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# Decommissioning Planning for Forsmark and Oskarshamn NPP:s

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## ABSTRACT

*Decommissioning studies have been carried out for the three BWR units of Oskarshamn nuclear power plant and the three BWR units of Forsmark nuclear power plant. The final closure of these units is far ahead but anyhow there has been a need for developing a more general decommissioning planning basis. The main objectives of the studies have been to establish an estimate of the waste amounts arising from these units during decommissioning and dismantling as well as providing a firm basis for funding of the decommissioning phase for these units. The waste amounts will be used when designing a repository for decommissioning waste of the same type as the existing facility for final disposal of short-lived low and intermediate level waste, the SFR, at Forsmark, Sweden. The broader studies will also be used to verify that the existing national decommissioning fund is of an adequate size.*

*In this paper information is given about the inventory of materials and radioactivity at the time for final shutdown. Furthermore, the resulting waste quantities are estimated. Some other features of the decommissioning planning are also presented.*

## INTRODUCTION

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 maintain an adequate funding basis for decommissioning of the nuclear power plant. The Swedish Nuclear Fuel and Waste Management Co. (SKB) is owned by the Swedish nuclear power utilities and is responsible for coordination of the national waste fund financed activities such as NPP decommissioning as well as for designing, building and operation of waste management facilities.

To meet these objectives, detailed plant-specific studies have been performed by Westinghouse in cooperation with the utilities of Forsmark (FKA) and Oskarshamn (OKG), on behalf of SKB. Westinghouse has previously performed a reference decommissioning study for typical Swedish BWR:s, based on Oskarshamn Unit 3. A similar methodology has now been used for individual decommissioning studies of

Oskarshamn Unit 1 and 2 (O1 and O2), as well as for Forsmark Unit 1, 2 and 3 (F1, F2 and F3).

All of the studied plants are BWR:s of ASEA-ATOM (now Westinghouse Electric Sweden) design.

**Table 1: Plant data on the studied BWR:s.**

| | **Commissioned** | **Thermal effect [MW]** | **Electrical effect [MW]** |
|---|---|---|---|
| **Oskarshamn 1** | 1972 | 1 375 | 491 |
| **Oskarshamn 2** | 1974 | 1 800 | 620 |
| **Forsmark 1** | 1980 | 2 928 | 987 |
| **Forsmark 2** | 1981 | 2 928 | 1 000 |
| **Forsmark 3** | 1985 | 3 300 | 1 192 |

A further objective of the studies has been to estimate the volume of different waste categories produced during decommissioning to provide a design basis for an expansion of the Swedish Final Repository for Short-lived Low and Intermediate Level Waste (SFR) and to estimate the capacity need for the coming Final Repository for Long-lived Low and Intermediate Level Waste (SFL).

## INVENTORY OF SYSTEMS, COMPONENTS AND STRUCTURES

Most of the calculations that produces the waste package volumes, the activity durations in the time schedule or the activity costs are based on the amount of material handled during that specific activity. It could be expressed as mass, or some other characteristic feature like length, area or number. Thus, it is very important to gather accurate data of all materials, components or building structures in the plant.

For the studied plants inventory lists have been produced out of component databases, drawings, specifications etc. When not available, measurements and estimates have been done during walk-downs of the stations.

The results of the total inventory are presented in Table 2 as total amounts, contaminated as well as non-radioactive materials, divided into metal scrap, concrete or sand. The sand origins from the off-gas treatment delay systems where the off-gas release is delayed in large sand-filled tanks and thus decayed before entering the main stack.

**Table 2:The inventory of materials.**

| | | **Material** | | | |
|---|---|---|---|---|---|
| **NPP** | | **Metal** | **Concrete** | **Sand** | **Total** |
| **Oskarshamn 1** | Weight, tonne | 17 000 | 159 000 | 400 | 176 400 |
| **Oskarshamn 2** | Weight, tonne | 16 000 | 127 000 | 1 500 | 144 500 |
| **Forsmark 1** | Weight, tonne | 34 000 | 315 000 | 2 600 | 351 600 |
| **Forsmark 2** | Weight, tonne | 30 000 | 238 000 | 2 600 | 270 600 |
| **Forsmark 3** | Weight, tonne | 37 000 | 304 000 | 3 300 | 344 300 |
| **Total** | Weight, tonne | 134 000 | 1 143 000 | 10 400 | |

The inventory of the components, excluding small valves and instrumentation components, were considered very accurate as either reliable documentation was used (e.g. assembly drawings, data sheets, FSAR, etc.) or data was derived from 3D-models (e.g. reactor pressure vessel, high pressure turbine). If the accuracy of the used documentation and 3D-models is assumed as ± 5%, the pipe inventory produced based on the isometric drawings having an average accuracy of ± 10% and the estimates having an average accuracy even as low as ± 30%, it can be reasonably assumed that the overall accuracy is better than ± 20% and for systems where only few estimations were made the accuracy can be expected to be at least ± 10%.

## RADIOACTIVITY INVENTORY

In order to classify the decommissioning waste material in different categories concerning radioactivity content, the materials inventory also has to be combined with data on contamination levels for each piece of material. This has been done by using measured data in combination with calculations and models of activity transfer and deposition throughout the plant systems. By combining the surface contamination with data of exposed area and mass of each component, an average specific activity (Bq/kg) could be calculated.

The decommissioning waste has then been classified according to its specific activity in different categories as shown in Table 3.

**Table 3: Activity Categorization.**

| Waste Category | Specific Activity [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 | 0 | Non-active material, uncontrolled area |

Thorough system decontamination is assumed to be applied for most of the primary systems, including one third of the reactor pressure vessel. The average decontamination factor has conservatively been set to 10.

The total amounts of materials in Table 2 have been sorted according to specific activity and the results are shown in Table 4 regarding metallic materials and in Table 5 regarding concrete waste.

**Table 4: Metals inventory for the NPP:s sorted by specific activity.**

| **Activity Category** | | | | **NPP** | | | |
|---|---|---|---|---|---|---|---|
| **Bq/kg** | | **O1** | **O2** | **F1** | **F2** | **F3** | **Total** |
| **$> 10^6$** | Weight, tonne | 1 000 | 900 | 1 800 | 1 700 | 3 200 | 8 600 |
| **$10^4 - 10^6$** | Weight, tonne | 400 | 1 200 | 1 700 | 1 600 | 1 300 | 6 200 |
| **$500-10^4$** | Weight, tonne | 1 300 | 300 | 0 | 0 | 0 | 1 600 |
| **$< 500$** | Weight, tonne | 5 000 | 12 000 | 16 000 | 15 100 | 10 000 | 58 100 |
| **0** | Weight, tonne | 9 300 | 1 600 | 14 500 | 11 600 | 22 500 | 59 500 |
| **Total** | Weight, tonne | 17 000 | 16 000 | 34 000 | 30 000 | 37 000 | |

**Table 5: Concrete inventory for the NPP:s sorted by specific activity.**

| **Activity Category** | | | | **NPP** | | | |
|---|---|---|---|---|---|---|---|
| **Bq/kg** | | **O1** | **O2** | **F1** | **F2** | **F3** | **Total** |
| **$> 10^6$** | Weight, tonne | 400 | 300 | 400 | 200 | 400 | 1 700 |
| **$10^4 - 10^6$** | Weight, tonne | 500 | 600 | 500 | 500 | 800 | 2 900 |
| **$500-10^4$** | Weight, tonne | 200 | 300 | 200 | 200 | 0 | 900 |
| **$< 500$** | Weight, tonne | 78 800 | 77 000 | 284 800 | 222 800 | 175 300 | 838 700 |
| **0** | Weight, tonne | 79 100 | 48 800 | 29 100 | 14 300 | 127 500 | 298 800 |
| **Total** | Weight, tonne | 159 000 | 127 000 | 315 000 | 238 000 | 304 000 | |

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 will change from the quantities presented in this paper. The total amount of active waste depends strongly on which components that can be free released. This amount will also be affected by the decay time between shutdown and the start of the decommissioning and of the degree of cleaning of the actual systems. The total amount of active waste estimated in this study thus contains some uncertainty.

## DISMANTLING TECHNIQUES

Given the wide range of equipment and material to be removed during dismantling of a nuclear plant, a range of techniques will be required, each appropriate for the task.

However, it is assumed that no major technical development activities would be needed for dismantling of the studied reactor units. Already today, there is sufficient experience with different techniques required for the dismantling operations. Some of them have been gained from the NPP dismantling projects already performed or currently on-going. In some cases 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 procedures. Also, during replacement of major components within operational plants, many useful techniques have been developed. An example is the wide variety of mechanical cutting techniques that have been used in the Nordic countries for handling of replaced reactor internal parts.

Taken into account that there will be many more years before the studied reactor units will undergo decommissioning, it would be even more so that the required technologies would be proven and easily available.

## MANAGEMENT OF DISMANTLING WASTE

A fit-for-purpose, modular waste screening facility is suggested to be constructed within the turbine building or a similarly sized building that makes use of re-usable modular containment and shielding. It will be 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.

When processed, the final decommissioning waste will be packaged in containers of similar type as those currently used for operational waste within the Swedish waste handling system. The chosen container types are as follows:

BFA-containers

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 located close to the core and is assumed to be placed in 0.1 m thick steel containers with the outer dimensions 3.30 x 1.30 x 2.30 m. The inner volume is approx. 7 $m^3$ and the maximum weight, including 12 tonne of waste, is 34 tonne. The long-lived waste is assumed to be disposed of in the final repository for long-lived low and intermediate level waste (SFL; not yet built but scheduled for operation in the year 2045).

Steel Boxes

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 with the outer dimensions 1.20 x 1.20 x 1.20 m (Figure 1) currently used for operational waste. An enlarged version is also foreseen to be used for practical reasons with the dimensions 2.40 x 2.40 x 1.20 m and the maximum total weight 20 tonne. The boxes are transported in shielded transport containers (Figure 2), and disposed of in the final repository for short-lived decommissioning waste (an extension of the present SFR facility for operational waste).

**Figure 1: Swedish standard 1.2m x 1.2m x 1.2m steel container for ILW disposal.**

ISO-Containers

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 (0 Bq/kg). The process equipment waste in the yellow and green categories is assumed to be disposed of in the SFR repository whilst the waste in the blue and white category is assumed to be transported to an appropriate disposal site for conventional waste or a recycling facility. The waste containers to be used for this kind of waste are assumed to be standard 20 ft half height ISO-type containers with top opening and outside measurements 6.06 x 2.50 x 1.30 m. The inner volume of these containers is approx. 15 $m^3$ and the total weight is limited to 20 tonne.

**Figure 2: SKB shielded transport container.**

For packaging of reactor 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 type of component is being packed. When calculating the number of waste containers needed for process equipment waste a packing degree of 1.1 tonne/m$^3$ is used.

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 is assumed to be the same as for crushed concrete, i.e. approx. 1.5 tonne/m$^3$. This packing degree is assumed for all concrete waste.

For the sand waste, the containers will only be filled to approx. 70 % not to exceed the maximum weight capacity.

When converting the amounts of original decommissioning waste into container volumes, the required repository volumes have been calculated according to Table 6.

A large portion of the free released concrete waste will be used to back-fill the plant cavities below ground level during site restoration.

**Table 6: Storage volume and waste categorisation of the studied BWR:s.**

| | | Net Storage Volume [m$^3$] | | | | | |
|---|---|---|---|---|---|---|---|
| **Waste Category** | **Repository** | **O1** | **O2** | **F1** | **F2** | **F3** | **Total** |
| Red (LL) | SFL | 89 | 99 | 118 | 118 | 148 | 572 |
| Red (SL) | SFR | 2 031 | 1 396 | 2 661 | 1 997 | 3 501 | 11 586 |
| Yellow & Green | SFR | 3 093 | 3 112 | 3 466 | 3 368 | 2 915 | 15 954 |
| Blue & White | Recycling | 35 038 | 17 883 | 38 503 | 34 210 | 42 659 | 168 293 |
| **Total** | | 40 251 | 22 490 | 44 748 | 39 693 | 49 223 | |

## DECOMMISSIONING PROGRAM

The decommissioning period starts with a planning phase when an Environmental Impact Assessment (EIA) is started, before the defueling period when the fuel is transported away from the site to the CLAB facility for intermediate storage. For different reasons a period of time might be needed to prepare the plant for dismantling after the defueling period. If this so called shutdown operation period becomes long there might be a need to upgrade certain functions of the plant before the dismantling operation could start. All the contaminated components and concrete are removed during the dismantling, where after the site is free released and the conventional demolition of the buildings start. The site restoration phase concludes the decommissioning period.

A model has been developed where the inventory data can be used to calculate work hours for taking care of all the different types of plant components. The working time estimates are then combined, together with general duration data for different activities during plant decommissioning and a specific site factor, unique to each area at each unit. This gives a time schedule for the complete program, from initial planning and preparatory activities to non-radioactive building demolition and site restoration.

The expected total duration, from plant shutdown to finalized landscaping, is typically 10 years, while the actual radioactive dismantling and demolition period is about 6 years.

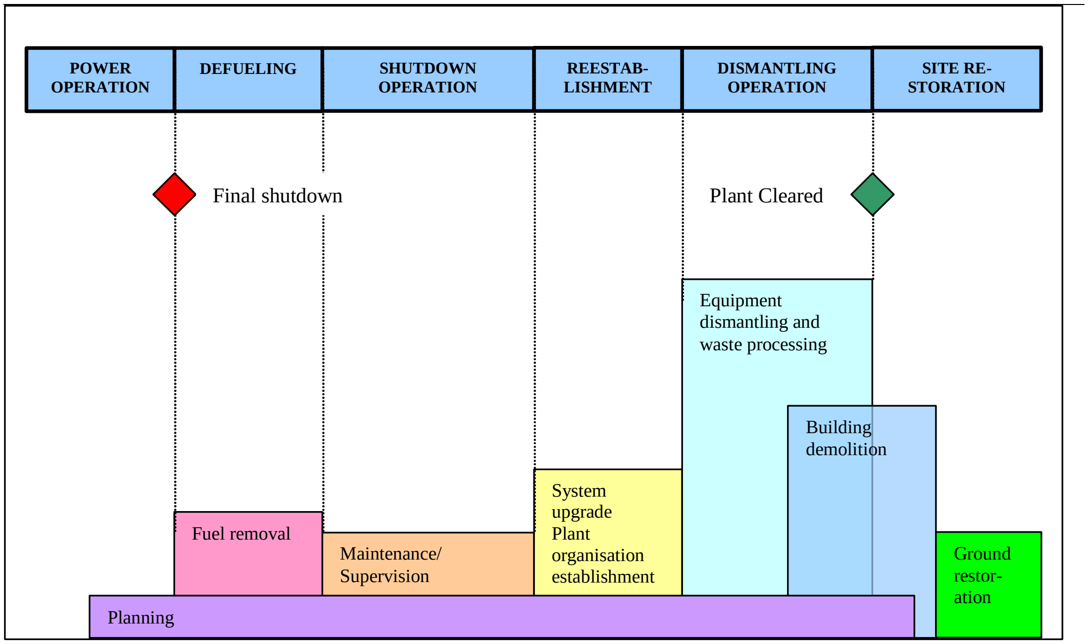

**Figure 3: Decommissioning phases.**

## DECOMMISSIONING COST ESTIMATES

The activity durations calculated for the time schedule could also be converted to costs by adding information on the work force that perform each task (number of different personnel categories and their corresponding rates) and other costs associated with each operation. This will also be done during the on-going study, but is currently not at a stage for presentation. Thus, no data is available in time for this paper.

## ALTERNATIVE TECHNIQUES

An alternative to segmenting the reactor pressure vessel (RPV) would be to remove it, complete either with or without reactor internals, in one piece as a single unit. In case this approach is chosen, a decrease of the container volume at SFR would be achieved. However, the intact RPV occupies a large volume by itself and consequently, removing the RPV in one piece will in fact increase the net storage volume by 100-250 $m^3$, depending on which reactor it is, compared to the segmentation alternative.

Process equipment waste may be size reduced off-site through e.g. smelting. This would decrease the net storage volume at SFR considerably, both through the sheer volume reduction from smelting, but also from the fact that some of the ingots may be free released after the process.

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.

A higher decontamination factor (DF) for the system decontamination would result in less activity in the dismantling waste. A DF of 30 would convert approximately 68 % of the ILW from the decontaminated systems into LLW, compared to approximately 10 % with a DF of 10. A higher DF than 30 gives very little change.

## CONCLUSIONS

The technologies required for the decommissioning work are for the most part readily proven. Taken into account that there will be many more years before the studied reactor units will undergo decommissioning, the techniques could even be called conventional at that time. This will help bring the decommissioning projects to a successful closure.

A national waste fund is already established in Sweden to finance amongst others all dismantling and decommissioning work. This will assure that funding for the decommissioning projects is at hand when needed.

All necessary plant data are readily available and this will, combined with a reliable management system, expedite the decommissioning projects considerably.

Final repositories for both long- and short-lived LILW respectively is planned and will be constructed and dimensioned to receive the decommissioning waste from the Swedish NPP:s. Since the strategy is set and well thought-through, this will help facilitate a smooth disposal of the radioactive decommissioning waste.

Considering the conclusions above, decommissioning planning is well under way, rests on firm assumptions and has every prospect of leading to successful, cost-effective and safe dismantling and decommissioning of the Swedish nuclear power plants.