Detailed Decommissioning Plans for the Oskarshamn and Forsmark Nuclear Power Plants in Sweden – 14008

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ABSTRACT

Decommissioning plans have been made for the three BWR units of Oskarshamn and the three BWR units of Forsmark nuclear power plants. The main objectives of the project have been to establish a viable technical platform, an estimate of the waste amounts, project schedule and costs for these units during decommissioning. The waste amount estimations will be used when designing the extension of the existing facility for final disposal of short-lived low- and intermediate level waste; the SFR, at Forsmark, Sweden.

A national waste fund is already established in Sweden to finance amongst others all decommissioning work. This will assure that funding for the decommissioning projects is at hand when needed. The cost estimates from the decommissioning plans will provide a firm and realistic basis for the estimation of the deposit to the national decommissioning fund.

The estimated radioactive decommissioning waste from the Oskarshamn site consist of 335 m^3 of long-lived waste, 2 390 m^3 of intermediate level waste and 11 435 m^3 of low level waste. From the Forsmark site the quantities are estimated to 385 m^3 of long-lived waste, 2 740 m^3 of intermediate level waste and 12 980 m^3 of low level waste.

The estimated total decommissioning cost for the Oskarshamn site is 790 M$ and for the Forsmark site 895 M$.

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 Company (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, decommissioning plans have during the recent five years been made individually for the three BWR units of Oskarshamn and the three BWR units of Forsmark nuclear power plants. The main objectives of the project have been to establish a viable technical platform, an estimate of the waste amounts, project schedule and costs for these units during decommissioning. The waste amount estimations will be used when designing the extension of the existing facility for final disposal of short-lived low- and intermediate level waste; the SFR, at Forsmark, Sweden.

Site decommissioning plans have then been made taking into account synergy effects when decommissioning a whole site with multiple units in series. The synergy effect benefits are e.g.

combined resource utilization in the form of utility staff organization positions, a shorter decommissioning project due to reduced lead time for the various tasks between the units, utilization of the same decommissioning tools and equipment throughout the project, erection and usage of a combined waste treatment facility for the units, etc.

With a foundation in the stand-alone, unit specific, decommissioning plans, broader cost estimates have been made taking into account the above mentioned synergy effects of serial multiple units decommissioning. The cost estimates from the site decommissioning plans allows for cost savings through more efficient use of resources than in the unit specific plans and will provide a firm and realistic basis for the estimation of the deposit to the national decommissioning fund.

The project has been performed by Westinghouse in cooperation with the utilities of Forsmark (FKA) and Oskarshamn (OKG), with a base in the utilities own decommissioning strategy. This has been done on behalf of SKB, the utility-owned Swedish waste management organization responsible for managing and disposing of all radioactive waste from the Swedish nuclear power plants as well as coordination of the national waste fund.

All of the studied plants are BWRs of ASEA-ATOM (now Westinghouse Electric Sweden) design. Some plant data can be seen in TABLE I.

TABLE I. Plant data on the studied BWRs.

	Commissioned	**Thermal power [MW]**	**Electrical power [MW]**
Oskarshamn 1	1972	1 375	491
Oskarshamn 2	1974	1 800	620
Oskarshamn 3	1985	3 900	1 450
Forsmark 1	1980	2 928	987
Forsmark 2	1981	2 928	1 000
Forsmark 3	1985	3 300	1 192

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 work 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 II as total amounts, contaminated as well as non-radioactive materials, divided into metal scrap, concrete and sand. The sand originates from the off-gas treatment delay systems where the radioactive noble gases are delayed in large sand-filled tanks and thus are decayed before entering the main stack. Noteworthy to mention is that unit 1 at Oskarshamn as well as Forsmark has common buildings that facilitate the rest of the respective site. Hence the extra mass for the respective unit 1.

TABLE II. The inventory of materials.

		Material			
NPP		**Metal**	**Concrete**	**Sand**	**Total**
Oskarshamn 1	Weight, tonne	15 600	159 100	400	175 100
Oskarshamn 2	Weight, tonne	21 800	135 400	1 500	158 700
Oskarshamn 3	Weight, tonne	37 700	303 000	3 200	343 900
Forsmark 1	Weight, tonne	33 700	317 200	2 600	353 500
Forsmark 2	Weight, tonne	29 900	238 300	2 600	270 800
Forsmark 3	Weight, tonne	37 400	304 000	3 200	344 600
Total	Weight, tonne	176 100	1 457 000	13 500	1 646 600

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 component or structure. 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 (Becquerel/kg) can be calculated.

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

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 II have been sorted according to specific activity and the results are shown in TABLE IV for metallic materials and in TABLE V for concrete waste.

If the applied limit for free release will differ from 500 Bq/kg, which is the assumed limit in the plans, the amount of free-releasable waste will change from the quantities presented in this paper. The total amount of active waste depends 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 the plans thus contains some uncertainty.

TABLE III. 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	-	Non-active material, uncontrolled area

TABLE IV. Metals inventory for the NPPs sorted by specific activity.

Activity Category		NPP						
Bq/kg		O1	O2	O3	F1	F2	F3	Total
> 10^6	Weight, tonne	800	1,100	1,900	1,200	1,200	2,600	8,800
10^4 - 10^6	Weight, tonne	500	1,200	2,800	2,300	2,200	1,700	10,700
500 - 10^4	Weight, tonne	900	200	200	100	0	200	1,600
< 500	Weight, tonne	7,800	16,500	21,800	27,200	24,800	21,600	119,700
-	Weight, tonne	5,600	2,700	11,000	2,900	1,700	11,300	35,200
Total	Weight, tonne	15,600	21,700	37,700	33,700	29,900	37,400	176,000

TABLE V. Concrete inventory for the NPPs sorted by specific activity.

Activity Category		NPP						
Bq/kg		O1	O2	O3	F1	F2	F3	Total
> 10^6	Weight, tonne	400	300	900	400	200	200	2,400
10^4 - 10^6	Weight, tonne	500	600	500	500	500	1,000	3,600
500 - 10^4	Weight, tonne	200	200	200	200	200	200	1,200
< 500	Weight, tonne	78,800	99,500	######	284,800	222,900	175,100	#######
-	Weight, tonne	79,200	34,800	######	31,300	14,500	127,500	414,600
Total	Weight, tonne	159,100	135,400	######	317,200	238,300	304,000	#######

MANAGEMENT OF DISMANTLING WASTE

When processed, the final decommissioning waste will be packaged in containers of different types depending on how the waste is categorized. So called BFA-tanks (3.30×1.30×2.30 m) will be used for long-lived waste. Steel boxes (2.40×2.40×1.20 m) will be used for short-lived waste in the red activity category, > 10^6 Bq/kg. 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 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 6.1 m (20 ft) half height ISO-type containers with the outside measurements 6.06×2.50×1.30 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 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.

The reactor pressure vessel (RPV) and their internal parts are treated separately. The RPV internals are removed and segmented as an initial step before the reactor pressure vessel is sealed and sent to the repository as a whole piece.

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 VI and TABLE VII.

A large portion of the free released concrete waste will be used to backfill the plant cavities up to one meter below ground level during site restoration.

TABLE VI. Waste container data for all the waste from the Oskarshamn site.

Suggested disposal facility	**Net disposal 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

TABLE VII. Waste container data for all the waste from the Forsmark site.

Suggested disposal facility	Net disposal volume (m^3)	Number of waste containers	Container	Waste category	Outside measurements (m)
SFL	385	39	BFA-tank	Red (LL)	3.30×2.30×1.30
SFR	2 703	391	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	12 979	659	ISO-type Container	Yellow & Green	6.06×2.50×1.30
Recycling	305 281	15 500	ISO-type Container	Blue & White	6.06×2.50×1.30

DECOMMISSIONING PROGRAM

The operating time is assumed in the plans to be 50 and 60 years for the Forsmark and Oskarshamn units, respectively. TABLE VIII shows the years for the different units when the shutdown commences.

TABLE VIII. The assumed shutdown dates for the units at the Forsmark and Oskarshamn site.

Unit	O1	O2	O3	F1	F2	F3
Shutdown year	2032	2035	2045	2030	2031	2035
	60 years of operation			50 years of operation		

Planning, EIA work etc. for the decommissioning of the site is required before the shutdown. This is part of a refined plan of the decommissioning plan that all power plants in Sweden are required to be in possession of.

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 this gives a time schedule for the complete program, from initial planning and preparatory activities to non-radioactive building demolition and site restoration.

A schematic overview of the decommissioning time schedules for Forsmark and Oskarshamn is given in Fig. 1 and Fig. 2. The expected total duration of the decommissioning program for Oskarshamn, from O1 plant shutdown to finalized landscaping of the Oskarshamn site, is about 21 years. The expected total duration of the decommissioning program for Forsmark, from F1 plant shutdown to finalized landscaping of F3, is about 12 years.

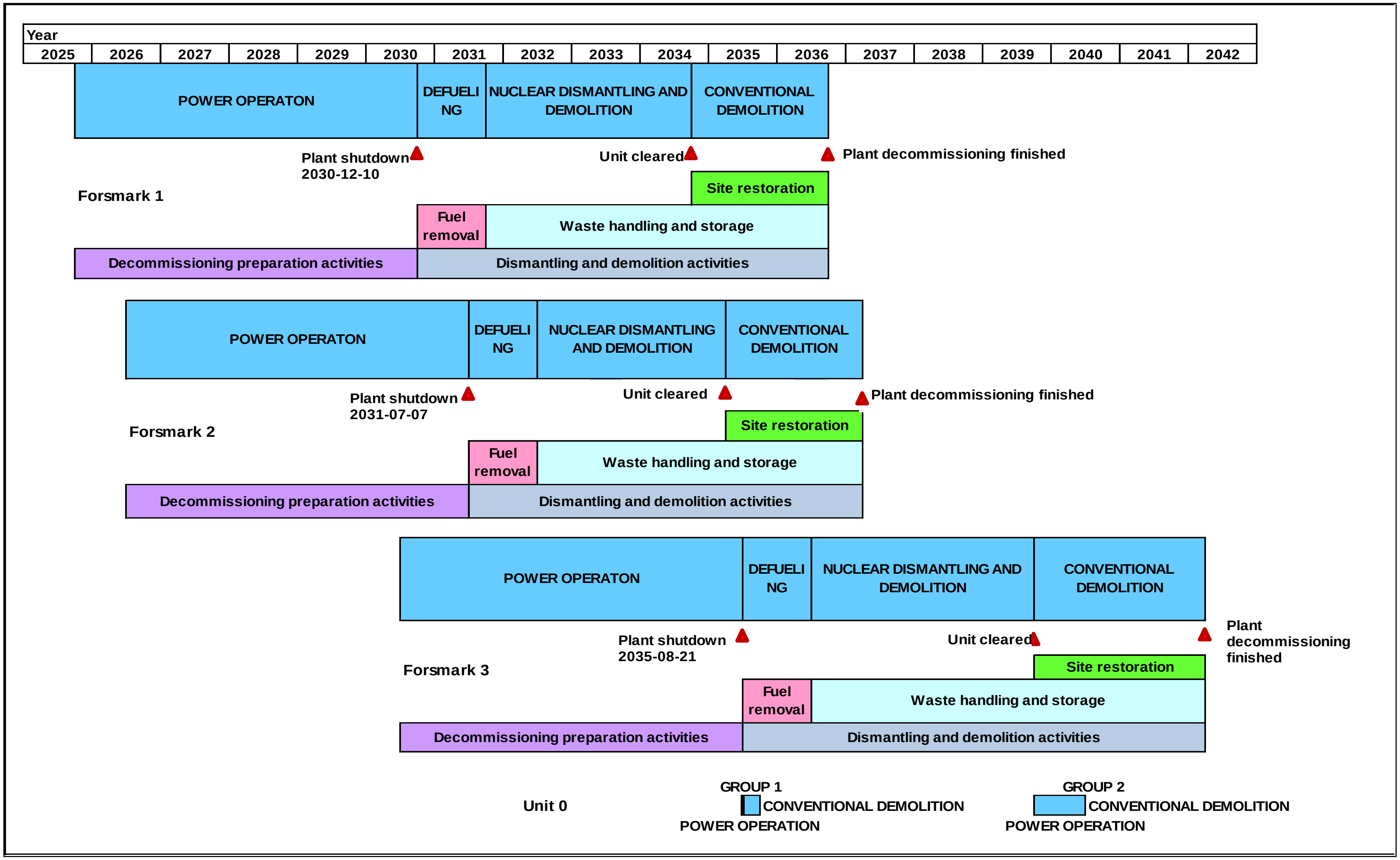

Fig. 1. The decommissioning schedule for the Forsmark site.

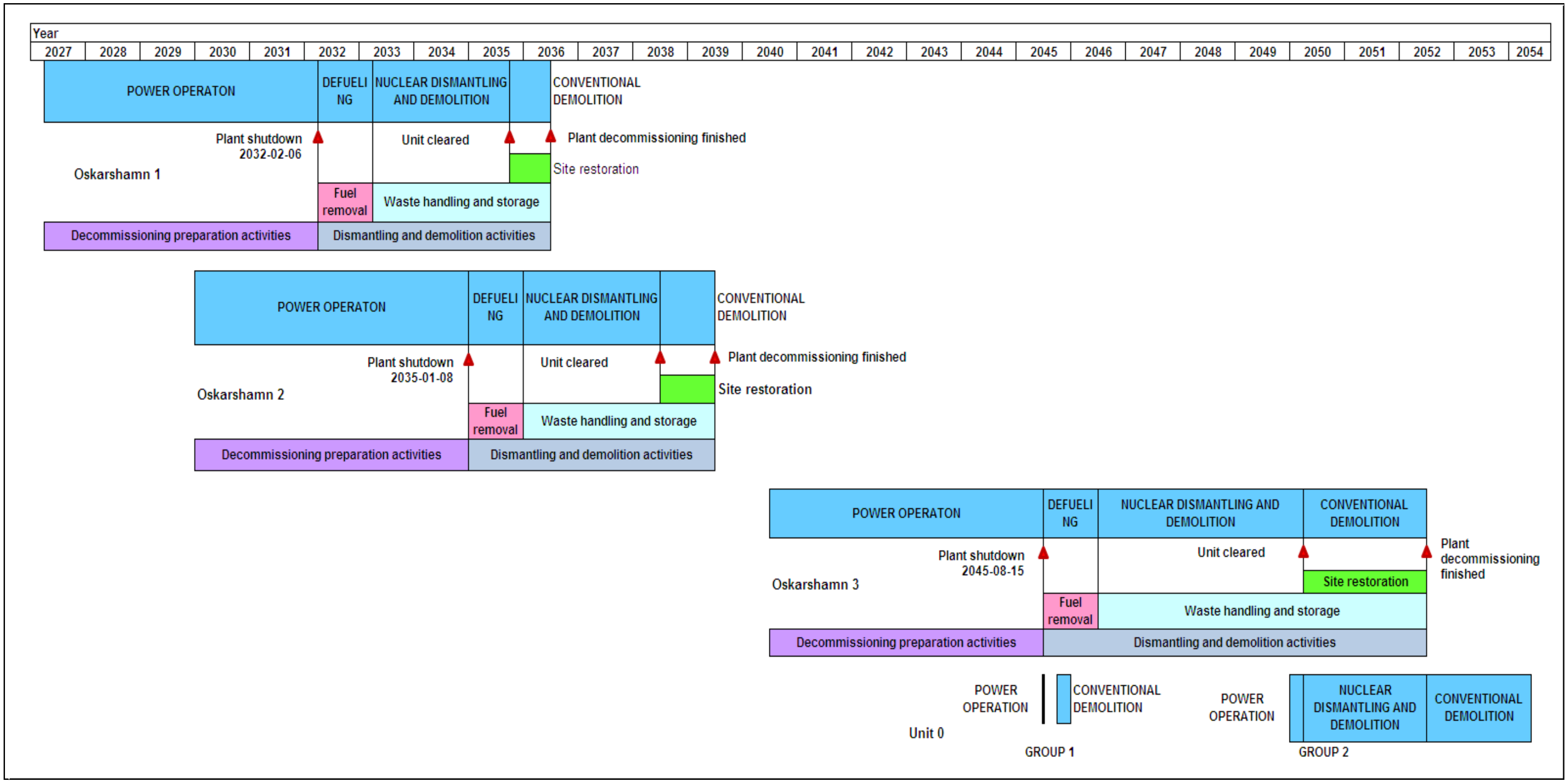

Fig. 2. The decommissioning schedule for the Oskarshamn site.

DECOMMISSIONING COST ESTIMATES

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. The WBS elements are generally arranged in a hierarchal format that reflects the organization chart. The topmost member or level of the WBS would be the overall project. Subsequent levels are used to track increasing levels of detail in the project. In most cases the costs are "rolled up" to Level 3 or Level 2 summary costs for management information.

The decommissioning cost estimates in the decommissioning plans can be considered as budgetary estimates.

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. The total costs for a project includes the costs for all categories as well as their contingencies. On top of that, risks are uncertainties that may occur throughout the project (unknown unknowns). The risks are not covered by the plans but are handled separately when developing the total basis for the funding.

The costs for decommissioning of the NPP:s Oskarshamn and Forsmark are also divided into the eleven categories according to the OECD/NEA standard ISDC. The percentage of each category is compared to cost of all categories, contingency for each category is also given in TABLE IX and TABLE X.

TABLE IX. The estimated decommissioning costs for the Oskarshamn site.

ISDC Matrix Elements		Cost		Contingency		Sum Cost + Cont.
		k$	%	k$	%	k$
01	Pre-decommissioning Activites	10 845	2%	1 056	10%	11 901
02	Facility Shutdown Activites	17 606	3%	2 653	15%	20 259
03	Additional Activities for Safe Enclosure	0	0%	0	-	0
04	Dismantling Activities within the Controlled Area	313 321	45%	40 218	13%	353 539
05	Waste Processing, Storage and Disposal	67 662	10%	9 062	13%	76 724
06	Site Infrastructure and Operation	43 096	6%	6 581	15%	49 677
07	Conventional Dismantling, Demolition and Site Restoration	118 159	17%	18 118	15%	136 277
08	Project Management, Engineering and Support	114 979	17%	19 620	17%	134 599
09	Research and Development	0	0%	0	-	0
10	Fuel and Nuclear Material	0	0%	0	-	0
11	Miscellaneous Expenditures	4 317	1%	1 241	29%	5 559
Total		**689 986**	**100%**	**98 550**	**14%**	**788 535**

TABLE X. The estimated decommissioning costs for the Forsmark site.

ISDC Matrix Elements		Cost		Contingency		Sum Cost + Cont.
		k$	%	k$	%	k$
01	Pre-Decommissioning Actions	9 166	1%	885	10%	10 051
02	Facility Shutdown Activities	12 148	2%	1 510	12%	13 659
03	Additional Activities for Safe Enclosure	0	0%	0	0%	0
04	Dismantling Activities within the Controlled Area	360 084	45%	41 683	12%	401 767
05	Waste Processing, Storage and Disposal	69 390	9%	8 644	12%	78 034
06	Site Infrastructure and Operation	43 515	5%	5 371	12%	48 886
07	Conventional Dismantling, Demolition and Site Restoration	185 841	23%	18 467	10%	204 308
08	Project management, Engineering and Support	117 905	15%	17 428	15%	135 333
09	Research and Development	0	0%	0	0%	0
10	Fuel and Nuclear Material	0	0%	0	0%	0
11	Miscellaneous Expeditures	2 662	0%	765	29%	3 428
Total		800 713	100%	94 754	12%	895 466

ALTERNATIVE TECHNIQUES

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

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 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 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.

A final repository for long-lived LILW and an extension of the existing final repository for short-lived LILW is planned and will be constructed and dimensioned to receive the decommissioning waste. 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[1] nuclear power plants.

[1] The published studies on the site decommissioning of Forsmark and Oskarshamn can be found on the Swedish Nuclear Fuel and Waste Management Company (SKB) homepage. http://www.skb.se