	67,566	
4.3	Dismantling and Demolition Activities	551,952	
4.4	Waste Handling and Storage	75,064	
5	Conventional Demolition	182,830	17%
5.1	Plant Operation Costs	21,390	
5.2	Purchaser's Projcet Management, Administration and Technical Support	19,220	
5.3	Dismantling and Demolition Activities	110,970	
5.4	Waste Handling and Storage	22,150	
5.5	Site Restoration	9,100	
Total		**1,074,501**	**100%**

Table 6-16. O2 – Total costs (WBS structure).

WBS		Cost kSEK	%
1	Power Operation	18,492	1%
2	Defueling	87,759	7%
3	Shutdown Operation	0	0%
4	Nuclear dismantling and demolition	949,461	75%
4.1	Plant Operation During Decommissioning	86,395	
4.2	Purchaser's Project Management, Administration and Technical Support	64,337	
4.3	Dismantling and Demolition Activities	738,453	
4.4	Waste handling and storage	60,275	
5	Conventional Demolition	205,522	16%
5.1	Plant Operation During Decommissioning	22,865	
5.2	Purchaser's Project Management Administration and Technical Support	26,664	
5.3	Dismantling and Demolition Activities	87,160	
5.4	Waste Handling and Storage	59,733	
5.5	Site Restoration	9,100	
Total		**1,261,233**	**100%**

Table 6-17. O3 – Total costs (WBS structure).

WBS		Cost kSEK	%
1	Power Operation	29,716	2%
2	Defueling	93,364	5%
3	Shutdown Operation	0	0%
4	Nuclear Dismantling and Demolition	1,237,390	71%
4.1	Plant Operating During Decommissioning	93,277	
4.2	Purchaser's Project Management, Admininstration and Technical Support	69,180	
4.3	Dismantling and Demolition Activities	918,299	
4.4	Waste Handling and Storage	156,633	
5	Conventional Demolition	374,598	22%
5.1	Plant Operating During Decommissioning	48,267	
5.2	Purchaser's Project Management, Admininstration and Technical Support	58,883	
5.3	Dismantling and Demolition Activities	209,840	
5.4	Waste Handling and Storage	17,509	
5.5	Site Restoration	40,100	
Total		**1,735,068**	**100%**

Table 6-18. O0 – Total costs (WBS structure).

WBS		Cost kSEK	%
1	Power Operation Group 1	0	0%
2	Dismantling and Demolition Group 1	4,322	1%
2.1	Plant Operation Costs	332	
2.2	Purchaser's Project Management, Administration and Technical Support	0	
2.3	Dismantling and Demolition Activities	3,990	
2.4	Waste Handling and Storage	0	
3	Conventional Demolition Group 1	1,159	0%
3.1	Plant Operation Costs	133	
3.2	Purchaser's Project Management, Administration and Technical Support	0	
3.3	Dismantling and Demolition Activities	1,026	
3.4	Waste Handling and Storage	0	
4	Power Operation Group 2	24,839	5%
5	Dismantling and Demolition Group 2	380,494	70%
5.1	Plant Operation Costs	31,290	
5.2	Purchaser's Project Management, Administration and Technical Support	24,762	
5.3	Dismantling and Demolition Activities	289,655	
5.4	Waste Handling and Storage	34,787	
6	Conventional Demolition Group 2	130,588	24%
6.1	Plant operation Costs	28,223	
6.2	Purchaser's Project Management, Administration and Technical Support	32,329	
6.3	Dismantling and Demolition Activities	9,436	
6.4	Waste Handling and Storage	0	
6.5	Site Restoration	60,600	
Total		**541,402**	**100%**

6.4.2 OECD/NEA structure

The difficulty in comparing various decommissioning cost estimates between different countries is generally recognized. Comparisons of individual cost estimates for specific facilities may show relatively large variations and several studies have attempted to identify the reasons for these variations. As the different kinds of costing methods define their cost items differently, value taken from one particular cost analysis, without regard to its context, is easily misunderstood and misinterpreted. One reason is that there has not been any standardized listing of cost items established, specific to decommissioning projects.

Based on similarly focused on-going activities with comparable objectives, the European Commission (EC), the International Atomic Energy Agency (IAEA) and the OECD/Nuclear Energy Agency (NEA) decided jointly to develop a common standardized list of decommissioning cost items. The objectives were to facilitate communication, promote uniformity and avoid inconsistency or contradiction of results or conclusions of cost calculations carried out by different organizations. The conclusion was that this would be a common interest for all the world's organizations involved in decommissioning activities, and thus it would be useful to encourage a common usage of the developed cost list.

The development work started in 1997 with a joint task force with representatives from the three organizations. In 1999 an interim report, "A Proposed Standardized List of Items for Costing Purposes" (OECD/NEA 1999), was published. The organizations behind this initiative hope that the list will be widely accepted and used for many cost calculation projects, thus creating a wider base for cost comparisons and bench-marking. Since then some organizations have adopted the format and made adjustments of their existing cost models.

In 2012 OECD/NEA issued "International Structure for Decommissioning Costing (ISDC) of Nuclear Installations" (OECD/NEA 2012). The 2012 OECD/NEA structure has been used in the Oskarshamn site study.

The standardized cost list groups the cost items into eleven main sections:

- Pre-decommissioning Actions.
- Facility Shutdown Activities.
- Additional Activities for Safe Enclosure or Entombment.
- Dismantling Activities.
- Waste Processing, Storage and Disposal.
- Site Infrastructure and Operation.
- Conventional Dismantling, Demolition and Site Restoration.
- Project Management, Engineering and Support.
- Research and Development.
- Fuel and Nuclear Material.
- Miscellaneous Expenditures.

The sections above are related to a specific cost type, regardless of the phases and activities of the project during which the cost is expected to appear. Thus, the structure is not so useful for project planning, only for cost comparisons. For example some preparatory activities from the Defueling operation of the WBS are sorted under the OECD/NEA cost item "Dismantling activities within the controlled area". For these reasons the present study has initially identified the cost items in the work breakdown structure (WBS) format. However, each WBS element is given a label which enables it to be transferred into the OECD/NEA structure. The costs, sorted according to the ISDC structure are summarized in Table 6-19.

Table 6-19. Total costs (according to OECD/NEA format).

ISDC Matrix Elements			Cost kSEK	%	Contingency kSEK	%	Sum Cost + Cont. kSEK
01		**Pre-decommissioning Activites**	**72,496**	**2%**	**7,058**	**10%**	**79,554**
	0100	Decommisioning Planning	25,599	35%	2,560	36%	28,159
	0200	Facility Characterisation	10,868	15%	845	12%	11,713
	0300	Safety, Security and Environmental Studies	12,397	17%	1,250	18%	13,647
	0400	Waste mamagement planning	0	0%	0	–	0
	0500	Authorisation	0	0%	0	–	0
	0600	Preparing Management Group and Contracting	23,633	33%	2,404	34%	26,036
02		**Facility Shutdown Activites**	**117,686**	**3%**	**17,737**	**15%**	**135,423**
	0300	Decontamination of Systems for Dose Reduction	115,693	98%	17,323	98%	133,016
	0400	Radiological Inventory Characterisation to Support Detailed Planning	1,994	2%	414	2%	2,407
03		**Additional Activities for Safe Enclosure**	**0**	**0%**	**0**	**–**	**0**
	0100	Preparation for Safe Enclosure	0	–	0	–	0
04		**Dismantling Activities within the Controlled Area**	**2,094,389**	**45%**	**268,837**	**13%**	**2,363,227**
	0200	Preparation and Support for Dismantling	14,172	1%	3,342	1%	17,514
	0500	Dismantling of Main Process Systems, Structures and Components	1,273,082	61%	107,326	40%	1,380,408
	0600	Dismantling of Other Systems and Components	601,074	29%	120,864	45%	721,938
	0700	Removal of Contamination from Building Structures	22,300	1%	4,322	2%	26,622
	0900	Final Radioactivity Survey for Release of Buildings	183,762	9%	32,982	12%	216,744
05		**Waste Processing, Storage and Disposal**	**452,287**	**10%**	**60,574**	**13%**	**512,860**
	0100	Waste Management System	176,929	39%	24,089	40%	201,017
	0800	Management of Decommissioning Intermediate-level Waste	24,580	5%	1,546	3%	26,126
	0900	Management of Decommissioning Low-level Waste	138,355	31%	18,857	31%	157,213
	1200	Management of Decommissioning Exempt Waste and Materials	112,423	25%	16,082	27%	128,505
	1300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0	0%	0	–	0
06		**Site Infrastructure and Operation**	**288,076**	**6%**	**43,989**	**15%**	**332,065**
	0100	Site Security and Surveillance	18,173	6%	2,576	6%	20,749
	0200	Site Operation and Maintenance	132,294	46%	18,682	42%	150,976
	0300	Operation of Support Systems	80,884	28%	13,678	31%	94,562
	0400	Radiation and Environamental Safety Monitoring	56,725	20%	9,054	21%	65,779
07		**Conventional Dismantling, Demolition and Site Restoration**	**789,835**	**17%**	**121,109**	**15%**	**910,945**
	0100	Procurement of Equipment for Conventional Dismantling and Demolition	81,755	10%	14,884	12%	96,639
	0200	Dismantling of systems and Building Components Outside the Controlled Area	158,927	20%	42,308	35%	201,235
	0300	Demolition of Buildings and Structures	414,521	52%	45,306	37%	459,827
	0400	Final Cleanup, Landscaping and Refurbishment	118,900	15%	16,812	14%	135,712
	0500	Final Radioactivity Survey of Site	15,732	2%	1,800	1%	17,532
08		**Project Management, Engineering and Support**	**768,575**	**17%**	**131,153**	**17%**	**899,728**
	0100	Mobilisation and Prepartory Work	0	0%	0	–	0
	0200	Project Management	435,891	57%	64,083	49%	499,974
	0300	Support Services	163,055	21%	25,242	19%	188,297
	1000	Demobilisation by contractors	169,630	22%	41,828	32%	211,457
09		**Research and Development**	**0**	**0%**	**0**	**–**	**0**
10		**Fuel and Nuclear Material**	**0**	**0%**	**0**	**–**	**0**
11		**Miscellaneous Expenditures**	**28,859**	**1%**	**8,297**	**29%**	**37,156**
	0100	Owner Costs	0	0%	0	–	0
	0400	Taxes	0	0%	0	–	0
	0500	Insurances	28,859	100%	8,297	100%	37,156
Total			**4,612,204**	**100%**	**658,755**	**14%**	**5,270,959**

The main part of the costs for equipment is included in contractors' fees and, thus is presented as part of the dismantling costs (04). No research and development costs (09) are foreseen as the decommissioning project will be carried out as a fully commercial project, using experienced sub-suppliers with fully developed technologies. By definition, no fuel costs (10) are presented as decommissioning costs in this study. The conditions listed in Section 6.2 should also be noted, e.g, that the scope of the study excludes costs associated with final disposal of radioactive wastes.

All costs, sorted according to the OECD/NEA-structure, have also been attributed to one of the cost variables, EEF-codes, which have been defined by Professor Ulf Jakobsson together with SKB. These EEFs (external economic factors) have been defined in a method for handling and analyzing future real price changes for the goods and services included in the system for management of the waste products of nuclear power. Each EEF-code is linked to historical data of real prices, and with this data future real prices can be calculated.

The variables which have been defined are:

- Real payroll costs per unit produced in the service sector (code 0).
- Real payroll costs per unit produced in the construction industry (code 1).
- Real price trend for machinery (code 2).
- Real price trend for building materials (code 3).
- Real price trend for consumable supplies (code 4).
- Real price trend for crude copper (code 5).
- Real price trend for bentonite and similar materials (code 6).
- Real price trend for energy (code 7).
- SEK/USD exchange rate (code 8).

Table 6-20, Table 6-21, Table 6-22 and Table 6-23 show the costs divided into the EEF-codes, as percentage of the total costs, for the Oskarshamn site.

Table 6-20. O1 – Total costs divided into EEF-codes.

O1 EEF-codes			Code 0, %	Code 1, %	Code 2, %	Code 3, %	Code 4, %	Code 5, %	Code 6, %	Code 7, %	Code 8, %
01		**Pre-decommissioning Activites**	**1.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Decommisioning planning	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Facility characterisation	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Safety, Security and Environmental Studies	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0400	Waste mamagement planning	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0500	Authorisation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0600	Preparing Management Group and Contracting	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
02		**Facility Shutdown Activites**	**0.6**	**0.4**	**2.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0300	Decontamination of Closed Systems for Dose Reduction	0.5	0.4	2.1	0.0	0.0	0.0	0.0	0.0	0.0
	0400	Radiological Inventory Characterisation to Support Detailed Planning	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03		**Additional Activities for Safe Enclosure**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Preparation for Safe Enclosure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
04		**Dismantling Activities within the Controlled Area**	**16**	**19**	**7.7**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0200	Preparation and Support for Dismantling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0500	Dismantling of Main Process Systems, Structures and Components	14.1	10.2	7.7	0.1	0.0	0.0	0.0	0.0	0.0
	0600	Dismantling of Other Systems and Components	1.7	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0700	Removal of Contamination from Building Structures	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0900	Final Radioactivity Survey for Release of Buildings	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
05		**Waste Processing, Storage and Disposal**	**3.5**	**2.0**	**0.9**	**0.9**	**2.0**	**0.0**	**0.0**	**0.5**	**0.0**
	0100	Waste Management System	1.8	2.0	0.9	0.9	0.0	0.0	0.0	0.0	0.0
	0800	Management of Decommissioning Intermediate-level Waste	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
	0900	Management of Decommissioning Low-level Waste	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0
	1 200	Management of Decommissioning Exempt Waste and Materials	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
	1 300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
06		**Site Infrastructure and Operation**	**6.0**	**0.0**	**0.0**	**0.0**	**0.5**	**0.0**	**0.0**	**1.1**	**0.0**
	0100	Site Security and Surveillance	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Site Operation and Maintenance	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Operation of Support Systems	0.6	0.0	0.0	0.0	0.5	0.0	0.0	1.1	0.0
	0400	Radiation and Environamental Safety Monitoring	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07		**Conventional Dismantling, Demolition and Site Restoration**	**0.7**	**14.5**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Procurment of Equipment for Conventional Dismantling and Demolition	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Dismantling of Systems and Building Components Outside the Controlled Area	0.5	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Demolition of Buildings and Structures	0.1	10.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	0400	Final Cleanup, Landscaping and Refurbishment	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0500	Ground restoration	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08		**Project Management, Engineering and Support**	**17**	**0.0**	**1.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Mobilisation and Prepartory Work	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Project management	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Support Services	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1000	Demobilisation by contractors	2.9	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
09		**Research and Development**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
10		Fuel and Nuclear Material	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11		Miscellaneous Expenditures	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0100	Owner Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Taxes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Insurances	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total			**46.4**	**36.3**	**12.1**	**1.1**	**2.5**	**0.0**	**0.0**	**1.6**	**0.0**

Table 6-21. O2 – Total costs divided into EEF-codes.

O2 EEF-codes			Code 0, %	Code 1, %	Code 2, %	Code 3, %	Code 4, %	Code 5, %	Code 6, %	Code 7, %	Code 8, %
01		**Pre-decommissioning Activites**	**1.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Decommisioning Planning	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Facility Characterisation	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Safety, Security and Environmental Studies	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0400	Waste mamagement planning	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0500	Authorisation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0600	Preparing Management Group and Contracting	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
02		**Facility Shutdown Activites**	**0.5**	**0.4**	**1.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0300	Decontamination of Systems for Dose Reduction	0.5	0.4	1.3	0.0	0.0	0.0	0.0	0.0	0.0
	0400	Radiological Inventory Characterisation to Support Detailed Planning	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03		**Additional Activities for Safe Enclosure**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Preparation for Safe Enclosure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
04		**Dismantling Activities within the Controlled Area**	**17.0**	**26.9**	**7.8**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0200	Preparation and Support for Dismantling	0.1	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	0500	Dismantling of Main Process Systems, Structures and Components	14.1	11.7	7.7	0.1	0.0	0.0	0.0	0.0	0.0
	0600	Dismantling of Other Systems and Components	2.7	11.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	0700	Removal of Contamination from Building Structures	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	0900	Final Radioactivity Survey for Release of Buildings	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
05		**Waste Processing, Storage and Disposal**	**5.4**	**1.5**	**2.1**	**0.0**	**0.0**	**0.0**	**0.0**	**1.0**	**0.0**
	0100	Waste Management System	1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0800	Management of Decommissioning Intermediate-level Waste	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
	0900	Management of Decommissioning Low-level Waste	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0
	1 200	Management of Decommissioning Exempt Waste and Materials	4.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
	1 300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
06		**Site Infrastructure and Operation**	**5.1**	**0.0**	**0.0**	**0.0**	**0.5**	**0.0**	**0.0**	**0.9**	**0.0**
	0100	Site Security and Surveillance	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Site Operation and Maintenance	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Operation of Support Systems	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.9	0.0
	0400	Radiation and Environamental Safety Monitoring	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07		**Conventional Dismantling, Demolition and Site Restoration**	**0.6**	**10.6**	**0.3**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Procurement of Equipment for Conventional Dismantling and Demolition	0.2	0.9	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	0200	Dismantling of systems and Building Components Outside the Controlled Area	0.4	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Demolition of Buildings and Structures	0.0	6.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	0400	Final Cleanup, Landscaping and Refurbishment	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0500	Final Radioactivity Survey of Site	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08		**Project Management, Engineering and Support**	**14.7**	**0.0**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Mobilisation and Prepartory Work	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0200	Project Management	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0300	Support Services	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1000	Demobilisation by contractors	2.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
09		**Research and Development**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
10		**Fuel and Nuclear Material**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
11		**Miscellaneous Expenditures**	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	0100	Owner Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0400	Taxes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0500	Insurances	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total			**45.5**	**39.4**	**12.5**	**0.3**	**0.5**	**0.0**	**0.0**	**1.9**	**0.0**

Table 6-22. O3 – Total costs divided into EEF-codes.

O3 ISDC Matrix Elements			Code 0, %	Code 1, %	Code 2, %	Code 3, %	Code 4, %	Code 5, %	Code 6, %	Code 7, %	Code 8, %
01		**Pre-decommissioning Actions**	**1,8**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Decommisioning planning	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Facility Characterisation	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Safety, Security and Environmental Studies	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0400	Waste mamagement planning	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0500	Authorisation	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0600	Preparing Management Group and Contracting	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
02		**Facility Shutdown Activites**	**0,4**	**0,3**	**1,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0300	Decontamination of Closed Systems for Dose Reduction	0,4	0,2	1,3	0,0	0,0	0,0	0,0	0,0	0,0
	0400	Radiological Inventory Characterisation to Support Detailed Planning	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
03		**Additional Activities for Safe Enclosure**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Preparation for Safe Enclosure	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
04		**Dismantling Activities within the Controlled Area**	**15,1**	**22,1**	**6,6**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0200	Preparation and Support for Dismantling	0,1	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0500	Dismantling of Main Process Systems, Structures and Components	12,7	7,5	6,5	0,0	0,0	0,0	0,0	0,0	0,0
	0600	Dismantling of Other Systems and Components	2,3	9,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0700	Removal of Contamination from Building Structures	0,0	0,7	0,1	0,0	0,0	0,0	0,0	0,0	0,0
	0900	Final Radioactivity Survey for Release of Buildings	0,0	4,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0
05		**Waste Processing, Storage and Disposal**	**2,2**	**1,3**	**6,6**	**0,0**	**0,0**	**0,0**	**0,0**	**0,5**	**0,0**
	0100	Waste management system	1,2	1,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0800	Management of Decommissioning Intermediate-level Waste	0,0	0,0	0,6	0,0	0,0	0,0	0,0	0,0	0,0
	0900	Management of Decommissioning Low-level Waste	0,0	0,0	6,0	0,0	0,0	0,0	0,0	0,0	0,0
	1200	Management of Decommissioning Exempt Waste and Materials	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0
	1 300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
06		**Site Infrastructure and Operation**	**4,3**	**0,0**	**0,0**	**0,0**	**0,4**	**0,0**	**0,0**	**0,8**	**0,0**
	0100	Site Security and Surveillance	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Site Operation and Maintenance	2,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Operation of Support Systems	0,4	0,0	0,0	0,0	0,4	0,0	0,0	0,8	0,0
	0400	Radiation and Environamental Safety Monitoring	1,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
07		**Conventional Dismantling, Demolition and Site Restoration**	**1,1**	**19,3**	**0,8**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Procurment of Equipment for Conventional Dismantling and Demolition	0,4	1,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Dismantling of Systems	0,7	3,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Demolition of Buildings and Structures	0,1	11,1	0,8	0,0	0,0	0,0	0,0	0,0	0,0
	0400	Final Cleanup, Landscaping and Refurbishment	0,0	2,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0500	Final Radioactivity Survay of Site	0,0	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0
08		**Project Management, Engineering and Site Support**	**14,0**	**0,0**	**0,7**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Mobilisation and Prepartory work	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Project Management	8,9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Support Services	3,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	1000	Demobilisation by contractors	1,9	0,0	0,7	0,0	0,0	0,0	0,0	0,0	0,0
09		**Reasearch and Development**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
10		**Fuel and Nuclear Material**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
11		**Miscellaneous Expenditures**	**0,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Owner Costs	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0200	Taxes	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Insurances	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total			**39,3**	**43,0**	**16,0**	**0,0**	**0,4**	**0,0**	**0,0**	**1,4**	**0,0**

Table 6-23. O0 – Total costs divided into EEF-codes.

O0 EEF-codes			Code 0, %	Code 1, %	Code 2, %	Code 3, %	Code 4, %	Code 5, %	Code 6, %	Code 7, %	Code 8, %
01		**Pre-decommissioning Activites**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Decommisioning planning	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Facility characterisation	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Safety, Security and Environmental Studies	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0400	Wate management planning	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0500	Authorisation	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0600	Preparing Management Group and Contracting	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
02		**Facility Shutdown Activites**	**0,4**	**0,3**	**3,7**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0300	Decontamination of Closed Systems for Dose Reduction	0,3	0,3	3,7	0,0	0,0	0,0	0,0	0,0	0,0
	0400	Radiological Inventory Characterisation to Support Detailed Planning	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
03		**Additional Activities for Safe Enclosure**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Preparation for Safe Enclosure	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
04		**Dismantling Activities within the Controlled Area**	**1,9**	**35,8**	**2,4**	**0,1**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0200	Preparation and Support for Dismantling	0,2	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0500	Dismantling of Main Process Systems, Structures and Components	1,7	5,7	0,0	0,1	0,0	0,0	0,0	0,0	0,0
	0700	Removal of Contamination from Building Structures	0,0	24,3	2,4	0,0	0,0	0,0	0,0	0,0	0,0
	0900	Final Radioactivity Survey for Release of Buildings	0,0	5,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0
05		**Waste Processing, Storage and Disposal**	**1,1**	**1,9**	**1,9**	**1,8**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Waste Management System	1,1	1,9	1,8	1,8	0,0	0,0	0,0	0,0	0,0
	0900	Management of Decommissioning Low-level Waste	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
	1200	Management of Decommissioning Exempt Waste and Materials	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	1300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
06		**Site Infrastructure and Operation**	**4,2**	**0,0**	**0,0**	**0,0**	**0,4**	**0,0**	**0,0**	**0,6**	**0,0**
	0100	Site Security and Surveillance	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Site Operation and Maintenance	2,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Operation of Support Systems	0,0	0,0	0,0	0,0	0,4	0,0	0,0	0,6	0,0
	0400	Radiation and Environamental Safety Monitoring	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
07		**Conventional Dismantling, Demolition and Site Restoration**	**1,1**	**19,3**	**0,0**	**0,1**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Procurment of Equipment for Conventional Dismantling and Demolition	0,7	3,8	0,0	0,1	0,0	0,0	0,0	0,0	0,0
	0200	Dismantling of Systems and Building Components Outside the Controlled Area	0,4	2,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Demolition of Buildings and Structures	0,0	1,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0400	Final Cleanup, Landscaping and Refurbishment	0,0	11,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0500	Final Radioactivity Survey of Site	0,0	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0
08		**Project Management, Engineering and Support**	**20,0**	**0,0**	**2,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Mobilisation and Prepartory Work	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Project management	10,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Support Services	4,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	1000	Demobilisation by Contractors	4,7	0,0	2,3	0,0	0,0	0,0	0,0	0,0	0,0
09		**Research and Development**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
10		**Fuel and Nuclear Material**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
11		**Miscellaneous Expenditures**	**0,9**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
	0100	Owner Costs	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0200	Taxes	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	0300	Insurances	0,9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total			**29**	**57**	**10**	**2,1**	**0,4**	**0,0**	**0,0**	**0,6**	**0,0**

6.4.3 Annual costs and work

Cost information can be presented as a function of time (i.e. per week, month or year). The annual total cost is shown in Figure 6-2.The annual work for the main personnel categories is shown in Table 6-24.

Table 6-24. Annual work (number of staff).

	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Utility Manager (cat.M)	0	0	0	0	0	0	2	2	2	4
Utility Engineer (cat.E)	0	3	4	8	8	8	59	70	67	117
Project Manager (cat. P)	0	0	0	1	0	0	5	7	6	11
Engineer (cat.1)	0	0	0	0	0	0	2	5	4	4
Foreman (cat. 2)	0	0	0	0	0	0	1	18	17	5
HP technician (cat.3)	0	0	0	0	0	0	1	6	5	2
Craftsmen (cat. 4)	0	0	0	0	0	0	5	12	10	7
Laborer (cat. 5)	0	0	0	0	0	0	3	124	98	14
Total	**0**	**3**	**4**	**9**	**9**	**8**	**77**	**243**	**209**	**163**
	2036	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**
Utility Manager (cat.M)	3	2	2	1	0	0	0	0	0	1
Utility Engineer (cat.E)	79	61	59	18	2	6	9	9	7	27
Project Manager (cat. P)	8	6	6	2	0	0	1	1	1	2
Engineer (cat.1)	8	4	1	0	0	0	0	0	0	0
Foreman (cat. 2)	32	15	2	0	0	0	0	0	0	0
HP technician (cat.3)	8	5	1	0	0	0	0	0	0	0
Craftsmen (cat. 4)	22	12	1	0	0	0	0	0	0	1
Laborer (cat. 5)	244	125	17	1	0	0	0	0	0	4
Total	**404**	**231**	**88**	**22**	**2**	**6**	**10**	**10**	**8**	**35**
	2046	**2047**	**2048**	**2049**	**2050**	**2051**	**2052**	**2053**	**2054**	**Total**
Utility Manager (cat.M)	2	2	2	3	3	2	1	0	0	34
Utility Engineer (cat.E)	61	61	61	75	74	50	26	7	0	1,035
Project Manager (cat. P)	6	6	6	9	9	6	3	1	0	102
Engineer (cat.1)	5	6	6	3	3	0	0	0	0	51
Foreman (cat. 2)	12	24	22	11	9	1	0	0	0	169
HP technician (cat.3)	5	6	6	2	2	0	0	0	0	49
Craftsmen (cat. 4)	15	22	15	5	4	0	0	0	0	128
Laborer (cat. 5)	88	196	196	65	68	3	0	0	0	1,246
Total	**195**	**322**	**314**	**173**	**171**	**62**	**30**	**8**	**0**	**2,815**

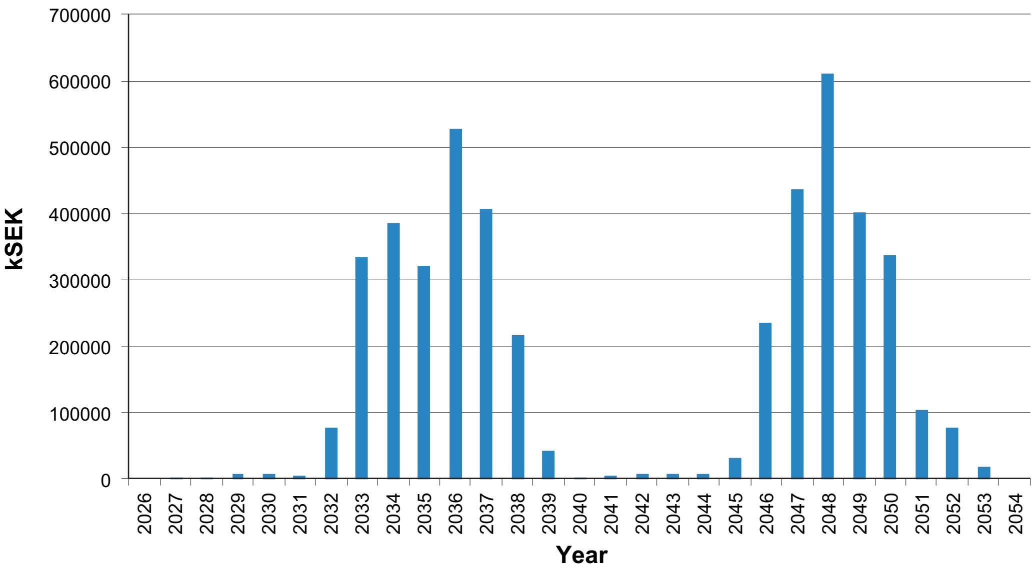

Figure 6-2. Annual Costs.

It is possible in MS Project to choose if the work volume for a specific activity should be proportional to the length of the activity (such as for security surveillance of the plant) or independent (such as a dismantling activity). This makes it feasible to investigate how the work volume, and the corresponding cost, is affected by altered length of the time schedule.

6.5 Contingency

This section contains an estimate of the project contingency. Contingency costs are for unforeseen, uncertain and unpredictable conditions typically encountered in decommissioning (known unknowns). In general, all contingency costs are spent as the project progresses, as these unforeseen events occur throughout the project. Note that risks are uncertainties that may occur throughout the project (unknown unknowns) and are excluded in this study.

The contingencies are of four basic types:

Contingencies related to the man-hour calculation

- Contingencies related to the accuracy of the material and equipment inventory
- Contingencies related to the specific activities (planning of resources, not specified technique, trouble shooting, difficulty in activity sequencing etc).

Contingencies related to experience based cost estimations

- Costs that are experience based will naturally have a lower contingency. The contingencies for experience based cost estimations are related to the differences between the conditions and assumptions in this specific study compared to earlier completed projects.

Contingencies related to organization

- Contingencies based on experience from changes in project organization.

Contingencies related to other costs

- Contingencies based on judgment of the input.

The contingencies have been estimated, in percent values, for individual cost items on a lower level in the ISDC structure. Then, the resulting contingency costs are summarized up to the higher level. The percentage is then recalculated considering the cost contribution of each contingency. The contingency is presented in Table 6-19.

The total contingency shown in Table 6-19, page 6-2, is approximately 659 MSEK, which results in a global contingency factor for the overall project of approximately 14%.

7 Summary, results and conclusions

7.1 Introduction

The purpose of this chapter is to summarize the main results, uncertainties and conclusions of the decommissioning study of the Oskarshamn nuclear power plant (NPP).

7.2 Summary results

7.2.1 General

The aim of this study is to provide a basis with the actual system inventory assessment, radiological inventory, time schedule, costs, waste production and waste types for the decommissioning of the Oskarshamn NPP. The waste amount estimations from the decommissioning studies of the Swedish nuclear power plants will be useful input to SKB for the extension of SFR.

The same methodology has been used as for the "Swedish BWR Reference Plant Decommissioning Study" made for Oskarshamn 3 in 2006 (Gustafsson et al. 2006). The decommissioning studies should be documents that are continually updated since new decommissioning techniques, strategies and plans are developed and reactors are uprated or modified in other ways.

7.2.2 Plant inventory

Plant inventories has been conducted (Gustafsson et al. 2006, Bergh 2010, Dahlberg and Eriksson 2009, Lundin 2009) to determine the quantities of material of different types, both radiological waste and clean materials, which will need to be managed during the decommissioning activity. This information has been based on plant specific databases and other plant specific data, such as e.g. drawings. Where necessary, walk-downs and engineering judgments have been applied.

7.2.3 Waste quantities and classification

The decommissioning waste generated has been categorized in activity categories. Based on the activity, type and quantity of the waste, the number of appropriate waste containers has been estimated. The waste categorization has been based on the site specific materials inventory data, described earlier, in combination with nuclide specific data. The basis for the nuclide data are a computer simulation of the levels that are expected one year after plant final shutdown i.e. the reference date for the activity calculations is 2036-01-01 for O1 (Jonasson 2012a), 2036-01-01 for O2 (Jonasson 2012b) and 2046-01-01 for O3 (Jonasson 2012c).

The resulting number of waste containers and their net storage volume at the repository for the Oskarshamn NPP is shown in Table 7-1 to Table 7-4.

The waste which will be disposed of in the repository for long-lived low and intermediate level waste (SFL) results from the segmentation of the reactor internals situated close to the core, e.g. the core shroud, core shroud head, core grid and parts of the control rod guide tubes.

Table 7-1. Waste container data: Process equipment waste for the Oskarshamn NPP.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFL	335	34	BFA-tank	Red (LL)	3.30×2.30×1.30
SFR	1,687	244	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	7,543	383	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Recycling	73,718	3,743	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 7-2. Waste container data: Concrete waste for the Oskarshamn NPP.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	567	82	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	3,151	160	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	119,194	6,052	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 7-3. Waste container data: Sand waste for the Oskarshamn NPP.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	102	15	Large Steel Box	Red (SL)	2.40×2.40×1.20
SFR	729	37	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Municipal Deposit	4,845	246	ISO-type Container	Blue & White	6.06×2.50×1.30

Table 7-4. Waste container data: Decontamination waste for the Oskarshamn NPP.

Suggested disposal facility	Net storage volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFR	36	21	Steel Box	Red (SL)	1.20×1.20×1.20
SFR	12	7	Steel Box	Yellow & Green	1.20×1.20×1.20

7.2.4 Decommissioning programme

A decommissioning programme for the Oskarshamn NPP has been developed. It shows the sequence and timing of the major activities to be carried out during the planning and execution of the decommissioning of the site.

In order to limit the total project time there has been an ambition to run several activities in parallel. The total reliance on proven tools and techniques that have been used on progressing or completed decommissioning projects in the USA and Europe is a key element in all sequences. In doing so, project programmes have been developed that do not include any research or development of techniques that could lead to delays or cost escalations.

The programme for the Oskarshamn NPP covers the whole decommissioning time span from shutdown of power production for O1 (including the initial planning that is done during the last five years of power operation) to hand-over of the cleared and decontaminated site with facilities demolished and backfilled up to one meter below ground level. The site will assumedly be used for other industrial purposes.

O1, O2 and O3 is supposed to be shut down in 2032, 2034 and 2045 after 60 years of operation.

The defueling period of one year will be used to defuel the reactor, manage the passage of the spent fuel through the spent fuel pools into longer term off-site storage, and to manage operational waste/fluids on site at the time of shutdown. The decommissioning activities during the defueling period comprise of planning, EIA work, large-scale primary circuit decontamination, object decontamination, reactor internals segmentation, radiological inventory characterization and plant system adaptation.

The activities associated with the segmentation of the reactor internals and the reactor pressure vessel have been described in more detail in the programme, as these activities will include the most complex tasks to be carried out and will be a part of the critical path of the project.

The expected total duration, from plant shutdown (O1) to finalized landscaping (Unit 0), is approximately 22 years, see Figure 7-1.

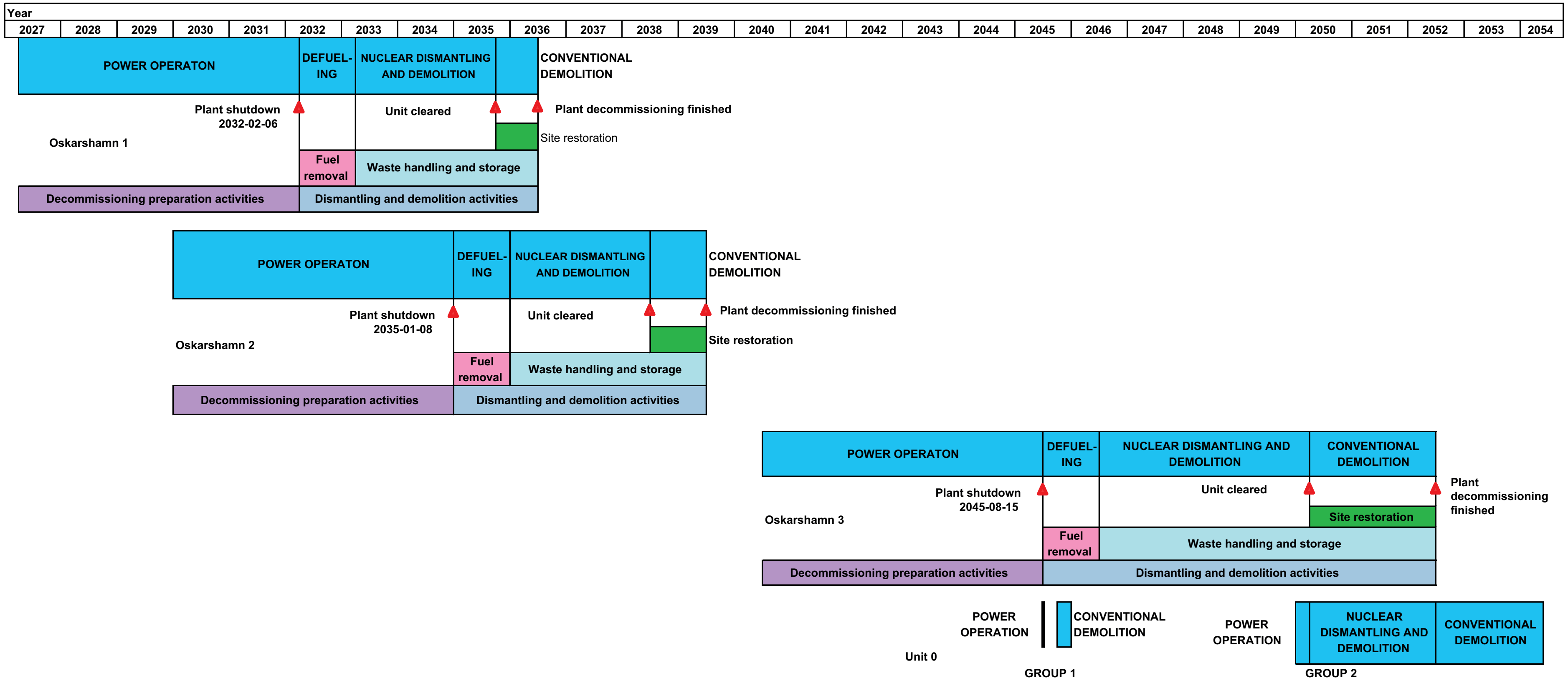

Figure 7-1. *The decommissioning phases for O1, O2, O3 and Unit 0.*

7.2.5 Organization

The utility site organization responsible for the decommissioning is established early in the process, approximately two years before shutdown of O1. This organization will purchase all services needed, mainly through larger contractors. The organization comprises the site manager and his/her staff and below a subdivision in two main branches; one including the project managers and the other including the operation and executing personnel. The project subdivision is fully concentrated on preparing the future decommissioning work while the other has a dual role, one to operate and perform maintenance to the plant and the other to assist the project managers with various technical services. All major decommissioning work will be executed as projects with separate project management and administration for each project. The plant owner has the overall responsibility for the relations with the authorities and the public.

The Oskarshamn NPP workforce will amount to at the most around 360 staff members per year including contractor personnel, utility project management teams and utility operation personnel. This will occur during the dismantling phase.

7.2.6 Cost estimate

The cost estimate for decommissioning of the Oskarshamn NPP covers the whole decommissioning phase from shutdown of power production (including the initial planning that starts 5 years prior to shutdown) to hand-over of the cleared and decontaminated site with facilities demolished and backfilled up to one meter below ground level. The site will assumedly be used for other industrial purposes. However, it is limited to activities that the plant owner is responsible for and that are related to decommissioning. Consequently, activities during the defueling period which are primarily aimed at keeping the plant in the intended state (i.e. activities not associated to the decommissioning) are excluded.

7.2.6.1 Reactor internals costs

The costs for segmentation of the reactor internals will be 339 MSEK. These costs include project administration, engineering, material and segmentation at site.

7.2.6.2 Total cost estimation results

The total cost for the whole decommissioning of the Oskarshamn NPP will be 5,271 MSEK. The total cost together with the contingency, is shown in Table 7-5. As it is difficult to compare various decommissioning cost estimates between different countries, the cost estimation result, together with the contingencies, has been sorted according to “International Structure for Decommissioning Costing (ISDC) of Nuclear Installations” from 2012 (OECD/NEA structures) as can be seen in Table 7-5.

Table 7-5. Total cost and contingencies sorted according to the OECD/NEA structure for the Oskarshamn NPP.

ISDC Matrix Elements			Cost		Contingency		Sum Cost + Cont.
			kSEK	%	kSEK	%	kSEK
01		**Pre-decommissioning Activites**	**72,496**	**2%**	**7,058**	**10%**	**79,554**
	0100	Decommisioning Planning	25,599	35%	2,560	36%	28,159
	0200	Facility Characterisation	10,868	15%	845	12%	11,713
	0300	Safety, Security and Environmental Studies	12,397	17%	1,250	18%	13,647
	0400	Waste mamagement planning	0	0%	0	–	0
	0500	Authorisation	0	0%	0	–	0
	0600	Preparing Management Group and Contracting	23,633	33%	2,404	34%	26,036
02		**Facility Shutdown Activites**	**117,686**	**3%**	**17,737**	**15%**	**135,423**
	0300	Decontamination of Systems for Dose Reduction	115,693	98%	17,323	98%	133,016
	0400	Radiological Inventory Characterisation to Support Detailed Planning	1,994	2%	414	2%	2,407
03		**Additional Activities for Safe Enclosure**	**0**	**0%**	**0**	**–**	**0**
	0100	Preparation for Safe Enclosure	0	–	0	–	0
04		**Dismantling Activities within the Controlled Area**	**2,094,389**	**45%**	**268,837**	**13%**	**2,363,227**
	0200	Preparation and Support for Dismantling	14,172	1%	3,342	1%	17,514
	0500	Dismantling of Main Process Systems, Structures and Components	1,273,082	61%	107,326	40%	1,380,408
	0600	Dismantling of Other Systems and Components	601,074	29%	120,864	45%	721,938
	0700	Removal of Contamination from Building Structures	22,300	1%	4,322	2%	26,622
	0900	Final Radioactivity Survey for Release of Buildings	183,762	9%	32,982	12%	216,744
05		**Waste Processing, Storage and Disposal**	**452,287**	**10%**	**60,574**	**13%**	**512,860**
	0100	Waste Management System	176,929	39%	24,089	40%	201,017
	0800	Management of Decommissioning Intermediate-level Waste	24,580	5%	1,546	3%	26,126
	0900	Management of Decommissioning Low-level Waste	138,355	31%	18,857	31%	157,213
	1200	Management of Decommissioning Exempt Waste and Materials	112,423	25%	16,082	27%	128,505
	1300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0	0%	0	–	0
06		**Site Infrastructure and Operation**	**288,076**	**6%**	**43,989**	**15%**	**332,065**
	0100	Site Security and Surveillance	18,173	6%	2,576	6%	20,749
	0200	Site Operation and Maintenance	132,294	46%	18,682	42%	150,976
	0300	Operation of Support Systems	80,884	28%	13,678	31%	94,562
	0400	Radiation and Environamental Safety Monitoring	56,725	20%	9,054	21%	65,779
07		**Conventional Dismantling, Demolition and Site Restoration**	**789,835**	**17%**	**121,109**	**15%**	**910,945**
	0100	Procurement of Equipment for Conventional Dismantling and Demolition	81,755	10%	14,884	12%	96,639
	0200	Dismantling of systems and Building Components Outside the Controlled Area	158,927	20%	42,308	35%	201,235
	0300	Demolition of Buildings and Structures	414,521	52%	45,306	37%	459,827
	0400	Final Cleanup, Landscaping and Refurbishment	118,900	15%	16,812	14%	135,712
	0500	Final Radioactivity Survey of Site	15,732	2%	1,800	1%	17,532
08		**Project Management, Engineering and Support**	**768,575**	**17%**	**131,153**	**17%**	**899,728**
	0100	Mobilisation and Prepartory Work	0	0%	0	–	0
	0200	Project Management	435,891	57%	64,083	49%	499,974
	0300	Support Services	163,055	21%	25,242	19%	188,297
	1000	Demobilisation by contractors	169,630	22%	41,828	32%	211,457
09		**Research and Development**	**0**	**0%**	**0**	**–**	**0**
10		**Fuel and Nuclear Material**	**0**	**0%**	**0**	**–**	**0**
11		**Miscellaneous Expenditures**	**28,859**	**1%**	**8,297**	**29%**	**37,156**
	0100	Owner Costs	0	0%	0	–	0
	0400	Taxes	0	0%	0	–	0
	0500	Insurances	28,859	100%	8,297	100%	37,156
Total			**4,612,204**	**100%**	**658,755**	**14%**	**5,270,959**

7.2.7 Uncertainties and accuracies

The uncertainties and accuracies differ due to different priorities and are described below. Some of the accuracies are taken into account in the contingencies estimation.

7.2.7.1 Components and structures inventory

The information regarding the inventory of the Oskarshamn NPP is mainly obtained from a comprehensive inventory described in Gustafsson et al. (2006), Bergh (2010), Dahlberg and Eriksson (2009) and Lundin (2009) as stated in Chapter 4.

In those instances where the above inventories fail to include required data, e.g. equipment weights or piping length runs, the corresponding estimates are based on the application of duly justified criteria, assumptions and extrapolations.

Engineering judgement has also been used to fill the gaps encountered in the available information.

The estimated accuracy of the inventory is discussed in Bergh (2010) and Dahlberg and Eriksson (2009). The accuracy of the process components is approximately:

- ± 5% for the components closest to the core, i.e. components in the activity category red.
- ± 10% for the low contaminated components, i.e. in the activity categories yellow and green.
- ± 20% for the non-contaminated components, i.e. in the activity categories blue and white.

The accuracy of the building inventory is made with different priorities:

- Activated or contaminated concrete, reinforcement and embedded plates in the biological shield in the reactor containment have an accuracy of ± 5%.
- Possibly contaminated steel constructions (not reinforcement or embedded plates) in the reactor containment and surfaces in controlled areas have an accuracy of ± 10%.
- Non-contaminated concrete, reinforcement, embedded plates and steel constructions in controlled areas (not reactor containment) have an accuracy of ± 20%.
- Buildings in uncontrolled areas have an accuracy of ± 20%.

The ventilation inventory has an accuracy of ± 10% for contaminated areas and ± 20% for uncontaminated areas.

The accuracy of the electrical systems is at least ± 20%.

7.2.7.2 Activity inventory

The estimated accuracy of the activity inventory is discussed in Jonasson (2012a, b, c). To conclude, the estimated total activity has relatively good accuracy as it depends to a great extent on the neutron induced activity in the internals. The accuracy of the total activity is approximately ± 50%.

If the applied limit for free release will differ from 500 Bq/kg which is the assumed limit in this study, the amount of free releasable waste might change from the quantities presented in this chapter. The experience from Oskarshamn is however that the amount of free-released waste will not significantly change with the new limits for free-released waste. The total amount of active waste depends strongly on which components that can be free released, e.g. components in the turbine building, where surface contamination is relevant only for surfaces that have been in contact with radioactive media. This amount will also be affected by the decay time between shutdown and the start of the decommissioning and of the grade of cleaning of the actual systems. The total amount of active waste estimated in this study thus contains some uncertainty.

A decontamination factor of 10 has been used throughout the study, which is an uncertainty since recent system decontamination campaigns in Sweden has shown a greater decontamination factor than 10.

The reference date for the activity calculations is one year after plant final shutdown, although the actual decommissioning work will start a few years after that. Thus there will be some years of extra radioactive decay time for the nuclide inventory which is good from an ALARA point of view.

Other uncertainties are those instances where estimates, assumptions and extrapolations have been used, as described in 7.2.7.1. Possible future fuel damages or malfunctions are scenarios not taken into account and have to be considered as uncertainties.

7.2.7.3 Waste amount estimation

The waste amount estimation contains the waste volumes of metals, concrete, sand and ion exchange resins from the system decontamination. No soft waste, contaminated or free release, in the form of PPE, decontamination liquids or abrasives from the decontamination of LILW is included. This is treated as an uncertainty.

In case the packing degrees for the different materials changes, the waste volumes will also change. This could have an impact on the volumes sent to SFR and is an uncertainty in the study.

7.3 Techniques and strategies

7.3.1 Segmentation of the reactor internals

Given the complex nature of the reactor internal components and their expected levels of radioactivity, it is proposed that more than one cutting process is used during their segmentation. Each cutting process will be selected on the basis of previous experience and applicability to the various cutting tasks required for successful dismantling.

It is expected that the removal and segmentation of the reactor internals and the subsequent disposal of the reactor vessel itself will be on the project critical path. There is therefore some benefit in completing these tasks quickly, if available processes and radiological considerations allow.

In this study the mechanical cutting techniques described in Chapter 3, constitute the base for the programme presented in Chapter 5 with respect to the segmentation of the reactor internals.

7.3.2 One-Piece removal of the reactor pressure vessel

The one-piece removal is the chosen alternative in this study. As described in Farías et al. (2008), the three intact RPV:s will occupy approximately 2,625 m^3 in the final repository.

7.3.3 Process equipment size reduction off-site

As described in Chapter 3, process equipment waste may be size reduced off-site through e.g. melting. The alternative of size reduction off-site is throughout the study taken as an example of an alternative treatment of some of the process waste.

Studsvik is used as an example of a licensed company that performs melting of radioactive waste. For Studsvik to be able to handle scrap or components for direct treatment there is a surface dose rate limit of < 0.2 mSv/h and a specific activity limit of < 5×10^5 Bq/kg.

The process equipment waste from the Oskarshamn NPP that fulfills the criteria stated above weighs 4,637 tonnes and equals 282 ISO-type containers. The total activity in the waste is approximately 5.8×10^{11} Bq. All of this waste comes from the Oskarshamn NPP.

Assuming a 75% weight reduction, 25% of the melt will contain all the activity and will need to be sent to SFR. The density of the melt metal is so high that it is assumed that the maximum weight capacity of the container, 18 tonnes, is reached.

The reduction of the number of ISO-type containers sent to SFR, by melting, gives an increased cost of 133 MSEK. These figures include the cost for transporting and melting the waste at the Studsvik melting facility, which is 140 MSEK, and the decreased container cost of 6.5 MSEK. However, the figures do neither include the transports to nor the reduced disposal cost in SFR.

Abbreviations

ALARA	As Low As Reasonably Achievable – dose minimisation philosophy
APRM	Average Power Range Monitoring
AWJC	Abrasive Water Jet Cutter
BFA-Tank	Container for core components
BNFL	British Nuclear Fuel Limited
BWR	Boiling Water Reactor
CITROX	A chemical decontamination method named after its main chemical reagent, a mixture of Citric Acid and Oxalic Acid
CLAB	The Swedish Central interim storage facility for spent nuclear fuel at Oskarshamn
CORD	Chemical Oxidation Reduction Decontamination – Siemens proprietary chemical decontamination process
CS	Carbon Steel
CSH	Core Shroud Head
DF	Decontamination Factor
DfD	Decontamination for Decommissioning – an EPRI licensed chemical decontamination process
DN	Nominal Diameter
EC	European Commission
EIA	Environmental Impact Assessment
EIAD	Environmental Impact Assessment for Decommissioning (as per EU Directive 97/11/EC)
EIS	Environmental Impact Statement
EPRI	Electric Power Research Institute
EW	Exempted Waste
F1	Forsmark 1
F2	Forsmark 2
F3	Forsmark 3
FRW	Free Release Waste
HEPA	High Efficiency Particulate Air (filter)
HLA	Facility for handling of low level waste at Oskarshamn
HP	Health Physics
IAEA	International Atomic Energy Agency
ICFM	In Core Fuel Management
ILW	Intermediate Level Waste
IRM	Intermediate Range Monitoring
LILW	Low and Intermediate Level Waste
LLA	Facility for storage of low level waste at Oskarshamn
LLW	Low Level Waste
LOMI	A chemical decontamination process; the name is an acronym of Low Oxidation-State Metal Ion
MDM	Metal Disintegration Machining
MLA	Ground repository for low level waste at Oskarshamn
NPP	Nuclear Power Plant
NWC	Natural Water Chemistry
O1	Oskarshamn 1
O2	Oskarshamn 2
O3	Oskarshamn 3
OFC	Oxy-fuel cutting

OECD/NEA	Organisation for Economic Co-operation and Development/Nuclear Energy Agency
PAC	Plasma Arc Cutter
PPE	Personal Protective Equipment
PRM	Power Range Monitoring
RPV	Reactor Pressure Vessel
SEK	Swedish Currency (Krona)
SF	Site Factor
SFL	The Swedish Final Repository for Long-lived Low and Intermediate Level Waste
SFR	The Swedish Final Repository for Short-lived Low and Intermediate Level Waste
SKB	Swedish Nuclear Fuel and Waste Management Co (Svensk Kärnbränslehantering AB)
SS	Stainless Steel
SS	Swedish Standard (Svensk Standard)
SSM	Strålsäkerhetsmyndigheten (*Swedish Radiation Safety Authority*)
STAL	Stal-Laval, Turbine Supplier
STF	Säkerhetstekniska driftförutsättningar (*Safety Operation Conditions)*
SRM	Source Range Monitoring
TIP	Traversing In-core Probe
TONNE	Metric ton (1,000 kg)
WAGR	Windscale Advanced Gas Reactor – UK gas-graphite research reactor decommissioned late 1990's to mid 2000's
WBS	Work Breakdown Structure
WPPF	Waste Processing and Packaging Facility
VS	Heating and Sanitation (Värme och Sanitet)

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1359832 ver 1.0	Avveckling och rivning av kärnkraftblock. (In Swedish.)	SKB, 2012

Appendix 1

Dismantling and waste management techniques

A1.1 In situ decontamination

Most Light Water Reactor decommissioning projects carry out a chemical decontamination of all major coolant systems prior to the start of main dismantling activities. The aim of this activity is to reduce radiation doses in the area of these systems, thereby reducing overall project man-dose in line with ALARA (As Low As Reasonable Achievable) principles.

Chemical decontamination of the major fluid systems using processes such as LOMI (Low Oxidation State Metal Ion) or CITROX (Citric Acid and Oxalic Acid) is often carried out during the operational life of a plant with the aim of reducing radiation dose rates during refueling and maintenance activities. The processes used after plant shutdown differ from those used operationally in that they are more aggressive, producing decontamination factors (DF) of up to 100 compared to a DF of 10 which is considered adequate for an operational decontamination (though a conservative DF of 10 may be assumed for the purpose of planning a decommissioning decontamination) . The higher decontamination factors are achieved by removing a small layer of the base metal of the circuit inner surface, as well as any corrosion film. Clearly, this would not be acceptable on a plant that had remaining useful life.

Two main competing processes are commercially available to carry out a decontamination of this type, the Electric Power Research Institute (EPRI) Decontamination for Decommissioning (DfD) Process; and the Siemens Chemical Oxidation Reduction Decontamination (CORD) Process and variations of it. Both have been used on decommissioning projects to the satisfaction of the plant owners. Both are employed on site in a similar manner. However, the two systems are very different chemically, as described in EPRI (1999).

No detailed comparison has been made of the full practical capability of the two systems. The nearest is a document commissioned by EPRI comparing the application of the EPRI DfD at Maine Yankee with the application of a variant of the Siemens CORD system known as CORD D UV (CORD Decommissioning Ultra-Violet) at Connecticut Yankee (EPRI 1999). This comparison is not complete, as the D=Decommissioning part of the CORD process, the part that removes a thin layer of base metal, was not applied due to equipment problems. However, it was judged that an acceptable decontamination factor had been achieved without this part of the process.

A simple comparison of the results of these two projects and the primary circuit decontamination of Big Rock Point and of Barsebäck 1 and 2 is shown in Table A1-1.

Table A1-1. Comparison of Key Results from Various Full Circuit Chemical Decontamination Projects (EPRI 1999, Jönsson 2008).

Plant	Method	Processing Time (days)	Time on Site (days)	Overall DF	Spent ion exchange resin produced (m^3)
Big Rock Point	EPRI DfD	15	~ 63	27	16.4
Maine Yankee	EPRI DfD	20	~ 71	31.5	17.7
Connecticut Yankee	Siemens CORD	25	~ 122	15.9	13.2
Barsebäck 1	Siemens CORD	11		298	5
Barsebäck 2	Siemens CORD	11		93	4

It can be seen in the comparison between the USA plants that the EPRI DfD process achieves a higher DF in a shorter time than CORD but produces a greater volume of Ion Exchange Resin. But compared to the decontaminations project in Barsebäck Plant the DF factor is much lower. The difference between Barsebäck 1 and 2 is due to the fact that Barsebäck 2 has been through a decontamination project before this project. All the internal parts were removed from the Barsebäck 1 and 2 Reactor Vessel. As part of any real decommissioning project there will be other factors that need to be considered before a preferred technique is selected.

The decontamination at Big Rock Point included the Reactor Vessel (with the internals removed), the circulation piping and pumps, the Steam Drum, the Shutdown Cooling System and the Reactor Water Cleanup System. It is envisaged that a similar decontamination scope would be adopted at Oskarshamn modified to suit the different design of the plants.

The actual DF achieved is variable depending on the initial surface contamination level.Table A1-2 shows the variation of the DF achieved against the Initial Contact Dose Rate based on experience at Maine Yankee.

Table A1-2. Average contact DF by Radiological Significance, Maine Yankee.

Initial Contact Dose Rate	DF
> 10 mSv/h	107.1
5 to 10 mSv/h	169.5
1 to 5 mSv/h	24.5
< 1 mSv/h	5.2

A1.2 Reactor internals segmentation

Given the complex nature of the Reactor Internal components and their expected levels of radioactivity, it is proposed that more than one cutting process is used during their segmentation. Each cutting process will be selected on the basis of previous experience and applicability to the various cutting tasks required for successful dismantling.

It is expected that the removal and segmentation of the Reactor Internals and the subsequent disposal of the Reactor Vessel itself will be on the project critical path. There is therefore some benefit in completing these tasks quickly, if available processes and radiological considerations allow.

The radiological condition of the internal components will require that they are segmented remotely underwater, probably in the Reactor Internals storage pools. Ease of cutting process deployment and recovery from fault conditions should also be considered in selection of processes.

Thermal techniques are generally faster than mechanical techniques in terms of both cutting and deployment speed and have been the preferred cutting technique for reactor internals segmentation in the USA. They are also non-contact, non-reaction force techniques, which assists their remote deployment as there is no need for bulky reinforcing of deployment systems. This, coupled with the fact that these techniques can cut in any direction (compared to blades which cut only in the direction the blade is facing) makes them highly maneuverable and well suited to cutting complex geometric structures.

However, thermal techniques have disadvantages in that the off-gases from the process need to be captured if airborne contamination levels are to be controlled and, more significantly, the off-gases can drive activated cutting debris up to the surface of the water during cutting. For this latter reason, mechanical cutting techniques are typically used in Sweden for segmentation of the reactor internal components.

Abrasive Water Jet Cutting techniques are another technique typically used for segmentation of the higher activity reactor internal components. Abrasive Water Jet Cutting (AWJC) techniques do not drive material to the surface and also have the advantage that they can cut very thick metal sections. However, AWJC is slower than thermal techniques and also requires the introduction of a cutting abrasive material such as garnet, which results in an additional waste stream. In extreme cases the quantity of abrasive material may reach unacceptable levels.

In addition to these techniques, Metal Disintegration Machining (MDM) will be used to remove bolts where necessary or advantageous, unless the bolts were routinely removed during operation/maintenance in which case they may simply be unbolted. Simple hydraulic shears will also be used to cut any slender sections such as small tubing etc.

While thermal/hydraulic cutting methods have generally been used in the USA, European projects have tended to use mechanical cutting processes. In the following sections, the mechanical cutting processes are discussed.

Mechanical techniques

A predominantly mechanical cutting methodology was adopted, for the BR-3 PWR decommissioning project in Belgium and a number of mid-life BWR reactor internals segmentation projects in Sweden and Finland.

Mechanical cutting has a number of general advantages over thermal/AWJC techniques. It produces no fumes and requires no cutting or fuel gas, both of which can bring radioactive material to the water surface resulting in the need to provide local ventilation at the water surface. Any secondary wastes produced are in the form of spent cutting blades, of which relatively few should be required and cutting swarf which will be in relatively large pieces which are easily collected. These larger pieces of cutting debris have less potential to disperse through the Reactor Pool water than is the case for thermal/AWJC debris, thereby reducing the potential for spread of contamination and reduction in visibility.

This reduction in visibility can have an adverse effect on the project programme if steps are not taken to manage waste arising, as time will be lost while water clarity is restored to allow segmentation to continue. The use of local containment measures, such as a segmentation cubicle helps prevent this occurring and causing a problem. These measures have been used on recent thermal segmentation projects and have proved successful in preventing the visibility problems that occurred on earlier projects. However, if mechanical segmentation techniques are used, the requirement for such local containments may be reduced or even become unnecessary.

The thermal and AWJC techniques make use of commercially available tools, though deployed via a purpose built deployment system. In the case of mechanical cutting tools it is more likely that custom built tools as well as the deployment system will be required, though it is noted that these tools employ relatively simple technology that should mean they are easy and cheap to produce and easy to use.

In the case of decommissioning work in Sweden there is also the specific advantage that there is experience of these techniques available within the Swedish nuclear industry. Use of mechanical techniques will not require new techniques to be learned or the import of expertise of abroad.

Mechanical internals segmentation techniques

The two main mechanical segmentation techniques used are shearing and sawing.

Shearing has the significant advantage that it produces no secondary wastes in the form of swarf or other cutting debris. The only secondary wastes likely to be produced are spent blades (though blade wear rates are typically low so the blades will not need to be replaced often) and possibly the shear tool itself upon completion of the project (if it cannot be decontaminated).

Shears are generally hydraulically powered and their cutting capacity varies with the design, though the ability to cut solid bar of up to 25 mm (1 inch) diameter or 65 mm (2.6 inch) diameter heavy wall tubing would be typical. Round or rectangular cross-sections can be cut.

Sawing techniques employ two main types of saw; circular saws and band saws. Both have been used on internals segmentation projects though the band saw appears to have greater flexibility as it is easier to deploy, has a greater cutting speed and produces less swarf than the circular saw.

Mechanical internals segmentation equipment

Shear tools

For cutting of long, slender items such as bars or tubing and for the cutting of the relatively thin sections of core support grids, sawing is not required as these sections can be cut with hydraulic shears. The main advantage of using shears in this situation is that they produce no secondary wastes during the cut. The shears will be designed specifically for the task to be performed to ensure that the cut is clean in every case and to ensure that the shear is easy to locate on each of the various pieces to be cut.

Figure A1-1 and Figure A1-2 show a hydraulic shear being used to cut the Core Spray and the Core Grid at the Forsmark Nuclear Power Plant during a mid-life refit. This shear has been designed specifically for cutting the 8 mm thick plate sections making up the grid. The tool was operated by two people and used to make around 340 cuts in the grid to the remove the grid structure itself leaving only the outer ring of the support grid, which was subsequently cut using a band saw.

The light shearing tool, with a weight of 40 kg, is a standard tool from the sub-supplier Nike Hydraulics. The connection in the top is designed by Westinghouse. The tool cuts pipes with a maximum dimension of 90×2.5 mm and flat bars with dimensions of 100×8 mm. The three different types of cutting blade can easily be replaced. The cutting force at 700 bar is about 314 kN. Other similar tools will be required for cutting bars, tubing and other sections of the internals.

The heavy shearing tool is used for tubes and flat bars with larger dimensions. The tool that weighs about 210 kg has been tested and used for cutting highly neutron radiated pipes with dimensions of 120×4 mm and flats bar of dimensions 130×10 mm. Because of the expensive cutting blades the tool maximum capacity has not been fully tested. An estimate is that tubes of dimensions 130×5 mm and flat bar of 140×12 mm, in material AISI 304, neutron radiated, could be cut by this tool. The tool has been used to cut flat bars and tubes on two complete core sprays without the need for replacement of the cutting blades. The cutting force at 800 bars is about 1,000 kN.

Hydraulic shears were also used to segment reactor internals at the BR-3 PWR decommissioning project in Belgium, where it was found that it was possible to use them as long handled tools at distances of up to 7 m.

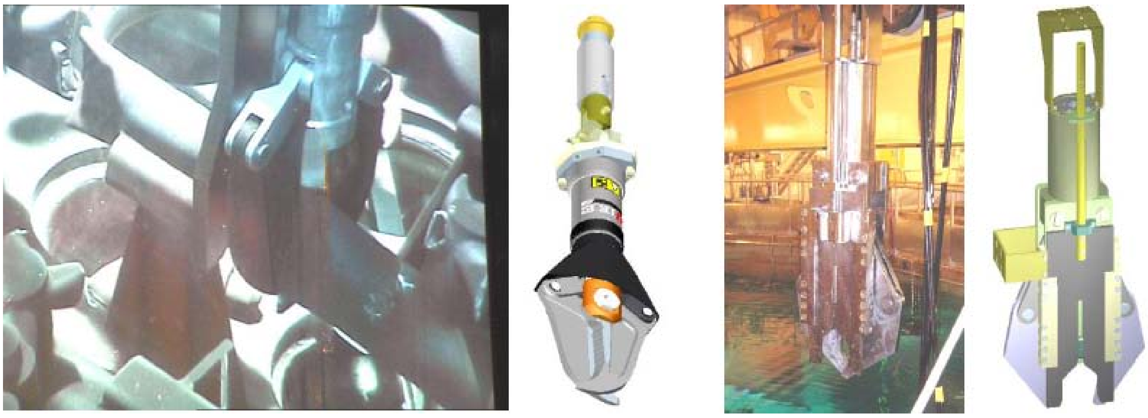

Figure A1-1. *Shearing tools used to cut the core spray system and flat bars on the core grid.*

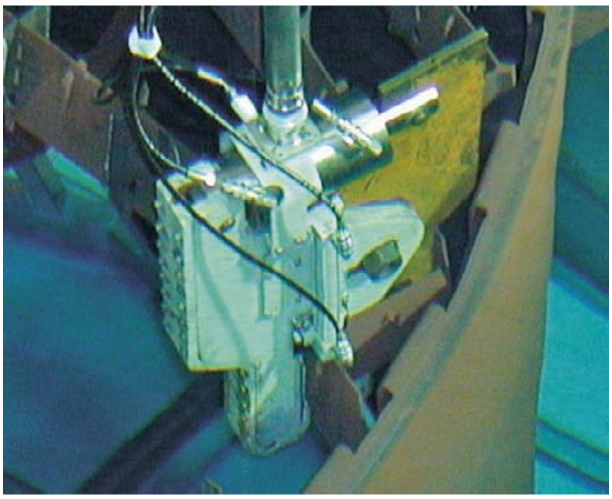

Figure A1-2. *Hydraulic Shears being used for cutting of the Core Grid removed from the Forsmark Nuclear Power Plant.*

Saws

For the more extensive and complex cutting operations, saws will be used. Two main types are available; band saws (as used on the Forsmark internals in Sweden) and circular saws (which were used for horizontal cuts at BR-3 in Belgium; the vertical cuts being made with a band saw).

Band saws

The band saws used at both Forsmark and BR-3 were of generally similar design as can be seen in Figure A1-3. Both saws consisted of a 3 sided square steel framework (the fourth side being left open) with 4 rollers, one on each corner of the framework. The saw is fed around these rollers and in both designs passes through blade guides on either side of the open side of the framework. The blade guides are adjustable to provide pre-tension of the saw blade and can also be rotated to allow the blade to be rotated through 90 degrees at the cutting position, which allows the saw to make vertical cuts as well as horizontal cuts. For those operations where the saw was required to change from vertical to horizontal cutting while the blade was in the work piece, a suitably sized hole was made beforehand using an MDM, the change of blade angle being made while the blade was in this hole. The dimensions of the frame in each design dictated the maximum size of each removed piece.

The most significant difference between the two band saws used on these projects was the deployment method, the Forsmark saw being mounted on a rotating arm and used to cut a fixed workpiece, while the BR-3 saw was held in a fixed position and cut a workpiece which rotated on a turntable.

Cutting speed naturally varies with the thickness of the material being cut. BR-3 reported speeds varying from 0.005 m/min for cutting of 200 mm thick sections, up to around 0.04 m/min for cutting of 1.65 mm sections. This is less than one tenth of the speed that can be achieved on similar sections using Plasma Arc Cutters, though the overall production rate, once time for preparation and waste management is considered, may show a lesser difference. The cutting is about 15–25% of the total time for the whole segmentation project on site.

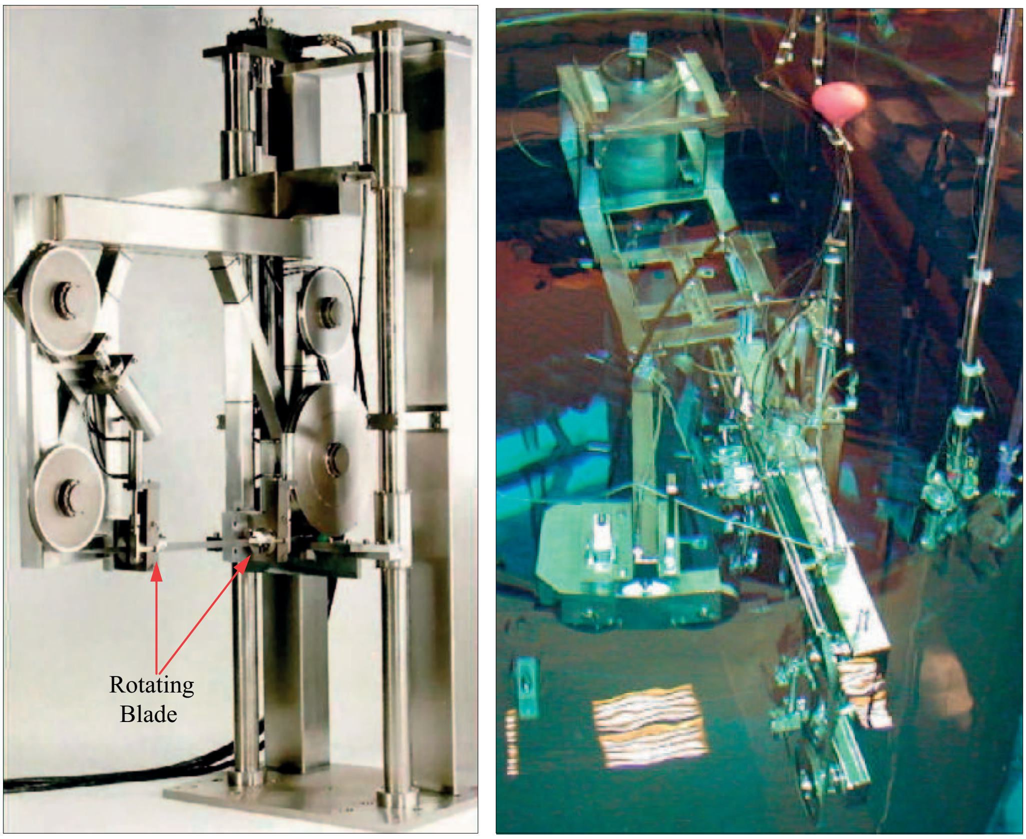

Figure A1-3. *Manufacturers photograph of the BR-3 Band Saw (left) and the Forsmark Band Saw being used to segment the Core Shroud (or Moderator Tank).*

Circular saw

Circular saws were used at BR-3, Forsmark and TVO to carry out horizontal cuts. The saw itself was mounted on a fixed extension to a turntable. The workpiece to be cut was mounted on the turntable and rotated during the cut. The saw itself could be moved up/down to enable cuts to be made at the correct location. It could also move in/out to cut deeper into the workpiece. The cutting tools that Westinghouse is using are based on equipment from Braun. One example is their wall saw, a BWS 15, with rail and clamps mounted to a fasting frame, designed by Westinghouse. Depending on the situation for the actual internal the fastening frame design has to be different. A Braun BTS 8 cutting machine has also been used.

Westinghouse has used disc saw cutting in the TVO segmentation in 2005 and the results were good, see Figure A1-4. Substantial testing has been performed since then and for the segmentation in Forsmark in 2010–2012 disc cutting will be the chosen technique for cutting of steam dryers. Disc sawing will also be used for some cuts on the core shroud head and almost all cuts on the core spray support frame.

Various sizes of blades can be used, as dictated by the cut. A maximum cut depth of 230 mm is achievable using the larger diameter (660 mm) blade, though the maximum cut in any single pass is 25–30 mm. For thinner sections, the cutting speed is similar to that for the band saw, but is slower by comparison for thicker sections. It is also noted that the circular saw produces more secondary wastes than the band saw as a thicker blade is required (6 mm compared to 2 mm). Experience from segmentation projects in Swedish Plants shows that the circular saw normally has a cutting speed of 1–200 mm/min for 10 mm plates and 1–25 mm/min for 50 mm plates.

The cutting or reaction force required for the circular saw is ~7,500 Nm compared to ~800 Nm for the band saw. This may be of significance during deployment of the saws for some cuts as the band saw is likely to require a less rigid deployment system which may allow a more versatile deployment system to be developed.

The tube cutter

The tube cutter in Figure A1-5 is used to cut the steam separator tubes on the core shroud head (CSH). The tube cutter is inserted in to the tube and cuts from the inside and out at a specific level above the CSH spherical surface. To fit different dimensions of tubes some parts can be replaced.

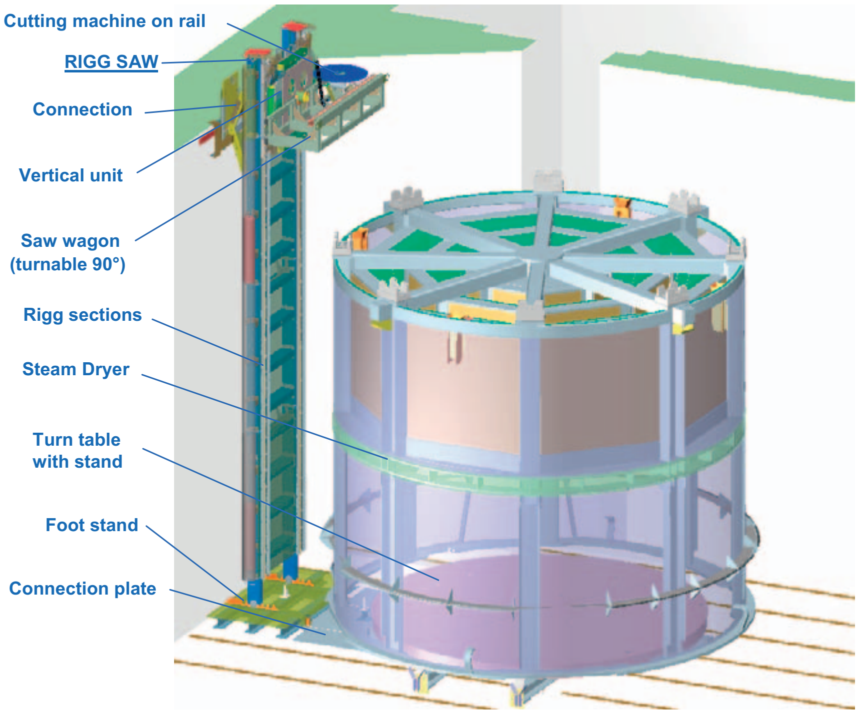

Figure A1-4. *Rig saw with a disc saw mounted to cut the Steam Dryer.*

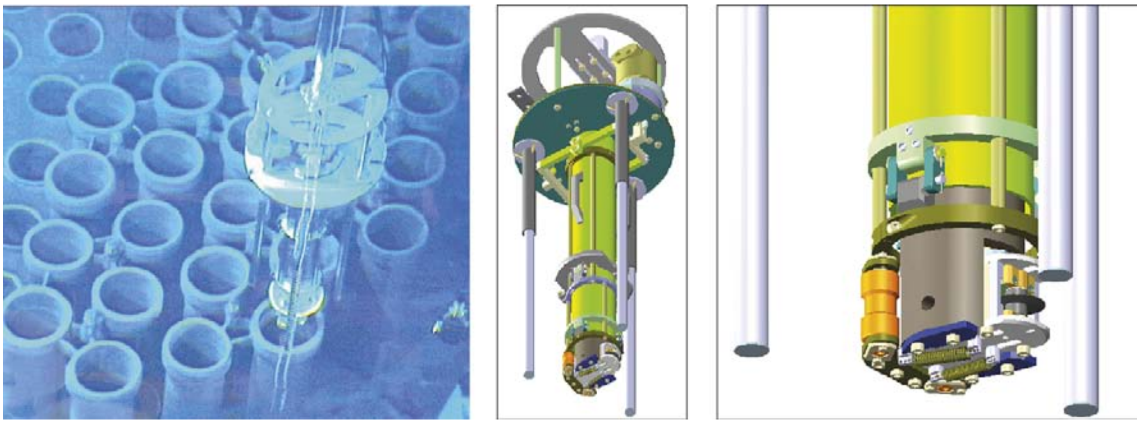

Figure A1-5. *The tube cutter is positioned above the CSH piping. 3D-model views of the tube Cutter.*

All power for clamping to the tube, rotation and forcing out the cutting wheel are done hydraulically. The development and design are done by Westinghouse.

The CSH tube is cut in about 20 min. The cutting wheel is normally replaced after 4–6 cuttings.

Other tools

As well as the shears and saws, which would carry out the main cutting operations in a mechanical segmentation strategy, other smaller tools will be required for specialist tasks.

The BR-3 project made some use of a pneumatically driven reciprocating saw which was fastened at only one end of the blade. This has a significant advantage over the band saw for certain particular tasks in that it only needs access to one side of the workpiece. As with the circular and band saws used on this project, the reciprocating saw was a purpose built piece of equipment.

MDM machines and drills may be required to make starter holes for cutting operations, or holes to allow the band saw to change cutting direction. In addition, MDM may be used to remove bolts, particularly those that have been welded in place, to allow the internals to be split into pieces for easier segmentation.

The existing tools for reactor servicing will also be used for disassembly of the reactor internals in the same way as is carried out during operational maintenance.

Other equipment in the form of support stands, specialist slings and rigging, grabs etc may also be required. In general this equipment will be similar to that required if thermal segmentation techniques are used.

Mechanical internals segmentation resources

Reactor Internals segmentation is typically carried out by specialist contractors who deploy a fully trained project team on site. Based on previous projects, a typical contractor site team for each unit during the entire on-site phase of the project would be as follows. The site team would be supported by off-site project management, engineering, ALARA advice etc during the pre-site and on-site phases:[10]

Quality Assurance Engineer – The project quality engineer develops and verifies compliance with the Project Quality Plan. He verifies compliance with all project specifications and maintains inspection and training records. In addition, the quality assurance engineer maintains equipment and personnel proficiency qualification records. When the project mobilizes on site, there will be one (1) QA Engineer assigned per shift.

[10] Information from the Westinghouse Electric Sweden SEM department.

Site Operations Manager – The site operations manager is directly responsible for the field implementation of the project work scope. His responsibilities include the safe and timely installation and operation of all project equipment assigned. He is responsible for the interfaces at site between the cutting contractor, subcontractors, and the utility. He maintains all project time sheets and site logs. The site operations manager maintains a point to point contact between site and the off-site Project Manager. All cutting contractor site personnel and subcontractor supervision assigned to the project report directly to the Site Operations Manager.

Machinist Technicians – The machinist technicians install and operate all cutting equipment. They also maintain and repair all mechanical equipment on the project. Under the direction of the foremen, they rig and move all cut pieces to the proper disposal containers according to the work description. The number of machinist technicians will be variable depending on the number of concurrent works areas, number and types of equipment to be deployed etc.

A typical organization diagram is therefore as follows in Figure A1-6.

A1.3 Reactor pressure vessel

Global experience for the reactor pressure vessel (RPV) disposal has largely been dependent upon the size and weight of the vessel to be disposed of as radioactive waste and the access to a radioactive waste disposal facility that will accept large components.

In the USA, most large Light Water Reactor (LWR) vessels, such as Big Rock Point, Yankee Rowe, Maine Yankee and Trojan, have been qualified as their own shipping containers and were therefore not segmented and packaged for disposal. Where segmentation has been carried out there are two main techniques that seem to be favorable; thermal or mechanical cutting.

In the following section, the One-Piece Removal is discussed and it is on this option the report is based.

One-piece removal of the RPV

The study (Farías et al. 2008) describes how the vessel can be taken out from the building with the help of a crane. The fuel, all of the internal parts and the water are first removed from the vessel. The crane is a Mammoet MSG 80 with a capacity of 1,200 tonnes, see Figure A1-7. The crane is placed on a rail and can rotate 360 degrees. The lifting speed is approx 10 m/h. The force to the ground can be up to 50 tonne/m^2 and therefore it is necessary to reinforce the ground. In other studies an alternative of handling the RPV is described by lifting the RPV through the wall.

To make the RPV reachable for the crane there must be an opening at the top of the reactor building. The lifting device will be attached to the RPV before the RPV will be released from the suspension device which holds the RPV in place in the building. The dismantling techniques will be the same as for the segmentation. A protection against radiation will be placed around the RPV before it is removed from the building.

The time for dismantling and removal of the RPV will approx take 10–15 weeks.

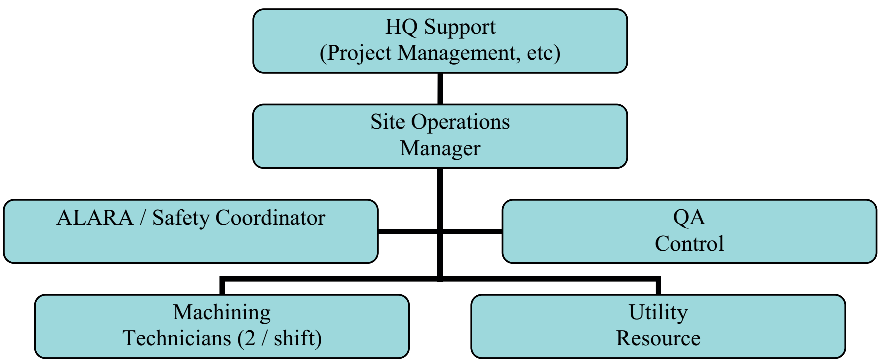

Figure A1-6. *Typical mechanical Internals Segmentation Contractor Site Organization, for one unit.*

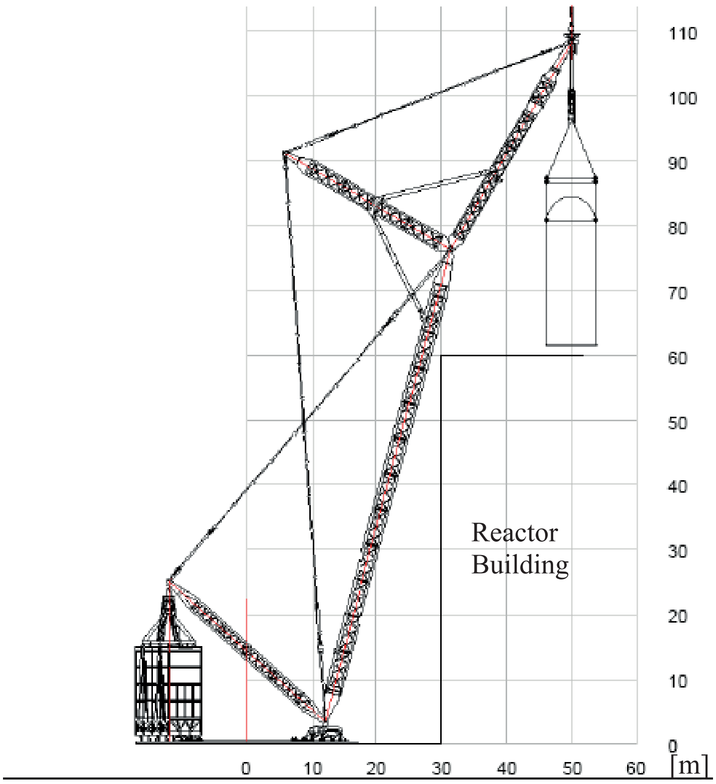

Figure A1-7. Lift of a RPV with a Mammoet MSG 80.

A1.4 Pipework

Large diameter pipework

A number of techniques are available for segmentation of large diameter pipework. The preferred technique will generally be selected on the basis of the radiological condition of the pipe to be cut and the working area around it.

For higher dose rate areas it is generally preferable to use techniques that can be quickly set up on the pipe and then remotely operated by the decommissioning personnel from a lower dose rate area. A number of these "non-contact" techniques are available. For lower dose rate working areas contact working methods are acceptable.

Clam shell pipe cutter

Clam Shell Cutters, or split frame pipe lathes as seen in Figure A1-8 and Figure A1-9, are a reasonably inexpensive mechanical method for cutting large bore pipes. They are ideal for cutting highly radioactive pipes and reactor vessel nozzles, and produce a sufficiently good quality cut so that end caps or other features can be welded onto the cut pipe with minimal additional preparation.

From a radiological standpoint they are desirable since they are not surface destructive and do not generate the airborne radioactivity or fume associated with thermal cutting methods. They are also quickly installed and allow the operator to move away from the workpiece during the cut, thereby avoiding unnecessary dose. The cutters require a radial clearance of 180 mm around the pipe to allow the cutting tool to move around the pipe and make the cut.

From a safety point of view, the cutters do not generate flames or applied heat, and therefore do not require a fire-watcher as part of the work team. They are also easy to use and quick to train operators in their use, compared to thermal cutting devices.

For decommissioning work in lower dose rate areas the clam shell cutters are less appropriate for thick components and do not cut as fast as plasma and oxy-fuel cutters. The overall time for each cut is longer than for hand held thermal cutters because of the set up time required. Table A1-3 provides information regarding one High Speed Clam Shell Cutter from Tri-Tool.

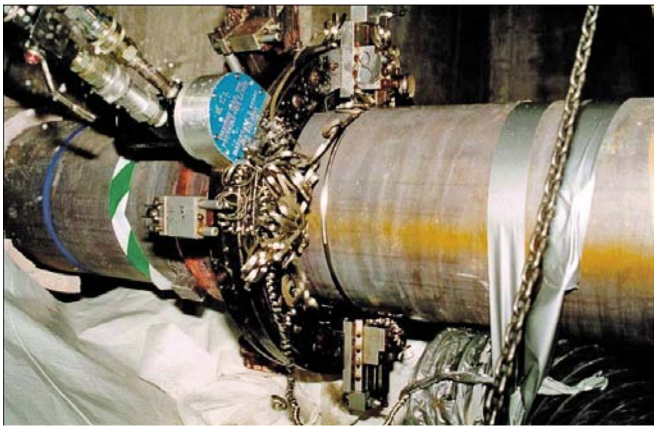

Figure A1-8. *"Clam Shell" pipe cutter in operation.*

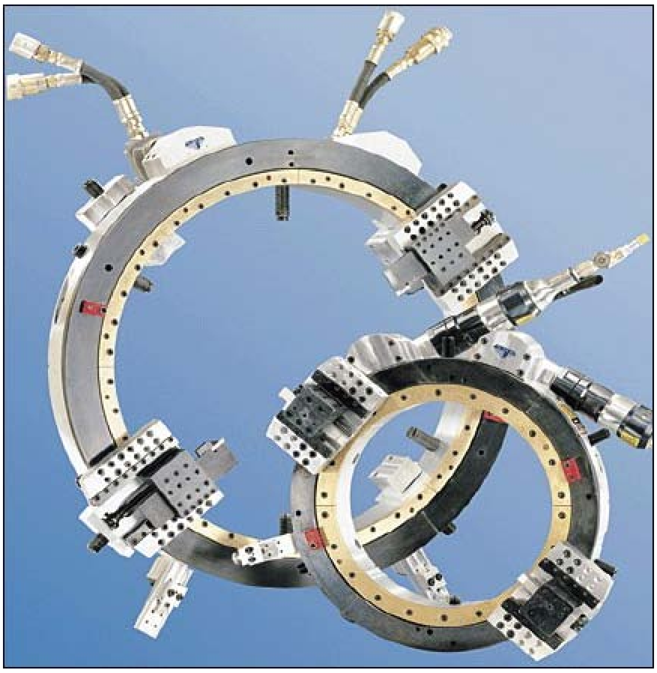

Figure A1-9. *Manufacturers photograph of clam shell cutters.*

Table A1-3. Information regarding Tri-Tool Inc high speed clam shell cutter.

Item	Tri-Tool Inc High Speed Clam Shell Cutter	Notes
Manpower Requirements	2 Operators	Plus labor as required to handle waste material
Equipment Cost	$25,300 for 460 to 610 mm (18 to 24 inch model) plus $12,500 for power pack, hoses etc	1998 values equipment can be rented at approx. one-fifth purchase cost per month
Capacity/performance	250 mm to 1.22 m (10 to 48 inch)and above 16 min for 610 mm (24 inch) diameter cut 16–24 min dismantle/set up time between cuts	No production rate data (other than that shown left) is available for this tool. However, based on the figures shown, a production rate of 5–6 large diameter cuts per day would appear reasonable.
Utility Requirements	240 / 440 V AC for the power pack	Internal batteries last 0.25 hrs of continuous operation, add on auxiliary battery provides an additional 0.8 hrs.
Weight	94 kg	
Secondary Wastes	Metal swarf	
Contact	www.tritool.com	Swedish distributor is SA Svetsteknik AB. Rimbo. +46 0 175 72323

Diamond wire saw

As an alternative to the Clam Shell Cutter, diamond wire saws can be used. These would be used in situations where contact working would not be advisable and there is either not enough space around the pipe to install a Clam Shell Cutter or where the pipe wall thickness is greater than the Clam Shell capacity.

The use of wire saws to cut metals is less common than for cutting concrete (see Appendix 1.6) and tends to be used in particular situations, e.g. when contact working is not preferred due to radiological conditions and the metal to be cut is beyond the capability of clam shell cutters. Because of this, and the fact that it is a relatively recent application of the wire saw technique, little comparative data is available.

As an example, the San Onofre Unit 1 Reactor Vessel nozzles were cut using diamond wire saws, see Figure A1-10.

Thermal cutting

Plasma Arc Cutting can also be applied to pipework removal, in particular the use of hand-held or tracked plasma cutters.

Clearly, production rates will be highly variable depending on pipe size, and perhaps more importantly, the working conditions such as confined spaces, work at height etc. For larger pipework sizes, oxy-fuel cutting tends to be more productive that plasma cutters though it produces more fume. Production rates of 0.65 man-hours per meter of pipework have been reported for oxy-fuel cutting.

A Track Cutting System for Plasma or Oxy-Fuels is illustrated in Figure A1-11.

Figure A1-10. *San onofre unit 1 reactor vessel nozzles after cutting with a diamond wire saw.*

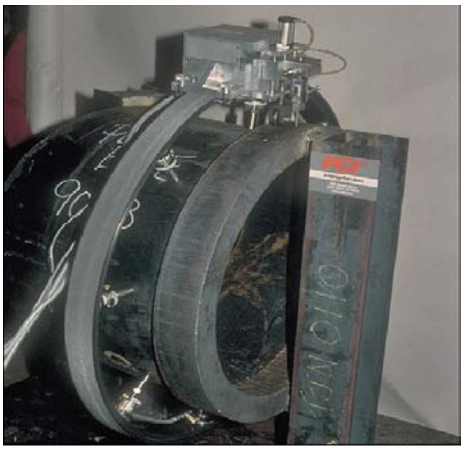

Figure A1-11. *Track cutting system for plasma or oxy-fuels.*

Small diameter pipework

Mechanical shears

A suitable tool for cutting of small-bore pipework and other similar sized steel supports, uni-strut etc, is the Mechanical Pipe Shears. They were developed as an alternative to the more common reciprocating blade cutters. There are a number of different devices available.

The Mega-Tech Services Inc. Blade Plunging Cutter BPC-4, see Figure A1-12 and Figure A1-13 was used extensively during the decommissioning of the Big Rock Point BWR. It is a hydraulic power cutting tool capable of cutting ~75 mm (3 inch) pipework and above. It has a 100 mm (4 inch) blade and is a piston-forced plunging cutter. The cutter weighs approximately 12.7 kg (28 pounds) and is 710 mm (28 inches) long. It requires one operator.

It is powered by a trolley mounted Hydraulic Power Unit which powers the tool with an operating pressure between 5,000 and 6,000 PSIG. The Hydraulic Power Unit requires 3 phase 440VAC/ 20 amps, and it weighs 159 kg and can be located remotely from the cutter, for example, in a non-contaminated area.

Information regarding the Mega-Tech Blade Plunging Cutter is given in Table A1-4.

The advantage of this type of cutter is that it offers a higher production rate than other methods of pipe cutting such as reciprocating saws. It also produces no secondary waste in the form of metal swarf or other cutting debris. It is also safer and quieter than other devices.

Its main disadvantage is that its weight makes it difficult to use above waist height (though it can be slung from a suitable support point and it can be hooked over the pipe being cut). Its weight also makes it heavy for continued use by the same operator.

The Mega-Tech Service Inc machine is a mainly electric powered device. Battery powered models are also available though the battery increases the weight. The battery is typically worn on a belt.

Table A1-4. Information regarding Mega-Tech Blade Plunging Cutter BPC-4.

Item	Mega-Tech Blade Plunging Cutter BPC-4	Notes
Manpower Requirements	1 Operator	Plus labor as required to handle waste material
Equipment Cost	$31,000	2001 values
Capacity/performance	Up to 75 mm (3 inch) pipe 46 sec. for 50 mm cut 20 sec. for 25 mm cut	Typical reported production rates for mechanical cutting of small pipework are ~1.0 man-hours per meter of pipe removed (including waste handling)
Utility Requirements	3-phase 440V AC / 20 Amps	
Weight	12.7 kg for the cutter plus 159 kg hydraulic power pack	
Secondary Wastes	Spent cutting blades	
Contact	Mega-Tech Services Inc	2804 Woodley Court, James Town, NC 27282, USA

Figure A1-12. Mega-Tech Services Inc. blade plunging cutter.

Figure A1-13. Mega Tech Blade Plunging Cutter being used to cut 2.5 inch OD pipe.

Portable Saw

Portable reciprocating saws use the mechanical action of a hardened steel saw blade to cut metals. The major advantage of this type of tool is the absence of the fumes produced by thermal cutting. Saws are usually used for cutting soft metals such as carbon steel, aluminum or copper.

The saws can be operated by clamping them onto a work piece and using the weight of the device to advance it into the metal. Saws may be electric or pneumatically powered and can be set up to operate without operator assistance.

Portable powered hacksaws that can cut piping up to 300 mm in diameter are available. A 200 mm pipe can typically be cut in around 6–8 minutes; a simple rule of thumb is that such saws take a minute for each inch of pipe diameter (based on Schedule 40 pipe).

A1.5 Other steelwork

Other steelwork will generally be segmented using one or more thermal or mechanical techniques. The final selection will generally depend upon the location and size of the steelwork to be cut.

Some steelwork items may also be removed efficiently and safely by dismantling, particularly auxiliary structural items such as stairs and platforms that were originally assembled using bolts. Powered nut-runners such as those used in car workshops may be used to remove bolts quickly for disassembly. This does not reflect a need to remove these items intact but the fact that they may often be removed quicker and with less secondary waste in this way than by cutting them in situ.

In the case of surface contaminated steel work, sprayed coatings may be applied to fix contamination prior to dismantling in order to minimize generation of airborne contamination.

Production rates for steelwork removal have been reported as around 11 man-hours per tonne contaminated steel and 3.6 man-hours per tonne for clean material.

Ventilation

Ventilation ducts etc will be removed by unbolting (or disassembly appropriate to the duct construction) where the ductwork construction makes this possible.

Contaminated ductwork will be sprayed with contamination fixing spray coatings and then removed by unbolting the duct sections. The removed sections will then be crushed flat for packaging. The duct sections will only be cut where the size or geometry of the removed section makes it too big for packaging in the selected container. Where necessary, cutting will be carried out using shears or saws.

Clean or very lightly contaminated ducting may be cleaned by wiping if this will be sufficient to allow release. Other more aggressive techniques may be applied depending on the cost benefit and the availability of appropriate waste disposal routes.

Cables etc

Segmented cables and cable trays etc will be removed by first ensuring that the cable is safely isolated from the system and then segmenting it using heavy duty cable cutters (similar to bolt cutters) into lengths suitable for disposal as required. Even in relatively high contamination areas, plastic sheathed cables represent an opportunity for recycling of a relatively high value scrap material as the copper cable itself is protected by the plastic. Cable clips can be cut to release the cable from the tray, the cable can then be wiped to remove surface contamination and where this is successful the cut cable lengths can be offered for recovery of the copper. External steel armored cables will be more difficult to handle so they would only be offered for recycling from non-radiological areas of the plant.

Automated copper cable recycling systems are available which are portable enough to be set up on site for a recycling campaign. These systems separate the plastic insulation from the copper and convert each into plastic and copper beads. An economic assessment would need to be done to determine the value of this option.

A1.6 Concrete removal

Surface concrete removal

At various places within the power plant contaminated and possibly activated concrete will need to be removed for controlled disposal. It is generally not possible to clean contaminated concrete, so decommissioning projects make use of techniques which remove the contaminated concrete with a view to leave behind a clean structure suitable for demolition using conventional techniques.

It is expected that various concrete removal techniques will be required for the decommissioning project. These can be broken down into two main categories:

- Techniques that remove a surface layer of concrete (e.g. contaminated concrete) until the clean concrete beneath is revealed
- Techniques that remove bulk concrete, for example in the situation that contamination penetration is sufficiently deep so that the entire structure or a significant depth of contaminated or activated concrete must be removed.

This section will consider surface concrete removal with bulk concrete removal in the section immediately following.

There are a wide variety of surface concrete removal techniques available that have been deployed, with some degree of success, on a decommissioning project. In some cases the techniques have been adapted to provide both a fast technique suited to a wide-area and a smaller scale, slower technique for smaller areas or areas that wide-area techniques cannot reach, e.g. concrete removal close to embedded features.

Manual techniques

Simple processes, such as brushing, washing and scrubbing, and vacuum cleaning, have been widely used since the need for decontamination/cleaning was first noted in the nuclear industry. These processes are generally labor-intensive and have the potential to increase worker dose, but they have the advantages of being versatile and leaving the concrete surface intact. They can be effective on very lightly contaminated concrete, concrete where the surface is very smooth and in good condition or on painted/epoxy coated concrete. In some cases they may remove the majority of the contamination leaving only some smaller areas requiring mechanical decontamination using either a simple abrasive grinding wheel or a manually operated version of one of the techniques described below.

They are also used as the first step (e.g. to vacuum dust and remove loose contamination) before or during dismantling, to prepare items for more aggressive decontamination using stronger mechanical processes as they reduce the potential for airborne contamination during those aggressive techniques.

High pressure water washing

This technique, also known as Hydro lazing, involves directing high-pressure water at the surface being decontaminated. Typically, the equipment is a hand held lance supplied by pumps delivering water at pressure; the pressure being dependent on the exact type of equipment used but typically between 3,500–350,000 kPa (500–50,000 psi). The technique is suitable for removal of surface or near surface contamination, in particular where the surface is inaccessible to the manual techniques above or is too large for the manual techniques to be easily or economically applied.

The technique does produce secondary waste in the form of the water used. The water needs to be retained by temporary bunds and collected for controlled disposal or cleaning to remove any solid material it has picked up. Typically for every 1,000 liters of water used, 1 liter of solid material will be produced. As an additional precaution against spread of activity, the area for the pressure water washed concrete should be isolated from the surrounding area by screens or other enclosure.

Scabbling

Scabbling is a scarification process used to remove concrete surfaces. Scabbling tools typically incorporate several pneumatically operated piston heads striking (i.e. chipping) a concrete surface. Available scabblers range from one to three headed hand-held scabblers to remotely-operated scabblers, with the most common versions incorporating three to seven scabbling pistons mounted on a wheeled chassis. Scabbling bits have tungsten carbide cutters, the bits having an operating life of about 80–100 h under normal use. Both electrically and pneumatically driven machines are available. Because scabbling may cause a cross-contamination hazard, vacuum attachments and shrouding configurations have been incorporated. According to the claims of at least one manufacturer, this enables scabbling to take place with no detectable increase in airborne exposures above background level, though filtered and ventilated enclosures can be used if airborne contamination is likely to be produced.

In practice, large area floor scabblers may only be moved to within some 50 mm of a wall. Other hand-held scabbling tools are therefore needed to remove the last 50 mm of concrete flooring next to a wall, as well as remove surface concrete on walls and ceilings.

Scabbling is a dry decontamination method – no water, chemicals or abrasives are required. The waste stream produced is only the removed debris. Work rates vary widely because of variations in concrete composition and characteristics, depth of contamination, as well as to the different types of bits that may be used. Typical removal rates against depth are shown in Table A1-5.

Table A1-5. Variation of scabbler production rates with depth.

Removal Depth (mm)	Production Rate (m^2/h)
4.25	2.78–3.72
6.35	1.30–2.23
12.70	0.65–1.12
25.40	0.28–0.56

Scabblers are best suited for removing thin layers (up to 15 or 25 mm thick) of contaminated concrete (including concrete block) and cement. It is recommended for instances where:

- Airborne contamination should be limited or avoided.
- The concrete surface is to be reused after decontamination.
- Waste minimization is envisaged.
- The demolished material is to be cleaned before disposal.

The scabbled surface is generally flat, although coarsely finished, depending on the cutting bit used. This technique is suitable for both large open areas and small areas.

The techniques can be applied to floors and walls, though the requirement to have a reaction force if the equipment is to be effectively used on walls often results in additional equipment requirements, e.g. hydraulic arms to hold the equipment in place.

Figure A1-14 shows a proprietary remotely operated floor scabbling device, in this case the Pentek Moose system. This is typical of devices on the market. It can scabble between 25–40 m^2/h at a concrete removal depth of 1.6 mm (slower at increased removal depths, e.g. 12.1 m^2/h for 3.2 mm demonstrated at Argonne National Labs) and scabbles a 450 mm wide strip. It uses 7 tungsten carbide tipped 57 mm diameter scabbling heads, as shown in Figure A1-15.

As it can only reach to with 150 mm of walls other smaller devices are used to scabble areas that have not been cleaned by the larger machine. These smaller devices will typically be wheeled 3 head devices capable of scabbling a 150 mm wide strip at 1.8–2.8 m^2/h for a removal depth of 1.6 mm. Slightly wider 5 head machines are also available. For obstructions and other features that cannot be removed hand held, single head scabblers are available.

Similar machines are available for use on hydraulic arms or frames for scabbling walls.

Figure A1-14. *PENTEK Moose® Remotely Operated Floor Scabbler.*

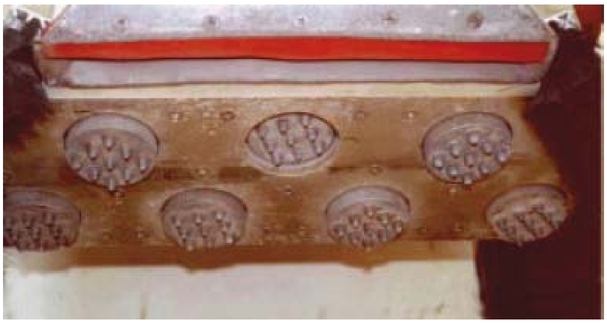

Figure A1-15. *View of underside of PENTEK Moose cutting head.*

Needle scaling

Needle scalers are usually pneumatically driven and use uniform sets of 2, 3, or 4 mm needles to obtain a desired profile and performance. Needle sets use a reciprocating action to chip contamination from a surface. Most of the tools have specialized shrouding and vacuum attachments to collect removed dust and debris during needle scaling with the result of no detectable increase in airborne dust concentrations above normal levels.

Needle scalers are an excellent tool in tight, hard-to-access areas (e.g. pipe penetrations, corners etc), and may also be used for wall and ceiling surface decontamination. This technique is a dry decontamination process and does not introduce water, chemicals or abrasives into the waste stream. Only the removed debris is collected for treatment and disposal. Production rates vary depending on the desired surface profile to be achieved. Nominal production rates vary between 1.8–2.8 m^2/h for 1.6 mm removal depth using a 44.5 mm wide cutting head (based on Pentek Corner Cutter needle gun).

Concrete shaving

A Concrete Floor Shaver is similar in appearance to a wheeled Scabbler. It has a quick-change diamond-tipped rotary cutting head designed to give smoother surface finish than a scabbler, easier to measure and ready for painting. It is capable of cutting through bolts and metal objects, which would have damaged the cutting head of a traditional scabbler. Actual cutting performance results in:

- A higher mean working rate for floor decontamination compared to scabbling.
- Much less physical load on the operators due to the absence of machine vibration.

The Marcrist Floor Shaver and the resulting floor surface are illustrated in Figure A1-16.

Figure A1-16. *Marcrist Floor Shaver and the resulting floor surface.*

The concrete shaver consists of the following components:

- A 250 mm wide 127 mm diameter shaving drum into which diamond impregnated blades are fitted. The number of blades is dependent on the required surface finish.
- An extraction port for use with a vacuum extraction unit for dust-free operation.
- A manual rotary wheel depth control with electronic display.

The machine can also be fitted onto hydraulic arms for shaving walls (see Figure A1-17).

Based on the positive experience with the floor shaver a remote controlled diamond wall shaving system has been developed as a solution for concrete decontamination of larger surfaces. The system consists of:

- A remote-controlled hydro-electric power pack for the remote-controlled shaving unit.
- A vacuum system to fix temporarily vacuum pads holding the horizontal and vertical rails of the shaving head.
- A simple xy-frame system containing a guide rail, a vertical rail and a carriage for the shaving head.
- A quick-change diamond-tipped rotary shaving head with dust-control cover for connection to existing dust-extraction systems.

The entire system is built up in sections, which are portable by one operator. It removes a concrete layer in a controlled and vibration-free manner with the removal depth being controllable between 1 and 15 mm per pass, producing a smooth-surface finish. The cutting head is designed to follow the contours of the surface being removed, and depth adjustments may be set manually in increments of 1 mm to minimize waste production. With 300 and 150 mm wide shaving heads available, both large areas and awkward corners may be accessed. When the vertical rail is fitted to the wall with the cutting head shaving, the horizontal rail may be disconnected and moved forward, thus ensuring continuous operation.

Production rates vary depending on the structure and the hardness of the concrete, the depth setting, the cutting speed and the type of diamond used. Heads can be used for shaving up to 2,000 m^2.

Summary

Table A1-6 below provides summary data (where readily available) for the various techniques for surface concrete removal described above.

Figure A1-17. *Shaver mounted on Brokk 250 for wall decontamination.*

Table A1-6. Summary data for surface concrete removal.

Technique	% Contamination Removed or Layer Thickness removed (mm)	Production Rate (m^2/h) (machine working time)	Operating Resources	Equipment Cost (2003)	Secondary Waste Produced	Contact
Manual Techniques	~20% Nil layer removed	2.8	2 laborers	~€21 /m^2	Cloths etc 0.005 m^3/h or 0.014 m^3/m^2	N/A
High Pressure Water washing	~25% for hard to remove contam. Higher for loose surface contam.	Up to 34	1 operator 2 laborers	~€8,000	Water 0.05 m^3/h or 0.0054 m^3/m^2	Available from numerous suppliers
Floor/Wall Scabbler – manually operated (1 head)	1.5 mm	1.13	1 operator	–	HEPA Filters for dust vacuum system, removed concrete dust	www.pentekusa.com
Floor Scabbler – Manually operated (5 Heads)	3 mm	2.5	1 operator	~€7,200 plus ~€500 for new heads every 113 m^2 or 45 hrs	HEPA Filters for dust vacuum system, removed concrete dust	www.pentekusa.com
Floor Scabbler – Remote Controlled (7 heads)	3.1 mm	12.1 (plus 2.5 h set time per location)	2 operators	~€170,000	HEPA Filters for dust vacuum system, removed concrete dust	www.pentekusa.com
Wall Scabbler (3 heads)	3 mm	4.6	–	–	HEPA Filters for dust vacuum system, removed concrete dust	www.pentekusa.com
Needle Scaler	1.6 mm	1.8–2.8	1 operator	~€1,300 plus ~€180 for new blades every 45 m^2 or 40 hrs	HEPA Filters for dust vacuum system, removed concrete dust	www.pentekusa.com
Floor/Wall Shaver	3 mm	11.9	1 operator	~€12,000 plus ~€7,900 for new blades every 1,860 m^2 or 156 hrs	HEPA Filters for dust vacuum system, removed concrete dust	www.marcrist.com

Bulk concrete removal

In cases where a significant depth of concrete has become activated or contamination has penetrated deep into the thickness of a concrete structure, e.g. a reactor biological shield, the entire concrete structure is removed. A number of techniques are available for this as described below.

Diamond wire saw

Diamond wire saw cutting is used to remove concrete, particularly reinforced concrete, as blocks, see Figure A1-18. This technique is particularly suitable if concrete needs to be removed cleanly, perhaps to generate access, or with minimal airborne contamination. A cart mounted unit drives a wire that carries diamond impregnated beads. Typically, three or four beads are held in place by springs mounted between smaller, fixed beads – see Figure A1-19. There are approximately forty 11 mm diameter beads per meter of wire. Wire saws are good at cutting through concrete with metal embedment, such as reinforcing bars, provided the material to be cut is solid (no voids or sections that can move during the cutting operation).

For cutting of large structures, the wire is threaded through holes drilled into the structure of approximately 50 mm diameter. For smaller structures the wire can be passed completely around the structure. There is no real limit to the depth of cut that can be achieved other than that determined by other practical factors such as the routing of the wire blade, the positioning of equipment or the ability to lift the removed pieces.

The cutting requires the introduction of water to act as both a dust suppressant and also as a lubricant for the blade. The resulting water/concrete dust mixture is a secondary waste that requires management. In the case of activated/contaminated concrete cutting, systems can be established to collect, filter and recycle the majority of the water used during the cutting.

Wire sawing techniques are also useful if removal of large components requires the removal of all or part of any surrounding concrete missile shields or bioshield walls.

Table A1-7 provides information regarding one Diamond Wire Saw Cutter.

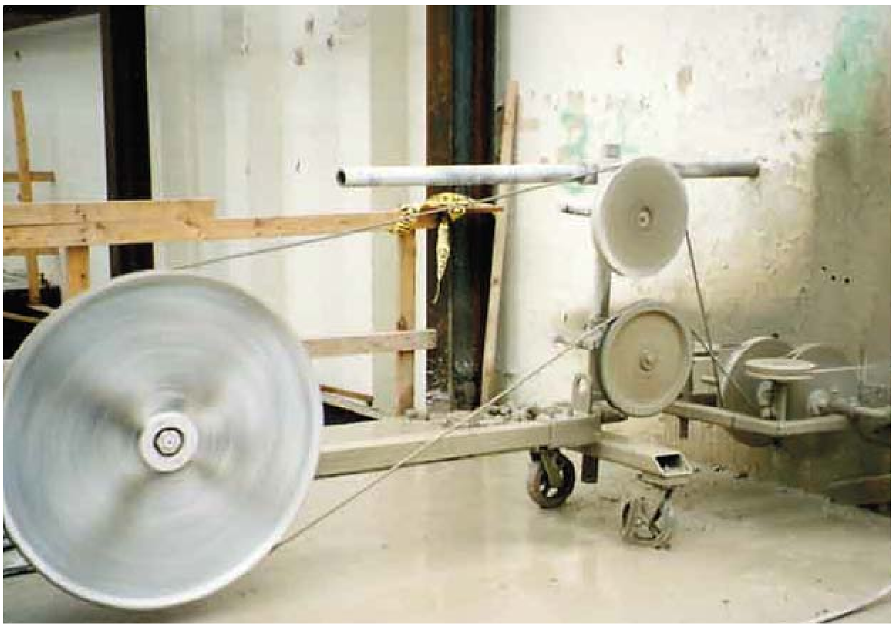

Figure A1-18. *Typical Wire Saw drive in action cutting a section of wall.*

Figure A1-19. *Close up of diamond wire saw blade.*

Table A1-7. Information regarding the Diamond Wire Saw Cutter.

Item	Diamond Wire Saw Cutter	Notes
Manpower Requirements	– 2 Equipment operators	Plus labor as required to handle waste material
Cost	– €5,000/week hire of 2 man team & equipment including power supply – €200/m wire	2003 values, UK rates
Capacity/performance	– No real limit other than that set by the practicality of equipment positioning, wire routing etc – Drilling of 50 mm diameter holes for wire saw blade access = up to 1.0 m per hour per unit – Approx 2 hours to set up wire saw equipment for each cut – Wire sawing up to 1.0 m^2 per hour	
Utility Requirements	– 3-phase 440V AC / 60 Amps	Required to power the hydraulic power unit
Weight	– 545 kg for the saw drive/tensioning gear plus 635 kg hydraulic power pack	
Secondary Wastes	– Slurry consisting of cooling/lubricating water and concrete debris – Water flow rate for wire sawing = 10–15 liter/min – Spent saw blade consumed at approx 1 m wire per 0.5 m^2 of cut	
Contact	– Various suppliers throughout Sweden and Europe generally	

As an alternative to water as a blade coolant, liquid gases have been used in trials. However, these techniques are not as widely available and are not effective at suppression of dusts, which is expected to be an important issue in a nuclear power plant decommissioning project.

Impact/crushing techniques

For situations where the care and precision of diamond wire sawing is not required, conventional demolition techniques can be used, such as impact and crushing techniques. These techniques use a combination of impact hammers (jackhammers or pneumatic drills) and concrete breaking jaws, typically mounted on small excavators of Brokk demolition machines, see Figure A1-20, Figure A1-21 and Figure A1-22.

Figure A1-20. *Brokk 330 demolition machine equipped for concrete breaking.*

Figure A1-21. *Brokk Demolition Machine (Model 40) equipped for remote control impact demolition.*

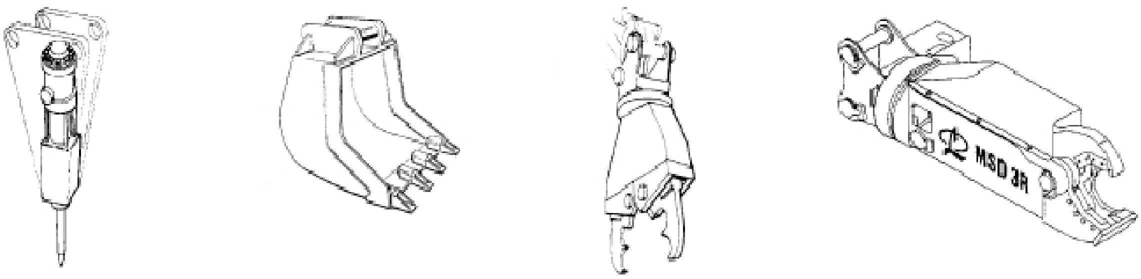

Figure A1-22. *Examples of tools for use with demolition machines.*

The impact hammer usually has a chisel point and impacts the surface to be removed at rates of up to 600 blows per minute delivering up to 2,700 Nm (~2,000 ft.lb) force per blow. The technique has been used extensively on many decommissioning applications largely because of its versatility and low cost.

Concrete breaking jaws can also be used where there is suitable access to the edge of a wall to allow the jaws to work.

There are issues of noise pollution and dust generation, which can lead to airborne contamination, to be considered when using these techniques. The impact on personnel can be mitigated through the use of suitable personnel protective equipment and the use of water mist/sprays to reduce dust.

The production rates achievable using concrete breaking hammers and jaws are highly variable depending on issues such as accessibility and radiological conditions.

Table A1-8 provides information regarding the "Brokk" type remote controlled Demolition Machine from Brokk.

Demolition

It is intended that all buildings, both contaminated and clean, are demolished using similar techniques. Contaminated buildings will be cleaned and surveyed as such and then demolished using conventional techniques appropriate to the building size and construction method.

Buildings will be stripped out of easily removed recyclable material. High level glass will also be removed as a safety measure. Concrete and brick buildings will be demolished using machine (excavator) mounted concrete crushers, breakers and grabs, with water spray applied where necessary to reduce creation of dust; which in this case would only be a conventional rather than a radiological hazard. The resulting debris will be crushed and metals separated out at this point. Concrete waste will be used as infill of below ground voids or transported off site as required.

Steel frame buildings represent an opportunity for relatively easy metals recycling and these will be demolished using mobile cranes, machine excavators and thermal/mechanical cutting tools.

Explosive demolition techniques may offer a safer demolition option on some taller structures, but may not be acceptable due to the presence of other nearby facilities.

Table A1-8. Information regarding the "Brokk" type remote controlled Demolition Machine.

Item	"Brokk" type remote controlled Demolition Machine	Notes
Manpower Requirements	1 Equipment operator	Plus labor as required to handle waste material
Cost	Variable depending on the model purchased and the precise application specific requirements	
Capacity/performance	Able to remove walls up to 0.9 m thick (3 feet) using Brokk mounted equipment. Larger scale equipment can handle greater thicknesses.	
	Production rate is highly variable but during monitored trials an average rate of 4.5 m^3 per day was achieved using a Brokk 150 removing a reinforced concrete structure up to 3 feet thick.	
Utility Requirements	Power supplies to suit model and location. Brokk 330 electric has 30 kW motor. Alternatively a diesel version of the largest model is available.	
Weight	Brokk 40–380 kg, plus max attachment weight 60 kg	
	Brokk 90–980 kg, plus max attachment weight 140 kg	
	Brokk 180–1,900 kg, plus max attachment weight 230 kg	
	Brokk 330–4,400 kg, plus max attachment weight 550 kg	
Secondary Wastes	Misc. operating wastes such as hydraulic hose, wipes etc	
Contact	Brokk Sweden	www.brokk.com

A1.7 Size reduction

Size reduction on site

A range of different types of size reduction equipment is likely to be required for the decommissioning of the Oskarshamn site.

The equipment is likely to include both conventional mechanical size reduction equipment and more advanced techniques. Conventional equipment includes:

- Hand held power tools e.g.:
  - Hack saw.
  - Fret saw.
  - Band saw.
  - Bow saw.
  - Circular saw.
- Shears.
- Pipe cutters.
- Diamond wire cutting rig.
- Balers (Figure A1-23).
- Compactors.
- Super Compactors.

The selection of the appropriate equipment will be largely driven by the nature of the object that is to be size reduced, although for some pieces of equipment, such as compactors, throughput economics will also be relevant. Many of the above techniques, particularly the saws, shears and pipe cutters, have the potential to be operated both manually and remotely.

More advanced techniques include the following:

- Abrasive water jet cutting.
  - Abrasive water injection jet (AWIJ).
  - Abrasive water suspension jet (AWSJ) – higher efficiency than AWIJ due to absence of air in system.
- Thermal cutting tools e.g.:
  - Flame cutting.
- For materials that react with oxygen in an exothermal combustion process and with an ignition temperature (~1,100°C) lower than the melting point, such as mild steel.
- For materials with an ignition temperature higher than the melting point, such as stainless steel or non-ferrous metals, additional powder injection will be required.
  - Oxygen lance cutting, using pressurised oxygen burning at up to 2,500°C to cut high melting point metals and minerals such as concrete, often with the addition of an iron/aluminium powder mixture to further raise the cutting temperature to above 4,000°C
  - Electrical (plasma arc) cutting.
- Transferred arc for electrically conductive materials, where the arc strikes between the electrode and the work piece.
- Non-transferred arc for conductive and non-conductive materials, where the arc strikes between the electrode and the nozzle of the cutting torch. This type of torch transmits less energy to the work piece.

The ability to deploy these more advanced techniques remotely largely depends on the ability to achieve effective remote control of the devices. This ability will partially depend on the means by which the device is deployed, but will more heavily depend on the ability to develop appropriate control software. As a result, these techniques are more likely to be deployed manually with the operatives wearing PPE as appropriate.

Figure A1-23. *Compaction of soft LLW into square bales at Oskarshamn.*

Size reduction off site

There are a lot of materials that can be size reduced off site by e.g. incineration, smelting or pyrolysis. These size reduction methods could be performed by Studsvik for the materials from Oskarshamn. Whether to use size reduction off site or not, and the method of size reduction, is determined by authority regulations for handling of this kind of waste material, profitability and the dose rate of the material. Studsvik cannot handle materials with dose rates higher than they are licensed to manage.

The incineration process takes place in the main incineration chamber where organic material is gasified into ash. The gas is led to an afterburning chamber containing oil burners where complete incineration takes place. The flue gas is led to the flue gas purification where lime and activated carbon is added to reduce the emissions. All emissions are continuously measured in the stack. The incineration is done in campaigns to avoid cross contamination between different plant's materials. The bottom ash and fly ash is collected and analysed before further transportation and treatment.

Smelting of metals is done in an induction oven. Prior to smelting the metals must be sorted into each respective type of metal and if necessary decontaminated. After the smelting, the slag is separated from the melt and then kept in containers modified for interim storage. Dust from filters and secondary process remnants are gathered and stored in containers modified for interim storage before they are analysed and transported for further treatment. Metals are measured with regard to activity, and are free released if possible.

A1.8 Waste monitoring

A range of monitoring equipment is available for characterizing the ILW and LLW streams within the waste management facilities. These range from swab and probe measurements to more automated systems that measure the activity content of waste contained in a range of package sizes, including drums and boxes. The most appropriate monitors for this application use gamma spectroscopy.

Representative samples of waste expected from its location and history to be suitable for free release will be subjected to swab and probe monitoring. Suitable waste may then be loaded into containers for final compliance monitoring using, for example, a RADOS Clearance Measurement Station. Alternatively a conveyor system, such as the IonSens Conveyorised Survey Monitor, could be used to monitor loose or bagged material. Examples are shown in the figures below.

Depending on the output required, use may be made of low or high resolution gamma spectroscopy (LRGS or HRGS). An alternative means of monitoring bulk waste in an ISO freight container is currently under development by BIL Solutions Ltd, a sister company of British Nuclear Group Project Services Ltd. This monitor offers significant cost benefits compared to manual survey and also offers opportunities for much greater throughputs.

Figure A1-24. *Swab Counter.*

Figure A1-25. *RADOS Mobile Clearance Measurement Station.*

Figure A1-26. *IonSens Conveyorised Survey Monitor.*

Figure A1-27. *Container Monitor for Bulk LLW.*

Monitoring techniques

In general it is not possible to prescribe that specific techniques should be used on certain wastes, as the choice of technique will be dependent on the nature of the suspected contamination or activation, the natural activity present in the materials concerned and whether the materials are potentially magnetic (non-shielded scintillators being susceptible to interference from magnetic fields).

In particular, equipment selection will depend upon a number of factors, including:

- The purpose of the monitoring11.
- The physical form of the materials to be monitored.
- The area and/or mass over which measurements are to be taken and averaged.
- The natural background level of radiation prevailing in the materials.
- The expected contamination fingerprint.
- The environment within which monitoring will be carried out (e.g. ease of access, nearby operations involving sources of radioactivity that may interfere with radiometric measurements, etc).
- Who will perform the measurements and the balance between manual and automatic monitoring.

Experience on UK Magnox power station sites has shown high resolution gamma spectroscopy (HRGS) to be suitable for the clearance monitoring of steel ductwork, fuel skips and transport containers and small shielded flasks. HRGS has been found in particular to offer considerable sensitivity and selectivity.

HRGS has also been found to be effective for the clearance monitoring of steel and concrete cooling water culverts and on concrete and steel plate breakwaters. Concrete assay can however pose some problems due to the absorption of contamination below the surface and the natural attenuation of gamma emissions through the concrete substrate. In such circumstances, coring may be needed to develop baseline fingerprints for the spectroscopic analysis.

[11] It is important to distinguish between sentencing for disposal and clearance. For example, drum monitors will be sensitive enough for sentencing ILW or LLW for disposal, but will not be sensitive enough for clearance purposes.

Some further guidance is given in a UK National Physical Laboratory document (McClelland and Lewis 2003) which recommends the use of passive total neutron counting (TNC), passive neutron coincidence counting (PNCC), passive neutron multiplicity counting (PNMC) and gross gamma counting techniques for the assay of lower level wastes. The document also recommends the consideration of segmented and tomographic gamma scanning for the assay of LLW drummed wastes.

With respect to the physical form of the wastes requiring monitoring, the following points should be noted:

1. For intact solids such as steel and brick, surface contamination monitoring will be relatively easy. Sampling of bulk material from these solids will however tend to require aggressive intervention (e.g. coring).
2. The use of hand-held health physics probes is likely to be appropriate for the monitoring of large numbers of small items of waste.
3. Direct surface monitoring of wire and narrow bore pipework will be difficult without prior size reduction. Bulk activity assessment will however be relatively easy.
4. Surface monitoring will generally require clean, dry surfaces that are free from dust, grease, paint and condensation.

Generally the larger the detector surface on the monitor, the more efficient is the measurement in terms of the number of sample points covered and the speed of measurement. Effective measurement will also require prior identification and measurement of background sources of radiation to provide a baseline against which clearance monitoring can take place[12]

A1.9 Principles of decommissioning and waste management

Reactor internals and pressure vessel

The development of options for dismantling and removal of the reactor internals and reactor pressure vessel (RPV) have been considered within other chapters of this study. However for completeness a summary of the main principles is included below.

Following defueling, one retrieval option involves the dismantling of the reactor internals under water. Waste items will be placed into an insert tray, which will be removed from the pool and placed in a BFA-tank.

The reactor pressure vessel will be removed, complete without reactor internals, in one piece as a single unit. This approach has previously been suggested for Forsmark 1 and Ringhals PWR (Farías et al. 2008) and will be used on all NPPs in Sweden. This method was utilised at San Onofre in the USA[13], with a similar scheme employed at several other US sites. This is shown in Figure A1-28.

If access can be gained to an external wall on the operating floor, the RPV could be skated out through a new access in the containment and lowered to ground level for onward transport as at Big Rock Point in the United States, shown in Figure A1-29.

Wastes generated from the RPV and internals will not be processed in the waste management system on site. If the RPV and internals are size reduced, the long-lived activity waste will be packaged in 3.3×1.3×2.3 m BFA-tanks. Alternatively, the RPV may be grouted intact with the vessel itself acting as the transport package. The containers or RPV package will be transported to SFR for interim storage pending the availability of a deep repository for long-lived wastes.

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[12] The presence of high natural levels of certain beta and gamma emitters will require the use of energy selective detectors to screen these emitters out.

[13] NB San Onofre is a PWR. Most BWR designs, including those in Sweden, do not have domed containment structures.

Figure A1-28. *Removal of the San Onofre RPV via the reactor containment.*

Figure A1-29. *Removal of the Big Rock Point Pressure Vessel via a new side access.*

Other primary wastes

The waste forms which will be managed by the waste management system include:

- The nuclear steam supply system (NSSS).
- Turbines and turbine hall.
- Radioactive waste from reactor service buildings and fuel storage facilities.
- Radioactive waste from other ancillary buildings.

It is recognized that in order to be cost-effective, decommissioning operations may be carried out simultaneously on several workfaces. This will depend on the following criteria:

- Activity and dose uptake to operators.
- Potential exit routes from the work area.
- Processing capacity of the waste management system.
- Potential for utilising of existing handling systems.
- Size/weight of waste.
- Operator safety.

Dismantling of plant and equipment in some areas may only require minimal containment for operators wearing basic protective clothing. Other areas will require a fabricated shielded enclosure with local ventilation for operators wearing full personal protective equipment (PPE). It is understood that a small amount of the total waste arisings will be classified as ILW and the processing of this waste will require a shielded area of the facility which will be equipped with a remote handling capability.

The scope for size reduction/dismantling of large items such as the turbine is determined by:

- Access.
- Potential for utilising of existing handling systems (e.g. building cranes).
- Dose uptake to operators.

Large items such as the turbine or a re-heater (Figure A1-30) can either be dismantled into their various components or size reduced either on site using hot or cold cutting techniques or off site through e.g. smelting. All these methods may be carried out remotely. Another alternative would be to split the turbine into two or three large pieces and package each piece whole in order to reduce dose to operators. Whichever on site option is chosen these operations can be done within the facility which may enclose the entire turbine.

Secondary wastes

During decommissioning operations, the generation of secondary waste is unavoidable. Secondary waste will be in the form of PPE, PVC sheeting, scaffolding, temporary modular containment and ventilation systems etc. Other examples of secondary waste are abrasives, used saw blades, grinding disks and filter cartridges. Generally any item introduced into the area to assist decommissioning operations will potentially become secondary waste, therefore it is important to strictly monitor and restrict the entry of new materials into the controlled areas. Large items such as sections of modular containment can be protected from contact with contamination, either for re-use or for secondary waste reduction by the application of strippable coatings. All secondary waste will follow the same route as the primary waste, some unavoidably will be LLW but the majority is expected to be consigned as FRW.

Figure A1-30. *Re-heater transported from Oskarshamn 2.*

Appendix 2

Waste activity and nuclide vectors

A2.1 Waste activity data: Process equipment waste for the OKG site

Table A2-1. Process Equipment Waste for O1.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	212.1	5	Co-60	2.7E+14	45.5	6.3E+10	BFA-tank	6.9	Red (LL)
2	213.1	6	Co-60	4.0E+14	9.7	3.5E+11	BFA-tank	1.8	Red (LL)
3	212.1	5	Co-60	1.7E+14	28.0	6.3E+10	Large Steel Box	6.0	Red (SL)
4	214.1	7	Co-60	1.9E+12	12.2	6.8E+08	Large Steel Box	4.7	Red (SL)
5	215.1	7	Co-60	5.9E+11	30.5	8.5E+07	Large Steel Box	11.7	Red (SL)
6	244.1	7	Co-60	1.3E+11	3.6	1.5E+08	Large Steel Box	0.5	Red (SL)
7	313.1	7	Co-60	3.7E+10	79.9	2.0E+06	Large Steel Box	11.1	Red (SL)
8	316.1	7	Co-60	3.2E+09	1.3	1.1E+07	Large Steel Box	0.2	Red(SL)
9	321.1	7	Co-60	9.4E+09	15.2	2.7E+06	Large Steel Box	2.1	Red (SL)
10	321.2	7	Co-60	3.7E+10	8.0	2.1E+07	Large Steel Box	1.1	Red (SL)
11	321.3	7	Co-60	2.6E+09	10.6	1.1E+06	Large Steel Box	1.5	Red (SL)
12	323.1	7	Co-60	2.4E+09	3.5	3.0E+06	Large Steel Box	0.5	Red (SL)
13	324.1	7	Co-60	2.4E+10	7.0	1.5E+07	Large Steel Box	1.0	Red (SL)
14	324.2	7	Co-60	2.0E+09	0.8	1.1E+07	Large Steel Box	0.1	Red (SL)
15	324.3	12	Co-60	2.7E+08	0.2	1.7E+07	Large Steel Box	0.0	Red (SL)
16	326.1	7	Co-60	5.4E+09	1.9	1.3E+07	Large Steel Box	0.3	Red (SL)
17	327.1	7	Co-60	2.0E+08	0.1	6.8E+06	Large Steel Box	0.0	Red (SL)
18	331.1	7	Co-60	7.2E+09	1.4	2.3E+07	Large Steel Box	0.2	Red (SL)
19	331.2	7	Co-60	5.4E+09	21.4	1.1E+06	Large Steel Box	3.0	Red (SL)
20	351.1	7	Co-60	3.0E+08	0.8	1.7E+06	Large Steel Box	0.1	Red (SL)
21	352.1	7	Co-60	4.2E+09	6.2	2.9E+06	Large Steel Box	0.9	Red (SL)
22	341.3	14	Cs-137	6.1E+08	0.3	2.4E+06	Large Steel Box	0.0	Red (SL)
23	441.2	7	Co-60	9.6E+09	12.0	3.5E+06	Large Steel Box	1.7	Red (SL)
24	552.1	14	Co-60	1.5E+09	0.8	2.2E+06	Large Steel Box	0.1	Red (SL)
25	231.1	7	Co-60	5.7E+09	25.3	9.7E+05	ISO-type Container	1.5	Yellow & Green
26	311.1	7	Co-60	5.4E+09	99.3	2.4E+05	ISO-type Container	6.0	Yellow & Green
27	312.1	7	Co-60	2.2E+08	5.6	1.7E+05	ISO-type Container	0.3	Yellow & Green
28	313.2	7	Co-60	7.2E+07	42.0	7.5E+03	ISO-type Container	2.5	Yellow & Green
29	314.1	7	Co-60	2.5E+09	16.7	6.5E+05	ISO-type Container	1.0	Yellow & Green
30	315.1	7	Co-60	5.1E+08	82.4	2.7E+04	ISO-type Container	5.0	Yellow & Green
31	321.4	7	Co-60	4.6E+06	4.1	4.9E+03	ISO-type Container	0.2	Yellow & Green
32	322.1	7	Co-60	3.2E+09	43.4	3.2E+05	ISO-type Container	2.6	Yellow & Green
33	323.2	7	Co-60	4.2E+08	10.6	1.7E+05	ISO-type Container	0.6	Yellow & Green
34	331.3	7	Co-60	1.7E+08	2.3	3.1E+05	ISO-type Container	0.1	Yellow & Green
35	331.5	7	Co-60	5.8E+07	2.3	1.1E+05	ISO-type Container	0.1	Yellow & Green
36	332.1	9	Co-60	2.3E+07	74.1	5.7E+02	ISO-type Container	4.5	Yellow & Green
37	341.1	14	Cs-137	5.0E+07	0.4	1.2E+05	ISO-type Container	0.0	Yellow & Green
38	331.4	13	Co-60	2.5E+07	0.4	1.1E+05	ISO-type Container	0.0	Yellow & Green
39	342.1	15	Co-60	1.9E+05	0.2	4.1E+03	ISO-type Container	0.0	Yellow & Green
40	342.4	15	Co-60	1.5E+05	0.2	3.8E+03	ISO-type Container	0.0	Yellow & Green
41	344.1	11	Co-60	2.7E+07	1.5	6.8E+04	ISO-type Container	0.1	Yellow & Green
42	354.1	7	Co-60	1.9E+08	24.5	3.3E+04	ISO-type Container	1.5	Yellow & Green
43	411.1	7	Co-60	2.9E+08	612.7	2.0E+03	ISO-type Container	37.1	Yellow & Green
44	411.2	7	Co-60	9.6E+09	115.4	3.6E+05	ISO-type Container	7.0	Yellow & Green
45	431.1	7	Co-60	3.9E+06	33.2	5.2E+02	ISO-type Container	2.0	Yellow & Green
46	433.1	7	Co-60	5.8E+07	31.9	8.0E+03	ISO-type Container	1.9	Yellow & Green
47	441.1	7	Co-60	4.9E+08	47.0	4.5E+04	ISO-type Container	2.8	Yellow & Green

Table A2-2. Process Equipment Waste for O0.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	342.1	15	Co-60	5.7E+07	53.1	4.1E+03	ISO-type Container	3,2	Yellow & Green
2	342.3	15	Co-60	3.5E+07	13.5	9.8E+03	ISO-type Container	0,8	Yellow & Green
3	342.4	15	Co-60	1.9E+07	19.2	3.8E+03	ISO-type Container	1,2	Yellow & Green
4	342.6	15	Co-60	6.8E+06	31.6	8.2E+02	ISO-type Container	1,9	Yellow & Green
5	342.7	15	Co-60	1.8E+07	62.8	1.1E+03	ISO-type Container	3,8	Yellow & Green
6	344.1	11	Co-60	1.3E+08	7.2	6.8E+04	ISO-type Container	0,4	Yellow & Green

Table A2-3. Process Equipment Waste for O2.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	212.1	5	Co-60	6.6E+14	53.7	1.3E+11	BFA-tank	8,9	Red (LL)
2	213.1	6	Co-60	3.5E+14	2.5	1.5E+12	BFA-tank	0,5	Red (LL)
3	212.1	5	Co-60	3.4E+14	27.5	1.3E+11	Large Steel Box	5,8	Red (SL)
4	214.1	7	Co-60	3.7E+12	18.5	7.3E+08	Large Steel Box	7,1	Red (SL)
5	215.1	7	Co-60	1.2E+12	22.0	1.9E+08	Large Steel Box	8,4	Red (SL)
6	221.1	7	Co-60	3.1E+10	1.5	7.4E+07	Large Steel Box	0,2	Red (SL)
7	211.2	4	Co-60	4.2E+08	3.2	1.9E+06	Large Steel Box	0,4	Red (SL)
8	243.1	7	Co-60	2.4E+12	66.9	1.3E+08	Large Steel Box	9,3	Red (SL)
9	244.1	7	Co-60	1.9E+11	14.1	4.9E+07	Large Steel Box	2,0	Red (SL)
10	245.1	7	Co-60	2.3E+10	4.7	1.8E+07	Large Steel Box	0,7	Red (SL)
11	313.1	7	Co-60	5.4E+10	67.1	3.0E+06	Large Steel Box	9,4	Red (SL)
12	316.1	7	Co-60	4.7E+09	0.4	4.5E+07	Large Steel Box	0,1	Red (SL)
13	321.1	7	Co-60	1.4E+10	5.0	1.0E+07	Large Steel Box	0,7	Red (SL)
14	321.2	7	Co-60	5.6E+10	26.6	7.7E+06	Large Steel Box	3,7	Red (SL)
15	321.3	7	Co-60	3.9E+09	13.3	1.1E+06	Large Steel Box	1,9	Red (SL)
16	323.1	7	Co-60	3.6E+09	3.8	3.5E+06	Large Steel Box	0,5	Red (SL)
17	324.1	7	Co-60	3.6E+10	11.5	1.2E+07	Large Steel Box	1,6	Red (SL)
18	324.3	10	Co-60	4.0E+10	3.5	2.4E+08	Large Steel Box	0,5	Red (SL)
19	326.1	7	Co-60	8.0E+09	1.3	2.2E+07	Large Steel Box	0,2	Red (SL)
20	327.1	7	Co-60	2.9E+08	0.5	2.1E+06	Large Steel Box	0,1	Red (SL)
21	331.1	7	Co-60	1.1E+10	1.5	2.7E+07	Large Steel Box	0,2	Red (SL)
22	331.2	7	Co-60	8.0E+09	21.6	1.4E+06	Large Steel Box	3,0	Red (SL)
23	331.4	11	Co-60	3.8E+09	1.4	5.0E+06	Large Steel Box	0,2	Red (SL)
24	351.1	7	Co-60	4.5E+08	0.2	7.4E+06	Large Steel Box	0,0	Red (SL)
25	352.1	7	Co-60	6.2E+09	5.6	4.1E+06	Large Steel Box	0,8	Red (SL)
26	414.1	7	Co-60	2.4E+10	87.7	1.0E+06	Large Steel Box	12,2	Red (SL)
27	231.1	7	Co-60	8.4E+09	39.3	7.9E+05	ISO-type Container	2,4	Yellow & Green
28	311.1	7	Co-60	8.1E+09	45.7	6.5E+05	ISO-type Container	2,8	Yellow & Green
29	312.1	7	Co-60	3.2E+08	27.6	4.5E+04	ISO-type Container	1,7	Yellow & Green
30	313.2	7	Co-60	1.1E+08	51.2	7.8E+03	ISO-type Container	3,1	Yellow & Green
31	314.1	7	Co-60	3.7E+09	39.4	3.5E+05	ISO-type Container	2,4	Yellow & Green
32	321.4	7	Co-60	6.8E+06	5.8	4.3E+03	ISO-type Container	0,4	Yellow & Green
33	322.1	7	Co-60	4.7E+09	35.2	5.0E+05	ISO-type Container	2,1	Yellow & Green
34	323.2	7	Co-60	6.2E+08	7.9	2.9E+05	ISO-type Container	0,5	Yellow & Green
35	324.2	7	Co-60	2.9E+09	16.9	6.4E+05	ISO-type Container	1,0	Yellow & Green
36	331.3	7	Co-60	2.5E+08	1.6	5.5E+05	ISO-type Container	0,1	Yellow & Green
37	331.5	7	Co-60	8.6E+07	52.6	6.1E+03	ISO-type Container	3,2	Yellow & Green
38	332.1	12	Co-60	3.4E+09	116.5	5.0E+04	ISO-type Container	7,1	Yellow & Green
39	341.1	13	Cs-137	5.3E+07	66.6	8.9E+02	ISO-type Container	4,0	Yellow & Green
40	354.1	7	Co-60	2.7E+08	18.9	5.4E+04	ISO-type Container	1,1	Yellow & Green
41	412.1	7	Co-60	1.4E+10	365.4	1.4E+05	ISO-type Container	22,1	Yellow & Green
42	413.1	7	Co-60	4.3E+08	166.4	9.5E+03	ISO-type Container	10,1	Yellow & Green
43	431.1	7	Co-60	1.3E+07	60.0	8.2E+02	ISO-type Container	3,6	Yellow & Green
44	441.1	7	Co-60	7.2E+08	191.2	1.4E+04	ISO-type Container	11,6	Yellow & Green
45	441.2	7	Co-60	1.4E+10	117.0	4.5E+05	ISO-type Container	7,1	Yellow & Green
46	455.1	7	Co-60	8.7E+07	7.6	4.2E+04	ISO-type Container	0,5	Yellow & Green

Table A2-4. Process Equipment Waste for O3.

No	Identity	Nuclide Vector	Normalized Against	Activity of Normalized Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	212.1	7	Co-60	1.7E+15	80.5	2.2E+11	BFA-tank	13.4	Red (LL)
2	216.1	8	Co-60	1.1E+15	6.0	8.7E+11	BFA-tank	0.8	Red (LL)
3	R.2	2	Co-60	3.6E+10	29.4	2.1E+07	Large Steel Box	4.1	Red (SL)
4	211.2	5	Co-60	8.1E+10	6.0	3.0E+07	Large Steel Box	0.8	Red (SL)
5	212.1	7	Co-60	3.1E+15	151.7	2.2E+11	Large Steel Box	33.6	Red (SL)
6	213.1	6	Co-60	3.3E+11	2.0	4.3E+08	Large Steel Box	0.3	Red (SL)
7	214.1	6	Co-60	1.3E+13	38.2	8.7E+08	Large Steel Box	14.7	Red (SL)
8	215.1	6	Co-60	2.1E+12	60.7	9.3E+07	Large Steel Box	23.3	Red (SL)
9	231.1	6	Co-60	1.6E+10	8.0	5.2E+06	Large Steel Box	1.1	Red (SL)
10	243.1	6	Co-60	1.1E+12	91.5	3.0E+07	Large Steel Box	12.8	Red (SL)
11	244.1	6	Co-60	8.8E+10	104.8	2.2E+06	Large Steel Box	14.6	Red (SL)
12	321.1	6	Co-60	3.6E+10	46.6	2.0E+06	Large Steel Box	6.5	Red (SL)
13	321.2	6	Co-60	1.7E+10	10.8	4.2E+06	Large Steel Box	1.5	Red (SL)
14	323.1	6	Co-60	3.7E+11	17.5	5.5E+07	Large Steel Box	2.4	Red (SL)
15	324.1	6	Co-60	2.1E+11	19.2	2.9E+07	Large Steel Box	2.7	Red (SL)
16	324.2	6	Co-60	1.4E+10	13.2	2.8E+06	Large Steel Box	1.8	Red (SL)
17	324.3	11	Co-60	4.4E+10	7.0	4.5E+07	Large Steel Box	1.0	Red (SL)
18	331.1	6	Co-60	3.0E+09	2.1	3.8E+06	Large Steel Box	0.3	Red (SL)
19	331.2	6	Co-60	2.1E+10	29.7	1.9E+06	Large Steel Box	4.1	Red (SL)
20	351.1	6	Co-60	1.8E+08	0.0	2.2E+07	Large Steel Box	0.0	Red (SL)
21	352.1	6	Co-60	7.4E+09	9.1	2.2E+06	Large Steel Box	1.3	Red (SL)
22	742.1	11	Co-60	1.7E+08	0.3	4.1E+06	Large Steel Box	0.0	Red (SL)
23	421.1	6	Co-60	1.9E+10	268.3	1.9E+05	ISO-type Container	16.3	Yellow & Green
24	422.1	6	Co-60	5.9E+10	444.6	3.5E+05	ISO-type Container	26.9	Yellow & Green
25	424.1	6	Co-60	1.4E+09	24.7	1.5E+05	ISO-type Container	1.5	Yellow & Green
26	461.1	6	Co-60	3.6E+11	1,158.9	8.1E+05	ISO-type Container	70.2	Yellow & Green
27	461.2	6	Co-60	9.8E+08	47.3	5.5E+04	ISO-type Container	2.9	Yellow & Green
28	463.1	6	Co-60	2.5E+10	298.1	2.2E+05	ISO-type Container	18.1	Yellow & Green
29	331.3	6	Co-60	8.0E+08	4.9	4.3E+05	ISO-type Container	0.3	Yellow & Green
30	331.4	12	Co-60	5.7E+08	6.9	1.6E+05	ISO-type Container	0.4	Yellow & Green
31	331.5	6	Co-60	4.6E+07	4.7	2.6E+04	ISO-type Container	0.3	Yellow & Green
32	342.7	6	Co-60	8.5E+07	118.2	1.9E+03	ISO-type Container	7.2	Yellow & Green
33	323.2	6	Co-60	5.4E+09	46.5	3.0E+05	ISO-type Container	2.8	Yellow & Green
34	321.3	6	Co-60	3.3E+09	25.2	3.4E+05	ISO-type Container	1.5	Yellow & Green
35	322.1	6	Co-60	1.8E+10	48.1	9.7E+05	ISO-type Container	2.9	Yellow & Green
36	251.1	6	Co-60	6.4E+08	14.0	1.2E+05	ISO-type Container	0.8	Yellow & Green
37	311.1	6	Co-60	7.0E+09	104.3	1.8E+05	ISO-type Container	6.3	Yellow & Green
38	314.1	6	Co-60	1.3E+09	42.5	8.1E+04	ISO-type Container	2.6	Yellow & Green
39	316.1	6	Co-60	9.0E+07	0.5	4.8E+05	ISO-type Container	0.0	Yellow & Green
40	312.1	6	Co-60	9.7E+08	25.9	9.8E+04	ISO-type Container	1.6	Yellow & Green
41	313.1	6	Co-60	1.4E+09	40.7	9.2E+04	ISO-type Container	2.5	Yellow & Green
42	327.1	6	Co-60	1.1E+08	10.8	2.6E+04	ISO-type Container	0.7	Yellow & Green
43	332.1	15	Co-60	1.9E+08	89.5	7.0E+03	ISO-type Container	5.4	Yellow & Green
44	341.1	13	Cs-137	6.2E+09	8.2	7.6E+05	ISO-type Container	0.5	Yellow & Green
45	341.3	13	Cs-137	5.5E+07	3.1	1.8E+04	ISO-type Container	0.2	Yellow & Green
46	342.1	14	Co-60	8.7E+08	24.9	1.3E+05	ISO-type Container	1.5	Yellow & Green
47	342.2	14	Co-60	3.6E+09	57.5	2.2E+05	ISO-type Container	3.5	Yellow & Green
48	342.3	14	Co-60	1.8E+07	4.5	1.4E+04	ISO-type Container	0.3	Yellow & Green
49	342.4	14	Co-60	7.0E+06	20.8	1.2E+03	ISO-type Container	1.3	Yellow & Green
50	354.1	6	Co-60	1.2E+08	14.4	2.2E+04	ISO-type Container	0.9	Yellow & Green
51	403.1	6	Co-60	2.1E+09	350.0	1.6E+04	ISO-type Container	21.2	Yellow & Green
52	423.1	6	Co-60	1.4E+09	82.0	4.6E+04	ISO-type Container	5.0	Yellow & Green

A2.2 Waste activity data: Decontamination waste assuming a DF of 10

Table A2-5. Decontamination Waste Assuming a DF of 10 for O1.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (kg)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	211.1	4	Co-60	6.2E+11	5,359	7.1E+08	Steel Box	3.306	Red (SL)
2	312.1	7	Co-60	2.0E+09	12	7.1E+08	Steel Box	0.007	Red (SL)
3	313.1	7	Co-60	3.3E+11	2,005	7.1E+08	Steel Box	1.237	Red (SL)
4	313.2	7	Co-60	6.5E+08	4	7.1E+08	Steel Box	0.002	Red (SL)
5	321.1	7	Co-60	8.4E+10	518	7.1E+08	Steel Box	0.320	Red (SL)
6	321.2	7	Co-60	3.4E+11	2,052	7.1E+08	Steel Box	1.266	Red (SL)
7	321.3	7	Co-60	2.4E+10	145	7.1E+08	Steel Box	0.090	Red (SL)
8	321.4	7	Co-60	4.1E+07	0	7.1E+08	Steel Box	0.0002	Red (SL)
9	326.1	7	Co-60	4.8E+10	294	7.1E+08	Steel Box	0.182	Red (SL)
10	327.1	7	Co-60	1.8E+09	11	7.1E+08	Steel Box	0.007	Red (SL)
11	331.1	7	Co-60	6.5E+10	396	7.1E+08	Steel Box	0.244	Red (SL)
12	331.2	7	Co-60	4.9E+10	296	7.1E+08	Steel Box	0.182	Red (SL)
13	331.3	7	Co-60	1.5E+09	9	7.1E+08	Steel Box	0.006	Red (SL)
14	331.4	13	Co-60	2.3E+08	1	7.1E+08	Steel Box	0.000	Red (SL)
15	331.5	7	Co-60	5.2E+08	3	7.1E+08	Steel Box	0.002	Red (SL)
16	352.1	7	Co-60	3.8E+10	230	7.1E+08	Steel Box	0.142	Red (SL)
17	354.1	7	Co-60	1.7E+09	10	7.1E+08	Steel Box	0.006	Red (SL)

Table A2-6. Decontamination Waste Assuming a DF of 10 for O0.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (kg)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	342.1	3	Co-60	5.1E+08	2,231	8.8E+05	Steel Box	1.377	Yellow & Green
2	342.2	3	Co-60	4.9E+06	21	8.8E+05	Steel Box	0.013	Yellow & Green
3	342.3	3	Co-60	3.1E+08	1,351	8.8E+05	Steel Box	0.833	Yellow & Green
4	342.4	3	Co-60	1.7E+08	747	8.8E+05	Steel Box	0.461	Yellow & Green
5	342.5	3	Co-60	3.3E+06	14	8.8E+05	Steel Box	0.009	Yellow & Green
6	342.6	3	Co-60	6.2E+07	267	8.8E+05	Steel Box	0.165	Yellow & Green
7	342.7	3	Co-60	1.6E+08	690	8.8E+05	Steel Box	0.426	Yellow & Green
8	344.1	8	Co-60	1.4E+09	6,023.5	8.8E+05	Steel Box	3.7165	Yellow & Green

Table A2-7. Decontamination Waste Assuming a DF of 10 for O2.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide	Total Waste Weight (kg)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	211.1	3	Co-60	3.0E+12	12,149	8.79E+08	Steel Box	4.630	Red (SL)
2	312.1	8	Co-60	2.9E+09	12	8.79E+08	Steel Box	0.005	Red (SL)
3	313.1	8	Co-60	4.9E+11	2,064	8.79E+08	Steel Box	0.787	Red (SL)
4	313.2	8	Co-60	9.7E+08	4	8.79E+08	Steel Box	0.002	Red (SL)
5	321.1	8	Co-60	1.3E+11	527	8.79E+08	Steel Box	0.201	Red (SL)
6	321.2	8	Co-60	5.0E+11	2,107	8.79E+08	Steel Box	0.803	Red (SL)
7	321.3	8	Co-60	3.5E+10	149	8.79E+08	Steel Box	0.057	Red (SL)
8	321.4	8	Co-60	6.1E+07	0	8.79E+08	Steel Box	0.0001	Red (SL)
9	326.1	8	Co-60	7.2E+10	302	8.79E+08	Steel Box	0.115	Red (SL)
10	327.1	8	Co-60	2.6E+09	11	8.79E+08	Steel Box	0.004	Red (SL)
11	331.1	8	Co-60	9.6E+10	406	8.79E+08	Steel Box	0.155	Red (SL)
12	331.2	8	Co-60	7.2E+10	303	8.79E+08	Steel Box	0.116	Red (SL)
13	331.3	8	Co-60	2.2E+09	9	8.79E+08	Steel Box	0.004	Red (SL)
14	331.4	12	Co-60	3.4E+10	73	8.79E+08	Steel Box	0.028	Red (SL)
15	331.5	8	Co-60	7.8E+08	3	8.79E+08	Steel Box	0.001	Red (SL)
16	352.1	8	Co-60	5.6E+10	236	8.79E+08	Steel Box	0.090	Red (SL)
17	354.1	8	Co-60	2.5E+09	10	8.79E+08	Steel Box	0.004	Red (SL)

Table A2-8. Decontamination Waste Assuming a DF of 10 for O3.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide	Total Waste Weight (kg)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	211.1	5	Co-60	9,2E+11	11,493	3,4E+08	Steel Box	4,380	Red (SL)
2	312.1	8	Co-60	8,7E+09	68	3,4E+08	Steel Box	0,026	Red (SL)
3	313.1	8	Co-60	1,3E+10	100	3,4E+08	Steel Box	0,038	Red (SL)
4	321.1	8	Co-60	3,2E+11	2,508	3,4E+08	Steel Box	0,956	Red (SL)
5	321.2	8	Co-60	1,5E+11	1,201	3,4E+08	Steel Box	0,458	Red (SL)
6	321.3	8	Co-60	3,0E+10	231	3,4E+08	Steel Box	0,088	Red (SL)
7	327.1	8	Co-60	9,6E+08	7	3,4E+08	Steel Box	0,003	Red (SL)
8	331.1	8	Co-60	2,7E+10	211	3,4E+08	Steel Box	0,080	Red (SL)
9	331.2	8	Co-60	1,9E+11	1,494	3,4E+08	Steel Box	0,569	Red (SL)
10	331.3	8	Co-60	7,2E+09	56	3,4E+08	Steel Box	0,021	Red (SL)
11	331.4	10	Co-60	5,1E+09	30	3,4E+08	Steel Box	0,011	Red (SL)
12	331.5	8	Co-60	4,2E+08	3	3,4E+08	Steel Box	0,001	Red (SL)
13	342.1	4	Co-60	7,9E+09	84	3,4E+08	Steel Box	0,032	Red (SL)
14	342.2	4	Co-60	3,2E+10	342	3,4E+08	Steel Box	0,130	Red (SL)
15	342.3	4	Co-60	1,6E+08	2	3,4E+08	Steel Box	0,0006	Red (SL)
16	342.4	4	Co-60	6,3E+07	1	3,4E+08	Steel Box	0,0003	Red (SL)
17	342.5	4	Co-60	1,2E+07	0	3,4E+08	Steel Box	0,00005	Red (SL)
18	342.7	8	Co-60	7,6E+08	6	3,4E+08	Steel Box	0,002	Red (SL)
19	352.1	8	Co-60	6,7E+10	523	3,4E+08	Steel Box	0,199	Red (SL)
20	354.1	8	Co-60	1,1E+09	8	3,4E+08	Steel Box	0,003	Red (SL)

A2.3 Waste activity data: process equipment waste for the okg site at maximum load capacity

Table A2-9. Process Equipment Waste for O1 at Maximum Load Capacity.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	212.1	5	Co-60	2.7E+14	45.5	6.3E+10	BFA-tank	3.8	Red (LL)
2	213.1	6	Co-60	4.0E+14	9.7	3.5E+11	BFA-tank	0.8	Red (LL)
3	212.1	5	Co-60	1.7E+14	28.0	6.3E+10	Large Steel Box	1.5	Red (SL)
4	214.1	7	Co-60	1.9E+12	12.2	6.8E+08	Large Steel Box	0.6	Red (SL)
5	215.1	7	Co-60	5.9E+11	30.5	8.5E+07	Large Steel Box	1.6	Red (SL)
6	244.1	7	Co-60	1.3E+11	3.6	1.5E+08	Large Steel Box	0.2	Red (SL)
7	313.1	7	Co-60	3.7E+10	79.9	2.0E+06	Large Steel Box	4.2	Red (SL)
8	316.1	7	Co-60	3.2E+09	1.3	1.1E+07	Large Steel Box	0.1	Red(SL)
9	321.1	7	Co-60	9.4E+09	15.2	2.7E+06	Large Steel Box	0.8	Red (SL)
10	321.2	7	Co-60	3.7E+10	8.0	2.1E+07	Large Steel Box	0.4	Red (SL)
11	321.3	7	Co-60	2.6E+09	10.6	1.1E+06	Large Steel Box	0.6	Red (SL)
12	323.1	7	Co-60	2.4E+09	3.5	3.0E+06	Large Steel Box	0.2	Red (SL)
13	324.1	7	Co-60	2.4E+10	7.0	1.5E+07	Large Steel Box	0.4	Red (SL)
14	324.2	7	Co-60	2.0E+09	0.8	1.1E+07	Large Steel Box	0.0	Red (SL)
15	324.3	12	Co-60	2.7E+08	0.2	1.7E+07	Large Steel Box	0.0	Red (SL)
16	326.1	7	Co-60	5.4E+09	1.9	1.3E+07	Large Steel Box	0.1	Red (SL)
17	327.1	7	Co-60	2.0E+08	0.1	6.8E+06	Large Steel Box	0.0	Red (SL)
18	331.1	7	Co-60	7.2E+09	1.4	2.3E+07	Large Steel Box	0.1	Red (SL)
19	331.2	7	Co-60	5.4E+09	21.4	1.1E+06	Large Steel Box	1.1	Red (SL)
20	351.1	7	Co-60	3.0E+08	0.8	1.7E+06	Large Steel Box	0.0	Red (SL)
21	352.1	7	Co-60	4.2E+09	6.2	2.9E+06	Large Steel Box	0.0	Red (SL)
22	341.3	14	Co-60	6.1E+08	0.3	2.4E+06	Large Steel Box	0.0	Red (SL)
23	441.2	7	Co-60	9.6E+09	12.0	3.5E+06	Large Steel Box	0.6	Red (SL)
24	552.1	14	Co-60	1.5E+09	0.8	2.2E+06	Large Steel Box	0.0	Red (SL)
25	231.1	7	Co-60	5.7E+09	25.3	9.7E+05	ISO-type Container	0.0	Yellow & Green
26	311.1	7	Co-60	5.4E+09	99.3	2.4E+05	ISO-type Container	0.3	Yellow & Green
27	312.1	7	Co-60	2.2E+08	5.6	1.7E+05	ISO-type Container	1.4	Yellow & Green
28	313.2	7	Co-60	7.2E+07	42.0	7.5E+03	ISO-type Container	5.5	Yellow & Green
29	314.1	7	Co-60	2.5E+09	16.7	6.5E+05	ISO-type Container	0.3	Yellow & Green
30	315.1	7	Co-60	5.1E+08	82.4	2.7E+04	ISO-type Container	2.3	Yellow & Green
31	321.4	7	Co-60	4.6E+06	4.1	4.9E+03	ISO-type Container	0.9	Yellow & Green
32	322.1	7	Co-60	3.2E+09	43.4	3.2E+05	ISO-type Container	4.6	Yellow & Green
33	323.2	7	Co-60	4.2E+08	10.6	1.7E+05	ISO-type Container	0.2	Yellow & Green
34	331.3	7	Co-60	1.7E+08	2.3	3.1E+05	ISO-type Container	2.4	Yellow & Green
35	331.5	7	Co-60	5.8E+07	2.3	1.1E+05	ISO-type Container	0.6	Yellow & Green
36	332.1	9	Co-60	2.3E+07	74.1	5.7E+02	ISO-type Container	0.1	Yellow & Green
37	341.1	14	Co-60	5.0E+07	0.4	1.2E+05	ISO-type Container	0.1	Yellow & Green
38	331.4	13	Co-60	2.5E+07	0.4	1.1E+05	ISO-type Container	4.1	Yellow & Green
39	342.1	15	Co-60	1.9E+05	0.2	4.1E+03	ISO-type Container	0.0	Yellow & Green
40	342.4	15	Co-60	1.5E+05	0.2	3.8E+03	ISO-type Container	0.1	Yellow & Green
41	344.1	11	Cs-137	2.7E+07	1.5	6.8E+04	ISO-type Container	34.0	Yellow & Green
42	354.1	7	Co-60	1.9E+08	24.5	3.3E+04	ISO-type Container	6.4	Yellow & Green
43	411.1	7	Co-60	2.9E+08	612.7	2.0E+03	ISO-type Container	1.8	Yellow & Green
44	411.2	7	Co-60	9.6E+09	115.4	3.6E+05	ISO-type Container	1.8	Yellow & Green
45	431.1	7	Co-60	3.9E+06	33.2	5.2E+02	ISO-type Container	2.6	Yellow & Green
46	433.1	7	Co-60	5.8E+07	31.9	8.0E+03	ISO-type Container	0.6	Yellow & Green
47	441.1	7	Co-60	4.9E+08	47.0	4.5E+04	ISO-type Container	0.0	Yellow & Green

Table A2-10. Process Equipment Waste for O0 at Maximum Load Capacity.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	342.1	15	Co-60	5.7E+07	53.1	4.1E+03	ISO-type Container	2.9	Yellow & Green
2	342.3	15	Co-60	3.5E+07	13.5	9.8E+03	ISO-type Container	0.7	Yellow & Green
3	342.4	15	Co-60	1.9E+07	19.2	3.8E+03	ISO-type Container	1.1	Yellow & Green
4	342.6	15	Co-60	6.8E+06	31.6	8.2E+02	ISO-type Container	1.8	Yellow & Green
5	342.7	15	Co-60	1.8E+07	62.8	1.1E+03	ISO-type Container	3.5	Yellow & Green
6	344.1	11	Co-60	1.3E+08	7.2	6.8E+04	ISO-type Container	0.4	Yellow & Green

Table A2-11. Process Equipment Waste for O2 at Maximum Load Capacity.

No	Identity	Nuclide Vector	Normalised Against	Activity of Normalised Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	212.1	4	Co-60	6.6E+14	53.7	1.3E+11	BFA-tank	4.5	Red (LL)
2	213.1	5	Co-60	3.5E+14	2.5	1.5E+12	BFA-tank	0.2	Red (LL)
3	212.1	4	Co-60	3.4E+14	27.5	1.3E+11	Large Steel Box	1.4	Red (SL)
4	214.1	6	Co-60	3.7E+12	18.5	7.3E+08	Large Steel Box	1.0	Red (SL)
5	215.1	6	Co-60	1.2E+12	22.0	1.9E+08	Large Steel Box	1.2	Red (SL)
6	221.1	6	Co-60	3.1E+10	1.5	7.4E+07	Large Steel Box	0.1	Red (SL)
7	211.2	4	Co-60	4.2E+08	3.2	1.9E+06	Large Steel Box	0.2	Red (SL)
8	243.1	7	Co-60	2.4E+12	66.9	1.3E+08	Large Steel Box	3.5	Red (SL)
9	244.1	7	Co-60	1.9E+11	14.1	4.9E+07	Large Steel Box	0.7	Red (SL)
10	245.1	7	Co-60	2.3E+10	4.7	1.8E+07	Large Steel Box	0.2	Red (SL)
11	313.1	7	Co-60	5.4E+10	67.1	3.0E+06	Large Steel Box	3.5	Red (SL)
12	316.1	7	Co-60	4.7E+09	0.4	4.5E+07	Large Steel Box	0.0	Red (SL)
13	321.1	7	Co-60	1.4E+10	5.0	1.0E+07	Large Steel Box	0.3	Red (SL)
14	321.2	7	Co-60	5.6E+10	26.6	7.7E+06	Large Steel Box	1.4	Red (SL)
15	321.3	7	Co-60	3.9E+09	13.3	1.1E+06	Large Steel Box	0.7	Red (SL)
16	323.1	7	Co-60	3.6E+09	3.8	3.5E+06	Large Steel Box	0.2	Red (SL)
17	324.1	7	Co-60	3.6E+10	11.5	1.2E+07	Large Steel Box	0.6	Red (SL)
18	324.3	10	Co-60	4.0E+10	3.5	2.4E+08	Large Steel Box	0.2	Red (SL)
19	326.1	7	Co-60	8.0E+09	1.3	2.2E+07	Large Steel Box	0.1	Red (SL)
20	327.1	7	Co-60	2.9E+08	0.5	2.1E+06	Large Steel Box	0.0	Red (SL)
21	331.1	7	Co-60	1.1E+10	1.5	2.7E+07	Large Steel Box	0.1	Red (SL)
22	331.2	7	Co-60	8.0E+09	21.6	1.4E+06	Large Steel Box	1.1	Red (SL)
23	331.4	11	Co-60	3.8E+09	1.4	5.0E+06	Large Steel Box	0.1	Red (SL)
24	351.1	7	Co-60	4.5E+08	0.2	7.4E+06	Large Steel Box	0.0	Red (SL)
25	352.1	7	Co-60	6.2E+09	5.6	4.1E+06	Large Steel Box	0.3	Red (SL)
26	414.1	7	Co-60	2.4E+10	87.7	1.0E+06	Large Steel Box	4.6	Red (SL)
27	231.1	7	Co-60	8.4E+09	39.3	7.9E+05	ISO-type Container	2.2	Yellow & Green
28	311.1	7	Co-60	8.1E+09	45.7	6.5E+05	ISO-type Container	2.5	Yellow & Green
29	312.1	7	Co-60	3.2E+08	27.6	4.5E+04	ISO-type Container	1.5	Yellow & Green
30	313.2	7	Co-60	1.1E+08	51.2	7.8E+03	ISO-type Container	2.8	Yellow & Green
31	314.1	7	Co-60	3.7E+09	39.4	3.5E+05	ISO-type Container	2.2	Yellow & Green
32	321.4	7	Co-60	6.8E+06	5.8	4.3E+03	ISO-type Container	0.3	Yellow & Green
33	322.1	7	Co-60	4.7E+09	35.2	5.0E+05	ISO-type Container	2.0	Yellow & Green
34	323.2	7	Co-60	6.2E+08	7.9	2.9E+05	ISO-type Container	0.4	Yellow & Green
35	324.2	7	Co-60	2.9E+09	16.9	6.4E+05	ISO-type Container	0.9	Yellow & Green
36	331.3	7	Co-60	2.5E+08	1.6	5.5E+05	ISO-type Container	0.1	Yellow & Green
37	331.5	7	Co-60	8.6E+07	52.6	6.1E+03	ISO-type Container	2.9	Yellow & Green
38	332.1	12	Co-60	3.4E+09	116.5	5.0E+04	ISO-type Container	6.5	Yellow & Green
39	341.1	13	Cs-137	5.3E+07	66.6	8.9E+02	ISO-type Container	3.7	Yellow & Green
40	354.1	7	Co-60	2.7E+08	18.9	5.4E+04	ISO-type Container	1.0	Yellow & Green
41	412.1	7	Co-60	1.4E+10	365.4	1.4E+05	ISO-type Container	20.3	Yellow & Green
42	413.1	7	Co-60	4.3E+08	166.4	9.5E+03	ISO-type Container	9.2	Yellow & Green
43	431.1	7	Co-60	1.3E+07	60.0	8.2E+02	ISO-type Container	3.3	Yellow & Green
44	441.1	7	Co-60	7.2E+08	191.2	1.4E+04	ISO-type Container	10.6	Yellow & Green
45	441.2	7	Co-60	1.4E+10	117.0	4.5E+05	ISO-type Container	6.5	Yellow & Green
46	455.1	7	Co-60	8.7E+07	7.6	4.2E+04	ISO-type Container	0.4	Yellow & Green

Table A2-12. Process Equipment Waste for O3 at Maximum Load Capacity.

No	Identity	Nuclide Vector	Normalized Against	Activity of Normalized Nuclide (Bq)	Total Waste Weight (tonne)	Mean Specific Activity (Bq/kg)	Container	Number of Containers	Waste Category
1	212.1	7	Co-60	1.7E+15	80.5	2.2E+11	BFA-tank	6.7	Red (LL)
2	216.1	8	Co-60	1.1E+15	6.0	8.7E+11	BFA-tank	0.5	Red (LL)
3	R.2	2	Co-60	3.6E+10	29.4	2.1E+07	Large Steel Box	1.5	Red (SL)
4	211.2	5	Co-60	8.1E+10	6.0	3.0E+07	Large Steel Box	0.3	Red (SL)
5	212.1	7	Co-60	3.1E+15	151.7	2.2E+11	Large Steel Box	8.0	Red (SL)
6	213.1	6	Co-60	3.3E+11	2.0	4.3E+08	Large Steel Box	0.1	Red (SL)
7	214.1	6	Co-60	1.3E+13	38.2	8.7E+08	Large Steel Box	2.0	Red (SL)
8	215.1	6	Co-60	2.1E+12	60.7	9.3E+07	Large Steel Box	3.2	Red (SL)
9	231.1	6	Co-60	1.6E+10	8.0	5.2E+06	Large Steel Box	0.4	Red (SL)
10	243.1	6	Co-60	1.1E+12	91.5	3.0E+07	Large Steel Box	4.8	Red (SL)
11	244.1	6	Co-60	8.8E+10	104.8	2.2E+06	Large Steel Box	5.5	Red (SL)
12	321.1	6	Co-60	3.6E+10	46.6	2.0E+06	Large Steel Box	2.5	Red (SL)
13	321.2	6	Co-60	1.7E+10	10.8	4.2E+06	Large Steel Box	0.6	Red (SL)
14	323.1	6	Co-60	3.7E+11	17.5	5.5E+07	Large Steel Box	0.9	Red (SL)
15	324.1	6	Co-60	2.1E+11	19.2	2.9E+07	Large Steel Box	1.0	Red (SL)
16	324.2	6	Co-60	1.4E+10	13.2	2.8E+06	Large Steel Box	0.7	Red (SL)
17	324.3	11	Co-60	4.4E+10	7.0	4.5E+07	Large Steel Box	0.4	Red (SL)
18	331.1	6	Co-60	3.0E+09	2.1	3.8E+06	Large Steel Box	0.1	Red (SL)
19	331.2	6	Co-60	2.1E+10	29.7	1.9E+06	Large Steel Box	1.6	Red (SL)
20	351.1	6	Co-60	1.8E+08	0.0	2.2E+07	Large Steel Box	0.0	Red (SL)
21	352.1	6	Co-60	7.4E+09	9.1	2.2E+06	Large Steel Box	0.5	Red (SL)
22	742.1	11	Co-60	1.7E+08	0.3	4.1E+06	Large Steel Box	0.0	Red (SL)
23	421.1	6	Co-60	1.9E+10	268.3	1.9E+05	ISO-type Container	14.9	Yellow & Green
24	422.1	6	Co-60	5.9E+10	444.6	3.5E+05	ISO-type Container	24.7	Yellow & Green
25	424.1	6	Co-60	1.4E+09	24.7	1.5E+05	ISO-type Container	1.4	Yellow & Green
26	461.1	6	Co-60	3.6E+11	1,158.9	8.1E+05	ISO-type Container	64.4	Yellow & Green
27	461.2	6	Co-60	9.8E+08	47.3	5.5E+04	ISO-type Container	2.6	Yellow & Green
28	463.1	6	Co-60	2.5E+10	298.1	2.2E+05	ISO-type Container	16.6	Yellow & Green
29	331.3	6	Co-60	8.0E+08	4.9	4.3E+05	ISO-type Container	0.3	Yellow & Green
30	331.4	12	Co-60	5.7E+08	6.9	1.6E+05	ISO-type Container	0.4	Yellow & Green
31	331.5	6	Co-60	4.6E+07	4.7	2.6E+04	ISO-type Container	0.3	Yellow & Green
32	342.7	6	Co-60	8.5E+07	118.2	1.9E+03	ISO-type Container	6.6	Yellow & Green
33	323.2	6	Co-60	5.4E+09	46.5	3.0E+05	ISO-type Container	2.6	Yellow & Green
34	321.3	6	Co-60	3.3E+09	25.2	3.4E+05	ISO-type Container	1.4	Yellow & Green
35	322.1	6	Co-60	1.8E+10	48.1	9.7E+05	ISO-type Container	2.7	Yellow & Green
36	251.1	6	Co-60	6.4E+08	14.0	1.2E+05	ISO-type Container	0.8	Yellow & Green
37	311.1	6	Co-60	7.0E+09	104.3	1.8E+05	ISO-type Container	5.8	Yellow & Green
38	314.1	6	Co-60	1.3E+09	42.5	8.1E+04	ISO-type Container	2.4	Yellow & Green
39	316.1	6	Co-60	9.0E+07	0.5	4.8E+05	ISO-type Container	0.0	Yellow & Green
40	312.1	6	Co-60	9.7E+08	25.9	9.8E+04	ISO-type Container	1.4	Yellow & Green
41	313.1	6	Co-60	1.4E+09	40.7	9.2E+04	ISO-type Container	2.3	Yellow & Green
42	327.1	6	Co-60	1.1E+08	10.8	2.6E+04	ISO-type Container	0.6	Yellow & Green
43	332.1	15	Co-60	1.9E+08	89.5	7.0E+03	ISO-type Container	5.0	Yellow & Green
44	341.1	13	Co-60	6.2E+09	8.2	7.6E+05	ISO-type Container	0.5	Yellow & Green
45	341.3	13	Cs-137	5.5E+07	3.1	1.8E+04	ISO-type Container	0.2	Yellow & Green
46	342.1	14	Co-60	8.7E+08	24.9	1.3E+05	ISO-type Container	1.4	Yellow & Green
47	342.2	14	Co-60	3.6E+09	57.5	2.2E+05	ISO-type Container	3.2	Yellow & Green
48	342.3	14	Co-60	1.8E+07	4.5	1.4E+04	ISO-type Container	0.2	Yellow & Green
49	342.4	14	Co-60	7.0E+06	20.8	1.2E+03	ISO-type Container	1.2	Yellow & Green
50	354.1	6	Co-60	1.2E+08	14.4	2.2E+04	ISO-type Container	0.8	Yellow & Green
51	403.1	6	Co-60	2.1E+09	350.0	1.6E+04	ISO-type Container	19.4	Yellow & Green
52	423.1	6	Co-60	1.4E+09	82.0	4.6E+04	ISO-type Container	4.6	Yellow & Green

A2.4 Nuclide vectors

Table A2-13. Nuclide vectors for O1 and O0.

Vector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
H-3	3.8E+01					1.5E–06		9.5E–08		3.0E–01						
Be-10	1.1E–08	9.9E–12	6.3E–12						6.4E–11			5.3E–11	5.1E–11		3.3E–11	
C-14	1.4E–02	7.2E–04	4.8E–04	1.7E–04	2.8E–03	5.3E+00		1.8E–04	1.7E–02	9.0E–04		0.0E+00	8.8E–05		4.8E–04	1.1E–03
Cl-36	4.7E–04	1.6E–07	1.1E–07	1.1E–07	1.4E–06	1.0E+00		5.6E–08	2.0E–07	5.1E–07		0.0E+00	1.7E–07		1.1E–07	1.6E–06
Ca-41	4.7E–02					3.0E–02										
Fe-55	2.4E+00	1.6E–01	2.3E–01	3.4E+00	5.1E+00	2.2E+00	4.6E–01	2.4E+00	1.1E–01	5.1E+00	6.6E–01	6.5E–01	1.0E–01		2.3E–01	1.1E+01
Co-60	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00		1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00		1.0E+00	1.0E+00
Ni-59	1.1E–04	2.3E–03	1.6E–03	1.3E–02	2.8E–02	2.0E–05	1.9E–02	1.0E–03	2.3E–03	7.2E–03	1.3E–02	8.3E–04	2.5E–03		1.6E–03	2.2E–03
Ni-63	1.1E–02	3.1E–01	2.1E–01	1.6E+00	4.3E+00	4.0E–08	2.4E+00	1.6E–01	3.1E–01	9.3E–01	1.7E+00	1.1E–01	3.3E–01		2.1E–01	2.1E–01
Se-79	1.6E–08	3.3E–09	2.2E–09			4.5E–03		5.5E–12	2.2E–08			1.8E–08	1.7E–08		1.2E–08	
Sr-90	1.7E–04	3.1E–03	2.2E–03	3.6E–03	8.4E–08	8.1E–05	6.5E–03	2.0E–05	2.0E–02	1.2E–05	7.4E–03	1.6E–02	1.6E–02	1.2E–01	1.2E–02	
Zr-93	3.2E–07	1.5E–06	1.0E–06	7.0E–06	1.6E–10	3.7E–04	1.3E–05	9.9E–10	1.5E–06	2.3E–08	8.7E–06	5.5E–07	1.6E–06		1.0E–06	
Nb-93m	1.0E–02	5.2E–02	4.0E–02	2.5E–01	1.6E–03	5.8E–05	4.3E–01	2.2E–03	5.2E–02	1.3E–02	3.3E–01	1.9E–02	5.5E–02		4.0E–02	5.6E–03
Nb-94	9.1E–05	8.5E–05	5.7E–05	5.0E–04	3.3E–05		6.9E–04	2.7E–06	8.5E–05	1.9E–05	4.7E–04	3.0E–05	9.0E–05		5.7E–05	4.7E–05
Mo-93	1.7E–07	5.2E–07	3.5E–07	1.5E–04	4.7E–04	1.4E–07	4.2E–06	1.6E–05	5.2E–07	2.9E–04	2.9E–06	1.9E–07	5.5E–07		3.5E–07	1.0E–04
Tc-99	3.3E–08	6.7E–05	4.5E–05	2.5E–05	7.4E–05		3.4E–06	2.0E–06	2.4E–04	4.5E–05	3.2E–06	1.0E–03	2.8E–04		2.4E–04	2.0E–05
Ru-106		2.0E–02	1.0E–01					1.0E–06	5.4E–03			9.5E–01	1.1E–02		5.5E–01	
Ag-108m	9.1E–03	5.7E–06	3.9E–06	2.6E–05	6.0E–10	2.9E–10	4.7E–05	2.0E–09	5.7E–06	8.5E–08	3.2E–05	2.0E–06	6.1E–06		3.9E–06	
Pd-107		5.7E–03	3.8E–03			4.1E–05		3.8E–12	3.0E–02			1.1E–02	3.2E–02		2.0E–02	
Cd-113m	3.3E–05	1.7E–02	1.4E–02					2.9E–11	9.2E–02			3.3E–02	9.8E–02		7.2E–02	
Sn-126		2.7E–02	1.8E–02	5.1E–08	1.2E–12		9.3E–08	5.2E–11	1.4E–01	1.7E–10	9.6E–08	5.2E–02	1.5E–01		9.7E–02	
Sb-125	2.5E–05	7.4E–04	1.1E–03	3.8E–03	2.2E–04		6.9E–03	1.0E–04	7.5E–04	2.8E–04	9.9E–03	2.7E–04	7.9E–04		1.1E–03	1.3E–04
I-129		2.4E–07	1.6E–07					6.2E–12	7.7E–06			7.3E–06	2.9E–07	7.6E–07	8.5E–07	
Cs-134	5.2E–02	3.5E–02	6.5E–02					1.1E–05	7.3E–03			1.7E+00	2.0E–02		3.4E–01	
Cs-135		2.4E–06	1.6E–06			1.4E–06		7.4E–11	9.2E–06			3.4E–05	1.0E–05	1.2E–04	8.4E–06	
Cs-137	1.8E–04	1.5E–01	1.1E–01			2.4E–07		2.0E–05	4.5E–02			7.1E+00	1.1E–01	1.0E+00	5.9E–01	
Ba-133	3.7E–03	5.4E–08	4.5E–08			1.1E–09		5.2E–12	1.6E–08			2.5E–06	3.8E–08		2.4E–07	
Pm-147	3.1E–03	5.6E–02	1.1E–01	2.5E–04	5.9E–09	9.0E–07	4.6E–04	8.1E–06	1.7E–02	8.4E–07	1.4E–03	2.6E+00	4.0E–02		5.9E–01	
Sm-151	1.1E–01	8.3E–04	3.6E–04	4.2E–05	9.8E–10	2.8E–07	7.6E–05	3.5E–08	2.4E–04	1.4E–07	5.0E–05	3.8E–02	5.8E–04		1.9E–03	
Eu-152	2.7E+00	9.5E–06	7.6E–06	1.9E–07	4.4E–12	1.9E–12	3.4E–07	1.4E–10	2.8E–06	6.3E–10	4.1E–07	4.4E–04	6.7E–06		4.0E–05	
Eu-154	1.1E–01	1.2E–02	5.0E–03	1.6E–04	3.7E–09	3.4E–12	2.9E–04	6.7E–07	3.5E–03	5.3E–07	1.8E–04	5.5E–01	8.4E–03		2.6E–02	
Eu-155	4.2E–02	6.5E–03	2.3E–03	5.0E–05	1.2E–09	1.5E–10	9.1E–05	3.6E–07	1.9E–03	1.7E–07	4.7E–05	3.0E–01	4.6E–03		1.2E–02	
Ho-166m	1.1E–03	5.3E–09	3.7E–09	3.3E–10	7.7E–15	2.2E–10	6.0E–10	4.2E–14	1.6E–09	1.1E–12	6.1E–10	2.4E–07	3.7E–09		1.9E–08	
U-232		1.3E–08	9.4E–09	6.0E–10	1.4E–14	1.7E–06	1.1E–09	4.7E–10	3.7E–09	2.0E–12	1.2E–09	5.8E–07	8.9E–09		5.0E–08	
U-236		4.2E–07	3.0E–07	2.6E–08	6.2E–13	2.2E–07	4.8E–08	9.2E–11	1.2E–07	8.8E–11	5.2E–08	1.9E–05	3.0E–07		1.6E–06	
Np-237		6.1E–07	2.9E–07	3.8E–08	8.9E–13	2.8E–07	7.0E–08	1.2E–10	1.8E–07	1.3E–10	4.9E–08	2.8E–05	4.3E–07		1.5E–06	
Pu-238		6.5E–05	4.5E–05	3.0E–04	6.9E–09	2.4E–05	5.4E–04	9.7E–07	4.4E–04	9.8E–07	3.6E–04	7.7E–06	3.8E–04		2.4E–04	
Pu-239	3.4E–05	1.1E–05	7.3E–06	3.8E–05	8.9E–10	1.2E–09	6.9E–05	4.3E–09	6.0E–05	1.3E–07	5.2E–05	9.2E–07	6.4E–05		3.8E–05	
Pu-240		1.7E–05	1.1E–05	5.0E–05	1.2E–09	4.4E–07	9.0E–05	5.0E–09	9.2E–05	1.6E–07	8.9E–05	1.6E–06	9.8E–05		5.9E–05	
Pu-241		1.4E–03	1.1E–03	4.2E–03	9.8E–08	1.6E–08	7.6E–03	8.0E–07	7.9E–03	1.4E–05	5.5E–03	2.5E–04	8.2E–03		5.7E–03	
Pu-242		2.3E–08	2.4E–08	2.1E–07	4.8E–12	1.2E–08	3.8E–07	3.1E–11	1.3E–07	6.9E–10	3.7E–07	4.0E–09	1.3E–07		1.3E–07	
Am-241		1.6E–05	5.8E–06	7.8E–05	1.8E–09	8.6E–09	1.4E–04	1.0E–08	8.2E–05	2.6E–07	6.1E–05	2.2E–06	9.3E–05		3.1E–05	
Am-242m		7.3E–07	2.1E–07	2.8E–06	6.6E–11	1.0E–06	5.1E–06	2.4E–10	3.3E–06	9.4E–09	1.2E–06	5.9E–08	4.4E–06		1.1E–06	
Am-243		4.7E–07	6.0E–07	2.1E–06	4.9E–11	2.3E–10	3.8E–06	3.6E–10	2.1E–06	7.0E–09	4.0E–06	3.8E–08	2.8E–06		3.2E–06	
Cm-243		6.2E–07	3.9E–07	1.5E–06	3.6E–11	7.1E–11	2.8E–06	2.2E–10	2.8E–06	5.1E–09	1.5E–06	5.0E–08	3.7E–06		2.1E–06	
Cm-244		5.1E–05	3.8E–05	1.8E–04	4.2E–09		3.3E–04	4.6E–08	2.9E–04	5.9E–07	2.2E–04	8.6E–06	3.0E–04		2.0E–04	
Cm-245		4.6E–09	3.1E–09	4.1E–08	9.5E–13		7.4E–08	7.6E–12	2.6E–08	1.4E–10	4.4E–08	7.8E–10	2.7E–08		1.6E–08	
Cm-246		1.4E–09	9.6E–10	1.3E–08	2.9E–13		2.3E–08	2.7E–12	8.0E–09	4.2E–11	1.4E–08	2.4E–10	8.3E–09		5.0E–09	
Normalized against	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Cs–137	Co–60	Co–60

Table A2-14. Nuclide vectors for O2.

Vector	1	2	3	4	5	6	7	8	9	10	11	12	13	14
H-3	3.1E+01			6.9E–04				1.0E–06	2.4E–01					
Be-10	7.3E–09	6.3E–12								3.4E–11	3.3E–11	4.1E–11		
C-14	9.6E–03	4.8E–04	4.7E–04	3.5E–02	1.9E–03	2.0E–03		1.5E–04	6.1E–04	0.0E+00	6.0E–05	1.1E–02		7.7E–04
Cl-36	3.2E–04	1.1E–07	3.5E–07	2.6E–02	6.3E–07	6.7E–07		1.6E–07	3.5E–07	0.0E+00	1.2E–07	1.3E–07		1.0E–06
Ca-41	3.1E–02			7.1E–01										
Fe-55	3.5E+00	2.3E–01	5.7E+00	1.3E+01	7.9E+00	8.4E+00	6.7E–01	1.4E+01	7.3E+00	9.3E–01	1.5E–01	1.6E–01		1.7E+01
Co-60	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00		1.0E+00
Ni-59	7.4E–05	1.6E–03	9.8E–03	4.3E–05	1.5E–02	1.3E–02	1.3E–02	3.2E–04	4.8E–03	5.6E–04	1.7E–03	1.6E–03		1.5E–03
Ni-63	7.4E–03	2.1E–01	1.2E+00	4.2E–03	1.6E+00	1.5E+00	1.7E+00	4.6E–02	6.4E–01	7.7E–02	2.2E–01	2.1E–01		1.5E–01
Se-79	1.0E–08	2.2E–09						4.9E–11		1.2E–08	1.1E–08	1.4E–08		
Sr-90	1.3E–04	2.2E–03	4.3E–03		6.7E–05	1.5E–05	7.4E–03	1.9E–04	1.3E–05	1.2E–02	1.1E–02	1.4E–02	1.2E–01	
Zr-93	2.2E–07	1.0E–06	5.1E–06		7.9E–08	1.8E–08	8.7E–06	4.0E–09	1.6E–08	3.7E–07	1.1E–06	1.0E–06		
Nb-93m	7.9E–03	4.0E–02	2.1E–01		7.0E–03	3.5E–03	3.3E–01	6.6E–03	9.7E–03	1.4E–02	4.2E–02	4.0E–02		4.3E–03
Nb-94	6.1E–05	5.7E–05	2.9E–04		2.2E–05	1.7E–05	4.7E–04	7.9E–06	1.3E–05	2.1E–05	6.1E–05	5.7E–05		3.1E–05
Mo-93	1.2E–07	3.5E–07	6.5E–05		1.5E–05	9.2E–06	2.9E–06	3.0E–05	1.9E–04	1.3E–07	3.7E–07	3.5E–07		6.9E–05
Tc-99	2.2E–08	4.5E–05	1.0E–05		2.6E–06	1.5E–06	3.2E–06	4.5E–06	3.0E–05	6.9E–04	1.9E–04	1.6E–04		1.3E–05
Ru-106		1.0E–01						7.0E–05		4.9E+00	5.7E–02	2.8E–02		
Ag-108m	6.2E–03	3.9E–06	1.9E–05		2.9E–07	6.6E–08	3.2E–05	1.0E–13	5.8E–08	1.4E–06	4.1E–06	3.9E–06		
Pd-107		3.8E–03						3.3E–11		7.3E–03	2.2E–02	2.0E–02		
Cd-113m	2.6E–05	1.4E–02						3.0E–10		2.6E–02	7.6E–02	7.2E–02		
Sn-126		1.8E–02	5.6E–08		8.7E–10	2.0E–10	9.6E–08	4.2E–10	1.8E–10	3.5E–02	1.0E–01	9.7E–02		
Sb-125	3.6E–05	1.1E–03	5.9E–03		2.0E–04	8.9E–05	9.9E–03	4.5E–04	4.0E–04	3.8E–04	1.1E–03	1.1E–03		1.9E–04
I-129		1.6E–07						5.5E–11		4.9E–06	1.9E–07	5.2E–06	7.1E–07	
Cs-134	9.5E–02	6.5E–02		1.9E–01				2.6E–04		3.1E+00	3.6E–02	1.3E–02		
Cs-135		1.6E–06						6.6E–10		2.3E–05	6.8E–06	6.2E–06	1.2E–04	
Cs-137	1.3E–04	1.1E–01						1.9E–04		5.1E+00	7.8E–02	3.3E–02	1.0E+00	
Ba-133	3.0E–03	4.5E–08						5.7E–11		2.1E–06	3.2E–08	1.3E–08		
Pm-147	4.6E–03	1.1E–01	8.1E–04		1.3E–05	2.9E–06	1.4E–03	1.6E–04	2.5E–06	5.2E+00	7.9E–02	3.3E–02		
Sm-151	7.3E–02	3.6E–04	2.9E–05		4.5E–07	1.0E–07	5.0E–05	2.9E–07	9.1E–08	1.7E–02	2.6E–04	1.1E–04		
Eu-152	2.2E+00	7.6E–06	2.4E–07		3.7E–09	8.6E–10	4.1E–07	1.3E–09	7.5E–10	3.5E–04	5.4E–06	2.2E–06		
Eu-154	9.8E–02	5.0E–03	1.1E–04		1.6E–06	3.8E–07	1.8E–04	7.4E–06	3.3E–07	2.3E–01	3.5E–03	1.5E–03		
Eu-155	4.4E–02	2.3E–03	2.8E–05		4.3E–07	9.9E–08	4.7E–05	4.9E–06	8.7E–08	1.0E–01	1.6E–03	6.6E–04		
Ho-166m	7.7E–04	3.7E–09	3.6E–10		5.6E–12	1.3E–12	6.1E–10	1.5E–13	1.1E–12	1.7E–07	2.6E–09	1.1E–09		
U-232		9.4E–09	7.1E–10		1.1E–11	2.5E–12	1.2E–09	4.3E–09	2.2E–12	4.3E–07	6.6E–09	2.8E–09		
U-236		3.0E–07	3.0E–08		4.7E–10	1.1E–10	5.2E–08	8.0E–10	9.4E–11	1.4E–05	2.1E–07	8.9E–08		
Np-237		2.9E–07	2.9E–08		4.4E–10	1.0E–10	4.9E–08	1.1E–09	8.9E–11	1.3E–05	2.0E–07	8.4E–08		
Pu-238		4.5E–05	2.1E–04		3.3E–06	7.5E–07	3.6E–04	8.6E–06	6.5E–07	5.3E–06	2.6E–04	3.0E–04		
Pu-239		7.3E–06	3.0E–05		4.7E–07	1.1E–07	5.2E–05	1.2E–08	9.4E–08	6.2E–07	4.3E–05	4.0E–05		
Pu-240		1.1E–05	5.2E–05		8.1E–07	1.9E–07	8.9E–05	1.1E–08	1.6E–07	1.1E–06	6.6E–05	6.2E–05		
Pu-241		1.1E–03	3.2E–03		5.0E–05	1.1E–05	5.5E–03	4.9E–06	1.0E–05	1.9E–04	6.4E–03	6.1E–03		
Pu-242		2.4E–08	2.1E–07		3.3E–09	7.7E–10	3.7E–07	1.4E–10	6.7E–10	4.3E–09	1.4E–07	1.4E–07		
Am-241		5.8E–06	3.6E–05		5.6E–07	1.3E–07	6.1E–05	1.5E–08	1.1E–07	6.4E–07	3.5E–05	2.8E–05		
Am-242m		2.1E–07	7.3E–07		1.1E–08	2.6E–09	1.2E–06	1.9E–10	2.3E–09	1.7E–08	1.3E–06	9.6E–07		
Am-243		6.0E–07	2.4E–06		3.7E–08	8.5E–09	4.0E–06	1.8E–09	7.4E–09	4.8E–08	3.6E–06	2.7E–06		
Cm-243		3.9E–07	8.5E–07		1.3E–08	3.0E–09	1.5E–06	1.0E–09	2.7E–09	3.2E–08	2.4E–06	1.8E–06		
Cm-244		3.8E–05	1.3E–04		2.0E–06	4.6E–07	2.2E–04	3.2E–07	4.0E–07	6.5E–06	2.3E–04	2.2E–04		
Cm-245		3.1E–09	2.6E–08		4.1E–10	9.3E–11	4.4E–08	4.0E–11	8.1E–11	5.2E–10	1.8E–08	1.7E–08		
Cm-246		9.6E–10	8.0E–09		1.2E–10	2.9E–11	1.4E–08	1.6E–11	2.5E–11	1.6E–10	5.6E–09	5.4E–09		
Normalized against	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Cs–137	Co–60

Table A2-15. Nuclide vectors for O3.

Vector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
H-3	3.1E+01							5.0E–08	6.3E–07	2.6E–01					
Be-10	7.3E–09		7.3E–14								8.5E–14	4.1E–13		3.1E–13	4.1E–13
C-14	9.5E–03	7.7E–04	5.6E–04	1.5E–04	2.7E–04		2.1E–03	1.1E–04	1.0E–04	4.7E–04	0.0E+00	8.7E–05		5.6E–04	6.5E–02
Cl-36	3.2E–04	1.0E–06	6.0E–08	1.1E–07	8.9E–08		6.8E–07	3.5E–08	1.1E–07	2.9E–07	0.0E+00	8.8E–08		6.0E–08	4.4E–08
Ca-41	3.1E–02														
Fe-55	3.5E+00	1.7E+01	5.7E–01	2.2E+00	1.0E+00	6.2E–01	7.8E+00	3.8E+00	1.7E+01	7.2E+00	1.0E+00	3.5E–01		5.7E–01	1.8E+00
Co-60	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00		1.0E+00	1.0E+00
Ni-59	7.4E–05	1.5E–03	1.2E–03	5.9E–03	2.1E–03	6.0E–03	1.5E–02	6.8E–04	2.5E–04	3.9E–03	3.8E–04	1.6E–03		1.2E–03	1.5E–03
Ni-63	7.4E–03	1.5E–01	1.6E–01	7.6E–01	2.1E–01	7.9E–01	1.7E+00	1.0E–01	3.4E–02	5.1E–01	5.3E–02	2.1E–01		1.6E–01	2.1E–01
Se-79	1.1E–08		1.7E–09					2.5E–12	3.1E–11		1.9E–09	9.2E–09		7.0E–09	9.4E–09
Sr-90	1.3E–04		1.9E–03	3.3E–03		3.8E–03	1.0E–05	1.2E–05	1.2E–04	8.7E–06	2.2E–03	1.0E–02	7.9E–03	7.8E–03	1.0E–02
Zr-93	2.2E–07		5.3E–07	2.4E–06		2.7E–06	7.6E–09	2.2E–09	2.5E–09	6.3E–09	1.7E–07	6.9E–07		5.3E–07	6.7E–07
Nb-93m	6.8E–03	3.7E–03	4.0E–02	1.8E–01	1.6E–03	2.0E–01	5.1E–03	2.0E–03	5.9E–03	9.6E–03	1.3E–02	5.2E–02		4.0E–02	5.1E–02
Nb-94	6.2E–05	3.2E–05	4.5E–05	2.0E–04	4.4E–06	2.2E–04	2.1E–05	2.0E–06	6.1E–06	1.1E–05	1.4E–05	5.9E–05		4.5E–05	5.8E–05
Mo-93	1.2E–07	6.9E–05	3.5E–07	2.7E–05	5.6E–06	1.7E–06	1.9E–05	1.5E–05	2.3E–05	1.7E–04	1.1E–07	4.5E–07		3.5E–07	4.4E–07
Tc-99	2.3E–08	1.3E–05	4.7E–05	4.5E–06	1.0E–06	1.6E–06	3.2E–06	1.9E–06	3.8E–06	2.7E–05	1.7E–04	2.1E–04		2.0E–04	2.0E–04
Ru-106			1.2E–01					3.5E–06	4.4E–05		1.4E+00	7.0E–02		4.9E–01	3.0E–02
Ag-108m	6.2E–03		5.5E–06	2.4E–05		2.7E–05	7.6E–08	2.0E–08	6.4E–14	6.4E–08	1.8E–06	7.2E–06		5.5E–06	7.0E–06
Pd-107			2.7E–05					1.7E–12	2.1E–11		3.7E–05	1.5E–04		1.2E–04	1.5E–04
Cd-113m	2.5E–05		6.7E–03					1.5E–11	1.9E–10		9.0E–03	3.7E–02		2.8E–02	3.6E–02
Sn-126			1.3E–04	4.3E–08		5.0E–08	1.4E–10	5.8E–11	2.7E–10	1.2E–10	1.7E–04	7.0E–04		5.4E–04	6.9E–04
Sb-125	3.6E–05	1.9E–04	7.9E–04	3.9E–03	4.0E–05	4.5E–03	1.4E–04	1.8E–04	6.0E–04	4.3E–04	2.5E–04	1.0E–03		7.9E–04	1.0E–03
I-129			2.1E–07					2.8E–12	3.5E–11		1.6E–06	3.8E–07	2.0E–06	9.0E–07	1.8E–05
Cs-134	9.6E–02		7.7E–02					1.3E–05	1.6E–04		9.5E–01	4.5E–02		3.3E–01	1.6E–02
Cs-135			1.6E–06					3.3E–11	4.1E–10		5.6E–06	7.4E–06	1.7E–04	6.8E–06	7.1E–06
Cs-137	1.3E–04		1.1E–01					9.5E–06	1.2E–04		1.3E+00	7.7E–02	1.0E+00	4.7E–01	3.5E–02
Ba-133	3.0E–03		2.4E–11					2.9E–12	3.6E–11		2.9E–10	1.7E–11		1.0E–10	7.5E–12
Pm-147	4.6E–03		1.1E–01	5.9E–04		6.8E–04	1.9E–06	8.5E–06	1.0E–04	1.6E–06	1.3E+00	7.5E–02		4.6E–01	3.4E–02
Sm-151	7.3E–02		4.5E–04	2.7E–05		3.2E–05	8.8E–08	3.8E–08	1.9E–07	7.3E–08	5.4E–03	3.1E–04		1.9E–03	1.4E–04
Eu-152	2.1E+00		7.6E–06	1.8E–07		2.1E–07	5.9E–10	2.2E–10	8.2E–10	4.9E–10	9.1E–05	5.2E–06		3.2E–05	2.4E–06
Eu-154	9.8E–02		6.0E–03	9.7E–05		1.1E–04	3.1E–07	4.6E–07	4.7E–06	2.6E–07	7.2E–02	4.1E–03		2.5E–02	1.9E–03
Eu-155	4.4E–02		2.3E–03	2.2E–05		2.5E–05	6.9E–08	2.7E–07	3.1E–06	5.8E–08	2.8E–02	1.6E–03		9.7E–03	7.2E–04
Ho-166m	7.7E–04		1.1E–08	7.9E–10		9.2E–10	2.6E–12	6.9E–13	9.4E–14	2.1E–12	1.3E–07	7.3E–09		4.5E–08	3.3E–09
U-232			9.5E–09	5.5E–10		6.4E–10	1.8E–12	2.2E–10	2.7E–09	1.5E–12	1.1E–07	6.6E–09		4.0E–08	3.0E–09
U-236			2.9E–07	2.2E–08		2.6E–08	7.2E–11	5.9E–11	5.0E–10	6.0E–11	3.5E–06	2.0E–07		1.2E–06	9.2E–08
Np-237			3.5E–07	2.6E–08		3.1E–08	8.5E–11	7.6E–11	6.7E–10	7.1E–11	4.2E–06	2.4E–07		1.5E–06	1.1E–07
Pu-238			5.1E–05	2.1E–04		2.4E–04	6.8E–07	6.2E–07	5.5E–06	5.6E–07	2.3E–06	3.1E–04		2.2E–04	3.2E–04
Pu-239	2.3E–05		6.3E–06	2.3E–05		2.7E–05	7.4E–08	2.0E–08	7.6E–09	6.2E–08	2.0E–07	3.9E–05		2.6E–05	3.8E–05
Pu-240			7.0E–06	3.0E–05		3.4E–05	9.5E–08	2.6E–08	6.8E–09	7.9E–08	2.6E–07	4.3E–05		3.0E–05	4.2E–05
Pu-241			1.3E–03	3.0E–03		3.5E–03	9.8E–06	2.9E–06	3.1E–06	8.2E–06	7.6E–05	7.7E–03		5.3E–03	7.6E–03
Pu-242			2.5E–08	1.8E–07		2.1E–07	5.8E–10	1.6E–10	8.7E–11	4.9E–10	1.5E–09	1.5E–07		1.1E–07	1.5E–07
Am-241			5.4E–06	3.1E–05		3.6E–05	1.0E–07	2.8E–08	9.5E–09	8.4E–08	2.3E–07	3.3E–05		2.3E–05	3.0E–05
Am-242m			2.0E–07	6.5E–07		7.6E–07	2.1E–09	5.7E–10	1.2E–10	1.8E–09	6.5E–09	1.2E–06		8.4E–07	1.1E–06
Am-243			7.0E–07	2.6E–06		3.0E–06	8.5E–09	2.4E–09	1.1E–09	7.1E–09	2.3E–08	4.3E–06		3.0E–06	3.8E–06
Cm-243			4.2E–07	8.7E–07		1.0E–06	2.8E–09	8.0E–10	6.4E–10	2.3E–09	1.4E–08	2.6E–06		1.8E–06	2.3E–06
Cm-244			6.5E–05	1.8E–04		2.1E–04	5.7E–07	1.7E–07	2.0E–07	4.8E–07	3.7E–06	3.9E–04		2.7E–04	3.9E–04
Cm-245			5.8E–09	4.0E–08		4.6E–08	1.3E–10	3.6E–11	2.5E–11	1.1E–10	3.3E–10	3.5E–08		2.4E–08	3.5E–08
Cm-246			2.4E–09	1.7E–08		1.9E–08	5.4E–11	1.5E–11	9.9E–12	4.5E–11	1.4E–10	1.5E–08		1.0E–08	1.5E–08
Normalized against	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Co–60	Cs–137	Co–60	Co–60

Appendix 3

WBS structure and decommissioning plan

A3.1 WBS decommissioning programme for the Oskarshamn site

ID	WBS	Main activities
0	0	Oskarshamn site decommissioning
1	100	O1 decommissioning
2	101	Power operation (related to decommissioning)
3	101.1	Plant operation costs
20	101.2	Project costs
21	101.2.1	Purchasers project management, administration and technical support
28	101.2.2	Decomissioning preparation activities
32	102	Defueling (related to decommissioning)
33	102.1	Plant operation costs
50	102.2	Project costs
51	102.2.1	Purchasers project management, administration and technical support
58	102.2.2	Decomissioning preparation activities
64	103	Shutdown operation (related to decommissioning)
95	104	Nuclear dismantling and demolition
96	104.1	Plant operation costs
127	104.2	Purchaser's project management, administration and technical support
134	104.3	Dismantling and demolition activities
135	104.3.1	Reactor vessel and internals
136	104.3.1.1	Reactor internals
141	104.3.1.3	Reactor vessel one-piece removal
146	104.3.2	Reactor containment
152	104.3.3	Reactor building
158	104.3.4	Turbine building
164	104.3.5	Demolition of radioactive concrete
168	104.3.6	Cleaning and clearance of controlled area buildings
171	104.3.7	Process dismantling uncontrolled area buildings
177	104.3.8	Misc undistributed costs
181	104.4	Waste handling and storage
182	104.4.1	Waste management system
186	104.4.2	Containers for transport and storage
189	104.4.3	Transports to repository and landfills
193	104.4.4	Repository and landfill storage fees
195	104.4.5	Handling of nonradioactive hazardous waste
196	105	Conventional demolition
197	105.1	Plant operation costs
212	105.2	Purchaser's project management, administration and technical support
219	105.3	Dismantling and demolition activities
220	105.3.1	Reactor containment
221	105.3.2	Reactor building
222	105.3.3	Turbine building
223	105.3.4	Other buildings
224	105.3.5	Building rubble random activity check
225	105.4	Waste handling and storage
226	105.4.1	Transports and repository
229	105.4.2	Handling of nonradioactive hazardous waste
230	105.5	Site restoration
233	106	Plant shutdown
234	107	Defueling finish
235	108	Shutdown operation finish
236	109	Building clearance finish
237	110	Plant decommissioning finish
238	200	O2 decommissioning
239	201	Power operation (related to decommissioning)
240	201.1	Plant operating costs
257	201.2	Project costs
258	201.2.1	Purchasers project management, administration and technical support
265	201.2.2	Decomissioning preparation activities
269	202	Defueling
270	202.1	Plant operating costs
287	202.2	Project costs
288	202.2.1	Purchasers project management, administration and technical support
295	202.2.2	Decomissioning preparation activities
304	203	Shutdown operation (related to decommissioning)

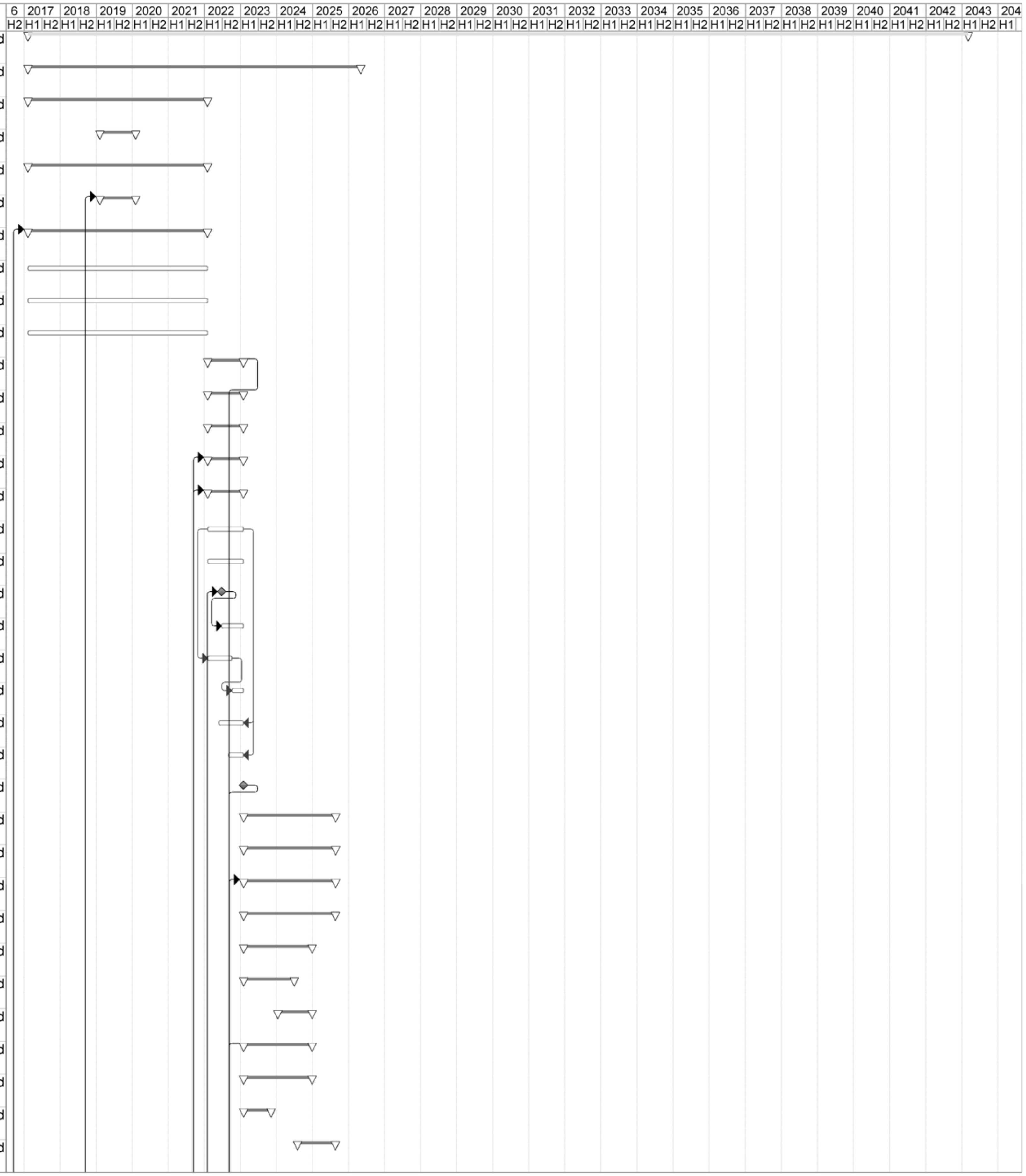
ID	WBS	Main activities
331	204	Nuclear dismantling and demolition
332	204.1	Plant operating costs
363	204.2	Purchaser's project management, administration and technical support
370	204.3	Dismantling and demolition activities
371	204.3.1	Reactor vessel and internals
372	204.3.1.1	Reactor internals
377	204.3.1.3	Reactor vessel one-piece removal
382	204.3.2	Reactor containment
388	204.3.3	Reactor building
394	204.3.4	Turbine building
400	204.3.5	Other controlled area buildings
406	204.3.6	Demolition of radioactive concrete
410	204.3.7	Cleaning and clearance of controlled area buildings
413	204.3.8	Process dismantling uncontrolled area buildings
419	204.3.9	Misc undistributed costs
423	204.4	Waste handling and storage
424	204.4.1	Waste management system
428	204.4.2	Containers for transport and storage
431	204.4.3	Transports to repository and landfills
435	204.4.4	Repository and landfill storage fees
437	204.4.5	Handling of nonradioactive hazardous waste
438	205	Conventional demolition
439	205.1	Plant operating costs
454	205.2	Purchaser's project management, administration and technical support
461	205.3	Dismantling and demolition activities
462	205.3.1	Reactor containment
463	205.3.2	Reactor building
464	205.3.3	Turbine building
465	205.3.4	Other buildings
466	205.3.5	Building rubble random activity check
467	205.4	Waste handling and storage
468	205.4.1	Transports and depository
471	205.4.2	Handling of nonradioactive hazardous waste
472	205.5	Site restoration
475	206	Plant shutdown
476	207	Defueling finish
477	208	Shutdown operation finish
478	209	Building clearance finish
479	210	Plant decommissioning finish
480	300	O3 decommissioning
481	301	Power operation (related to decommissioning)
482	301.1	Plant operating costs
499	301.2	Project costs
500	301.2.1	Purchasers project management, administration and technical support
507	301.2.2	Decommissioning preparation activities
511	302	Defueling (related to decommissioning)
512	302.1	Plant operating costs
529	302.2	Project costs
530	302.2.1	Purchasers project management, administration and technical support
537	302.2.2	Decommissioning preparation activities
545	303	Shutdown operation (related to decommissioning)
546	304	Nuclear dismantling and demolition
547	304.1	Plant operating costs
578	304.2	Purchaser's project management, administration and technical support
585	304.3	Dismantling and demolition activities
586	304.3.1	Reactor vessel and internals
587	304.3.1.1	Reactor internals
592	304.3.1.3	Reactor vessel one-piece removal
597	304.3.2	Reactor containment
603	304.3.3	Reactor building
609	304.3.4	Turbine building
615	304.3.5	Other controlled area buildings
621	304.3.6	Demolition of radioactive concrete
625	304.3.7	Cleaning and clearance of controlled area buildings
628	304.3.8	Process dismantling uncontrolled area buildings
634	304.3.9	Misc undistributed costs
638	304.4	Waste handling and storage
639	304.4.1	Waste management system
643	304.4.2	Containers for transport and storage

ID	WBS	Main activities
646	304.4.3	Transports to repository and landfills
650	304.4.4	Repository and landfill storage fees
652	304.4.5	Handling of nonradioactive hazardous waste
653	305	Conventional demolition
654	305.1	Plant operating costs
669	305.2	Purchaser's project management, administration and technical support
676	305.3	Dismantling and demolition activities
677	305.3.1	Reactor containment
678	305.3.2	Reactor building
679	305.3.3	Turbine building
680	305.3.4	Other buildings
681	305.3.5	Building rubble random activity check
682	305.4	Waste handling and storage
683	305.4.1	Transports and repository
686	305.4.2	Handling of nonradioactive hazardous waste
687	305.5	Site restoration
690	306	Plant shutdown
691	307	Defueling finish
692	308	Shutdown operation finish
693	309	Building clearance finish
694	310	Plant decommissioning finish
695	400	Oskarshamn 0 decommissioning
696	401	Power operation group 1 (related to decommissioning)
727	402	Dismantling and demolition group 1
728	402.1	Plant operating costs
749	402.2	Purchaser's project management, administration and technical support
756	402.3	Dismantling and demolition activities
757	402.3.1	Process dismantling uncontrolled area buildings
763	402.3.2	Misc undistributed costs
767	402.4	Waste handling and storage
768	402.4.1	Waste management system
771	402.4.2	Containers for transport and storage
773	402.4.3	Transports to repository and landfills
775	402.4.4	Repository and landfill storage fees
777	402.4.5	Handling of nonradioactive hazardous waste
778	403	Conventional demolition group 1
779	403.1	Plant operation costs
794	403.2	Purchaser's project management, administration and technical support
801	403.3	Dismantling and demolition activities
804	403.4	Waste handling and storage
805	403.4.1	Transports and repository
808	403.4.2	Handling of nonradioactive hazardous waste
809	404	Power operation group 2 (related to decommissioning)
844	405	Nuclear dismantling and demolition group 2
845	405.1	Plant operation costs
866	405.2	Purchaser's project management, administration and technical support
873	405.3	Dismantling and demolition activities
874	405.3.1	Other controlled area
880	405.3.2	Demolition of radioactive concrete
883	405.3.3	Cleaning and clearance of controlled area buildings
886	405.3.4	Process dismantling uncontrolled area buildings
892	405.3.5	Misc undistributed costs
896	405.4	Waste handling and storage
897	405.4.1	Waste management system
901	405.4.2	Containers for transport and storage
903	405.4.3	Transports to repository and landfills
906	405.4.4	Repository and landfill storage fees
908	405.4.5	Handling of nonradioactive hazardous waste
909	406	Conventional demolition group 2
910	406.1	Plant operation costs
925	406.2	Purchaser's project management, administration and technical support
932	406.3	Dismantling and demolition activities
935	406.4	Waste handling and storage
936	406.4.1	Transports and repository
939	406.4.2	Handling of nonradioactive hazardous waste
940	406.5	Site restoration
943	407	Group 1 building clearance finish
944	408	Group 2 building clearance finish
945	409	O0 plant decommissioning finish

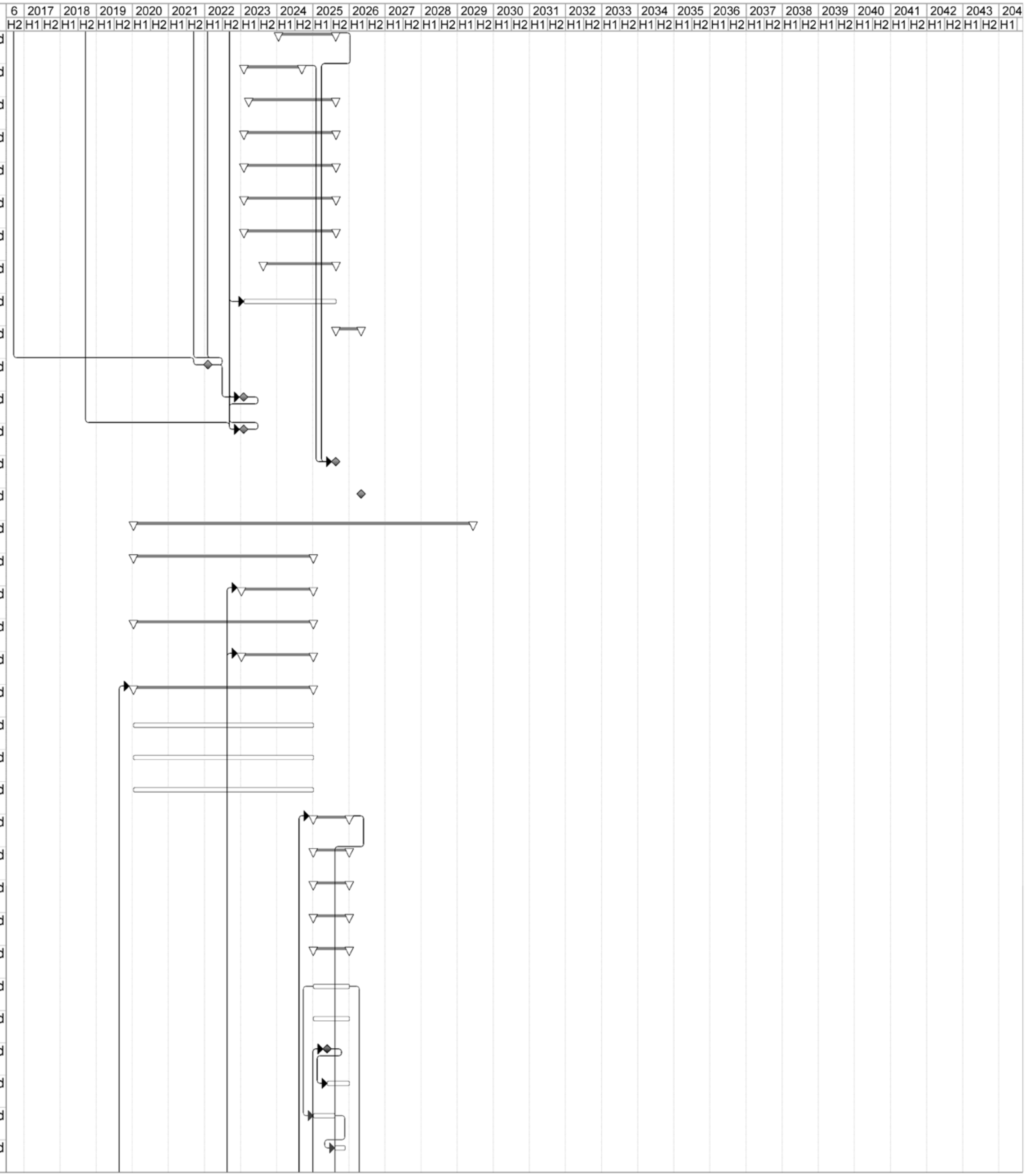
(The dates are shifted 10 years due to that the MS Project application does not accept dates after year 2050)

Decommissioning Programme for the Oskarshamn Site

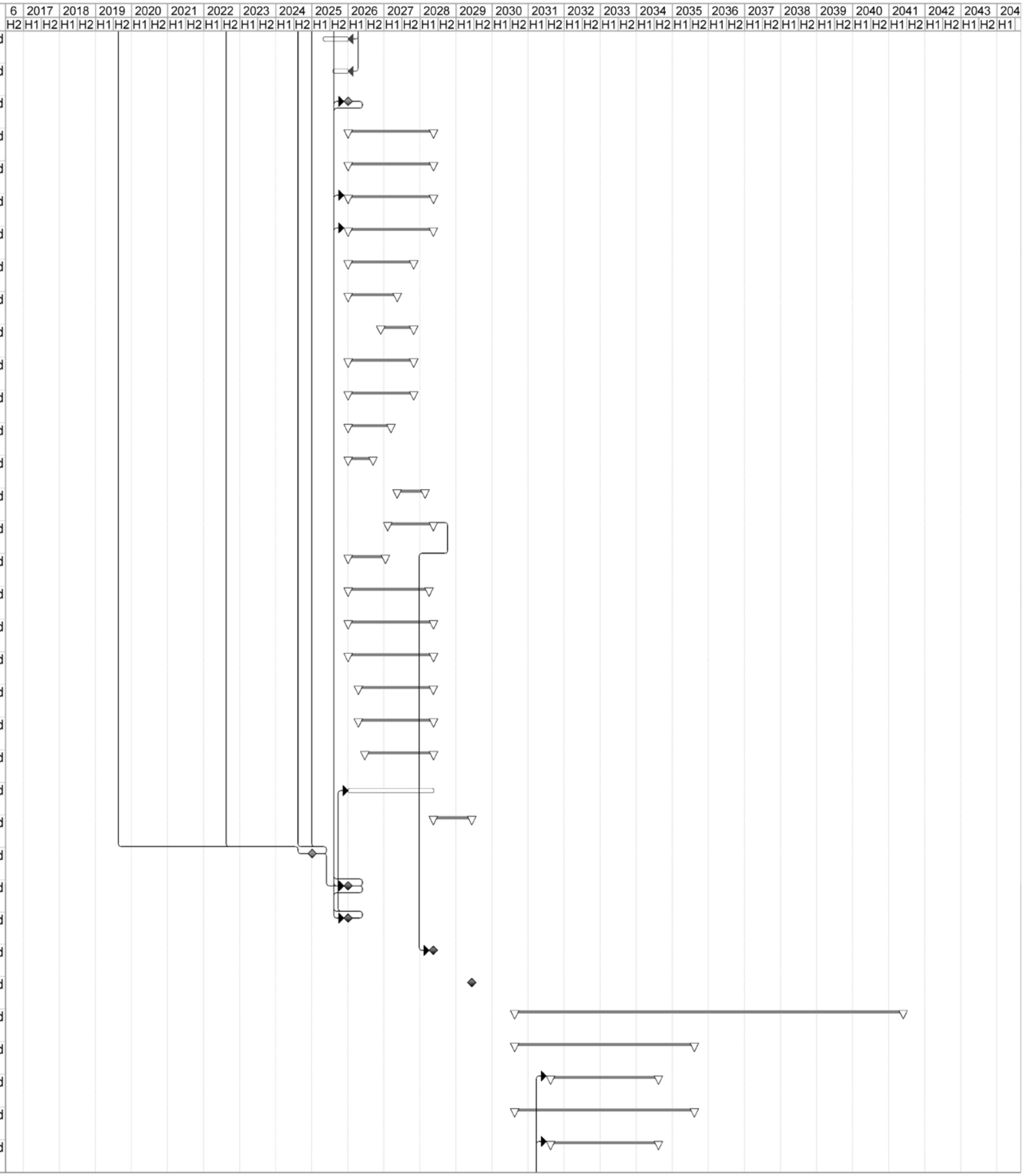
ID	WBS	Task Name	Duration
0	0	**Oskarshamn Site Decommissioning**	6021 d
1	100	**O1 Decommissioning**	2138 d
2	101	**POWER OPERATION (related to decommissioning)**	1150 d
3	101.1	**PLANT OPERATION COSTS**	230 d
20	101.2	**PROJECT COSTS**	1150 d
21	101.2.1	**Purchasers project management, administration and technical support**	230 d
28	101.2.2	**Decomissioning preparation activities**	1150 d
29	101.2.2.1	Preliminary EIA work	1150 d
30	101.2.2.2	Decommissioning planning work	1150 d
31	101.2.2.3	Information gathering	1150 d
32	102	**DEFUELING (related to decommissioning)**	230 d
33	102.1	**PLANT OPERATION COSTS**	230 d
50	102.2	**PROJECT COSTS**	230 d
51	102.2.1	**Purchasers project management, administration and technical support**	230 d
58	102.2.2	**Decomissioning preparation activities**	230 d
59	102.2.2.1	EIA work	230 d
60	102.2.2.2	Decommissioning planning work	230 d
61	102.2.2.3	All fuel in the fuel pool	1 d
62	102.2.2.4	Primary circuit decontamination	129 d
63	102.2.2.5	Object decontamination, conservation	155 d
64	102.2.2.6	Radiological inventory characterisation, Tank inventory	75 d
65	102.2.2.7	Pre-decommissioning system adaption	150 d
66	102.2.2.8	General preparatory activities	100 d
67	103	**SHUTDOWN OPERATION (related to decommissioning)**	0 d
95	104	**NUCLEAR DISMANTLING AND DEMOLITION**	586 d
96	104.1	**PLANT OPERATION COSTS**	586 d
127	104.2	**PURCHASER'S PROJECT MANAGEMENT, ADMINISTRATION AND TECHNICAL SUPPORT**	586 d
134	104.3	**DISMANTLING AND DEMOLITION ACTIVITIES**	585 d
135	104.3.1	**Reactor vessel and internals**	496 d
136	104.3.1.1	**Reactor internals**	367 d
141	104.3.1.2	**Reactor vessel one-piece removal**	248 d
146	104.3.2	**Reactor containment**	440 d
152	104.3.3	**Reactor building**	440 d
158	104.3.4	**Turbine building**	180 d
164	104.3.5	**Demolition of radioactive concrete**	245 d



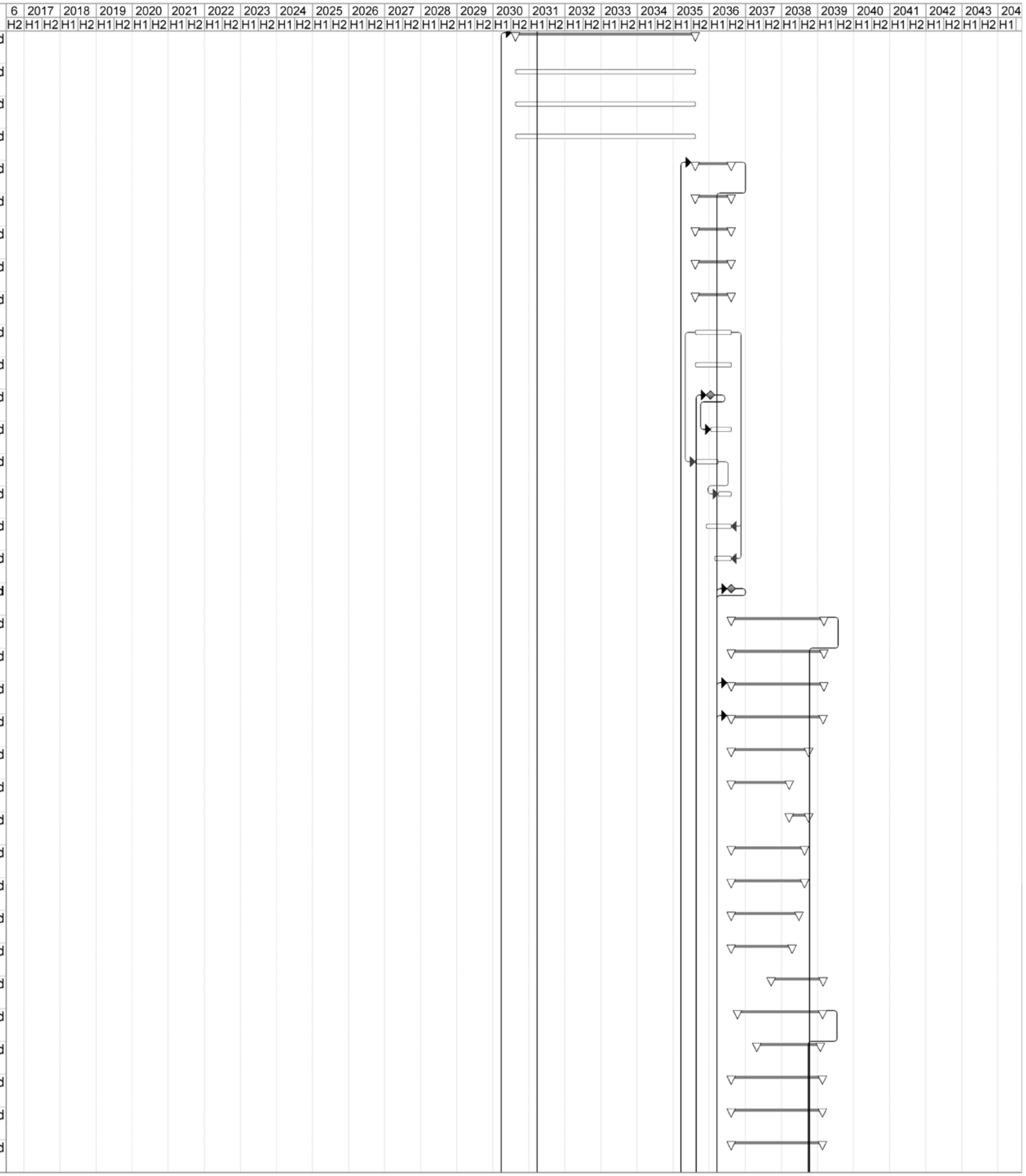
ID	WBS	Task Name	Duration
168	**104.3.6**	**Cleaning and clearance of controlled area buildings**	365 d
171	**104.3.7**	**Process dismantling uncontrolled area buildings**	370 d
177	**104.3.8**	**Misc undistributed costs**	550 d
181	**104.4**	**WASTE HANDLING AND STORAGE**	586 d
182	**104.4.1**	**Waste management system**	586 d
186	**104.4.2**	**Containers for transport and storage**	586 d
189	**104.4.3**	**Transports to repository and landfills**	586 d
193	**104.4.4**	**Repository and landfill storage fees**	466 d
195	104.4.5	Handling of nonradioactive hazardous waste	586 d
196	**105**	**CONVENTIONAL DEMOLITION**	173 d
233	106	Plant shutdown (Should be 32-02-06)	0 d
234	107	Defueling finish	0 d
235	108	Shutdown operation finish	0 d
236	109	Building clearance finish	0 d
237	110	Plant decommissioning finish	0 d
238	**200**	**O2 Decommissioning**	2183 d
239	**201**	**POWER OPERATION (related to decommissioning)**	1150 d
240	**201.1**	**PLANT OPERATING COSTS**	460 d
257	**201.2**	**PROJECT COSTS**	1150 d
258	**201.2.1**	**Purchasers project management, administration and technical support**	460 d
265	**201.2.2**	**Decomissioning preparation activities**	1150 d
266	201.2.2.1	Preliminary EIA work	1150 d
267	201.2.2.2	Decommissioning planning work	1150 d
268	201.2.2.3	Information gathering	1150 d
269	**202**	**DEFUELING**	230 d
270	**202.1**	**PLANT OPERATING COSTS**	230 d
287	**202.2**	**PROJECT COSTS**	230 d
288	**202.2.1**	**Purchasers project management, administration and technical support**	230 d
295	**202.2.2**	**Decomissioning preparation activities**	230 d
296	202.2.2.1	EIA work	230 d
297	202.2.2.2	Decommissioning planning work	230 d
298	203.2.2.3	All fuel in the fuel pool	1 d
299	202.2.2.4	Primary circuit decontamination	129 d
300	202.2.2.5	Object decontamination, conservation	135 d
301	202.2.2.6	Radiological inventory characterisation, Tank inventory	75 d



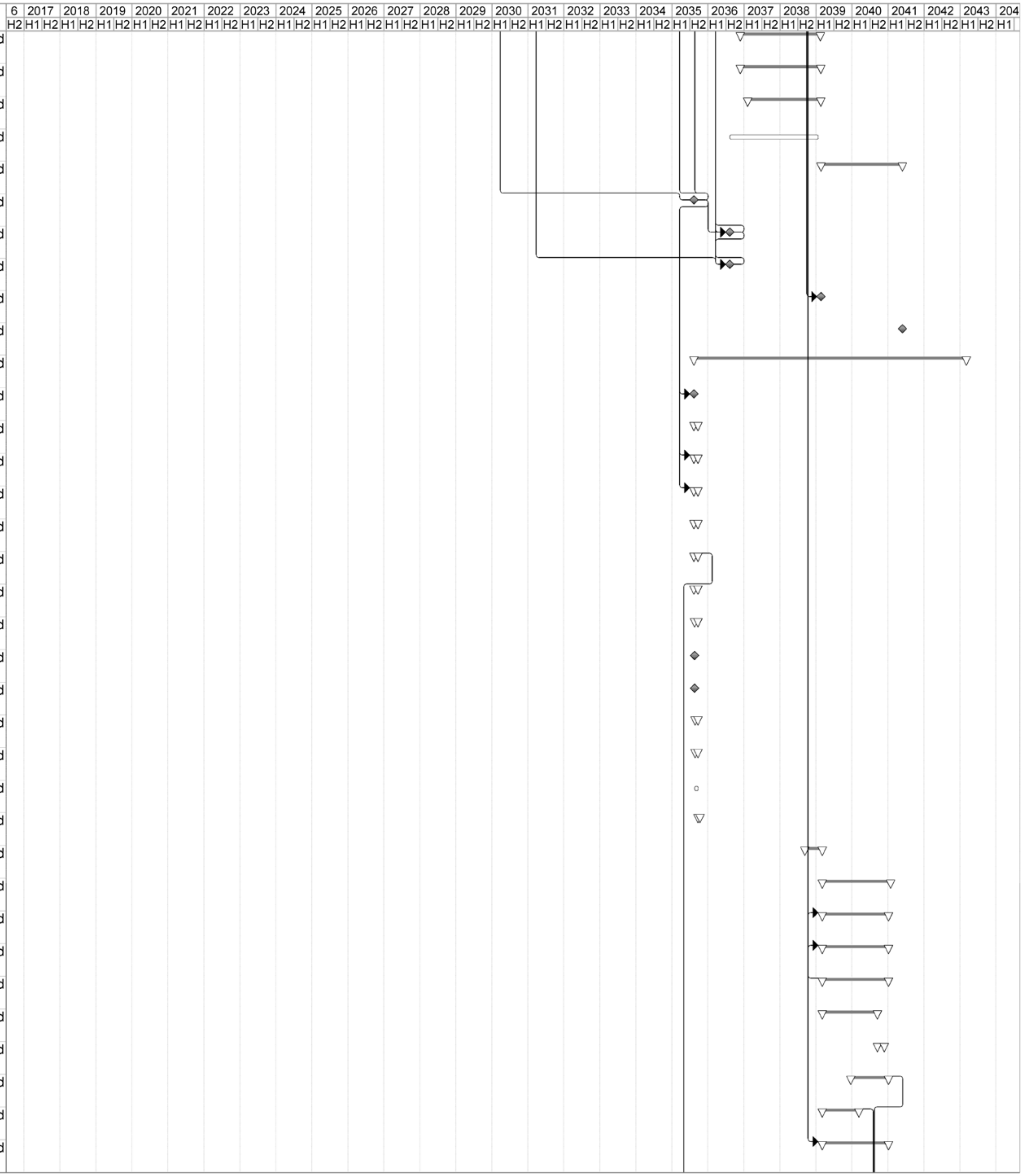
ID	WBS	Task Name	Duration
302	203.2.2.7	Pre-decommissioning system adaption	150 d
303	203.2.2.8	General preparatory activities	100 d
304	**203**	**SHUTDOWN OPERATION (related to decommissioning)**	0 d
331	**204**	**NUCLEAR DISMANTLING AND DEMOLITION**	558 d
332	**204.1**	**PLANT OPERATING COSTS**	558 d
363	**204.2**	**PURCHASER'S PROJECT MANAGEMENT, ADMINISTRATION AND TECHNICAL SUPPORT**	558 d
370	**204.3**	**DISMANTLING AND DEMOLITION ACTIVITIES**	557 d
371	**204.3.1**	**Reactor vessel and internals**	474 d
372	**204.3.1.1**	**Reactor internals**	355 d
377	**204.3.1.2**	**Reactor vessel one-piece removal**	238 d
382	**204.3.2**	**Reactor containment**	424 d
388	**204.3.3**	**Reactor building**	424 d
394	**204.3.4**	**Turbine building**	280 d
400	**204.3.5**	**Other controlled area buildings**	160 d
406	**204.3.6**	**Demolition of radioactive concrete**	173 d
410	**204.3.7**	**Cleaning and clearance of controlled area buildings**	300 d
413	**204.3.8**	**Process dismantling uncontrolled area buildings**	240 d
419	**204.3.9**	**Misc undistributed costs**	525 d
423	**204.4**	**WASTE HANDLING AND STORAGE**	558 d
424	**204.4.1**	**Waste management system**	558 d
428	**204.4.2**	**Containers for transport and storage**	483 d
431	**204.4.3**	**Transports to repository and landfills**	484 d
435	**204.4.4**	**Repository and landfill storage fees**	438 d
437	204.4.5	Handling of nonradioactive hazardous waste	558 d
438	**205**	**CONVENTIONAL DEMOLITION**	247 d
475	206	Plant shutdown (Should be 35-01-08)	0 d
476	207	Defueling finish	0 d
477	208	Shutdown operation finish	0 d
478	209	Building clearance finish	0 d
479	210	Plant decommissioning finish	0 d
480	**300**	**O3 Decommissioning**	2501 d
481	**301**	**POWER OPERATION (related to decommissioning)**	1150 d
482	**301.1**	**PLANT OPERATING COSTS**	690 d
499	**301.2**	**PROJECT COSTS**	1150 d
500	**301.2.1**	**Purchasers project management, administration and technical support**	690 d



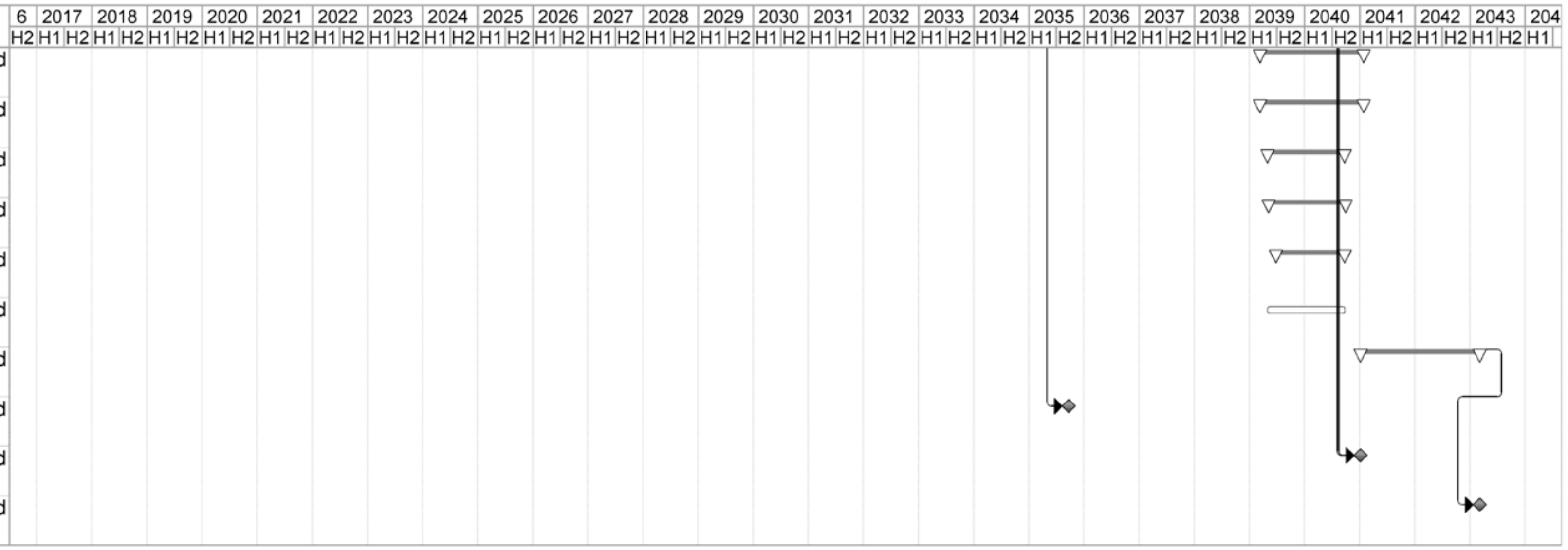
ID	WBS	Task Name	Duration
507	**301.2.2**	**Decommissioning preparation activities**	1150 d
508	301.2.2.1	Preliminary EIA work	1150 d
509	301.2.2.2	Decommissioning planning work	1150 d
510	301.2.2.3	Information gathering	1150 d
511	**302**	**DEFUELING (related to decommissioning)**	230 d
512	**302.1**	**PLANT OPERATING COSTS**	230 d
529	**302.2**	**PROJECT COSTS**	230 d
530	**302.2.1**	**Purchasers project management, administration and technical support**	230 d
537	**302.2.2**	**Decommissioning preparation activities**	230 d
538	302.2.2.1	EIA work	230 d
539	302.2.2.2	Decommissioning planning work	230 d
540	302.2.2.3	All fuel in the fuel pool	1 d
541	302.2.2.4	Primary circuit decontamination	129 d
542	302.2.2.5	Object decontamination, conservation	155 d
543	302.2.2.6	Radiological inventory characterisation, Tank inventory	75 d
544	302.2.2.7	Pre-decommissioning system adaption	150 d
545	302.2.2.8	General preparatory activities	100 d
546	**303**	**SHUTDOWN OPERATION (related to decommissioning)**	**0 d**
547	**304**	**NUCLEAR DISMANTLING AND DEMOLITION**	600 d
548	**304.1**	**PLANT OPERATING COSTS**	600 d
579	**304.2**	**PURCHASER'S PROJECT MANAGEMENT, ADMINISTRATION AND TECHNICAL SUPPORT**	600 d
586	**304.3**	**DISMANTLING AND DEMOLITION ACTIVITIES**	594 d
587	**304.3.1**	**Reactor vessel and internals**	560 d
588	**304.3.1.1**	**Reactor internals**	419 d
593	**304.3.1.2**	**Reactor vessel one-piece removal**	141 d
598	**304.3.2**	**Reactor containment**	471 d
604	**304.3.3**	**Reactor building**	471 d
610	**304.3.4**	**Turbine building**	450 d
616	**304.3.5**	**Other controlled area buildings**	400 d
622	**304.3.6**	**Demolition of radioactive concrete**	335 d
626	**304.3.7**	**Cleaning and clearance of controlled area buildings**	546 d
629	**304.3.8**	**Process dismantling uncontrolled area buildings**	400 d
635	**304.3.9**	**Misc undistributed costs**	590 d
639	**304.4**	**WASTE HANDLING AND STORAGE**	590 d
640	**304.4.1**	**Waste management system**	590 d



ID	WBS	Task Name	Duration
644	**304.4.2**	**Containers for transport and storage**	510 d
647	**304.4.3**	**Transports to repository and landfills**	513 d
651	**304.4.4**	**Repository and landfill storage fees**	470 d
653	304.4.5	Handling of nonradioactive hazardous waste	570 d
654	**305**	**CONVENTIONAL DEMOLITION**	530 d
691	306	Plant shutdown (Should be 2045-08-15)	0 d
692	307	Defueling finish	0 d
693	308	Shutdown operation finish	0 d
694	309	Building clearance finish	0 d
695	310	Plant decommissioning finish	0 d
696	**400**	**Oskarshamn 0 Decommissioning**	1754 d
697	**401**	**POWER OPERATION GROUP 1 (related to decommissioning)**	0 d
728	**402**	**DISMANTLING AND DEMOLITION GROUP 1**	29 d
729	**402.1**	**PLANT OPERATING COSTS**	29 d
750	**402.2**	**PURCHASER'S PROJECT MANAGEMENT, ADMINISTRATION AND TECHNICAL SUPPORT**	29 d
757	**402.3**	**DISMANTLING AND DEMOLITION ACTIVITIES**	29 d
758	**402.3.1**	**Process dismantling uncontrolled area buildings**	29 d
764	**402.3.2**	**Misc undistributed costs**	29 d
768	**402.4**	**WASTE HANDLING AND STORAGE**	24 d
769	**402.4.1**	**Waste management system**	0 d
772	**402.4.2**	**Containers for transport and storage**	0 d
774	**402.4.3**	**Transports to repository and landfills**	21 d
776	**402.4.4**	**Repository and landfill storage fees**	21 d
778	402.4.5	Handling of nonradioactive hazardous waste	24 d
779	**403**	**CONVENTIONAL DEMOLITION GROUP 1**	15 d
810	**404**	**POWER OPERATION GROUP 2 (related to decommissioning)**	116 d
845	**405**	**NUCLEAR DISMANTLING AND DEMOLITION GROUP 2**	435 d
846	**405.1**	**PLANT OPERATION COSTS**	420 d
867	**405.2**	**PURCHASER'S PROJECT MANAGEMENT, ADMINISTRATION AND TECHNICAL SUPPORT**	420 d
874	**405.3**	**DISMANTLING AND DEMOLITION ACTIVITIES**	420 d
875	**405.3.1**	**Other controlled area**	350 d
881	**405.3.2**	**Demolition of radioactive concrete**	50 d
884	**405.3.3**	**Cleaning and clearance of controlled area buildings**	233 d
887	**405.3.4**	**Process dismantling uncontrolled area buildings**	236 d
893	**405.3.5**	**Misc undistributed costs**	420 d



ID	WBS	Task Name	Duration
897	**405.4**	**WASTE HANDLING AND STORAGE**	430 d
898	**405.4.1**	**Waste management system**	430 d
902	**405.4.2**	**Containers for transport and storage**	315 d
904	**405.4.3**	**Transports to repository and landfills**	315 d
907	**405.4.4**	**Repository and landfill storage fees**	275 d
909	405.4.5	Handling of nonradioactive hazardous waste	315 d
910	**406**	**CONVENTIONAL DEMOLITION GROUP 2**	504 d
944	407	Group 1 Building clearance finish	0 d
945	408	Group 2 Building clearance finish	0 d
946	409	O0 Plant decommissioning finish	0 d



Appendix 4

ISDC structure and compositions and rates

A4.1 Work team composition

Macrocomponent based manhour calculation – process equipment work team composition

WP	Personnel categories (no.)* Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Short description of WP scope
1a	0.2	0.7	0.5	0.1	6.3	Preparations of work area – radiolgical areas
1b	0.15	0.6	0	0.1	6	Preparations of work area – non radiolgical areas
2	0.1	0.3	0.2	0	2.5	Removal of insulation from pipes and components
3a	0.1	0.4	0.2	1	2.5	Dismantling of high-active pipes >DN50
3b	0.1	0.4	0.2	1	3	Dismantling of low-active pipes >DN50
3c	0.1	0.3	0.2	0	2.5	Dismantling of pipes up to and including DN50
3d	0.1	0.3	0.2	0	2.5	Dismantling of valves and actuators
4	0.1	0.4	0.1	0	4	Internal transports of waste
7	0.1	0.5	0.1	1.5	3.5	Dismantling and internal transportation of large components and tanks
8	0.1	0.5	0	0	5	Dismantling of steel (pipe supports, greeting, ladders, beams etc)
10	0.05	0.3	0.15	0	2.5	Dismantling of cables and cabletrays etc
11a	0.1	0.3	0.1	0.5	4	Dismantling of HVAC ducts
11b	0.1	0.5	0.1	0	4.3	Dismantling of HVAC components
13a	0	1	0	0	4	Pool liner – preparations, scaffolding and lifting preparations
13b	0	0.2	0.5	0	3	Pool liner – decontamination by HP-cleaning
13c	0	0.5	0	0	3	Pool liner – cutting, dismantling and removal
14	0.1	0.5	0	0	3	Dismantling and transportation of cranes
15a	0	0.2	0	0	2	Dismantling and transportation of cabinets
15b	0	0.2	0	0	4	Dismantling and transportation of electrical components
16	0.1	0.5	0.1	1.5	3.5	Dismantling of turbine & generator

* Definition of categories:

Cat.1: Engineer
Cat.2: Foremen
Cat.3: Health Physics (HP) Technician
Cat.4: Craftsmen (electricians, cutters etc)
Cat.5: Laborer (cleaners, scaffolders etc)

Oskarshamn Site Decommissioning Study

MACROCOMPONENT BASED MANHOUR CALCULATION - PROCESS EQUIPMENT

PRODUCTIVITY RATES

						O1					O2					O3					O0
MACROCOMPONENT	**WP**	**SHORT DESCRIPTION OF ACTIVITY**	**Productivity Rate**	**PR-unit**	**Previous SF**	**Current SF A**	**B**	**D**	**K**	**OK**	**Current SF A**	**B**	**D**	**K**	**OK**	**Current SF A**	**B**	**D**	**K**	**OK**	**OK**
	[no.]	*[-]*	*[value]*	*[team h/?]*																	
WORK AREAS																					
- Preparation of work areas, radiological	1a	Preparations of work area - radiolgical areas	13,750	no.	2,5	4,45	3,18	3,62	3,19		4,14	2,96	2,96	2,96		3,85	2,75	2,75	2,75		
- Preparation of work areas, non radiological	1b	Preparations of work area - non radiolgical areas	13,750	no.	2,5					1,91					1,77					1,65	1,65
PUMPS																					
- Pumps, <500 kg	7	Dismantling and internal transportation of large components and tanks	2,217	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Pumps, >500 kg	7	Dismantling and internal transportation of large components and tanks	0,0049	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
HEAT EXCHANGERS																					
- Heat exchangers, 3501-10000 kg	2	Removal of insulation from pipes and components	0,390	m^2	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	7	Dismantling and internal transportation of large components and tanks	0,0050	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Heat exchangers, 501-3500 kg	7	Dismantling and internal transportation of large components and tanks	0,0061	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Heat exchangers, 0-500 kg	7	Dismantling and internal transportation of large components and tanks	2,534	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
TANKS																					
- Tanks, 0 - 200 kg	7	Dismantling and internal transportation of large components and tanks	1,700	m^2	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Tanks, 201 - 750 kg	7	Dismantling and internal transportation of large components and tanks	2,500	m^2	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Tanks, 751 - 115000 kg	7	Dismantling and internal transportation of large components and tanks	2,900	m^2	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
PRESSURE VESSELS ETC.																					
- Pressure Vessels, 5001 kg -	7	Dismantling and internal transportation of large components and tanks	0,0049	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Pressure Vessels, 1501 - 5000 kg	7	Dismantling and internal transportation of large components and tanks	0,0056	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Pressure Vessels, 501 - 1500 kg	7	Dismantling and internal transportation of large components and tanks	0,0066	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Pressure Vessels, 0 - 500 kg	7	Dismantling and internal transportation of large components and tanks	2,529	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
VALVES (>DN50) & ACTUATORS																					
- Valves, >DN50	3d	Dismantling of valves and actuators	0,009	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,781	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Actuators, valves >DN50	3d	Dismantling of valves and actuators	2,139	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,756	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Actuators, valves <DN50	3d	Dismantling of valves and actuators	2,139	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,756	no.	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
PIPING																					
- Piping, diam. up to and incl. DN25	2	Removal of insulation from pipes and components	0,175	m	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	3c	Dismantling of pipes up to and including DN50	0,100	m	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,008	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Piping, DN25 < diam. up to and incl. DN50	2	Removal of insulation from pipes and components	0,175	m	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	3c	Dismantling of pipes up to and including DN50	0,150	m	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,008	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Piping, DN50 < diam. up to DN300	2	Removal of insulation from pipes and components	0,175	m	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	3b	Dismantling of low-active pipes >DN50	0,035	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,008	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
- Piping, DN300 and above	2	Removal of insulation from pipes and components	0,350	m	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	3a	Dismantling of high-active pipes >DN50	0,010	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,008	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
HVAC																					
- HVAC, components	11b	Dismantling of HVAC components	0,010	kg	1	1,91	1,28	1,28	1,28	1,02	1,77	1,18	1,18	1,18	0,95	1,65	1,10	1,10	1,10	1,00	1,00
- HVAC, ducts	2	Removal of insulation from pipes and components	0,021	kg	2,5	4,45	3,18	3,62	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	11a	Dismantling of HVAC ducts	0,034	kg	1	1,91	1,28	1,28	1,28	1,02	1,77	1,18	1,18	1,18	0,95	1,65	1,10	1,10	1,10	1,00	1,00
CABLES (& cable trays)																					
- Cables, cable trays	10	Dismantling of cables and cabletrays etc	0,034	kg	2,5	4,47	2,55	2,55	2,55	1,66	4,14	2,37	2,37	2,37	1,54	3,85	2,20	2,20	2,20	1,43	1,43
	4	Internal transports of waste	0,0032	kg	2,5	4,47	2,55	2,55	2,55	1,66	4,14	2,37	2,37	2,37	1,54	3,85	2,20	2,20	2,20	1,43	1,43
CABINETS																					
- Cabinets	15a	Dismantling and transportation of cabinets	0,0067	kg	1	2,55	1,91	1,91	1,91	1,28	2,37	1,77	1,77	1,77	1,18	2,20	1,65	1,65	1,65	1,10	1,10
ELECTRICAL COMPONENTS																					
- Electrical components	15b	Dismantling and transportation of electrical components	0,0050	kg	1	2,55	1,91	1,91	1,91	1,28	2,37	1,77	1,77	1,77	1,18	2,20	1,65	1,65	1,65	1,10	1,10
POOL LINING																					
- Pool lining	13a	Pool liner - preparations, scaffolding and lifting preparations	0,311	m^2	1	1,66	1,28	1,28			1,54	1,18	1,18			1,43	1,10	1,10			
	13b	Pool liner - decontamination by HP-cleaning	0,214	m^2	1	1,66	1,28	1,28			1,54	1,18	1,18			1,43	1,10	1,10			
	13c	Pool liner - cutting, dismantling and removal	0,103	m^2	1	1,66	1,28	1,28			1,54	1,18	1,18			1,43	1,10	1,10			
STEEL																					
- Steel	8	Dismantling of steel (pipe supports, greeting, ladders, beams etc)	0,009	kg	2,5	4,45	3,18	3,18	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
	4	Internal transports of waste	0,0026	kg	2,5	4,45	3,18	3,18	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65
TURBINE PLANT																					
- Turbine Line Parts	16	Dismantling of turbine & generator	0,0019	kg	1			1,45					1,18					1,10			
- Other Turbine Plant components	7	Dismantling and internal transportation of large components and tanks	0,0070	kg	2,5			2,90					2,37					2,20			
MICELLANOUS PROCESS EQUIPMENT																					
- Miscellaneous Process Components	7	Dismantling and internal transportation of large components and tanks	0,009	kg	2,5	4,47	3,19	3,19	3,19	1,91	4,14	2,96	2,96	2,96	1,77	3,85	2,75	2,75	2,75	1,65	1,65

A4.3 ISDC cost estimation breakdown per unit

Table A4-1. O1 ISDC Matrix Elements.

O1 ISDC Matrix Elements			Cost kSEK	%	Contingency kSEK	%	Sum Cost + Cont. kSEK
01		**Pre-decommissioning Activites**	**20,424**	**2%**	**1,972**	**10%**	**22,396**
	0100	Decommisioning planning	8,211	40%	821	10%	9,032
	0200	Facility characterisation	3,462	17%	266	8%	3,727
	0300	Safety, Security and Environmental Studies	4,025	20%	405	10%	4,430
	0400	Waste mamagement planning	0	0%	0	–	0
	0500	Authorisation	0	0%	0	–	0
	0600	Preparing Management Group and Contracting	4,727	23%	481	10%	5,207
02		**Facility Shutdown Activites**	**33,168**	**3%**	**3,317**	**10%**	**36,485**
	0300	Decontamination of Closed Systems for Dose Reduction	32,628	98%	3,263	10%	35,891
	0400	Radiological Inventory Characterisation to Support Detailed Planning	540	2%	54	10%	594
03		**Additional Activities for Safe Enclosure**	**0**	**0%**	**0**	**0%**	**0**
	0100	Preparation for Safe Enclosure	0	–	0	–	0
04		**Dismantling Activities within the Controlled Area**	**461,929**	**43%**	**39,337**	**9%**	**501,266**
	0200	Preparation and Support for Dismantling	0	0%	0	–	0
	0500	Dismantling of Main Process Systems, Structures and Components	345,520	75%	22,529	7%	368,049
	0600	Dismantling of Other Systems and Components	84,990	18%	11,466	13%	96,456
	0700	Removal of Contamination from Building Structures	3,700	1%	629	34%	4,329
	0900	Final Radioactivity Survey for Release of Buildings	27,720	6%	4,712	17%	32,432
05		**Waste Processing, Storage and Disposal**	**105,445**	**10%**	**15,932**	**15%**	**121,377**
	0100	Waste Management System	59,929	57%	9,086	15%	69,015
	0800	Management of Decommissioning Intermediate-level Waste	6,300	6%	441	7%	6,741
	0900	Management of Decommissioning Low-level Waste	15,234	14%	3,047	20%	18,281
	1 200	Management of Decommissioning Exempt Waste and Materials	23,982	23%	3,358	14%	27,340
	1 300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0	0%	0	–	0
06		**Site Infrastructure and Operation**	**81,124**	**8%**	**13,692**	**17%**	**94,816**
	0100	Site Security and Surveillance	4,715	6%	719	15%	5,435
	0200	Site Operation and Maintenance	34,725	43%	5,369	15%	40,094
	0300	Operation of Support Systems	23,712	29%	4,511	19%	28,223
	0400	Radiation and Environamental Safety Monitoring	17,972	22%	3,092	17%	21,064
07		**Conventional Dismantling, Demolition and Site Restoration**	**166,473**	**15%**	**30,098**	**18%**	**196,572**
	0100	Procurment of Equipment for Conventional Dismantling and Demolition	8,367	5%	1,270	15%	9,637
	0200	Dismantling of Systems and Building Components Outside the Controlled Area	34,595	21%	8,709	25%	43,304
	0300	Demolition of Buildings and Structures	112,341	67%	18,458	16%	130,799
	0400	Final Cleanup, Landscaping and Refurbishment	9,100	5%	1,310	14%	10,410
	0500	Ground restoration	2,070	1%	352	17%	2,422
08		**Project Management, Engineering and Support**	**193,053**	**18%**	**35,485**	**18%**	**228,538**
	0100	Mobilisation and Prepartory Work	0	0%	0	–	0
	0200	Project management	109,563	57%	17,792	16%	127,355
	0300	Support Services	39,871	21%	6,725	17%	46,595
	1000	Demobilisation by contractors	43,620	23%	10,968	25%	54,588
09		**Research and Development**	**0**	**0%**	**0**	**–**	**0**
10		**Fuel and Nuclear Material**	**0**	**0%**	**0**	**–**	**0**
11		**Miscellaneous Expenditures**	**12,884**	**1%**	**3,704**	**29%**	**16,589**
	0100	Owner Costs	0	0%	0	–	0
	0200	Taxes	0	0%	0	–	0
	0300	Insurances	12,884	100%	3,704	29%	16,589
Total			**1,074,501**	**100%**	**143,537**	**13%**	**1,218,038**

Table A4-2. O2 ISDC Matrix Elements.

O2 ISDC Matrix Elements			Cost kSEK	%	Contingency kSEK	%	Sum Cost + Cont. kSEK
01		**Pre-decommissioning Activites**	**20,424**	**2%**	**1,972**	**10%**	**22,396**
	0100	Decommisioning Planning	8,211	40%	821	10%	9,032
	0200	Facility Characterisation	3,462	17%	266	8%	3,727
	0300	Safety, Security and Environmental Studies	4,025	20%	405	10%	4,430
	0400	Waste mamagement planning	0	0%	0	–	0
	0500	Authorisation	0	0%	0	–	0
	0600	Preparing Management Group and Contracting	4,727	23%	481	10%	5,207
02		**Facility Shutdown Activites**	**27,703**	**2%**	**4,739**	**17%**	**32,442**
	0300	Decontamination of Systems for Dose Reduction	27,163	98%	4,638	17%	31,801
	0400	Radiological Inventory Characterisation to Support Detailed Planning	540	2%	101	19%	641
03		**Additional Activities for Safe Enclosure**	**0**	**0%**	**0**	**–**	**0**
	0100	Preparation for Safe Enclosure	0	–	0	–	0
04		**Dismantling Activities within the Controlled Area**	**653,486**	**52%**	**120,275**	**18%**	**773,761**
	0200	Preparation and Support for Dismantling	6,420	1%	1,204	19%	7,624
	0500	Dismantling of Main Process Systems, Structures and Components	423,291	65%	46,706	11%	469,998
	0600	Dismantling of Other Systems and Components	174,347	27%	54,505	31%	228,852
	0700	Removal of Contamination from Building Structures	5,400	1%	1,053	20%	6,453
	0900	Final Radioactivity Survey for Release of Buildings	44,028	7%	16,807	38%	60,835
05		**Waste Processing, Storage and Disposal**	**127,984**	**10%**	**16,473**	**13%**	**144,457**
	0100	Waste Management System	38,065	30%	4,065	11%	42,129
	0800	Management of Decommissioning Intermediate-level Waste	7,000	5%	525	8%	7,525
	0900	Management of Decommissioning Low-level Waste	19,860	16%	2,731	14%	22,591
	1 200	Management of Decommissioning Exempt Waste and Materials	63,059	49%	9,153	15%	72,212
	1 300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0	0%	0	–	0
06		**Site Infrastructure and Operation**	**81,601**	**6%**	**13,472**	**17%**	**95,073**
	0100	Site Security and Surveillance	4,598	6%	589	13%	5,187
	0200	Site Operation and Maintenance	36,688	45%	5,563	15%	42,251
	0300	Operation of Support Systems	23,010	28%	4,358	19%	27,368
	0400	Radiation and Environamental Safety Monitoring	17,305	21%	2,962	17%	20,267
07		**Conventional Dismantling, Demolition and Site Restoration**	**145,437**	**12%**	**26,293**	**18%**	**171,730**
	0100	Procurement of Equipment for Conventional Dismantling and Demolition	14,011	10%	3,591	26%	17,602
	0200	Dismantling of systems and Building Components Outside the Controlled Area	32,514	22%	10,720	33%	43,234
	0300	Demolition of Buildings and Structures	85,852	59%	9,781	11%	95,633
	0400	Final Cleanup, Landscaping and Refurbishment	9,100	6%	1,706	19%	10,806
	0500	Final Radioactivity Survey of Site	3,960	3%	495	13%	4,455
08		**Project Management, Engineering and Support**	**198,623**	**16%**	**35,740**	**18%**	**234,363**
	0100	Mobilisation and Prepartory Work	0	0%	0	–	0
	0200	Project Management	114,963	58%	18,278	16%	133,241
	0300	Support Services	41,450	21%	6,847	17%	48,296
	1000	Demobilisation by contractors	42,210	21%	10,616	25%	52,826
09		**Research and Development**	**0**	**0%**	**0**	**–**	**0**
10		**Fuel and Nuclear Material**	**0**	**0%**	**0**	**–**	**0**
11		**Miscellaneous Expenditures**	**5,975**	**0%**	**1,718**	**29%**	**7,693**
	0100	**Owner Costs**	**0**	**0%**	**0**	**–**	**0**
	0400	Taxes	0	0%	0	–	0
	0500	Insurances	5,975	100%	1,718	29%	7,693
Total			**1,261,233**	**100%**	**220,682**	**17%**	**1,481,916**

Table A4-3. O3 ISDC Matrix Elements.

O3 ISDC Matrix Elements		Cost kSEK	Cost %	Contingency kSEK	Contingency %	Sum Cost + Cont. kSEK
01	**Pre-decommissioning Actions**	**31,648**	**2%**	**3,114**	**10%**	**34,762**
0100	Decommisioning planning	9,177	29%	918	10%	10,095
0200	Facility Characterisation	3,945	12%	314	8%	4,258
0300	Safety, Security and Environmental Studies	4,347	14%	441	10%	4,788
0400	Waste mamagement planning	0	0%	0	–	0
0500	Authorisation		0%	0	–	
0600	Preparing Management Group and Contracting	14,180	45%	1,442	10%	15,622
02	**Facility Shutdown Activites**	**33,308**	**2%**	**5,691**	**17%**	**38,999**
0300	Decontamination of Closed Systems for Dose Reduction	32,610	98%	5,473	17%	38,083
0400	Radiological Inventory Characterisation to Support Detailed Planning	698	2%	218	31%	915
03	**Additional Activities for Safe Enclosure**	**0**	**0%**	**0**	**–**	**0**
0100	Preparation for Safe Enclosure	0	–	0	–	0
04	**Dismantling Activities within the Controlled Area**	**761,822**	**44%**	**70,760**	**9%**	**832,582**
0200	Preparation and Support for Dismantling	6,420	1%	1,766	28%	8,186
0500	Dismantling of Main Process Systems, Structures and Components	463,809	61%	29,810	6%	493,618
0600	Dismantling of Other Systems and Components	197,537	26%	30,379	15%	227,916
0700	Removal of Contamination from Building Structures	13,200	2%	2,640	20%	15,840
0900	Final Radioactivity Survay for Release of Buildings	80,856	11%	6,166	8%	87,022
05	**Waste Processing, Storage and Disposal**	**182,500**	**11%**	**22,691**	**12%**	**205,190**
0100	Waste management system	43,358	24%	5,515	13%	48,873
0800	Management of Decommissioning Intermediate-level Waste	10,500	6%	525	5%	11,025
0900	Management of Decommissioning Low-level Waste	103,260	57%	13,080	13%	116,340
1200	Management of Decommissioning Exempt Waste and Materials	25,382	14%	3,571	14%	28,953
1300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0	0%	0	–	0
06	**Site Infrastructure and Operation**	**97,374**	**6%**	**12,052**	**12%**	**109,426**
0100	Site Security and Surveillance	4,774	5%	487	10%	5,261
0200	Site Operation and Maintenance	45,612	47%	5,269	12%	50,881
0300	Operation of Support Systems	28,683	29%	3,902	14%	32,585
0400	Radiation and Environamental Safety Monitoring	18,305	19%	2,393	13%	20,698
07	**Conventional Dismantling, Demolition and Site Restoration**	**366,961**	**21%**	**46,740**	**13%**	**413,702**
0100	Procurment of Equipment for Conventional Dismantling and Demolition	34,295	9%	5,800	17%	40,094
0200	Dismantling of Systems	77,309	21%	19,152	25%	96,461
0300	Demolition of Buildings and Structures	207,518	57%	15,556	7%	223,074
0400	Final Cleanup, Landscaping and Refurbishment	40,100	11%	5,614	14%	45,714
0500	Final Radioactivity Survay of Site	7,740	2%	619	15%	8,359
08	**Project Management, Engineering and Site Support**	**256,180**	**15%**	**37,293**	**15%**	**293,473**
0100	Mobilisation and Prepartory work	0	0%	0	–	0
0200	Project Management	154,822	60%	19,332	12%	174,154
0300	Support Services	55,482	22%	7,261	13%	62,743
1000	Demobilisation by contractors	45,876	18%	10,700	23%	56,576
09	**Reasearch and Development**	**0**	**0%**	**0**	**–**	**0**
10	**Fuel and Nuclear Material**	**0**	**0%**	**0**	**–**	**0**
11	**Miscellaneous Expenditures**	**5,275**	**0%**	**1,517**	**29%**	**6,792**
0100	Owner Costs	0	0%	0	–	0
0200	Taxes	0	0%	0	–	0
0300	Insurances	5,275	100%	1,517	29%	6,792
Total		**1,735,068**	**100%**	**199,858**	**12%**	**1,934,926**

Table A4-4. O0 ISDC Matrix Elements.

O0 ISDC Matrix Elements		Cost kSEK	%	Contingency kSEK	%	Sum Cost + Cont. kSEK
01	**Pre-decommissioning Activites**	**0**	**0%**	**0**	**–**	**0**
0100	Decommisioning planning	0	–	0	–	0
0200	Facility characterisation	0	–	0	–	0
0300	Safety, Security and Environmental Studies	0	–	0	–	0
0400	Wate management planning	0	–	0	–	0
0500	Authorisation	0	–	0	–	0
0600	Preparing Management Group and Contracting	0	–	0	–	0
02	**Facility Shutdown Activites**	**23,507**	**4%**	**3,990**	**17%**	**27,497**
0300	Decontamination of Closed Systems for Dose Reduction	23,291	99%	3,950	17%	27,241
0400	Radiological Inventory Characterisation to Support Detailed Planning	216	1%	41	19%	257
03	**Additional Activities for Safe Enclosure**	**0**	**0%**	**0**	**–**	**0**
0100	Preparation for Safe Enclosure	0	–	0	–	0
04	**Dismantling Activities within the Controlled Area**	**217,152**	**40%**	**38,465**	**18%**	**255,617**
0200	Preparation and Support for Dismantling	1,332	1%	373	0%	1,705
0500	Dismantling of Main Process Systems, Structures and Components	40,462	19%	8,281	20%	48,743
0700	Removal of Contamination from Building Structures	144,200	66%	24,514	17%	168,714
0900	Final Radioactivity Survey for Release of Buildings	31,158	14%	5,297	17%	36,455
05	**Waste Processing, Storage and Disposal**	**36,359**	**7%**	**5,478**	**15%**	**41,836**
0100	Waste Management System	35,578	98%	5,423	15%	41,001
0900	Management of Decommissioning Low-level Waste	780	2%	55	7%	835
1200	Management of Decommissioning Exempt Waste and Materials	1	0%	0	15%	1
1300	Management of Decomissioning Waste and Materials Gernerated Outside Controlled Areas	0	0%	0	–	0
06	**Site Infrastructure and Operation**	**27,977**	**5%**	**4,774**	**17%**	**32,751**
0100	Site Security and Surveillance	4,086	15%	781	19%	4,867
0200	Site Operation and Maintenance	15,269	55%	2,480	16%	17,749
0300	Operation of Support Systems	5,479	20%	906	17%	6,386
0400	Radiation and Environamental Safety Monitoring	3,143	11%	607	19%	3,750
07	**Conventional Dismantling, Demolition and Site Restoration**	**110,964**	**20%**	**17,977**	**16%**	**128,941**
0100	Procurment of Equipment for Conventional Dismantling and Demolition	25,083	23%	4,224	17%	29,307
0200	Dismantling of Systems and Building Components Outside the Controlled Area	14,509	13%	3,727	26%	18,236
0300	Demolition of Buildings and Structures	8,810	8%	1,512	17%	10,322
0400	Final Cleanup, Landscaping and Refurbishment	60,600	55%	8,181	14%	68,781
0500	Final Radioactivity Survey of Site	1,962	2%	334	17%	2,296
08	**Project Management, Engineering and Support**	**120,719**	**22%**	**22,634**	**19%**	**143,354**
0100	Mobilisation and Prepartory Work	0	0%	0	–	0
0200	**Project management**	**56,543**	**47%**	**8,681**	**15%**	**65,224**
0300	Support Services	26,252	22%	4,410	17%	30,662
1000	Demobilisation by Contractors	37,924	31%	9,544	25%	47,468
09	**Research and Development**	**0**	**0%**	**0**	**–**	**0**
10	**Fuel and Nuclear Material**	**0**	**0%**	**0**	**–**	**0**
11	**Miscellaneous Expenditures**	**4,724**	**1%**	**1,358**	**29%**	**6,083**
0100	Owner Costs	0	0%	0	–	0
0200	Taxes	0	0%	0	–	0
0300	Insurances	4,724	100%	1,358	29%	6,083
Total		**541,402**	**100%**	**94,677**	**17%**	**636,079**