SKI Report 2003:11

Research

Ågesta-BR3 Decommissioning Cost Comparison and Benchmarking Analysis

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November 2002

ISSN 1104–1374
ISRN SKI-R-03/11-SE

SKI perspective

Background

Assuring appropriate financial contributions to the Swedish Nuclear Waste Fund is crucial for the sustainability and long term credibility of the financing system that underpins Sweden's nuclear waste liabilities. One particular task is to assure an appropriate level of collections to the part of the fund that is governed by the Studsvik Act. A deficit situation may arise if the level of accruals to the fund becomes inappropriate in relation to future expected disbursements/withdrawals.

SKI is conducting pro-active work through applied studies on some major cost elements in the program, in order to reduce the uncertainties in the estimated costs of these program elements and thereby mitigating the risk of creating a deficit in the Swedish Nuclear Waste Fund.

The decommissioning cost for older research reactors is one of the major cost areas where more information is warranted. During year 2001 a study with special focus on the decommissioning program of the Westinghouse Test Reactor (WTR) at the Westinghouse Waltz Mill site in Pennsylvania was published. The WTR experience was compared with estimates for the Studsvik R2 research reactor in Sweden. This work was published as SKI Report 02:2 with the title "R2/R0-WTR Decommissioning Cost Comparison and Benchmarking Analysis".

During year 2002 SKI continued the analysis by a comparative study of the Ågesta plant in Sweden and the decommissioning of the BR3 reactor at Mol in Belgium.

Purpose of the project

At present there is limited empirical data from work within Sweden that is pertinent to estimating decommissioning costs for Swedish research reactors. Therefore, newer and better estimates of decommissioning costs for such reactors needs to be derived to enhance the quality of capital budgeting and planning.

Accordingly, the prime objective of this study has been to continue the acquisition of detailed empirical information on the resources expended in actual decommissioning programs for pertinent research reactors elsewhere. Specifically, in this case to retrieve actual costs that could be used for a comparative study between the estimated costs for decommissioning of the Ågesta plant with actual cost from a decommissioning project of a reactor that is similar in many of its principal features. A secondary objective has been to collect, analyse and present data in a more structured way, including benchmarking results, in order to provide a meaningful, quantitative basis for future cost comparisons and the development of more accurate cost estimates for the Swedish research reactors.

Results

The study gives a description of the costs for five discrete work packages:

1. Primary coolant piping decontamination
2. Primary coolant piping dismantling
3. Vulcain reactor internals dismantling
4. Westinghouse reactor internals dismantling
5. Reactor vessel dismantling.

The detailed raw data has been normalised into resources needed on a unit basis, e.g. per cubic meter, per metric ton, hours worked and per unit of equipment, for different types of cost within the decommissioning program. The essential results are:

- Estimated costs for different packages were available only within broad ranges for Ågesta and for this reason there is a need to continue the study.
- Accordingly, additional data collection should be done on a more detailed level. Importantly, more in-depth analysis of the expected costs ought to be carried out before any firm conclusions, or inference, about the reasonableness of the expected decommissioning costs for Ågesta can be stated.
- Even in cases where the Ågesta estimates for a particular package of decommissioning work appear to be reasonably good, there still are some questions concerning the validation of the data and the methodology adopted. It is evident that the process of capital budgeting for the expected future decommissioning cost must be shown step by step and clearer references would be beneficial.

Continued work

The work reported here indicates that there is a need for additional studies concerning the development of non-monetary estimates, e.g. labour hours expected, to facilitate pan-European and/or international comparisons. In the short run more studies need to be undertaken in order to provide contributions to a better understanding of the major cost-drivers in the decommissioning process. By creating a more comprehensive platform of decommissioning cost information and interpretation, it will be possible to enhance quality and accuracy in the planning stage of the process, so that cumbersome extra-work can be avoided.

Effects on SKI work

SKI will be able to draw inferences from this study in the ongoing monitoring and review of the yearly cost estimates presented by the company AB SVAFO.

Project information

At SKI Staffan Lindskog have been responsible to supervise and co-ordinate the project.

SKI reference: 14.9 – 020218/02097

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November 2002

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Summary

This report presents the results of decommissioning cost analyses focussing on discrete working packages within the decommissioning program of the BR3 reactor in Mol, Belgium and comparison of them with cost estimate data for the Ågesta research reactor in Sweden.

The specific BR3 work packages analysed were:

- Primary coolant piping decontamination
- Primary coolant piping dismantling
- Vulcain reactor internals dismantling
- Westinghouse reactor internals dismantling
- Reactor vessel dismantling

Benchmarking results derived from analysis of the BR3 decommissioning program were as follows:

D&D Activity	Benchmark Resources Needed
Primary Loop decontamination	10,956 hrs fixed + 2.65 hrs/m^2 decontaminated
Primary Loop Pipework Dismantling	740 hrs/MT including work on equipment removal to create access
Vulcain internals Dismantling	4,444 hrs fixed + 228 hrs/m^2 + fixed costs of MSEK 7.5 (or 12,000 hrs) + consumables MSEK 3.15 (equivalent to MSEK 0.13/m^2)
Westinghouse Internals Dismantling [a]	2,910 hrs fixed + 100 to 200 hrs/m^2 (probably closer to the high estimate) + fixed costs of MSEK 0.44 + Consumables of MSEK 0.85 (equivalent to MSEK 0.05/m^2)
Reactor Pressure Vessel (RPV) Dismantling	31,919 hrs fixed + 160 to 200 hrs/m^2 + fixed costs MSEK 4.1 (investments) + MSEK 4.61 consumables (equivalent to MSEK 0.16 to 0.2/m^2)

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a. The fixed costs are artificially low due to the same equipment being used as was accounted for in the Vulcain internals dismantling analysis.

The main conclusions to be drawn from the analyses are that:

- The fixed costs related to decontamination and dismantling activities generally are a very important part of the overall resources needed to execute the work, with the RPV seemingly being significantly more demanding than other major components.
- Cutting activities tend to need something like 150 to 200 labour hours per m^2 of reactor equipment dismantled.
- Fixed investment costs to set up the equipment needed to cut up major vessels or internals appear to be in the range of MSEK 4 to 8. Once set-up, dismantling equipment can be used for more than one work package.

- Consumables costs vary according to the nature of the equipment being dismantled. The thicker the metal being cut, the higher the attrition rate for things such as cutting blades. The range of consumables costs at BR3 have been in the range of MSEK 0.1 to 0.2/m^2 dismantled.

Overall Reasonableness of the Ågesta Estimate

The extent of detailed information available in the 1996 Ågesta estimate is not sufficient to enable a full comparison with the BR3 decommissioning results. A global first comparison has been attempted by summing the resources expended on the BR3 work packages described in this report with the combined dismantling data presented in the 1996 Ågesta cost estimate report.

Very broadly the cost of decontamination plus dismantling of the main process equipment at Ågesta appears to be in the order of MSEK 70, of which MSEK 4 is labour on preparatory/planning work, MSEK 40 is labour on actual decontamination and dismantling and MSEK 25 is equipment. The BR3 work packages described in this report add up to something like 83,000 labour hours plus about MSEK 13 of investments and consumables costs. At Swedish average team labour rates 83,000 hours would equate to about MSEK52. Adding the investment cost of MSEK 13 gives a total of about MSEK 65. This of course is quite close to the Ågesta figure but it would be wrong to draw immediate, firm conclusions based on these data. Such a comparison should take into account, *inter alia*:

- The number and relative sizes of the equipments decontaminated and dismantled at Ågesta and BR3
- The assumed productivity in the Ågesta estimate compared to the actual BR3 figures
- The physical scale of the Ågesta reactor is somewhat larger than the BR3 reactor, so all other things being equal, one might expect the Ågesta decommissioning cost estimate to be higher than for BR3
- Ågesta has better access overall, which should help to constrain costs
- The productivity ratio for workers at BR3 on average was high – generally 80 per cent or more, so this is unlikely to be exceeded at Ågesta and might not be equalled, which would tend to push the Ågesta cost up relative to the BR3 situation.
- There is an additional question of the possible extra work performed at BR3 due to the R&D nature of the project. The BR3 data analysed has tried to strip away any such “extra” work but nevertheless there may be some residual effect on the final numbers.

Analysis and comparison of individual work packages has raised several conclusions, as follows:

Primary Loop Decontamination

The constructed cost for Ågesta using BR3 benchmark data is encouragingly close to the Ågesta estimate value but it is not clear that the way of deriving the Ågesta estimate for decontamination was entirely rigorous. It is understood that the cost/manhours needed were scaled from the Oskarshamn 3 (commercial NPP) estimate on a per MT basis. i.e. not even on a per m^2 basis that would seem to be the most reasonable basis. Details of the scaling process were not available for this analysis. The reliability of the Ågesta estimate on these grounds therefore might reasonably be questioned.

A significant discrepancy between the BR3 and Ågesta cases appears to exist in respect of the volumes of waste arising from the decontamination activity. A factor of 15 different in ion exchange resin volume (Ågesta higher) is puzzling and no explanation has been found, other than that the volumes were "estimated" rather than calculated in accordance with a clearly defined method statement.

Primary Coolant Pipework Dismantling

The work analysed for comparisons included preparation work before the actual dismantling of the primary pipes and the auxiliary circuits plus the actual cutting of the primary pipes into small pieces of 0.8 m long to fit in the chemical reactor of the BR3 decontamination process.

The estimated grand total resources required was 4,734 hours, for a unit requirement of 740 hours /MT. This is very close to the Westinghouse Test reactor (WTR) benchmark figure for this activity (see SKI Report 02:2). The total resource requirements for primary pipework dismantling were dominated by the preparatory activities rather than the cutting activity itself. A comparison with the Ågesta cost estimate would be possible only if a more detailed breakdown of projected manhour information could be provided for Ågesta.

Ågesta RPV

The non-discovery of key information about specific packages of work included in the Ågesta estimate has been problematic, in particular in relation to analysing the removal and dismantling of the RPV. The basis for the preparatory work and actual removal of the Ågesta RPV is unclear and may not have been particularly rigorous. Information on the relevant assumed productivity ratio assumptions for this part of the project have not been discovered.

In the absence of more detailed information being discovered, it is difficult to have a high degree of confidence in the Ågesta RPV estimate. Comparison with BR3 benchmarking data suggests that the Ågesta estimate for the RPV could be significantly low. However, actual experience of steam generator (SG) removal at Ågesta provides evidence of very efficient execution of similar work, which might contradict the BR3 experience. The available data does not support reaching a detailed conclusion. A clear possibility is that the nature of the two jobs (SG and RPV) is radically different, either due to size, radiological conditions, physical access etc., or a combination of all factors, with RPV work being more demanding. If this is correct, the Ågesta SG experience may not be particularly relevant, whilst the BR3 experience would indicate the need for further scrutiny of the Ågesta RPV estimate.

1. Introduction

Statenskärnkraftinspektion (SKI) charged NAC International with the task of determining whether or not the decommissioning cost estimates for Swedish research reactors research reactors were reasonable. The reactors concerned were R2/R0 (hereafter simply referred to as "R2") and Ågesta. The associated work has been performed in phases. The objective in Phase I was to make global comparisons of the R2 and Ågesta decommissioning estimates with the estimates/actual costs for the decommissioning of similar research reactors in other countries. In January 2001, the Phase I results were presented in the report, "Comparisons of Cost Estimates for the Decommissioning of Nuclear Research Reactors".

The objective in Phase II was to focus on selected discrete work packages within the decommissioning programs of the BR3 and BR3 reactors. In a first part of Phase II the BR3 reactor was analysed and a report summarising the results was issued in October 2001. To the extent possible a comparison of the BR3 tasks was made with estimates for the R2 reactor, as a basis for providing an opinion on the reasonableness of the R2 estimate. Based on such detailed raw data, normalised unit resources (e.g. per cubic meter, per MT, per unit of equipment) were derived for selected parts of the decommissioning program, as a first step towards developing benchmarking data for D&D activities at research reactors.

This report presents the results of the second part of the Phase II analysis, focussing on discrete working packages within the decommissioning program of the BR3 reactor in Mol, Belgium and comparison of them with cost estimate data for the Ågesta research reactor.

The specific BR3 work packages analysed include:

- Primary coolant piping decontamination
- Primary coolant piping dismantling
- Reactor vessel dismantling
- Vulcain reactor internals dismantling
- Westinghouse reactor internals dismantling

The specific tasks were characterised and analysed in terms of fundamental parameters including:

- Task definition

- Labour hours expended
- Labour cost
- Labour productivity
- Length of work week
- Working efficiency
- Working environment and impact on job execution
- External costs (contract labour, materials and equipment)
- Total cost
- Waste volumes
- Waste packaging and transport costs

As in the case of the R2-BR3 comparison, the detailed raw data has been used to derive normalised unit resources (e.g. per cubic meter, per MT, per unit of equipment) as a further contribution to developing benchmarking data for D&D activities at research reactors.

2. Comparison of Ågesta and BR3

2.1 Basic Assumptions and General Information for the Comparison

The Ågesta reactor was a pressurised water reactor developed in an independent effort by Sweden. It had a thermal power of 65 MW and a net electrical output of 10 MW, with the balance of 55 MW being used for district heating in the local community of Farsta. The reactor core comprised principally natural UO_2 fuel assemblies and the reactor was moderated and cooled by heavy water.

The Ågesta reactor achieved first criticality in July 1963 and achieved full power in March 1964. Built inside a rock outcrop, it was to be a prototype for district heating reactor systems. In addition it was to be used to provide, *inter alia*, valuable experience of a generic nature for a future foreseen nuclear program, relating to technical, administrative, safety, commissioning, environmental, maintenance and operations areas. Ågesta also conducted some experiments, including fuel assembly testing. Fuel assembly tests were performed in support of the Marviken and Oskarshamn projects and some Italian fuel assemblies containing plutonium also were loaded in the core. Some fuel failures and other incidents did occur during the operational life of Ågesta, all of which contributed to the base of knowledge passed on to the future Swedish commercial nuclear power program. Ågesta was shut down finally in June 1974, due to the high cost of investments that were needed in order to upgrade reactor safety systems.

The BR3 reactor was the first Pressurized Water Reactor (PWR) ordered and connected to the grid in Western Europe. It started operation in October 1962 with a thermal power of 40,9 MWth and electrical output of 11,5 MWe gross for 10,5 MWe net. BR3 was used mainly for training commercial reactor operators and for testing advanced fuels (high burn up, burnable poison, MOX fuels) in full PWR conditions., The reactor was definitively shut down on June 30, 1987.

During its lifetime BR3 has produced 946.3 GWh of electricity in 11 operating campaigns within three main operational configurations:

- Initial operations used the original Westinghouse internals.
- In 1964 the reactor internals were removed and exchanged by new ones for carrying out an experiment called "Vulcain". This experiment, involving a mixture of heavy and light water, required also some changes to the auxiliary loops in order to control

the mixture composition and to recover the heavy water. Tritium was not a problem during the decommissioning work because the tritiated water was separately stored and long ago evacuated. In 1975 the primary loop was decontaminated by a chemical process called Turco.

- Finally, in 1984 a wet annealing of the pressure vessel was performed to decrease the neutron induced embrittlement of the reactor pressure vessel (RPV) material and thus to allow further operation of the plant.

Cost comparisons presented in this report are quoted in Swedish Crowns. The Ågesta cost estimate information made available for the purposes of this comparison was dated 1996. The BR3 decommissioning work began physically in early 1991 and is ongoing. To aid comparisons, financial summaries based on BR3 program data have been normalised to the exchange rates and money values applying in 1996.

A majority of the work at BR3 has been performed by the BR3 in-house staff. Some work has been performed by external contractors. The categories of personnel referred to in respect of the BR3 program are as shown in Table 2-1. The categories for Ågesta also are shown in Table 2-1. A direct one-to-one comparison is not possible, so the categories are grouped against the approximate equivalent in the other project.

Table 2-1 Personnel Categories

BR3 MOL	ÅGESTA
Project Engineer ■ M.Sc. engineer in charge of the project	Team Leader/Manager
Engineer ■ industrial engineer in charge of the execution of the D&D activities ■ health physics engineer Skilled Operators ■ foremen ■ qualified technicians ■ health physics technician Operators ■ craftsmen	Foreman Fitters Health physics and safety
Not Applicable	Cleanup

Worker effective hours as a proportion of gross hours always is an important factor in modelling project resources needed. For the analyses of the BR3 project in this report the base assumption is a working week of 36.5 hours gross over five days, giving 7.3 hours per day. Of this 5 to 6 hours per day would be effective hours inside the containment and 6 to 7 hours outside the containment. For This report avereage figures of 5.5 hours and 6.5 hours respectively have been assumed, equivalent to 75 per cent productivity ratio inside and 89 per cent outside the containment. Any exceptions to this general assumption are noted in the text.

Radioactive waste from the BR3 D&D operations falls into one of three categories, as summarised in Table 2-2.

Table 2-2 BR3 Waste Categories

Waste Category	Surface Dose Rate of Package
LLW	< 2 mSv/hr
ILW	< 0.2 Sv/Hr
HLW	> 0.2 Sv/hr

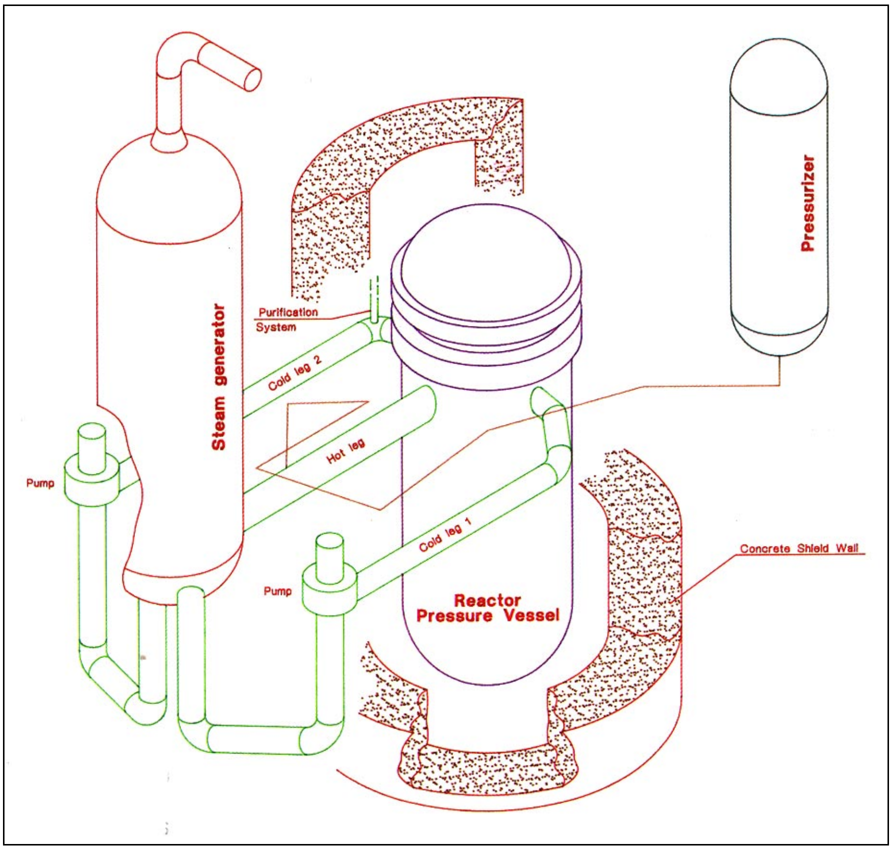
2.2 Primary Loop Decontamination

2.2.1 Definition of the Task

2.2.1.1 System Description

The main system to be decontaminated was the reactor primary loop shown schematically in Figure 2-1. It comprises only one steam generator but, for obvious safety reasons, two primary pumps were included in this so-called 1.5 loop system, a configuration with two cold legs and one hot leg. The decontamination was performed with the fuel unloaded but with the internals still loaded. The total water inventory of the loop and related systems was approximately 15 m^3, corresponding to a surface area to be decontaminated of about 1200 m^2.

Figure 2-1 Reactor Primary Loop



An auxiliary system of the primary loop, the so-called Purification System, also was included in the decontamination process. The activity released by the decontamination process was fixed on ion exchange resins. Six ion exchange columns were used during the application of the CORD process; three BR3 plant columns with a capacity of 210-l each and three mobile Siemens columns with a capacity of 100-l each.

The columns were interconnected so that different configurations could be used for different steps of the decontamination cycles. The supplementary mobile equipment delivered by Siemens comprised:

- a 120 kW heater
- a cooler of 58 kW capacity cooled by the component cooling System
- a 1 m^3 surge tank which collected all the vent lines of the 6 ion exchange columns
- a Chemical Injection Skid for the injection of the chemicals in the purification unit surge tank.

Two important components of the Residual Heat Removal system (RHR loop) also were treated by the decontamination solutions; these were the Shutdown Cooling Heat Exchanger and the Emergency Shutdown Condenser, together with their associated piping connecting them to the PU loop.

The total surface decontaminated of about 1200 m^2, of which most of the material in contact with the chemicals was SS 304. Smaller parts were SS 316 (9 m^2), carbon steel (15 m^2), chromium plated SS (10 m^2) and Zircaloy-4 (5,5 m^2).

2.2.1.2 Work Execution

As part of the dismantling strategy for the BR3 reactor, it was decided to perform a Full System Decontamination (FSD) of the primary circuit. The objectives were mainly reducing the radiation dose rates in the vicinity of the low and non-activated components and secondly limiting the transfer of surface contaminants during subsequent dismantling operations. The FSD resulted in a mean decrease by a factor of 10 of the dose rate on the contaminated equipment of the primary circuit. This dose rate allowed subsequent hands-on dismantling of the contaminated circuits with a reasonable dose uptake by the operators. The decontamination operation was divided into 3 main phases.

PHASE I: THE PREPARATION PHASE

Closure of the reactor pressure vessel, performed manually so it had to be prepared carefully to minimize the exposure of the workers.

- Review and thorough checking of the plant, especially the mechanically active components and the instrumentation. After a shutdown of 4 years, some repairs and replacements had to be performed.

- Adaptations to respect the operating working parameters, in particular modifications to the secondary side of the steam generator and replacement of the Pressure Relief Safety Valve of the Pressurizer.
- Installation of equipment for chemical injection and dosing.
- Ionization chambers were placed at several locations in the plant to provide continuous monitoring of dose rate levels.

PHASE II: THE DECONTAMINATION PERIOD ITSELF

The decontamination process was carried out from April 9, 1991until April 18 - a period of exactly 9 days of continuous operation. No incident occurred and the primary leak rate remained negligible throughout.

PHASE III: THE POST DECONTAMINATION OPERATIONS

These operations were essentially the evacuation of solid and liquid waste, the opening of the reactor pressure vessel and the evacuation of the resins.

2.2.2 *Execution Period*

The work of the preparatory phase (phase I) and the post decontamination operations were not considered at that time as a part of the real execution of the decontamination work. This means that there was no detailed follow up of this work in the controlled area. Global values have been estimated from the project imputation files. The preparatory work was executed in the years 1989 and 1991 and the post decontamination work took place in 1991 and 1992.

2.2.3 *Labour Hours, Labour Cost and Productivity*

The combination of SCK•CEN man-hours and the man-hours of external workers for each phase of the decontamination of the primary loop are listed in Table 2-3. These are gross hours. In the preparation phase, the productivity factor was roughly 80 %; in the decontamination phase, the productivity factor was around 95 % (because the operation was performed in shifts on a continuous basis and the workers remained in the controlled area throughout the shift); for the post decontamination operation the productivity factor was roughly 80 %. These productivity ratios were somewhat higher than the standard ratios referred to in section 2.1 of this report.

Table 2-3 Manhours Expended on Primary Loop Decontamination

Man-hours for cat.	Phase I Preparation	Phase II Decontamination	Phase III Post Decontamination	Total
Project engineer	1.240	488	783	2.511
Engineer	1.395	1.183	290	2.868
Skilled Operators	3.565	1.215	1.498	6.278
Operators	1.240	294	946	2.480
Total	**7.440**	**3.180**	**3.516**	**14.136**

2.2.4 Main External Costs

Consumables amounted to a cost of ε426k in 1991 money values. This expenditure related to the decontamination activity itself. Other investments were made by the subcontractor (Siemens) and are not available. The project at this time was a joint European Community effort and sometimes resources were provided by one of the participants without any specific cost value being recorded. The cost of the mobile columns for example is not included in the figures presented here.

2.2.5 Waste Volumes and Cost

681-l of resins were produced by the decontamination of the primary loop. These wastes were in the HLW category. The wastes were transferred into a transport container and shipped to the Doel reactor site in Belgium for conditioning. The conditioned wastes then were delivered to the Belgian national wastes agency, ONDRAF/NIRAS. All of this work, including any containers and wastes packages was provided under the terms of standard waste service charges. Such costs are specific to Belgium and accordingly are not relevant to the current international comparison, as different standard charges will apply in Sweden.

2.2.6 Normalised Resources and Comparison

2.2.6.1 Analysis of BR3 Decontamination Costs

The preparation and post-decontamination effort expended should be considered essentially as fixed costs, more or less independent of the size of the system to be decontaminated. The actual decontamination effort itself in a first approximation should be considered to be proportional to the surface area of the system to be decontaminated.

Table 2-4 summarises the BR3 labour hours expended on decontamination along with costs also listed by combining the hours with Swedish labour rates. The labour rates applied are weighted average figures based on the decommissioning team compositions presented in the 1996 Ågesta cost estimate report.

Table 2-4 BR3 Decontamination Labour Hours Converted to Swedish 1996 Cost Base

Work Phase	Hours	1996 Rate SEK/hr	1996 Cost (kSEK)	Totals (MSEK)
Phase I Preparation	1,240	750	930	
	6,200	612	3,794	4.724
Phase II Decon	488	750	366	
	2,692	612	1,648	2.014
Phase III Post Decon	783	750	587	
	2,733	612	1,673	2.260
				8.998

Additional costs included 17.2 BEF in 1991 money values. Escalating at Belgian inflation rates to 1996 and converting to SEK at the 1996 rate, this equates to a 1996 cost of approximately MSEK 4.2.

Based on this information a normalised unit cost associated with primary loop decontamination may be constructed as follows:

- Fixed costs MSEK 6.984
- Variable Costs: MSEK 2.014 labour plus MSEK 4.2 consumables for 1200 m^2 of surface decontamination for a unit variable cost of SEK 5,180 per m^2

There may be additional fixed equipment costs depending on the scale of ion exchange resin equipment available at the reactor. Also there could be some additional costs associated with the planning of decontamination, which in the case of BR3 may have been performed in part by Siemens as a subcontractor.

In non-monetary units the fixed resources expended were 10,956 labour hours and the variable hours 3,180, or 2.65 hrs/m^2.

2.2.6.2 *Comparison with Ågesta Decontamination Cost Estimate*

The Ågesta 1996 estimate includes MSEK 8.4 for labour costs associated with decontamination plus MSEK 10.0 for equipment. The labour estimate is almost equivalent to the BR3 derived cost but the surface area to be decontaminated at Ågesta is higher. The significantly contaminated surface area is estimated at 1,735 m^2. In addition Ågesta includes up to 2000 m^2 of surface area that might be included in the primary circuit work but would have little or no contamination. This extra area therefore perhaps should not be included in the calculations, as it would not be putting any significant additional burden on the ion exchange activity removal system.

The equipment cost estimated for Ågesta is higher than at BR3 but this may be entirely reasonable to allow for extra ion exchange equipment and subcontractor services. Regarding the labour estimate, at BR3 the average productivity ratio was around 83 percent. The 1996 Ågesta cost estimate assumption nominally assumed a ratio of 40 percent. However, the construction of the Ågesta estimate appears not to have been terribly rigorous. That is to say, in practice the cost/manhours needed were scaled from the Oskarshamn 3 (commercial NPP) estimate on a per MT basis. i.e. not even on a per m^2 basis that would seem to be the most reasonable basis. Details of the scaling process were not available for this analysis. The reliability of the Ågesta estimate on these grounds therefore might reasonably be questioned.

If we apply the BR3 benchmarking rates to Ågesta with 1735 m^2 we arrive at the following:

BR3 Fixed:	MSEK 6.984
BR3 Variable:	MSEK 2.104 labour plus MSEK 4.2 consumables for 1200 m^2
	SEK 1678/m^2 labour plus SEK 3500/m^2 for consumables

Ågesta constructed cost:

Fixed:	MSEK 6.984
Variable:	MSEK 2.911 labour plus MSEK 6.072 consumables

The total Ågesta estimate then would be MSEK 15.97 compared with the Swedish estimate of MSEK 18.4

However, the labour cost theoretically should really be adjusted for the assumed difference in productivity - 40% instead of 83%. Labour on this basis would increase from MSEK 2.911 to MSEK 6.04 for a total constructed cost of MSEK 19.1, just 3.8% higher than the Swedish 1996 estimate.

This result is encouragingly close but it is not clear that the way of deriving the Ågesta estimate for decontamination was entirely rigorous. However, with regard to the reasonableness of the final result for Ågesta it does seem to be satisfactory.

A significant discrepancy between the BR3 and Ågesta cases appears to exist in respect of the volumes of waste arising from the decontamination activity. At BR3 the volume was 681 litres but the Ågesta estimate appears to quote at least 10 m^3 of ion exchange resin, which is equivalent to 10,000 litres, plus up to 8 m^3 of other wastes. The factor of 15 different in ion exchange resin volume is puzzling and no explanation has been found, other than that the volumes were “estimated” rather than calculated.

2.3 Primary Coolant Pipework Dismantling

2.3.1 Definition of the Task and Work Execution

The pipework and main components of the primary circuit located under the operating deck are illustrated in Figure 2-2. The cutting strategy for the steam generator involved moving the steam generator from its operational location, the room called SOD, to the refuelling pool. A large opening had to be made in the operating deck (this was the work floor around the refuelling pool which formed also the ceiling of the room SOD) in order that the dismantling of all the circuits, including the primary circuit, situated in the room SOD, could start. The dismantling of the remaining circuits in the room SOD (i.e. under the Operating Deck or Sub-Operating Deck) was executed in three phases called SOD 1, SOD 2 and SOD 3.

SOD 1

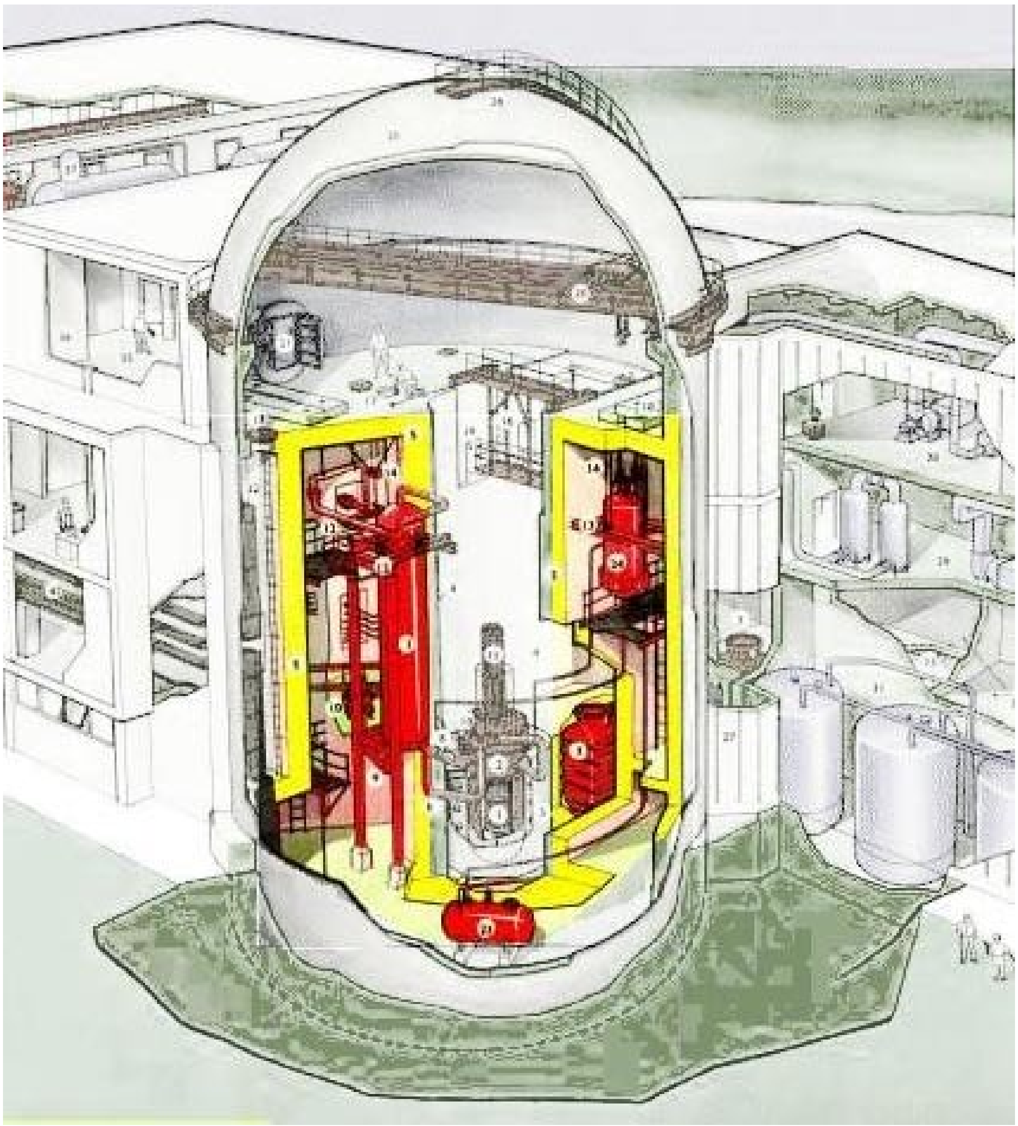
This phase included preparation work before the actual dismantling of the primary pipes (SOD 2) and the auxiliary circuits (SOD 3). This work comprised some modifications to circuits that would remain in service as well as a little dismantling of some circuits in order to facilitate installation of the necessary scaffolding and cranes.

The removal of the rotor and stator of the two primary pumps also was done in this period but dismantling of these components will be performed later.

SOD 2

This phase was the actual cutting of the primary pipes. First the circuit was cut on-site into large pieces using a quite common automatic pipe cutter, employing two lathe tools diametrically opposed. These large pieces then were brought to a band saw (the same as used for the dismantling of the reactor internals and the reactor vessel) for further cutting into small pieces of 0.8 m long to fit in the chemical reactor of the BR3 decontamination process. These two jobs were performed in parallel. Almost all the pieces of the primary piping were authorised for free release after decontamination. The total weight of pipework dismantled was 6.4 MT.

Figure 2-2 Pipework and main components of the primary circuit



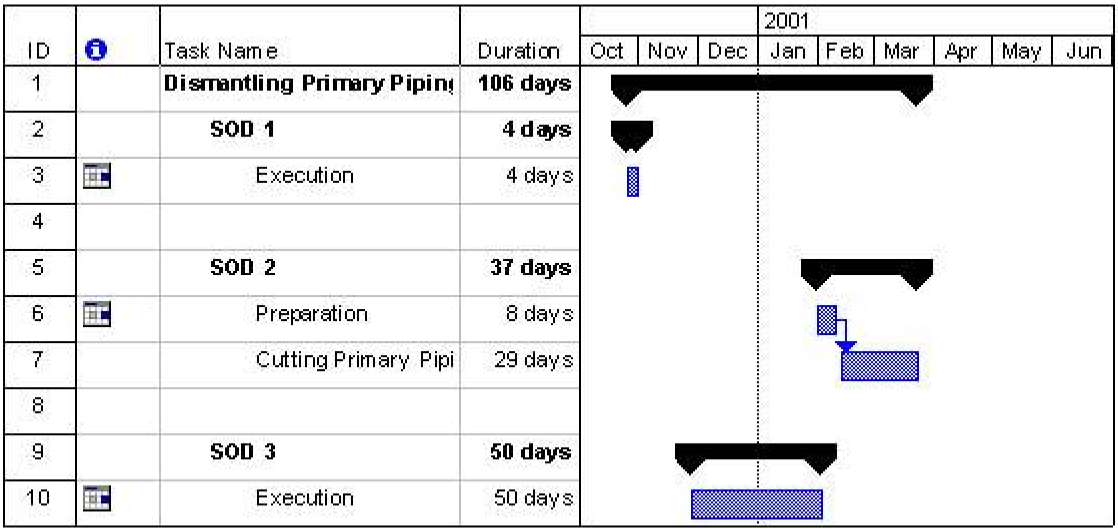
SOD 3

This phase included the dismantling of all circuits in the room SOD that were not useful anymore. The used tools were very common tools like electrical saws, grinders and oxy-acetylene torches. This phase was executed before SOD 2. In order to have as much free space as possible for the handling of the large cut pieces of the primary piping to the band saw.

2.3.2 *Execution Period*

The dismantling work took place over a period of approximately five months, as illustrated in Figure 2-3. The actual cutting up of the pipework under task SOD 2 extended over a period of about two months.

Figure 2-3 Timeline of Primary Pipework Dismantling Activities



ID	ℹ	Task Name	Duration
1		**Dismantling Primary Pipin**	**106 days**
2		**SOD 1**	**4 days**
3	▦	Execution	4 days
4			
5		**SOD 2**	**37 days**
6	▦	Preparation	8 days
7		Cutting Primary Pipi	29 days
8			
9		**SOD 3**	**50 days**
10	▦	Execution	50 days

2.3.3 *Labour hours, labour costs and productivity*

The breakdown of labour hours expended for each phase of the dismantling of the primary loop piping (SOD2) is summarised in Table 2-5.

Table 2-5 Labour Hours on Primary Pipework Dismantling

Man-hours for cat	Preparation	Dismantling	Total
Project engineer	58	52	110
Engineer	7	0	7
Skilled Operators	371	273	645
Operators	22	0	22
Total	**458**	**325**	**784**

2.3.4 *Main external costs*

There was no specific external investment for this work package. Tools already used in the previous dismantling phases of the BR3 decommissioning project (e.g. RRA band saw, tube cutter etc.) were used. Strictly speaking some allocation of equipment costs to this work package should be made.

2.3.5 *Waste volumes and costs*

The primary loop was decontaminated and authorised for free release after measurement. In some cases this was achieved only after melting. As stated the total weight of pipework was 6.4 MT.

2.3.6 Normalised resources and comparison

2.3.6.1 Analysis of BR3 Pipework Dismantling Costs

The breakdown of labour hours expended specifically on pipework cutting (including directly related preparation work) is presented in Table 2-6.

Table 2-6 BR3 Pipework Dismantling Labour Hours Converted to Swedish 1996 Cost Base

Work Phase	Hours	1996 Rate SEK/hr	1996 Cost (kSEK)	Totals (kSEK)
	58	750	43.5	
Preparation	400	612	244.8	288.3
	52	750	39.0	
Dismantling	273	612	167.1	206.1
				494.4

Dividing the total number of hours by the total weight of pipework (6.4 MT) gives a unit resource required of 122 hours/MT. This might be refined further if it is assumed that the preparation is largely a fixed cost and the dismantling work variable in proportion to the amount of pipework i.e. 458 hours fixed plus 51 hours/MT. Due to the nature of this job, with numerous disconnections to be made and a relatively complex overall configuration, with other equipments to be moved to facilitate the pipework dismantling, it is not obvious that a normalisation to say pipework surface area, or volume, would be more meaningful than the selected measure of gross weight.

2.3.6.2 Comparison with Other Pipework Dismantling Cost Estimates

The 1996 Ågesta cost estimate report does not provide a separate resource cost for dismantling of the primary pipework. The only meaningful reference available at this time for comparison with the BR3 experience is the information reported in the October 2001 SKI report 02:2 for the Westinghouse Test Reactor (WTR). The benchmarking result from that analysis derived a figure of about 750 hours/MT of pipework dismantled. The WTR figure was based on the total hours expended, including all of the preparation and set-up, as well as decontamination of the primary coolant tunnels and emergency piping coolant water pump shaft pit. Accordingly a direct comparison with the information in section 2.3.6.1 would not be valid.

A more valid comparison may be made by including the scope of work under SOD1 and SOD2, as described above. The 8 days of preparation under SOD2 required 458 manhours – a much higher daily rate than for the actual cutting work. If a similar level of effort per day were applied to the 69 days of additional work under SOD1 and SOD3, this would correspond to about 3,950 manhours. The grand total then would be 4,734 hours, for a unit requirement of 740 hours /MT. This is very close to the WTR benchmark figure for this activity. Such an analysis would conclude that the total resource requirements for primary pipework dismantling are dominated by the preparatory activities rather than the cutting activity itself.

The preceding analysis is not as robust as might be desired but at least it does not give rise to an obvious major discrepancy or inconsistency. To establish more confidence in the comparison would need additional detailed data on the BR3 manhours. A comparison with the Ågesta cost estimate would be possible only if a more detailed breakdown of projected manhour information could be provided for Ågesta.

2.4 Vulcain reactor internals dismantling

2.4.1 Description of the components

A schematic of the Vulcain internals is presented in These internals consisted of three main pieces or subassemblies; namely the Lower Core Support Assembly, the Spray Box and the Instrumentation Basket with the Reactor Vessel Collar. Beside these three main parts, there was also some auxiliary equipment.

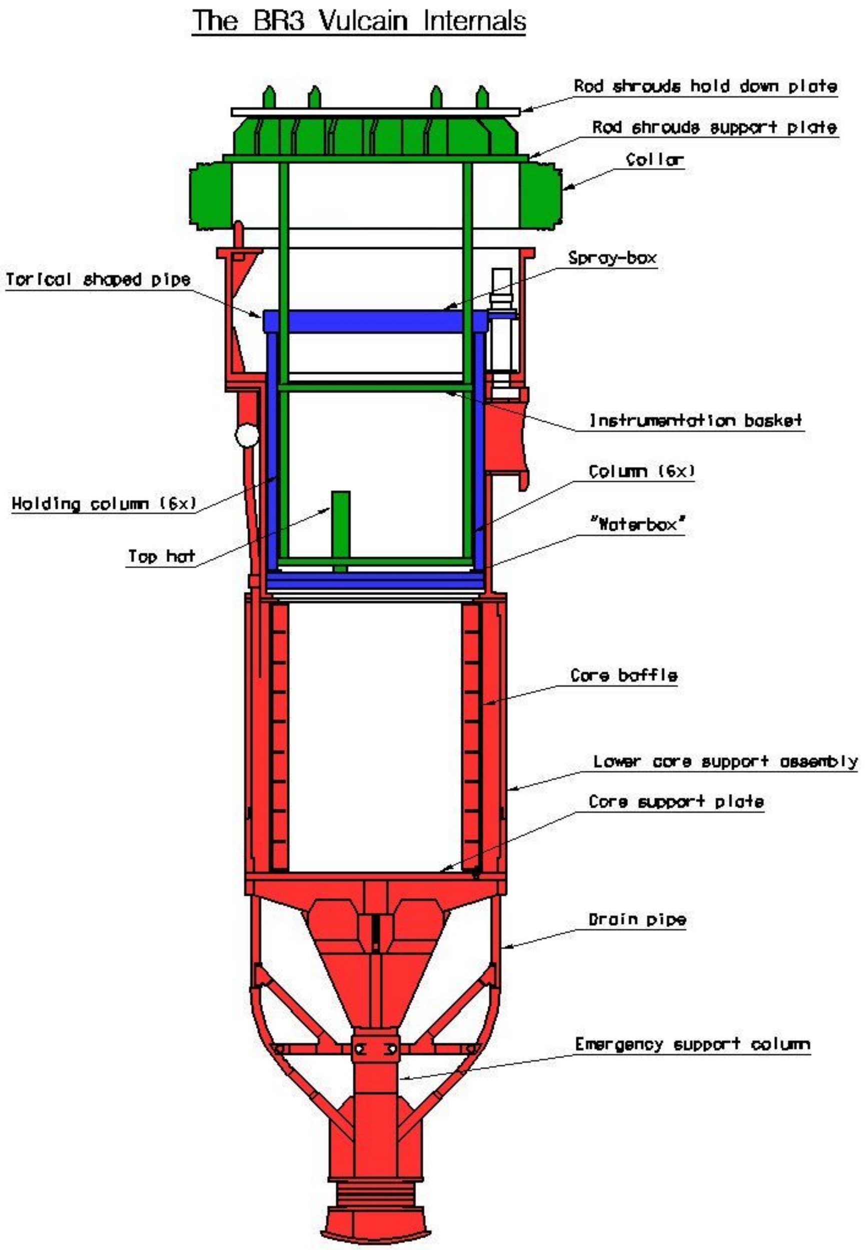
THE LOWER CORE SUPPORT ASSEMBLY OR LCSA

The LCSA (the red coloured part in Figure 2-1) was a stainless steel assembly of about 4,5 m heigh, a main wall thickness of 25 mm and a weight of 4 tons. The assembly rested on a ledge near the vessel top flange. It comprised three main cylindrical parts bolted to each other: an internal honeycomb structure, situated around the reactor core; the "core baffle", the core support plate and a supplementary "emergency support column"; and drain pipes situated at the lower part.

THE SPRAY BOX

This was a 470 kg stainless steel piece (the blue coloured part in Figure 2-4) located at the top of the reactor core. It consisted mainly of a torus shaped pipe from which six columns were hanging, and a "waterbox" allowing spraying the core with water in case of core dry-out. At the top of the torus shaped pipe were three lifting points for the removal of the Spray Box during the loading and unloading of the reactor core.

Figure 2-4 Schematic of Vulcain Internals



THE REACTOR VESSEL COLLAR AND INSTRUMENTATION BASKET

This assembly (weight: 5 tons) consisted of two main subassemblies: the reactor collar and the instrumentation basket (the green coloured part in Figure 2-4).

The reactor vessel collar was an annular piece in carbon steel, clad by stainless steel (wall thickness: 194 mm; outside diameter: 1715 mm; height: 310 mm), fitted with 76 penetrations for in-core instrumentation and primary water drain pipes through the vessel. The collar supported a reinforced plate (so called "rod shrouds support plate") at which the instrumentation basket was hung by 6 cylindrical columns.

The instrumentation basket consisted mainly of 2 plates (35 mm thick) suspended on the six holding columns. In these plates were holes for the guide tubes of the reactor control rods. On the lower plate, small thin-walled cylinders (so-called "top hats") were welded at locations situated above each fuel assembly.

These "top hats", with calibrated cross-sections were used to distribute and control the primary water flow rate among the different fuel channels. Some of them were equipped with instrumentation to measure the water temperature or the flow rate.

The two subassemblies "reactor vessel collar" and "instrumentation basket" were then intimately assembled in two ways: first through the "rod shroud support plate" and the basket support columns, and secondly by the different penetrations in the collar ending at different places of the instrumentation basket.

2.4.2 *Work Execution*

THE INSTRUMENTATION BASKET

First the control rod drive shafts, the so called "spaghetti-bundles", had to be removed in order to liberate the access to the rod shrouds support plate. Due to their relatively great distance from the reactor core mid-plane, their radiation was low enough to cut them out of the water. In order to transport the shafts in a 200-l drum to the waste conditioner, they were cut with an angle grinder into pieces 60 cm in length.

The next step was the removal of the rod shroud support plate to facilitate access to the instrumentation basket. For this activity, a radiation optimisation was carried out to select between a dismantling at a short distance (1,5 m water) and a long distance (6 m water). Based on this study and the ALARA optimisation, the first approach was chosen. For carrying out this work, an aluminium work platform was mounted on the guide studs of the reactor vessel, 1,5 m above the reactor vessel.

Before starting the dismantling work on the rod shroud support plate, all the required equipment was brought into the reactor building and the platform was installed. The bolts could be divided into two groups depending on the position of the bolt head. One group was formed by bolts with the head on the top. This meant that the head was readily accessible. They were unbolted by a pneumatic un-bolter (for the secured bolts) attached to a long handling tool (almost 2 m) with on the end a welded hexagonal key (all the bolts were hexagonal socket head screws). The other group was formed by bolts in a so-called "top down" position which meant that the head was not accessible. These bolts were cut by Electro Discharge Machining (EDM) using a hollow electrode. The bolts that were not situated under a reinforcement rib of the rod shroud support plate were cut with the electrode in a vertical position. The bolts under a reinforcement rib were cut with the electrode in an angular position of 45°. As soon as the rod shroud support plate was removed and stored in the pool, all the instrumentation in the instrumentation basket and outside the reactor vessel collar (the penetration tubes) was cut using the hydraulic shears. So, the connection between the collar and the instrumentation basket was removed.

The next step was the cutting of the remaining pieces of the penetration tubes, which were on the inside of the collar, as close as possible to the collar. This was necessary to fix the collar in its own clamping system of the turntable for segmenting later on. For the cutting of these penetration tubes (a total of 76) the reciprocating saw was used. A special tool support was installed for placing the saw on the collar and for guiding the saw during the cut. The feed was controlled manually by means of a long handling tool. After the removal of the penetration tubes, the collar was withdrawn out of the water and stored outside the pool. The remaining part of the instrumentation basket was then dismantled by unbolting with a modified long handling tool and an hydraulic shear. The two plates of the basket have not yet been dismantled. They are stored in the pool cutting at a later time.

THE SPRAY BOX

The upper ring of the spray box was cut into pieces with the pneumatic reciprocating saw, fixed on a special clamping device. Then, the pieces of the upper ring and the bottom plate were disassembled from the six columns by using modified long handling tools and the hydraulic shears. The bottom plate was also stored in the pool for later dismantling with the band saw.

THE LOWER CORE SUPPORT ASSEMBLY

This big cylindrical piece was first cut into rings by a circular saw machine. Later on, the rings were segmented with the band saw. Every time a piece had to be cut, it was clamped on the so-called turntable which was fixed on the reactor vessel flange.

A first cutting campaign comprised the execution of the horizontal cuts. First, the turntable and the circular saw were brought in. The turntable was installed, the work floor (situated 11 m above the reactor vessel) was cleaned up and prepared for the work and the pool was filled with 6,5 m of water. Before starting the eight horizontal cuts, the piping on the emergency column (at the bottom of the LCSA) and some pipes around the LCSA were cut by use of hydraulic shears. After the horizontal cuts, one plate including the emergency support column (also called "Dash-pot") and seven rings were produced and ready for segmentation. When the horizontal cutting campaign was finished, all the cutting equipment remained in the reactor building.

The preparatory work for the segmentation of the rings and plates consisted only of bringing in the band saw, the clamping system for the rings and the cleaning up of the working area. The seven rings, the collar and five plates (one of the LCSA, one of the spray box, two of the instrumentation basket, the rod shrouds support plate and another plate, the rod shrouds hold down plate) were segmented with the band saw. Also, the emergency support column was cut into 4 pieces (3 pieces with a complex geometry and one plate) with the band saw. Therefore, the emergency support column was turned over and three horizontal cuts were executed.

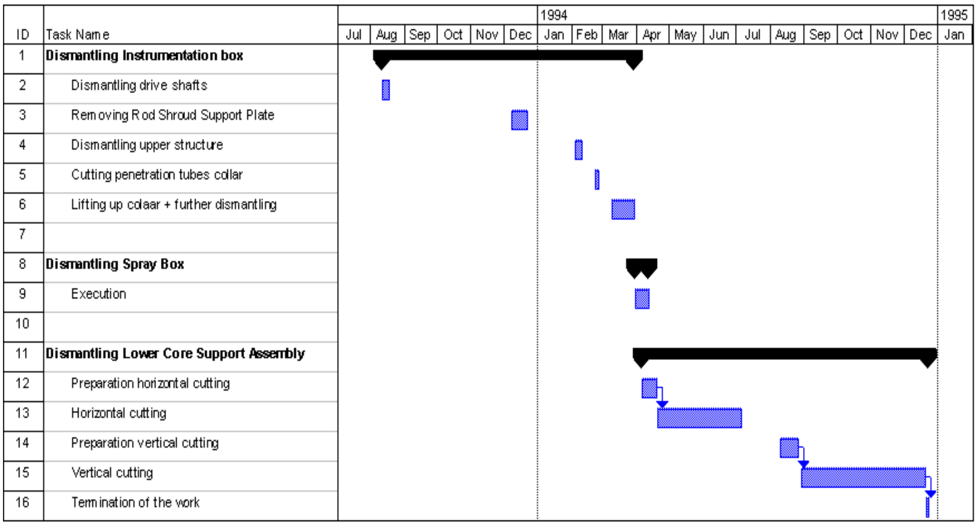
For segmenting the plates, they were clamped vertically on the turntable. Depending on the diameter, the plates were cut into four or more pieces. Because the saw blade could twist over 90°, the band saw was able to carry out vertical as well as horizontal cuts which were necessary for the segmentation of the plates.

After the segmentation campaign, the band saw also remained in the reactor building. The turntable was withdrawn from the water for a manual decontamination and for a complete mechanical control and maintenance.

2.4.3 Execution period

The dismantling of the Vulcain internals took place over a calendar period of approximately 17 months. The sequence of the operations and the durations for individual parts of the work are presented in Figure 2-5.

Figure 2-5 Timeline of Vulcain Internals Dismantling



2.4.4 *Labour hours, labour cost and productivity*

The combinations of SCK•CEN man-hours and man-hours of external workers for each phase of the dismantling of the VULCAIN internals are listed in Table 2-7.

Table 2-7 Breakdown of Labour Hours for Vulcain Internals Dismantling

Labour Category	Preparation, cold testing & handling	Dismantling		Total Gross
		Effective Hours	Gross Hours	
Project engineer	1,911	766	901	2,812
Engineer	438	1,070	1,259	1,697
Skilled Operators	1,957	2,666	3,136	5093
Operators	138	194	228	366
Total	**4,444**	**4,695**	**5,524**	**9,968**

The dismantling hours provided by BR3were the effective working hours in a controlled area dedicated to the cutting activities. The estimated productivity ratio was 85%, which has been used to derive the gross hours column of numbers.

2.4.5 *Main external costs*

The investment in equipment for dismantling of the Vulcain internals also was used for dismantling of the Westinghouse internals and the reactor pressure vessel (RPV). The net cost attributable to the Vulcain internals dismantling therefore should be lower, in proportion to the overall cost of each package. A summary of investments in equipment and consumables attributed to the Vulcain internals work in BR3 records is presented in Table 2-8. These data are based on 1994 value BEF escalated to 1996 according to Belgian inflation indices and then converted to SEK at the then applicable rate.

Table 2-8 External Costs for Vulcain Internals Dismantling

	(MSEK)
Investments	7.53
Consumables	3.15
Total	**10.68**

The consumables corresponded to items including cutting blades and other cutting equipment, clothing and other protective equipment. Blade attrition tends to be a function of the thickness of the cuts being made. The thicker the cuts the higher the attrition rate, with this effect being non-linear.

2.4.6 Waste volumes and cost

The volumes of waste generated in the dismantling of the Vulcain internals are summarised in Table 2-9.

Table 2-9 Waste Volumes from Vulcain Internals Dismantling

Category	Sub-category	Volume (m^3)	Primary package
LLW	compactable	3,59	220 l
LLW	non compressible	3,00	400 l
MLW	-	1,59	400 l
HLW	-	5,37	400 l
	Total	**13,55**	

For low level waste the primary package also was the transport container. The 400 l drums of medium or high level waste were placed inside a transport container in order to achieve a contact dose-rate lower than 2 mSv/h and 0,1 mSv/h at 1 m distance. All the waste was transported from the BR3 facility to the Belgoprocess site where the waste was treated, conditioned and stored (awaiting final disposal). A service charge was made for dealing with these wastes, which is country specific and therefore excluded from further analysis in this report.

2.4.7 Normalised resources and comparison

2.4.7.1 Analysis of BR3 Vulcain Internals Dismantling Costs

The breakdown of labour hours expended on Vulcain internals dismantling is presented in Table 2-10.

Table 2-10 BR3 Vulcain Internals Dismantling Labour Hours Converted to Swedish 1996 Cost Base

Work Phase	Hours	1996 Rate SEK/hr	1996 Cost (MSEK)	Totals (MSEK)
Preparation	1,911	750	1.43	
	2,533	612	1.55	2.98
Dismantling	901	750	0.68	
	4,623	612	2.83	3.51
				6.49

The major part of the cutting work, to which the dismantling hours figures refer, related to the LCSA. A majority of this was relatively thin – about 25mm. It is estimated that about 25m of horizontal cuts and 25 m of vertical segmentation cuts will have been required to dismantle the main body of this component. The lower support column and the other components of the Vulcain internals will have needed roughly a further 20m of cuts for a grand total of about 70m. The surface area of the LCSA is estimated at about 12m^2. The surface area of other components that were dismantled during this phase is estimated to add perhaps 12m^2 for a total of perhaps 24 m^2. The total weight of the Vulcain internals was about 10 MT.

Division of the labour hours by the surface area dismantled results in benchmarking results as follows:

Fixed Cost	Variable Cost
4,444 hrs	228 hrs/m^2

In addition there were external costs for fixed investments of MSEK 7.53 plus variable costs related to consumables of MSEK 3.15.

2.4.7.2 *Comparison with Other Dismantling Cost Estimates*

The 1996 Ågesta cost estimate report does not provide a separate resource cost for dismantling of the RPV. Some additional information has been collected separately through dialogue with the author of the 1996 report. This is discussed further in section 2.8 (Conclusions) as it is pertinent to comparisons with dismantling of the Westinghouse internals and the BR3 RPV as well. The only meaningful reference available at this time for comparison with the BR3 experience is the information reported in the October 2001 SKI report 02:2 for the Westinghouse Test Reactor (WTR). The benchmarking results from that analysis for dismantling and removal of the RPV are pertinent, using the derived results for the BR3 approach of segmentation followed by removal, which were as follows:

Activity	Fixed Cost	Variable Cost
Segmentation	4,000 to 5,500 hrs	100 to 138 hrs/m^2
Removal	7,800 Craft Labour 1,000 Engineering Labour 0.6 MSEK	141 hrs/m^3 craft labour

Because the work programs were executed in different ways and the hours needed reported in different ways, it is difficult to split out the fixed and variable components of cost exactly. The overall WTR manhours exceeded the BR3 hours by a factor of 2.75 to 3 (WTR 27,350 – 30,390 compared with BR3 9,968). However the BR3 project reports external fixed costs for investments of MSEK 7.53, compared with only MSEK 0.6 for the WTR project. At average WTR team personnel labour rates, the difference of MSEK 6.93 would equate to between about 8,000 and 12,000 labour hours. Adding this into the equation would bring the BR3 and WTR benchmark data more in line but still with the WTR total between 25% and 70% higher than at BR3.

Productivity ratio always can be a factor underlying such differences. In the case of BR3 a ratio of 85% is claimed. The WTR work also is believed to have been executed with high utilisation but a precise number is not known. If this factor alone were to correct for the above mentioned difference, the WTR achieved productivity would have had to be in the range of 50% to 68%.

Another possible explanation of the residual large difference is the relative sizes of the two RPVs. The actual execution method for the WTR vessel was removal followed by segmentation at an off-site location. The WTR vessel was ten times heavier than the BR3 vessel, requiring a large amount of engineering effort in preparation, including the erection of a dedicated lifting gantry and hoist and equipment to remove the vessel from the reactor building. These requirements accounted for a large part of the engineering labour quoted above and a significant proportion of the craft labour used on removal. In report SKI 02:2, the analyses for dismantling of the R2 RPV assumed that a 50 per cent saving on fixed labour hours would accrue due to segmentation before removal. This was an estimate only and could be wrong.

Concerning the difference in derived variable costs for cutting of the respective vessels (BR3 228 hrs/m^2; WTR 67-92 hrs/m^2) the fact that the WTR figures are lower is not unexpected. First of all the WTR RPV was segmented in a dedicated environment at an off-site location, which almost certainly made access and job execution easier than in the confined spaces of BR3. Furthermore, the WTR vessel was much bigger, so a greater surface area could be cut for a given equipment set-up.

2.5 Westinghouse reactor internals dismantling

2.5.1 Description of the components

A schematic of the Westinghouse internals is presented in Figure 2-6. These were the original internals of the reactor and they were all made in stainless steel. They consisted of two main subassemblies: the Upper Core Support Assembly and the Lower Core Support Assembly and a number of, as follows:

THE UPPER CORE SUPPORT ASSEMBLY (UCSA) (GREEN COLOURED PART IN FIGURE 2-6)

This comprised two main subassemblies: the upper core support barrel and the upper core support plate. The upper core support barrel was a cylindrical assembly with top and bottom flanges. The cylinder comprised a circular hole for the water flow to the hot leg. The upper core support plate was a rigid assembly of two perforated plates welded to a spacer ring at their circumference. The overall height of the upper core support plate is 101,6 mm. The upper plate of the assembly supported 12 dashpot stops. The total weight of the upper core support assembly was 1220 kg.

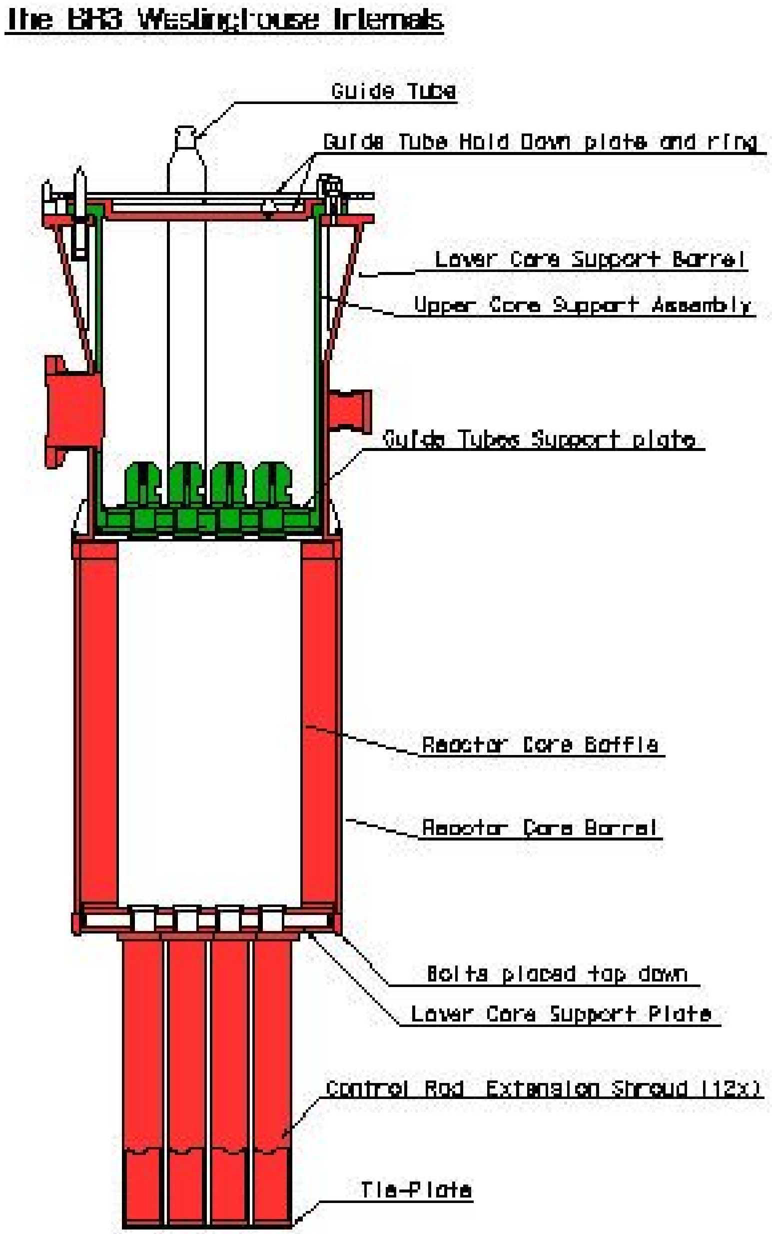
THE LOWER CORE SUPPORT ASSEMBLY (LCSA) (RED COLOURED PART IN FIGURE 2-6)

This comprised the following subassemblies:

- the Lower Core Support Barrel;
- the Reactor Core Barrel;
- the Reactor Core Baffle;
- the Lower Core Support Plate;
- twelve Control Rod Extension Shrouds
- a Tie Plate at the end of those Shroud Tubes.

The lower core support barrel consisted of a conical and a cylindrical section with top and bottom flanges. The cylindrical section had a nozzle (hot leg) and two guide spacers. It was bolted at its bottom flange to the core barrel and the core baffle.

Figure 2-6 Schematic of the Westinghouse Internals



The core barrel was a cylindrical piece (diameter = 1181/1130 mm; H = 1693 mm) with top and bottom rings. It contained the core baffle (bolted to its upper ring). At its bottom ring, it is fastened to the lower core support plate by 18 bolts placed top down.

The reactor core baffle consisted of a square structure made of plates and ribs with circular top and bottom flanges. Its main thickness was about 6,35 mm.

The lower core support plate was similar to the upper core support plate. The upper part of the lower core support plate supports the guide blocks.

The control rod extension shrouds were 12 cylindrical pieces (H = 1286 mm, diameter = 168/154 mm) hanging at the lower core support plate. They were bolted to the lower plate of the core support plate by cap screws.

The tie plate was attached by cap screws to the lower end of the shroud tubes.

GUIDE TUBE HOLD DOWN PLATE AND RING

These two pieces were 25,4 mm thick plates. The guide tubes hold down plate was embedded inside the guide tubes hold down ring to form a subassembly of the reactor. The overall diameter is about 1450 mm. The weight of both pieces together was 294 kg.

GUIDE TUBES

There were twelve guide tubes. A guide tube had a cylindrical geometry with a conical top end (diameter = 171,4/154 mm; H = 1657 mm). These tubes were used to guide the control rod into the reactor core. The weight of the twelve guide tubes amounted to 564 kg.

GUIDE TUBES SUPPORT PLATE

This plate was a 32 mm thick plate with twelve big holes for the guiding tubes.

2.5.2 *Work Execution*

The preparation work on site was much less than for the Vulcain internals due to the presence of all the cutting equipment used during the preceding operations. Indeed, all the cutting levels were in such a way determined that the existing cutting equipment and clamping devices could be used with very few adaptations. The Westinghouse internals were cut into rings before later segmentation.

THE UPPER INTERNAL

Before taking the internals out of their lead shielded containment, two plates and one ring (low activated) situated on the top of the internals, were withdrawn from the water and were cut into pieces with a plasma torch in a dedicated size reduction workshop.

After the removal of the plates there was an easy access to the guide tubes. These low activated tubes also were withdrawn from the water and cut into pieces with a reciprocating saw on the work floor near the pool.

In a second step the upper internal was withdrawn from the containment and placed on the turntable. One horizontal cut was made to disassemble the bottom plate from the internal.

The remaining part of the internal was cut into two rings by using the ability of the band saw to perform a horizontal cutting.

Therefore, eight vertical cuts were made in the upper part (making so-called "teeth"). The last cut ended in a hole so that the saw blade could twist to execute the horizontal cut. Each time a "tooth" was cut away, it was taken out of the water (low activated) and stored in 400-l drums for waste evacuation.

The remaining ring was then cut vertically into segments.

THE LOWER INTERNAL

Once again the same procedure was followed: first making rings, then segmenting these rings. In a first step, the bottom structure of the lower internal (bottom plate with the control rods extension shrouds and tie-plate) was unbolted from the internal. Because the bolts were placed "top down", a special hydraulic unbolter with counter-gear was used. Once the lower structure was liberated, it was turned over for unbolting the tie-plate with the corresponding hexagonal key attached to a long handling tool. Afterwards, the tie-plate was cut with the plasma torch in the BR3 size reduction workshop.

The following step was the separation and the cutting of the control rods extension shrouds. The separation was carried out with the hexagonal key attached to a long handling tool. The cutting was carried out with the reciprocating saw, placed on a special support structure.

Then, the lower internal was cut into nine rings by seven horizontal cuts by the circular saw. The last horizontal cut was done by the band saw in the same way as for the upper internal. First eight vertical cuts were made (making "teeth") at the top of the internal, then, after the last vertical cut, the saw blade was turned over 90° to make the horizontal cut.

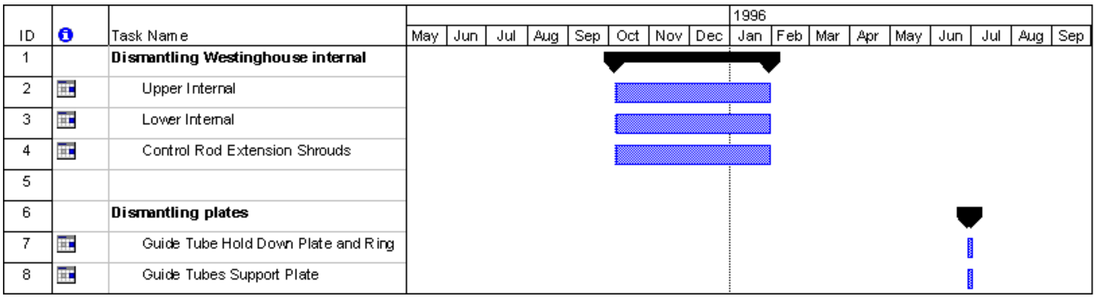
After the horizontal cuts, all the rings and plates of the Westinghouse internals were segmented with the band saw and placed in special evacuation racks pending removal.

The cutting campaign was finished by transporting all the evacuation racks to the deactivation pool and by carrying out the last evacuation campaign to the waste conditioner and intermediate storage facility.

2.5.3 *Execution Period*

Almost all of the work described was conducted over a period of three months. A small amount of work was conducted in a short period of time some five months after completion of the main phase of work, as shown in Figure 2-7.

Figure 2-7 Timeline of Westinghouse Internals Dismantling



ID		Task Name
1		**Dismantling Westinghouse internal**
2	▦	Upper Internal
3	▦	Lower Internal
4	▦	Control Rod Extension Shrouds
5		
6		**Dismantling plates**
7	▦	Guide Tube Hold Down Plate and Ring
8	▦	Guide Tubes Support Plate

2.5.4 *Labour hours, labour cost and productivity*

The combinations of SCK•CEN man-hours and man-hours of external workers for each phase of the dismantling of the Westinghouse internals are listed in Table 2-11.

Table 2-11 Breakdown of Labour Hours for Westinghouse Internals Dismantling

Man-hours for cat	Preparation cold testing handling	Dismantling	Total
Project engineer	1,414	798	2,212
Engineer	378	467	845
Skilled Operators	1,004	2,104	3,108
Operators	114	32	146
Total	**2,910**	**3,401**	**6,311**

The productivity ratio for this work was declared to be approximately 85 per cent.

2.5.5 *Main external costs*

The equipment used for the dismantling of the Westinghouse internals also was used for the dismantling of the Vulcain internals and for the RPV, so effectively the investments were shared. The investments shown in Table 2-12 are only the incremental new investments specifically for the Westinghouse internals dismantling. In practice a proportion of the Vulcain internals investment cost should be attributed to the Westinghouse internals as well. A summary of investments in equipment and consumables attributed to the Westinghouse internals work in BR3 records is presented in Table 2-12. These data are based on 1995 value BEF escalated to 1996 according to Belgian inflation indices and then converted to SEK at the then applicable rate.

Table 2-12 External Costs for Dismantling of the Westinghouse Internals

	(MSEK)
Investments	0.44
Consumables	0.85
Total	**1.29**

2.5.6 Waste volume and costs

The volumes of waste generated during the dismantling of Westinghouse internals are summarised in Table 2-13.

Table 2-13 Wastes from Dismantling the Westinghouse Internals

Category	Sub-category	Volume (m³)	Primary package
LLW	compactable	0,41	220 l
LLW	non compressible	3,04	400 l
MLW	-	0,00	400 l
HLW	-	4,32	400 l
	Total	**7,77**	

2.5.7 Normalised Resources and Comparison

2.5.7.1 Analysis of BR3 Westinghouse Internals Dismantling Costs

The breakdown of labour hours expended on Westinghouse internals dismantling is presented in Table 2-14.

Table 2-14 BR3 Westinghouse Internals Dismantling Labour Hours
Converted to Swedish 1996 Cost Base

Work Phase	Hours	1996 Rate SEK/hr	1996 Cost (MSEK)	Totals (MSEK)
Preparation	1,414	750	1.06	
	1,496	612	0.92	1.98
Dismantling	798	750	0.6	
	2,603	612	1.59	2.19
				4.17

The total surface area cut in the dismantling phase is estimated to be approximately 17m^2 excluding the guide tubes and the control rod extension shrouds or 35m^2 including these other components. The available information does not make clear the extent of effort required to cut up these other components. Division of the labour hours by the surface area dismantled results in benchmarking results as follows:

Fixed Cost	Variable Cost
2,910 hrs	100 to 200 hrs/m^2

In addition there were external costs of MSEK 0.44 for fixed investments plus a variable cost related to consumables of MSEK 0.85.

2.5.7.2 Comparison with Other Dismantling Cost Estimates

Compared to the Vulcain internals dismantling the fixed hours expended on the Westinghouse internals was about 50 per cent. The variable cost was 44 to 88 per cent of the Vulcain requirement. The lower fixed cost is explained by the fact that the Westinghouse internals cutting could use very much the same equipment set-up as for the Vulcain internals (reflected by the much lower investment cost of MSEK0.4 equivalent compared to MSEK7.53 for the Vulcain internals. The upper estimate for the Westinghouse internals variable cost is quite close to the Vulcain estimate.

The Vulcain consumables cost was about 3.7 times higher than the Westinghouse internals cost. This may be related to, at least in part, the higher average thickness of material being cut in the case of the Vulcain internals. Further comments on this issue are presented in section 2.8.

2.6 Reactor pressure vessel dismantling

2.6.1 Description of the components

The main components of the RPV are depicted in Figure 2-8. The RPV was a cylindrical container with a hemi-spherical bottom and a removable top head, approximately 5.48 m overall height and 1.47 m inside diameter. The total weight of the empty vessel was approximately 28 tons (without reactor head).

The 13.43 m cylindrical shell course was fabricated of SA-302 grade B steel plate 111 mm thick. This course was Babcock & Wilcox Croloy, clad with a 28 mm thick SA-240 grade S stainless steel sheet by a resistance welding process and had an inside diameter of 1473 mm to the cladding. The bottom head was forged of SA-105 grade II steel, 60 mm thick and clad internally with weld metal deposited stainless steel.

Two 305 mm nominal nozzles (253 mm I.D.) were located in the upper portion of the cylindrical shell at the same elevation and 180° apart. One 406 mm nozzle (314 mm I.D.) was located at the same elevation but 90° from the inlet nozzles. The nozzle forgings were fabricated of SA-105 grade II, carbon steel, clad with weld metal deposited stainless steel.

The removable closure head, made out of a forged ring with hemispherical dished centre section, was fabricated from SA-105 grade II steel 149 mm thick. The concave surface, the sealing surface and the cut-out portion of the outer edge of the flange were clad with weld metal deposited stainless steel. Four half round key slots accomplished the alignment of the head on the vessel; three handling lugs were permanently attached to the head for handling.

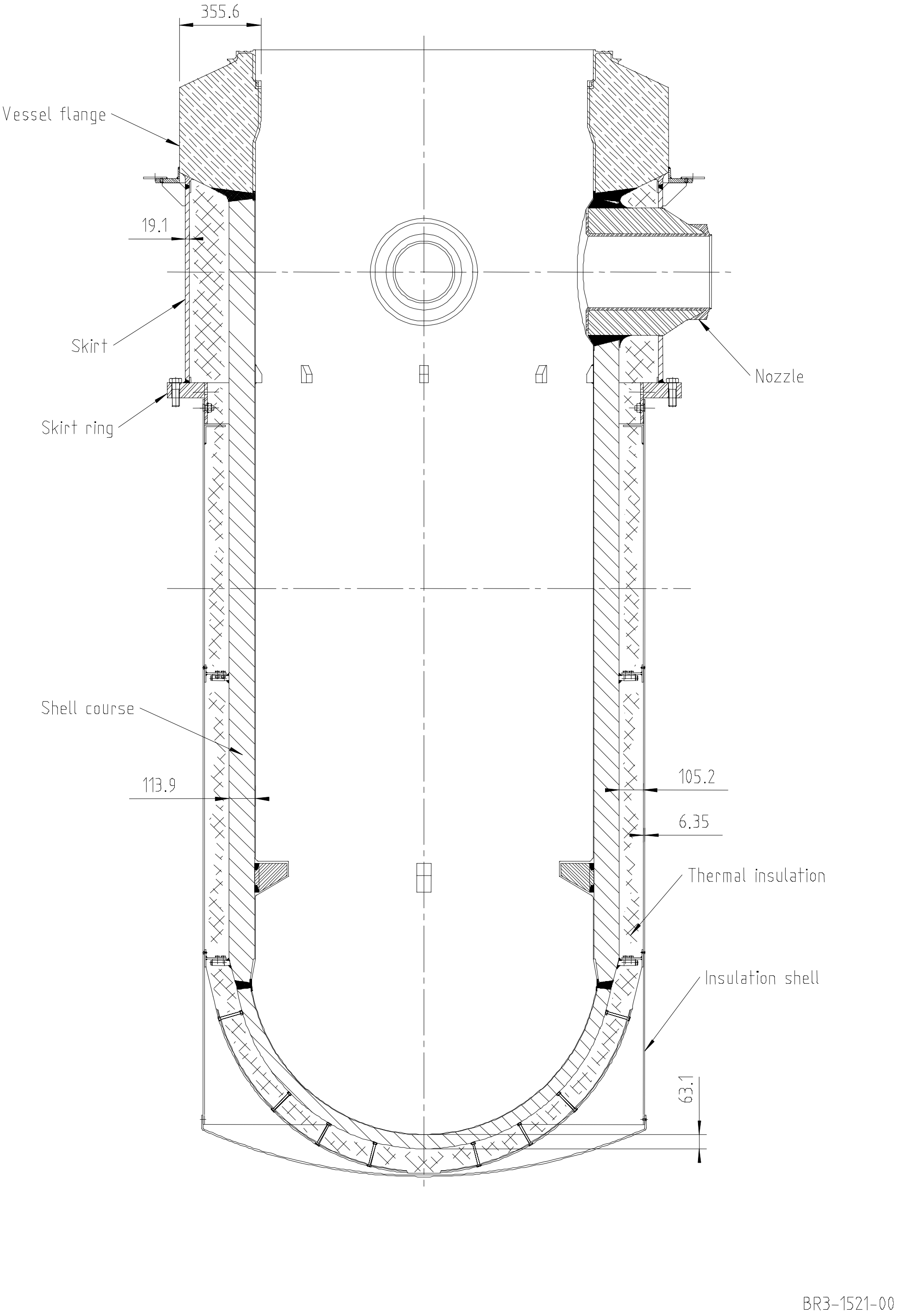
The upper surface of the shell forging, made of SA-105 grade II steel, was drilled and tapped to receive the 32 special closure head studs, which passed through borings of the head flange, and secured the head to the vessel by means of spherical washers and nuts.

The vessel was insulated by special fibreglass insulating wool, without binder, contained in an insulation can. The insulation covered the shell, from underneath the support skirt to the bottom.

A removable head insulation covered the flanges and the nuts, and avoided stresses on the flanges.

The vessel was supported by an annular skirt made of SA-212 grade B Carbon steel plate. This skirt, 2,04 m ID x 18 mm thick, rested on the neutron shield tank (NST), by means of a ring, 76 mm thick.

Figure 2-8 Main Components of the RPV



2.6.2 Work Execution

Underwater dismantling of the RPV proceeded, in outline, according to the following sequence:

PRELIMINARY OPERATIONS

- Separation of the RPV from the bottom of the reactor pool, from the Neutron Shield Tank (NST) and from the hot and cold legs.
- Reinstallation of the water tightness in the reactor pool (sealing system)
- Removal of the metallic protection shroud (insulation shell)
- Removal of the thermal insulation as well as the thermal insulation itself and the fixation devices of the metallic protection shroud.

DISMANTLING OPERATIONS OF THE RPV

These operations followed the same cutting methodology as the one selected for the cutting of the two sets of internals of the BR3, namely:

- Cutting the RPV in rings;
- Cutting the rings in segments.

A more detailed description of the executed operations is given hereafter.

PRELIMINARY OPERATIONS

SEPARATION OF THE RPV FROM THE BOTTOM OF THE REACTOR POOL

The selected process for cutting the bottom of the reactor pool was the plasma arc torch. The cutting had to be done quickly to limit the dose uptake of the operators (radioprotection optimization). Some actual cutting tests at the bottom of the reactor pool were executed to have access to the fastening bolts of the RPV support flange, and also to the hot and cold legs for inspection.

SEPARATION OF THE RPV FROM THE NST

The selected procedure was pneumatic unbolting. Tests were executed on two bolts, through the holes made by the plasma arc torch (see description in the previous paragraph).

SEPARATION OF THE RPV FROM THE HOT AND COLD LEGS

The selected procedure was the internal pipe cutter. It was decided to make a second cut of the primary pipe connections just above the support flange of the RPV in order to get access to all the RPV fastening bolts. The cutting tool was an automatic milling cutter with a diameter of 40 mm.

REINSTALLATION OF THE WATER TIGHTNESS OF THE NST AND THE REACTOR POOL

To reinstall the water tightness of the reactor pool, three stainless steel tightness devices were glued on the three holes in the Neutron Shield Tank. These 3 holes guided the two cold legs and the hot leg. Before gluing the tightness devices, the contact surface on the NST had to be sandblasted.

REMOVAL OF THE INSULATION SHELL

The insulation shell was bolted to the RPV through two profiles and on the upper side it was bolted to the RPV supporting skirt. It was necessary to remove 60 bolts to free the insulation shell from the RPV. Because of the horizontal position of these bolts, they had to be drilled by a remote hydraulic hole cutter. In order to reach easily the different levels at which the bolts were placed, the remote hydraulic cutter could move up and down along a beam. The whole system was placed on an extension of the turntable (the same turntable used during the dismantling of the reactor internals).

REMOVAL OF THE INSULATION AND THE FASTENING PROFILES OF THE INSULATION SHELL

The insulation shell was bolted on the RPV by T-shaped fastening profiles and connection pieces on two levels. Between and on top of these fastening profiles, there was a thermal glass fibre insulation, fastened with a metal mesh. The insulation was also held together with metal strips. On the bottom side of the RPV, the insulation was held to the RPV with eight strips. These strips were attached on the RPV by bolts throughout the insulation material.

As the mesh was totally rusty, the removal of the insulation was done using a simple long handling tool. The insulation liberated in this way fell into a fishing net previously installed on the pool floor. By remotely closing the fishing net, the insulation was taken out of the water and evacuated as standard low level waste.

In a first study, it was foreseen to unscrew the bolts of the fastening profiles of the insulation. Finally, the T-shaped profiles were remotely attached to the Plant Container crane with a V-shaped cutting tool and torn out, i.e. the crane basically just ripped them out of their locations. As the fastening profiles were low active, their further dismantling was done by hand.

DISMANTLING OF THE RPV

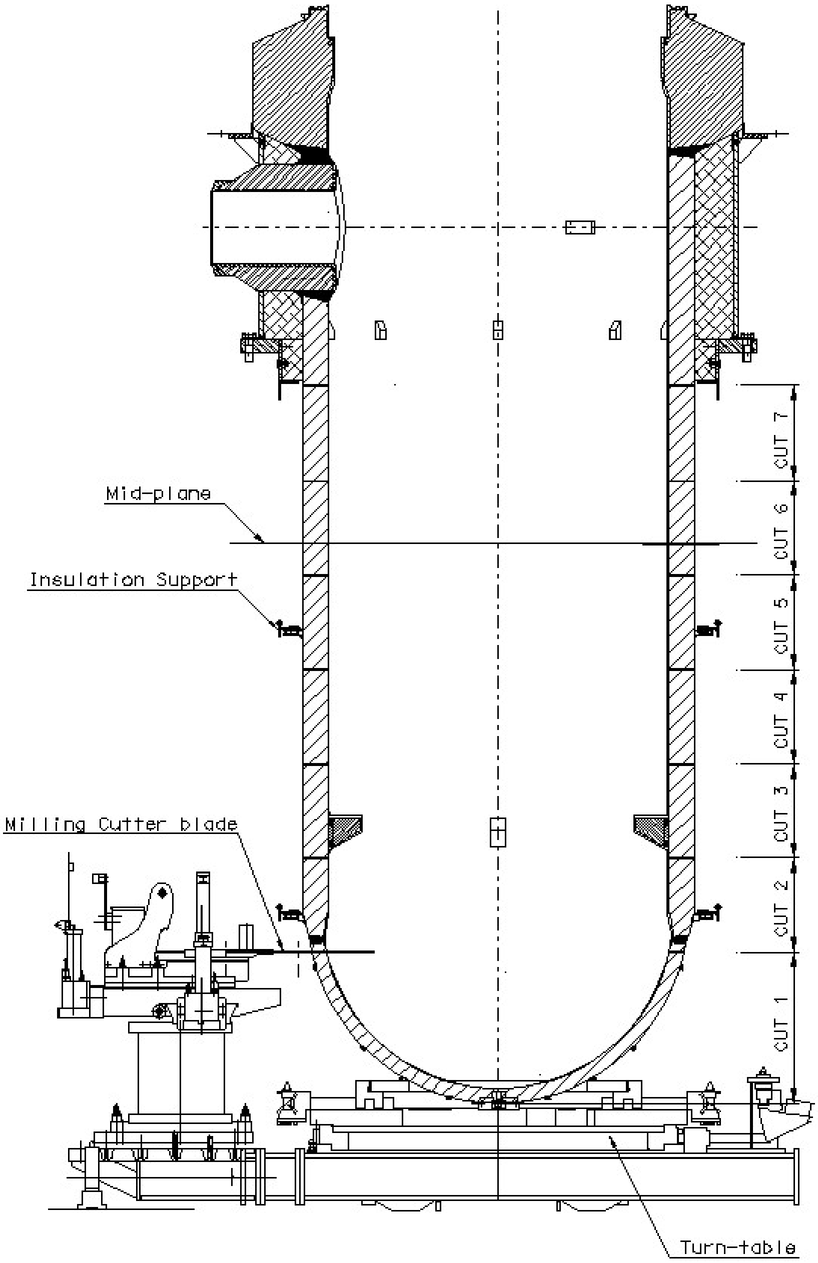
Cutting of the RPV into rings

After completion of a planning study, the adaptation pieces, the positioning and the clamping devices were ordered and fabricated. Figure 2-9 shows the different levels of the horizontal cuts. These cuts were made by a circular saw available at BR3. The tests in the pool on a mock-up of the RPV (scale 1/1) were programmed for validation of the cutting parameters. Cut 1, at the bottom of the RPV, was the most difficult one and the fist clamping system was not perfect (lots of vibrations during cutting). This problem led to a design review. Some additional clamping devices were added and the cutting procedure was adapted. For the RPV flange cutting, a band saw system was used.

Cutting the rings into segments

These cuts were done by a band saw used before for the dismantling of the reactor internals. The tests in the pool on a mock-up of the RPV (scale 1/1) were also programmed for validation of the cutting parameters. The most difficult cut was the one through the RPV flange. Nevertheless, on the mock-up, the cut was successful at the first attempt.

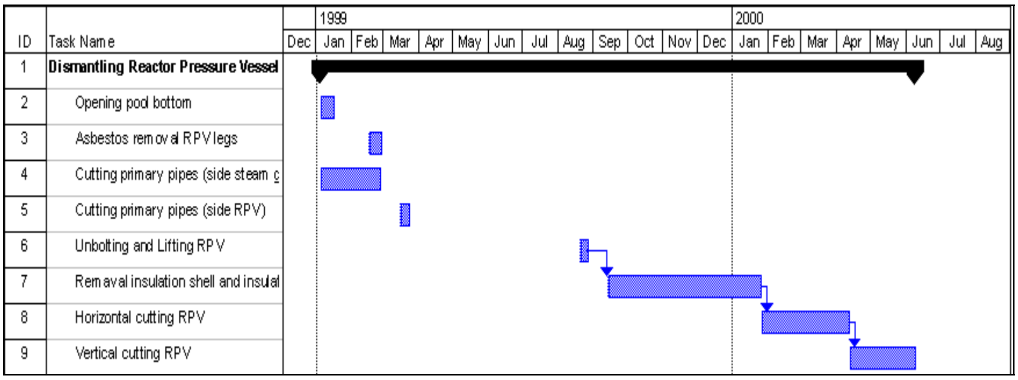
Figure 2-9 Cutting Levels for RPV Dismantling



2.7 Execution Period

RPV dismantling extended over a calendar period of almost 18 months but the work was not continuous through this period. The timeline sequence of events is summarised in Figure 2-10.

Figure 2-10 Timeline of RPV Dismantling Activity



2.7.1 *Labour hours, labour cost and productivity*

The combination of SCK•CEN man-hours and man-hours of external workers for each phase of the dismantling of the RPV is summarised in Table 2-15.

Table 2-15 Breakdown of Labour Hours for RPV Dismantling

		Dismantling[b]		
Labour Category	**Preparation, cold testing & handling[a]**	**Effective Hours**	**Gross Hours**	**Total Gross**
Project engineer	6,760	266	313	7,073
Engineer	3,759	906	1,066	4,825
Skilled Operators	19,863	2,501	2,942	22,805
Operators	1,537	140	165	1,702
Total	**31,919**	**3,813**	**4,486**	**36.405**

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[a] **"Preparation, cold testing and handling" also include the "preliminary operations" described here above.**

[b] **Dismantling hours are the effective working hours in a controlled area dedicated to the cutting activities. Productivity ratio 85%.**

2.7.2 *Main external costs*

The equipment investments made for the dismantling of the Vulcain and Westinghouse internals were also used for the dismantling of the RPV. The investments reported in Table 2-16 mainly concern only the decommissioning tools required for the preparation phase (i.e. preliminary operations) of work on the RPV.

Table 2-16 External costs for RPV Dismantling

	MSEK
Investments	4.1
Consumables	4.6
Total	**8.7**

To arrive at a more realistic picture of costs for the RPV, a proportion of the equipment investments made earlier for the Vulcain and Westinghouse internals should be allocated to the RPV.

2.7.3 Waste volumes and costs

The volume of wastes arising from dismantling of the RPV are summarised in Table 2-17.

Table 2-17 Waste Volumes from RPV Dismantling

Category	Sub-category	Volume (m³)	1st package
LLW	compactable	2,20	220 l
LLW	non compactable	7,20	400 l
MLW	-	6,00	400 l
HLW	-	3,60	400 l
	Total	**18,00**	

2.7.4 Normalised Resources and Comparison

2.7.4.1 Analysis of BR3 RPV Dismantling Costs

The breakdown of labour hours expended on RPV dismantling is presented in Table 2-18.

Table 2-18 BR3 RPV Dismantling Labour Hours Converted to Swedish 1996 Cost Base

Work Phase	Hours	1996 Rate SEK/hr	1996 Cost (MSEK)	Totals (MSEK)
	6,760	750	5.07	
Preparation	25,159	612	15.4	20.47
	313	750	0.23	
Dismantling	4,173	612	2.55	2.78
				23.25

The total surface area cut in the dismantling phase is estimated to be approximately 22 to 28m^2. Division of the labour hours by the surface area dismantled results in benchmarking results as follows:

Fixed Cost	Variable Cost
31,919 hrs	160 to 204 hrs/m^2

In addition there were external costs of MSEK 4.08 for fixed investments plus a variable cost related to consumables of MSEK 4.61.

2.7.4.2 Comparison with Other Dismantling Cost Estimates

The variable dismantling resource estimates for the RPV fall within the range of estimates for the Vulcain and Westinghouse internals. The amount of consumables used for the RPV also was higher at MSEK 4.6 equivalent compared with MSEK 3.15 for the Vulcain internals and only MSEK 0.85 for the Westinghouse internals.

This is to be expected due to the RPV being four to five times thicker than the Westinghouse internals and two to four times thicker than most of the Vulcain internals (see also section 2.8).

2.8 Conclusions

2.8.1 BR3 Dismantling Benchmark Data

The meaningful benchmarking data that can be extracted from the BR3 D&D project relates to actual decontamination and dismantling activities. The dismantling benchmarks derived in the preceding analyses are presented in Table 2-19.

Table 2-19 Summary of BR3 Dismantling Benchmark Results

D&D Activity	Benchmark Resources Needed
Primary Loop decontamination	10,956 hrs fixed + 2.65 hrs/m^2 decontaminated
Primary Loop Pipework Dismantling	740 hrs/MT including work on equipment removal to create access
Vulcain internals Dismantling	4,444 hrs fixed + 228 hrs/m^2 + fixed costs of MSEK 7.5 (or 12,000 hrs) + consumables MSEK 3.15 (equivalent to MSEK 0.13/m^2)
Westinghouse Internals Dismantling [a)]	2,910 hrs fixed + 100 to 200 hrs/m^2 (probably closer to the high estimate) + fixed costs of MSEK 0.44 + Consumables of MSEK 0.85 (equivalent to MSEK 0.05/m^2)
RPV Dismantling	31,919 hrs fixed + 160 to 200 hrs/m^2 + fixed costs MSEK 4.1 (investments) + MSEK 4.61 consumables (equivalent to MSEK 0.16 to 0.2/m^2)

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a. The fixed costs are artificially low due to the same equipment being used as was accounted for in the Vulcain internals dismantling analysis.

One of the main conclusions to be drawn from these analyses is that the fixed costs related to decontamination and dismantling activities generally are a very important part of the overall resources needed to execute the work. In the case of the BR3 project for the work packages analysed, the fixed component corresponds to between 65 and 75 per cent of the total number of labour hours expended, although this in large part is the result of the extensive preparation needed on the RPV. For equipment such as the reactor internals, which did not require a large amount of work to detach them and bring them into position for segmentation, the fixed hours expended were not too high – roughly in the range of 3,000 to 4,500 hours. The lower figure relates to a situation with equipment already in place for cutting and the upper figure for a first of a kind exercise.

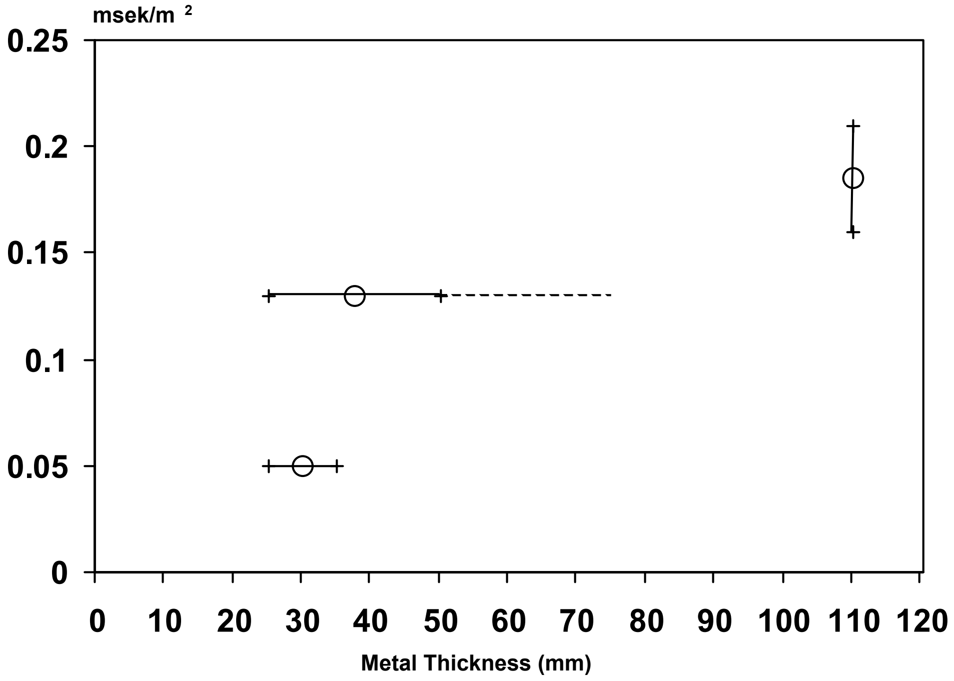
In the specific case of the RPV, considerably more work was needed at BR3 to detach the vessel from the rest of the plant, after which there was also a need for remedial work such as making parts of the plant water tight again. The relatively confined space at BR3 probably meant that the hours expended were higher than they would have been in a more open environment with comparatively clear access. Another contributing factor to the large number of fixed hours expended on the RPV probably relates to the preparation and cold-testing before actual dismantling began. The need for this type of activity can be project dependent. Where the physical layout and access is good it may not be so necessary but, if access is poor, such additional preparation may be a prudent measure to take.

The main quantitative result is that cutting activities tend to need something like 150 to 200 labour hours per m^2 of reactor equipment dismantled.

Fixed investment costs to set up the equipment needed to cut up major vessels or internals appear to be in the range of MSEK 4 to 8. Once set-up, dismantling equipment can be used for more than one work package.

Consumables costs vary according to the nature of the equipment being dismantled. The thicker the metal being cut, the higher the attrition rate for things such as cutting blades. The range of consumables costs at BR3 have been in the range of MSEK 0.1 to $0.2/m^2$ dismantled. Figure 2-11 presents the available, approximate data to investigate the extent of any correlation between metal thickness and consumables costs (e.g. including in particular cutting blades or other cutting materials). With so few data points the precise shape of the curve that might fit the data is unclear but the progressive increase with thickness is evident. The dotted line for the Vulcain data is meant to reflect the fact that, although most of the metal cut was in the thickness range 25 to 50 mm, a small proportion was much thicker (up to almost 200 mm) so the effective average could be considered to be a little higher than indicated by the solid line for this data point.

Figure 2-11 Approximate Correlation of Consumables Cost to Thickness of Metal Cut



A further comparison that may be instructive is between the removal and dismantling activities for the Ågesta RPV and the BR3 internals and RPV.

In the case of the Ågesta RPV the surface area of the barrel is 18.85 m^2, plus 2 x 16.3 m^2 for the top and bottom discs, for a total area of about = 51 m^2. The BR3 benchmarks are:

	Fixed Hours	Variable Hours
Vulcain Internals	4,444	228/m^2
Westinghouse Internals	2,910	100-200/m^2
RPV	31,919	160-200/m^2

On this basis the Ågesta constructed value would be 5,100 to 11,628 hours variable, plus a fixed cost. The Ågesta estimate assumes removal in one piece and then cutting afterwards. The cutting work itself was estimated to require 800 man hours only. In addition there is an estimated MSEK 3 that will have to be spent on installing a water tank that will be used for cutting the RPV. Using a labour rate of SEK 600 per hour this would equate to about 5,000 hours of work (less in practice after accounting for materials). Other attributable expenditure relates to consumables (MSEK 5) and equipment for re-use (MSEK 7.5) but these figures are for the whole plant, not for the RPV work alone. Information on the estimate for preparation and removal has proved to be elusive and the available indications are that any estimate made may not have been particularly rigorous. Equally, information on the relevant assumed productivity ratio assumptions for this part of the project have not been discovered.

The initial conclusion one might draw from this comparison is that the Ågesta estimate for the RPV is significantly low. At the very least, in the absence of more detailed information being discovered, it is difficult to have a high degree of confidence in the Ågesta RPV estimate. However, actual experience of steam generator (SG) removal at Ågesta provides evidence to the contrary, as follows.

Based on Ågesta dose uptake expectations in the plan for SG removal (studsvik/NW-92/73, page 17) the total manhours has been derived as approximately 400 over a 19 or 20 day working period. In practice a total of 14 people were involved but almost certainly not for the whole period. In fact direct feedback from people involved at the time indicates that typically there were 4 or 5 people at any one time working on the job. 4 or 5 people for 19 days working 12 hour shifts (maximum) gives 912 to 1140 hours. Roughly 1,000 hours in round terms.

Each steam generator is 10.5 m high and 1.7 m OD, for a volume of 24 m^3 each. Applying the WTR benchmarking data for RPV removal to this volume, excluding any preparatory engineering, would give 232 hrs/m^3 x 24 m^3 = ~ 5,500 hrs. This is more than 5 times higher than the total manhour investment in removing **both** Ågesta SGs, including getting them out of the building on a transporter. And this comparison does not take into account all of the preparatory and other engineering work. The productivity ratio for the WTR work was believed to be quite high, as they were working 10 hour shifts with little down time, so probably there is no meaningful basis to make any adjustments in this regard before comparison with the Ågesta data.

Given this actual experience, the preliminary conclusion has to be that the nature of the two jobs is radically different in some way, either due to size, radiological conditions, physical access or suchlike. The available data does not support reaching a more detailed conclusion.

2.8.2 Overall Reasonableness of the Ågesta Estimate

The extent of detailed information available in the 1996 Ågesta estimate is not sufficient to enable a full comparison with the BR3 decommissioning results. A global first comparison may be attempted by summing the resources expended on the BR3 work packages described in this report with the combined dismantling data presented in the 1996 Ågesta cost estimate report.

Very broadly the cost of decontamination plus dismantling of the main process equipment at Ågesta appears to be in the order of MSEK 70, of which MSEK 4 is labour on preparatory/planning work, MSEK 40 is labour on actual decontamination and dismantling and MSEK 25 is equipment. The BR3 work packages described in this report add up to something like 83,000 labour hours plus about MSEK 13 of investments and consumables costs. At Swedish average team labour rates 83,000 hours would equate to about MSEK52,500. Adding the investment cost of MSEK 13 gives a total of about MSEK 65. This of course is quite close to the Ågesta figure but it would be wrong to draw immediate, firm conclusions based on these data. The comparison should take into account, *inter alia*:

- The number and relative sizes of the equipments decontaminated and dismantled at Ågesta and BR3
- The assumed productivity in the Ågesta estimate compared to the actual BR3 figures

On a tentative basis, the physical scale of the Ågesta reactor is somewhat larger than the BR3 reactor, (the power generation figures are 80 MW and 40 MW respectively), so all other things being equal, one might expect the Ågesta decommissioning cost estimate to be higher than for BR3. But Ågesta has better access overall, which should help to constrain costs. The productivity ratio for workers at BR3 on average was high – generally 80 per cent or more, so this is unlikely to be exceeded at Ågesta and might not be equalled, which would tend to push the Ågesta cost up relative to the BR3 situation.

There is an additional question of the possible extra work performed at BR3 due to the R&D nature of the project. The analyses performed for this report have attempted to first subtract any such “extra” work form the raw data, in order to provide a basis for comparison that would reflect normal decommissioning project conditions. Nevertheless the data used may still include some residual component related to the R&D project effect.

In summary therefore:

- The non-discovery of key information about specific packages of work included in the Ågesta estimate make it difficult to have a high degree of confidence in certain parts of that estimate, in particular in relation to removal and dismantling of the RPV.
- A preliminary analysis of actual work carried out at Ågesta historically (SG removal) with work carried out at BR3, WTR and projections in the Swedish estimate for Ågesta, suggest that the resources needed for this type of work can vary significantly

due to specific context, such as radiological status, access etc., but the available level of detail does not facilitate arrival at firm conclusions in this regard.

- The Ågesta estimate for primary circuit decontamination appears to arrive at a reasonable total cost but the process to arrive at this, largely by scaling from an Oskarshamn estimate using what appears to be a non-rigorous approach, could be improved upon.
- Also in connection with this decontamination work, the volume of ion-exchange resin assumed to be created for disposal (and possibly other wastes) could be overestimated if BR3 experience is used as a benchmark.