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Prepared by a special working group within SKBF/KBS,
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TECHNOLOGY AND COSTS FOR DISMANTLING A SWEDISH NUCLEAR POWER PLANT

Prepared by a special working group
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October 1979

This report concerns a study which was conducted for the KBS project. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

A list of other reports published in this series is attached at the end of this report. Information on KBS technical reports No. 1 - 120 in an earlier series is available through SKBF/KBS.

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SUMMARY

Various estimates concerning the costs of decommissioning a redundant nuclear power reactor to the green fields state are given in the literature. The purpose of this study is to provide background material for the Swedish nuclear power utilities to estimate the costs and time required to dismantle an ASEA-ATOM Boiling Water Reactor.

The units Oskarshamn II and Barsebeck 1, both with an installed capacity of approximately 600 MW, serve as reference plants. The time of operation before final shutdown is assumed to be 40 years. Dismantling operations are initiated one year after shutdown. When the dismantling of the plant is finished, the site is to be released for unrestricted use.

The costs for dismantling and subsequent final disposal of the radioactive waste are estimated at approximately SEK 500 million* (∿ US$ 120 million) in terms of 1979 prices. The sum includes 25% contingency. The dismantling cost is equivalent to 10-15% of the installation cost of an equivalent new nuclear power plant. The exact percentage is dependent on the interest rate during the construction period.

It is shown in the study that a total dismantling can be accomplished in less than five years.

This report is a compilation of studies performed by ASEA-ATOM and VBB based on premises given by KBS.

The reports from these studies are presented in appendices.

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* 1 US$ ∿ 4.20 SEK (Swedish crowns)

1 BACKGROUND

Widely digressing figures for the cost of dismantling a nuclear power plant have been quoted in discussions of the final costs of nuclear power. This question has been brought up once again in Sweden in connection with the work of the Government-appointed committee on organizational and financing matters for the handling and storage of spent nuclear fuel and radioactive waste.

Cost estimates made to date for the dismantling of a Swedish nuclear power plant (for example ref. 6) have been based on studies made in the United States and West Germany (ref. 7-9). The results of these studies are difficult to apply reliably to ASEA-ATOM reactors, which differ in design from American and German boiling water reactors. This is further complicated by the difficulty of comparing the costs of labour, materials etc.

This study has therefore been carried out in order to provide a preliminary estimate of the cost and time required to dismantle a boiling water reactor of ASEA-ATOM design. The study was completed in about three months so that the results could be used in the work of the aforementioned committee. With this purpose in mind, some sections provide only a sketchy outline, while others go into more detail. The calculated cost for dismantling a nuclear power plant is therefore approximate.

In two of the foreign studies (ref. 7 and 9), a comparison has been made between the cost of dismantling a BWR and a PWR. The difference is estimated to be less than 15%, with the PWR being somewhat cheaper. The costs calculated in this study should therefore also be applicable to the dismantling of a PWR plant.

The study has been performed within the framework of the KBS project (Nuclear Fuel Safety Project) with ASEA-ATOM and VBB (Vattenbyggnadsbyrån - consulting engineers) as subcontractors. The work was lead and coordinated by a special working group consisting of:

Bertil Mandahl	OKG
Karl-Erik Sandstedt	Swedish State Power Board
Bengt Norman	Sydkraft
Hans Forsström	KBS

The working group has compiled this report on the basis of ASEA-ATOM's and VBB's reports (ref. 1-4, references 1 and 4 are given as appendices).

2 PREMISES

The premises which apply for the study were given by the working group. They are general and not based on any attempt at optimization. Some of the premises can therefore be discussed from various viewpoints. The premises are listed below with comments.

Reference plants: Oskarshamn II, Barsebeck 1.
Operating life before final shutdown: 40 years.

1 Dismantling shall start as soon as possible after final shutdown and removal of spent fuel, control rods, neutron detectors and operating waste, i.e. after about one year.

Starting earlier than one year afterwards is hardly possible, in view of the above-mentioned measures that must be taken. Removal of the fuel will probably be the time-determinant factor and will, in view of the short time available, impose relatively high demands on transportation systems to and receiving arrangements at the fuel storage facility.

One advantage of an early start is that operating maintenance personnel are still available and their knowledge can be utilized to some extent in planning and supervising the dismantling work.

2 Dismantling shall be carried out by means of currently known techniques.

3 No incidents leading to a major release of radioactivity shall have occurred during the operating life of the plant. In other words, the release of radioactivity within the controlled area has been limited to normal leakage.

4 The choice of working method shall be made with a view towards protecting personnel and preventing releases to the environment. In cases where temporary radiation shields, remote control or provisional ventilation systems with filters are required, this should be specified.

5 The inventory of radioactive elements shall be calculated. Comparisons shall be made with published foreign studies, wherever possible. Swedish studies concerning activity build-up in systems (the so-called MADAC studies) shall be taken into consideration.

6 It shall be assumed that chemical decontamination of entire systems or components will not be carried out. Simpler decontamination methods will, however, be employed, for example chipping away of contaminated concrete and washing with a high-pressure water spray.

The possibility of decontaminating turbines and turbine systems shall be taken into consideration, in view of the fact that the spread of activity to turbines and turbine systems is generally small and the activity is often easy to remove.

The reasons why decontamination with chemical solutions will not be assumed in this study is that satisfactory disposal methods for many known decontamination solutions have not yet been devised. Chemical decontamination is nevertheless of great interest with respect to both dose reduction and the possibility of reuse of material.

7 Surfaces shall be regarded as clean if radioactive contamination is less than 10^{-4} $\mu Ci/cm^2$ for β^- and γ-emitters and 10^{-5} $\mu Ci/cm^2$ for α-emitters.

Materials with induced or absorbed activity less than 0.002 $\mu Ci/g$ shall be regarded as inactive.

Generally accepted values of what is to be considered clean or inactive do not exist. The values that are used in this study for permissible degree of contamination correspond to those permitted by international recommendations on the outside of packages containing radioactive material in connection with transportation via public means of transport. The value for what is not to be regarded as radioactive material is the value in the Radiation Protection Act which is the upper limit for when permission is not required for possession, processing etc.

Calculations are being carried out at the present time in various countries in order to determine permissible values for release of material. But it is expected to take a long time before such values are established for the nuclides of interest in connection with dismantling.

8 The following shall be assumed concerning the contamination of concrete:

a) in the water pools with stainless steel lining, leakage has led to a penetration by radioactivity to a depth of 5 cm over the entire surface behind the lining. In addition, cracks in the concrete have led to a contamination of an additional approx. 5 m^3 of concrete

b) in pump pits, the concrete has been contaminated to a depth of 10 cm. Cracking has led to the contamination of an additional 1 m^3 of concrete

c) spillage in rooms with a limited amount of radioactive process equipment has led to contamination of 1% of the floor surface. In rooms with higher leakage risks, 10% of the floor area is contaminated.

Limited experience necessitates these rough assumptions.

9 It shall be assumed that no other operations take place on the site during dismantling. In practice, this may entail a waiting period before the dismantling work is begun. A calculation of the consequences of a waiting period for dose burden, costs etc. will not be performed.

10 It shall be assumed that the final storage of radioactive waste will be effected in a central waste repository in accordance with the National Council for Radioactive Waste's ALMA study. The waste shall be transported to the facility in accordance with the proposals of the same study.

Transport packages used to transport the waste shall comply with international recommendations.

11 Inactive dismantling waste shall be treated in the conventional manner. The possibility of using such waste as filler material for restoring the reactor site shall be taken into consideration.

Possibilities of reuse shall be indicated but not credited in money.

12 The reactor site shall be restored so that it can freely be used for unspecified activities.

13 Estimated costs shall be given in terms of the cost level prevailing in the summer of 1979. Wherever possible, costs shall be specified in a manner that permits the estimates to be used later for other Swedish nuclear power plants than the reference plants.

3 MATERIAL QUANTITIES AND ACTIVITY CONTENTS

As a basis for determining the need for radiation shielding in connection with the dismantling work and the quantity of material that must be treated as radioactive waste, the activity level in the plant's different systems and building components has been estimated. Both computer programs and recorded data from the operation of the Swedish nuclear power plants have been utilized for this purpose. Four types of radioactive material have been considered:

- material with induced activity
- material with surface contamination (crud)
- material with absorbed activity
- sand from the delay tank for radioactive off-gases

The method of calculation used and the results of the estimate of the activity level for these types of radioactive material are described in brief below. A more detailed account is provided in reference 3.

Material with induced activity

The induced activity has been determined by means of neutron transport calculations. The composition of the constituent constructional materials used in the calculations has been based on material certificates. For concrete, the composition was determined from samples from e.g. the concrete in Barsebeck. The calculations assume 40 years of operation, 7 200 hours per year.

Since the neutron flux density declines very rapidly outside the reactor core, only the reactor vessel and its internal components as well as the immediately surrounding insulation and concrete will have an induced activity that exceeds the limit value of 2 μCi/kg. See Fig. 3.1. Crud activity starts to dominate only a few metres from the core.

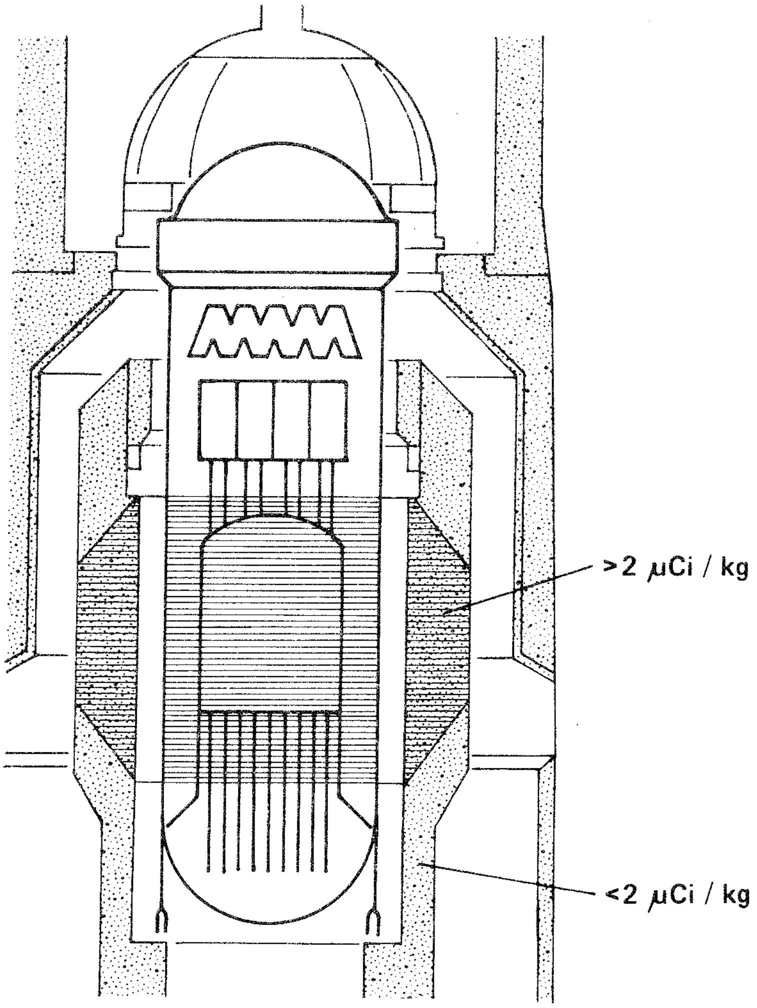


Fig. 3.1 Induced activity in the reactor vessel and surrounding radiation shield (biological shield).

The induced activity is dominated from the viewpoint of dose by Co-60. In the most active parts, for example the core grid, the concentration is calculated to be about 10 Ci/kg, which corresponds to dose rates of more than 10^4 rem/h.

In the biological shield, the Co-60 activity is considerably lower, <1 mCi/kg, which means that the dose rate on the inside of the shield is <100 mrem/h.

In connection with long-term storage, long-lived isotopes such as Ni-63, Ni-59, Nb-94 and Ca-41 are critical. No detailed analysis of these isotopes has been made in this study, since the classification of materials as active/inactive is done after one year from shutdown, at which point Co-60 dominates. Values for the nickel isotopes are also given in reference 3.

Material with surface contamination (crud)

All systems that come into contact with reactor water becomes more or less contaminated with radioactive metallic particles, known as "crud". Documented data on crud build-up at different points in the reactor systems have been accumulated by means of measurements in connection with repair and maintenance work.

With these data as a basis, a system-by-system classification has been made of expected activity level. This classification has not assumed any reduction in the activity level through decontamination in reactor systems. However, it has been assumed that the turbine systems after the high-pressure turbine can be cleaned to a large extent by means of washing with a high-pressure spray and wiping with rags. The classification is illustrated schematically in the process diagram in Appendix 9.4.

The crud activity is also dominated from the viewpoint of radiation dose by Co-60, but some contribution is also obtained from fission products such as Cs-137 (<10%). MADAC measurements have shown that the surface activity of Co-60 is approx. 10 mCi/m^2 in systems that come into contact with uncleaned reactor water. After 40 years of operation, it is estimated that this value will increase to max. 50 mCi/m^2. The dose rate from the scrap will then be on the order of 1 rem/h. Most of the systems, however, will have lower activity.

Material with absorbed activity

The fuel, reactor and condensation pools are lined with stainless steel. Experience shows that this lining is not completely tight, which means that radioactive water can leak out to the surrounding concrete. The concrete has been found to possess a very good filtration capacity, so that the radioactivity accumulates in a thin layer near the surface. This layer has been assumed here to be 5 cm thick. However, the radioactivity penetrates more deeply at certain points in the concrete due to cracks. Nevertheless, the activity level in the concrete is expected to be low everywhere.

Due to spillage, a certain portion of the floors in the plant will also be contaminated with radioactivity. Here, it has been assumed that 10% of the total floor area in process areas for systems with hot, uncleaned reactor water and 1% of the floor area in other process areas has been contaminated to a depth of 1-2 cm.

Sand from the delay tank for radioactive off-gases

Daughter products of radioactive noble gases accumulate in the delay tank for radioactive off-gases. The tank contains a total of 965 m^3 sand and its activity content has been calculated to be 13 Ci, of which 8 Ci from Cs-137 and 5 Ci from Sr-90. Most of the activity should be in the bottom of the sand tank, while the upper part can probably be classified as inactive.

Quantities of radioactive material

With these calculations as a basis, the quantity of radioactive material has been estimated. The material has thereby been classified into three classes, according to the type of transport container that will be required.

1. To be packaged in non-shielding transport container
2. To be packaged in shielding transport container
3. To be packaged in shielding transport container with extra shielding

The transportation system and the transportation containers are described in greater detail in Chapter 5.

Table 3:1 shows the quantity of radioactive material and the number of transport containers required to transport it to the final repository.

If the systems are decontaminated, the quantity of radioactive components that must be disposed of can be reduced. However, this reduction has not been estimated.

Table 3:1

Estimate of quantity of radioactive material obtained from dismantling of an ASEA-ATOM BWR with a capacity of 600 MW.

	Material weight metric tonnes	Number of transport containers Type 1	Type 2	Type 3
Reactor vessel with internals and containment head	700	12	30	34
Reactor vessel insulation	50	7		
Radioactive systems	3 700	308	61	
Biological shield	580		18	
Contaminated concrete	450	12		
Sand tank x)	500	14		
Total, approx.	6 000	350	150	

x) 20% is assumed to be radioactive

4 DISMANTLING SEQUENCE AND METHODS

The main features of the dismantling sequence proposed by ASEA-ATOM and VBB in ref. 1, 2 and 4 are described below.

A cross-section of the power plant buildings and the reactor vessel with internal components is presented in Appendices 9.2 and 9.3.

After a plant has been shut down, a year is required to discharge the fuel and transport it away. Core components such as control rods and guide tubes for neutron detectors etc., which are normally replaced during the operating period, are also transported away. During this period, the reactor's clean-up and safety systems continue to operate at normal capacity.

Dismantling of the reactor tank with internal components, other active piping systems and activated or contaminated concrete is carried out within the power plant buildings, which are still externally intact. This facilitates filtration and monitoring of the ventilation air during the work so that the dispersal of radioactivity to the environment is prevented. The power plant's waste system for treatment of contaminated water is also in normal operation.

Dismantling of the reactor vessel with internal components is time-determinant for the entire dismantling job and is therefore started as soon as possible.

Those parts of the reactor located close to the fuel - the moderator tank, moderator tank head, core grid and control rod guide tubes etc. - have become highly radioactive during operation. These components are made of stainless steel of relatively small thickness and can be cut up into suitably sized pieces by means of e.g. plasma cutting under water. The scrap is packed under water in special inner containers, which then act as extra radiation shields in the transport containers.

The reactor vessel is dismantled by cutting in air. Special radiation-shielding equipment is used for this work. This equipment can be designed in different ways. An example has been sketched in ref. 2.

Parallel with the work on the reactor vessel, dismantling of the piping systems in the reactor building is begun. The same methods and procedures are used for cutting up pipes, valves etc. as for services and reconstruction work in nuclear power plants.

Pipe lathes or cold saws are normally used for heavy gauge material. Small-diameter tube is cut with hydraulic shears. Larger units, such as heat exchangers and tanks, are cut up into suitable pieces by means of e.g. plasma cutting.

Pipes and components in radioactive areas are cut up in as large units as possible in order to minimize personnel exposure. The units are then taken to an adjacent area, where the scrap is cut up into pieces that fit into the waste containers.

Inactive systems, i.e. cooling systems and parts of the turbine systems, are dismantled by means of conventional methods.

The stainless steel linings in the pools in the reactor hall and in the reactor containment are cut or ground up at the joints.

When most of the piping system has been dismantled, the demolition of concrete structures is begun. First, the activated concrete nearest the reactor vessel and contaminated concrete behind the pool linings, in floor drains and in the surface layer of some floor areas is removed and transported away.

The largest and most contaminated concrete item is the biological shield nearest the reactor vessel. However, the level of radioactivity in this part is not so high that extensive protective measures are required. The activated portion, a total of approximately 240 m^3, is broken up into blocks by means of drilling and splitting or by means of cutting with a thermic lance.

Other contaminated concrete is removed mainly by means of breaking or splitting of large surfaces. All contaminated concrete is packed into transport containers. Each container holds 14 - 18 m^3 of loosely-packed concrete waste. A total of about 30 transport containers are required for the concrete.

Approximately 450 transport containers are required for radioactive piping systems and components, including the reactor vessel, of which about 130 shall have special radiation shielding. In addition, containers are required for slightly contaminated sand from the delay tank for radioactive off-gases.

Inactive building components are dismantled in a conventional manner. The roof structure can generally be lifted off in pieces by a mobile crane. The concrete framework is blasted into suitably sized pieces so that the rubble falls down into the basement.

The reactor containment with associated pools is particularly sturdily built, and additional cutting and splitting is required here in order to bring the structure down in a controlled manner and to obtain a good degree of compaction in lower-lying areas.

Small quantities of liquid and airborne waste are generated in connection with dismantling of the waste station. This waste is disposed of by a provisional system.

After completed dismantling, the station site is levelled off and covered with a layer of natural material. The details of this restoration work will vary depending upon how the site is planned to be used in the future.

5 WASTE TRANSPORTATION AND STORAGE

Active waste

The amount of material with an activity level such that it must be managed as radioactive waste is specified in Chapter 3. Since the activity level varies widely between different waste shipments, different disposal methods could be used for the different categories, for example ground disposal or placement in rock caverns. However, it has been conservatively assumed in this study that all waste will be deposited in rock caverns. The final repository for low- and medium-level radioactive waste, ALMA, studied by the National Council for Radioactive Waste (PRAV) has been used as a model for a final repository. The transportation system proposed by PRAV will be used for the transportation of dismantling waste to ALMA. A brief description of the transportation system and the final repository is provided below. They are described in more detail in ref. 11-13.

Transportation system

The transportation system is based on container transport on a specially built roll-on roll-off ship. This ship, which has a cargo capacity of about 1 100 tonnes, will also be used for transporting fuel casks containing spent nuclear fuel. It should also be possible to use conventional ships for a large portion of the waste from dismantling.

A special type of terminal vehicle will be used to handle the transport containers at the nuclear power plants and at the final repository.

Two types of transport containers will be used: one non-shielding steel container and one shielding concrete container (wall thickness 35 cm). Both have internal dimensions of 2.5 x 3.7 x 2.7 m, w x l x h. Empty, they weigh 10 and 52 tonnes, respectively. The total weight of the containers, when full, may not exceed 100 tonnes.

Most of the waste comes under the category of "low-level solid waste" in accordance with the transport regulations of IAEA and may therefore be transported in a "strong industrial package", which the containers are. The dose rate may not exceed 200 mrem/h on the surface of the container and 10 mrem/h at a distance of 2 m.

In order to comply with these rules, the surface dose rate of waste placed in non-shielding containers must be lower than 30 mrem/h, while the surface dose rate of waste placed in shielding containers must be less than 1 rem/h. A limit of 1 rem/h has also been set for waste to be handled in the final repository.

A smaller portion of the waste, mainly the internal components of the reactor vessel, has such a high level of activity that it requires additional radiation shielding beyond that provided by the shielding container. (Up to 70 cm extra concrete.) Inner containers, which are deposited in the final repository together with the waste, are used for this waste.

As was reported in Chapter 3, a total volume equivalent to about 500 containers will be required to transport all dismantling waste. The frequency with which the containers are filled is highest during the first two years, when the reactor vessel with internal components and active systems is being dismantled. A maximum of about 25 containers will be filled per month, of which 10 shielding and 15 non-shielding.

Each shipload can take between 14 and 24 containers, depending upon the weight of the containers, and a round trip from the nuclear power plant to ALMA and back to the plant will take a maximum of 7 days, including time in harbours for loading and unloading the containers. In order to prevent the number of containers from limiting the dismantling work, about 80 containers will be required, 30 of which are shielding.

The cost of transporting the dismantling waste has been calculated on the basis of the cost estimate carried out in ref. 11. The values have been adjusted up to the price level for the summer of 1979.

The cost for the transports will be about SEK 30 000 per container and transport. A total of about 500 containers will be transported, which entails a total cost of SEK 15 million for the transports.

Final repository

According to the proposal in ref. 13, the final repository for low-and medium-active waste, ALMA, consists of a number of rock vaults or caverns with a span of 25 m and a length of 150-300 m. The waste is stored in the vaults in large concrete pits. The walls in the pit act as supports for stacking and as radiation shielding. As the pits are filled with waste, they are backfilled with concrete. When the repository is sealed, the space between the pit and the rock wall is filled with a mixture of sand and bentonite clay.

The final repository has remote-controlled equipment for unloading the containers and stacking the waste, as well as for backfilling the pits with concrete.

The cost of final storage is estimated to be about SEK 3 500 per m^3 of waste. This includes both investment and operating costs. The total cost for final storage of the dismantling waste will be about SEK 35 million.

It should be pointed out in this context that a simpler disposal method, for example shallow land buried next to the dismantling site, for a large portion of the dismantling waste would lead to a considerable reduction in cost.

Inactive waste

The waste from dismantling inactive building components will be used primarily to fill the lower parts of the reactor and turbine buildings. Such material could also conceivably be deposited in the coolant water channels. At the Oskarshamn station, all material can be deposited on the site, while about 25 000 m^3 will be left over at the Barsebeck station. This material will be transported in the normal manner to an outside landfill site.

Inactive system components and cabling should have some value as scrap. It has therefore been assumed that these materials will be sold to scrap dealers, who will also remove it from the site.

6 TIMETABLE AND PERSONNEL REQUIREMENTS

It is assumed that the dismantling work will commence about one year after the plant has been shut down. The timetable is shown in Fig. 6.1. During the first year, year zero, fuel etc. is transported away and the dismantling work is planned in detail. It is assumed that the power station's operating organization is largely intact during this year. The work-force amounts to about 140 persons at one reactor unit.

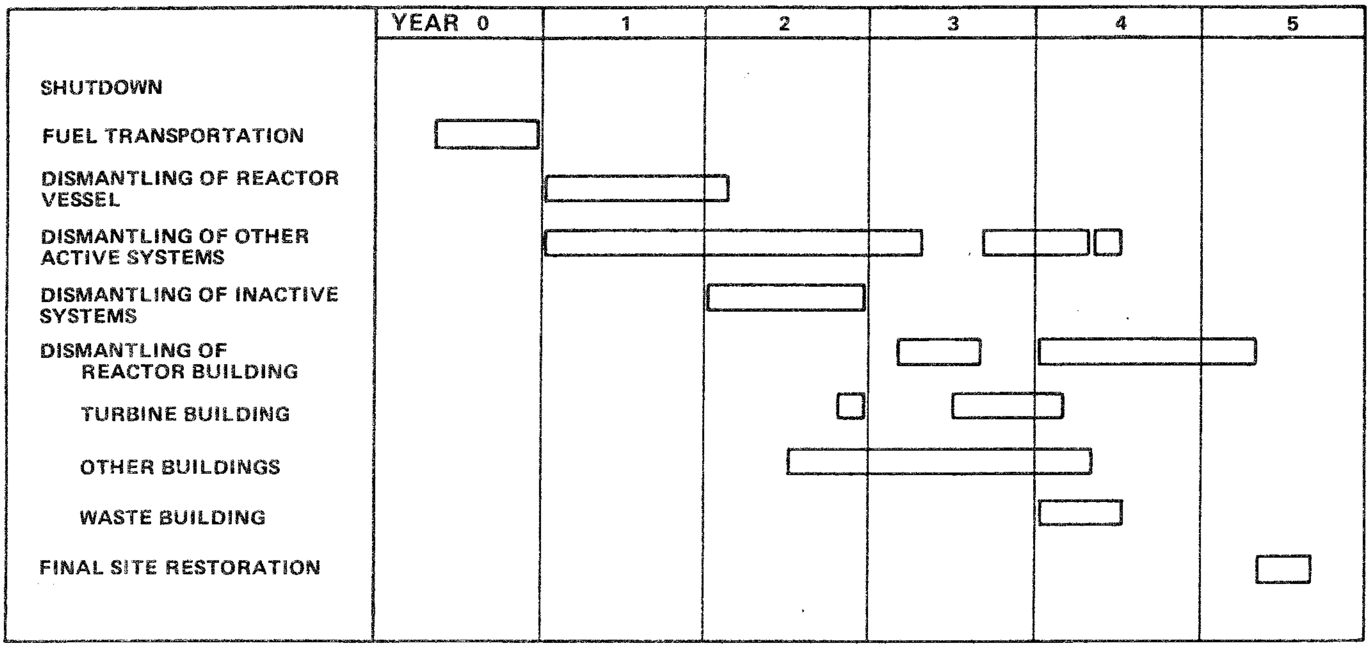


Fig. 6.1 Main timetable

The time-determinant factor for the entire dismantling operation is the sequence that starts with the reactor vessel and continues with dismantling of the reactor containment with pools and finally the reactor building itself. The timetable has been drawn up under the assumption that only normal daytime work, five days a week, will be used.

The dismantling of the reactor vessel and internal components is expected to take slightly more than one year.

Some dismantling of the remaining mechanical equipment will be done during year 1, but most of the work will be done during year 2.

Demolition of buildings will take place mainly during years 3 and 4.

The personnel requirements for the actual dismantling and demolition work are reported in ref. 1 and 4. In addition, some operating shift personnel (2-4 men/shift) will be required to attend the waste facility, ventilation system etc. Two guards will be required round the clock during the first three years to guard the demolition site. Staff for project management, office work, radiation protection, industrial safety, fire protection and housekeeping will be taken mainly from the operating organization.

Table 6:1 shows personnel requirements in addition to the personnel required for the actual dismantling work, which is reported in ref. 1 and 4.

Table 6:1

Category	Year 1	Year 2	Year 3	Year 4	Year 5
Project management	10	10	10	7	5
Operation	20	20	12	12	2
Office service	5	5	5	5	4
Security and protection	10	10	8	6	4
Housekeeping	10	10	10	5	5
Total	55	55	45	35	20

Personnel requirements during the entire dismantling phase are summarized in Fig. 6.2

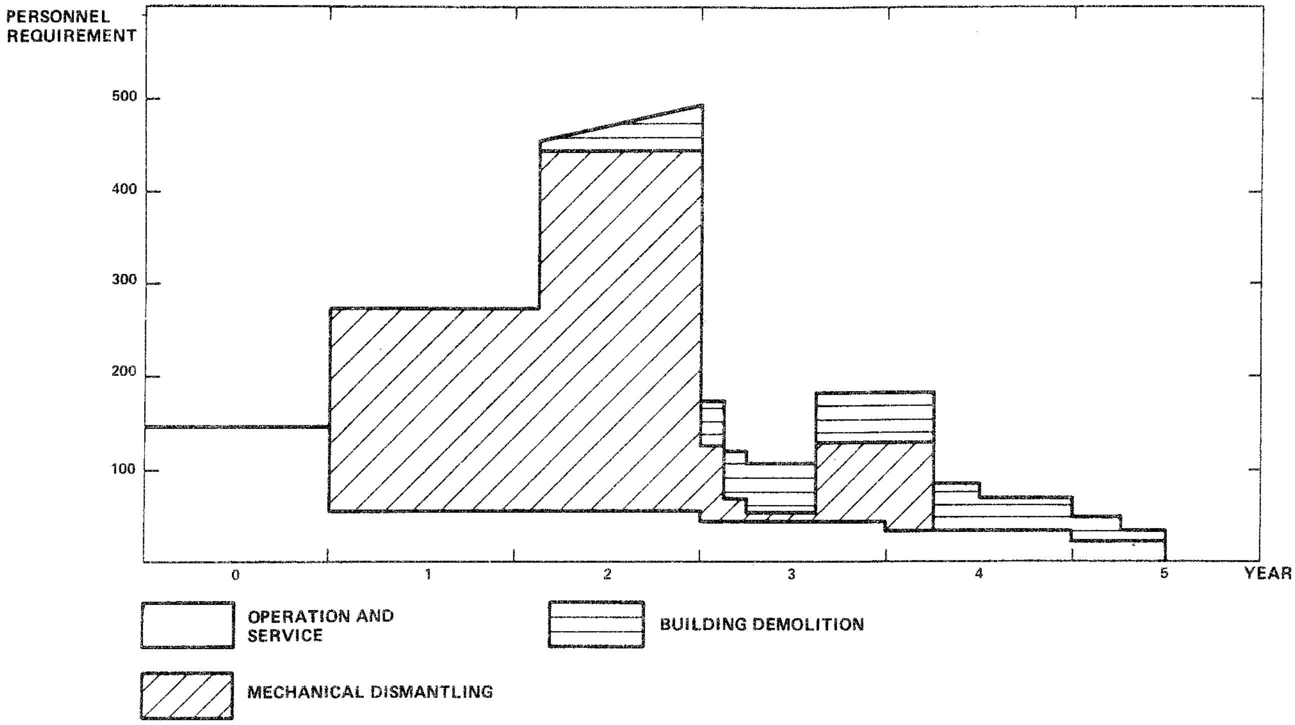


Fig. 6.2 Personnel resource plan

The maximum personnel requirement of around 500 persons during year 2 is of the same order of magnitude as during a normal maintenance period in a nuclear power plant. Existing personnel facilities, such as catering etc., are therefore designed for such large temporary requirements.

The study shows that a nuclear power plant can be dismantled in a shorter period than five years and with a reasonable labour input. No attempt has been made to optimize timetables and resource plans. With some adjustments, a more even personnel resource plan and utilization of transport capacity can be obtained.

7 RADIOLOGICAL CONSEQUENCES

Doses to dismantling personnel have been estimated. However, available data are uncertain. More reliable data can only be obtained after matters such as activity build-up in systems, working methods and working times, dismantling planning for different areas, material flows and waste management have been dealt with in greater detail.

In ref. 1, the total dose has been calculated to be 1 200 manrem. Even though the data are deficient in many respects, the calculated dose would seem to be reasonable. Discussions with radiation protection personnel with experience from maintenance work at this type of plant point to similar dose values, when the possibilities of shielding and rapid removal of more active components are taken into account (ref. 14). In this context, it has also been suggested that calculated working times in radioactive environments appear to be exaggerated.

Releases to the environment have not been calculated. Since the main releases in connection with dismantling involve particulate radioactivity, emissions can be kept very low by means of suitable filtered ventilation. The same applies to liquid effluents, which should also be filtered. It should be possible to keep environmental impact substantially below the threshold limit values that apply during operation.

8 COST ESTIMATE

Premises

General

The costs are estimated in terms of the price level in the summer of 1979. A contingency allowance of 25% is made for unforeseen costs.

Dismantling of active systems

The personnel requirement for dismantling of three representative systems has been studied in detail and compared with the known personnel requirement for the installation of the same systems. The personnel requirement for the dismantling of active systems will be twice as large as for the installation of the systems. The ratio of white-collar to blue-collar employees has been found by experience to be 36/64 in connection with installation. A ratio of 30/70 is assumed for dismantling. Dismantling of the reactor vessel has been studied specially, whereby personnel requirements and costs of equipment have been estimated.

Dismantling of inactive systems

It is assumed that pipes, valves and electrical cables can be dismantled and taken away by scrap dealers or accompany the rest of the demolition materials. The cost of dismantling, cutting up (where required) and transport to a landfill site has been estimated for each large item of equipment. The personnel requirement for dismantling has thereby been assumed to be 70% of the personnel requirement for installation.

Dismantling of building components

The building volumes are known. The components that are radioactive have been calculated or estimated in the premises. Prices based on experience (SEK/m^3) have been used for the dismantling of inactive building components. For active building components, these unit prices have been multiplied by a factor of 2-3.

Cost itemization

The estimated costs for the entire dismantling operation and the final storage of active components have been itemized in Table 8.1. The chronological distribution of the costs is presented in Table 8.2.

Table 8.1 Estimated costs

Cost	SEK millions, incl. 25% contingency allowance
Dismantling of reactor vessel with internals	50
Dismantling of other active systems	245
Dismantling of inactive systems	5
Demolition of active building components	8
Demolition of inactive building components	45
Project management	16
Operation	24
Radiation protection, housekeeping, security, office service	27
Electricity and heating	10
Insurance premiums and fees to authorities	10
Transportation of waste	15
Final storage of waste	35
Total cost of demolition and final storage	490

Table 8.2 Chronological distribution of costs

Year	Item	SEK millions
-1	Planning, licensing, ordering of special equipment	15
0	Planning, licensing, delivery of special equipment	30
1	Dismantling of reactor vessel, certain active systems	125
2	Dismantling of systems and buildings	215
3	Dismantling of systems and buildings	55
4	Dismantling of buildings (demolition)	35
5	Concluding work	15
	Total	490

The total dismantling cost of SEK 490 million is approximately 10-15% of what it would cost to erect a 600 MWe nuclear power station today. The exact percentage depends on what assumptions are made concerning interest costs during the construction period.

Cost comparison with other studies

Dismantling costs reported in other studies are presented in Table 8.3. The costs pertain to dismantling as soon as possible after decommissioning.

Table 8.3 Comparison with other studies

Study	Reactor type	Costs 1978 level	Costs SEK mill. 1979 level
AIF American, 1975 (ref.7)	Approx. 1200 MWe, BWR and PWR	US$ 35 mill x)	160
NRC-BNWL American, 1978	Approx, 1200 MWe, PWR	US$ 39 mill.	180
Bardtenschlager et al, German, 1978 (ref.10)	Approx. 1200 MWe, BWR and PWR	DM 250 mill.	650
Essman et al, German, 1978 (ref.10)	Approx. 1200 MWe, BWR and PWR	DM 200 mill.	420
This study KBS, 1979	Approx, 600 MWe, BWR	-	490

x) Adjusted to 1978 price level by ref. 6.

As is evident from the above table, the dismantling cost arrived at in this study is higher than in the American studies, despite the fact that the reactor type studied was of a lower capacity. The explanation probably lies in a generally higher cost level in Sweden plus the fact that in this study we have assumed a larger manpower requirement and that the costs of waste management are higher.

Approximate costs for dismantling other Swedish nuclear power plants

A first rough estimate of the costs for dismantling the other Swedish nuclear power plants has been done.

For each plant the material weight data for system components and concrete in the building structures were gathered. These data were then compared to the corresponding data for the reference plant, given in appendices 1 and 2, and the costs for dismantling a system or building component were calculated by a simple proportioning based on the relative quantities of material.

The results of the calculations and some basic data for the power plants are given in table 8.4.

Table 8.4 Data for Swedish nuclear power plants

Reactor	Type	Capacity (MW_e)	Building volume total (1000 m^3)	Building volume specific (m^3/MW)	Active system material weight (tonnes)*	Dismantling costs (SEK mill.)
Oskarshamn I	BWR	450	200	450	2.700	380
Oskarshamn II	BWR	590	350	600	3.700	490
Oskarshamn III	BWR	1050	670	640	6.800	850
Ringhals 1	BWR	760	385	510	4.700	600
Ringhals 2	PWR	820	405	500	2.200	430
Ringhals 3	PWR	915	450	500	2.200	440
Ringhals 4	PWR	915	450	500	2.200	440
Barsebäck 1	BWR	590	430	730	3.700	500
Barsebäck 2	BWR	590	430	730	3.700	500
Forsmark 1	BWR	900	525	590	5.900	730
Forsmark 2	BWR	900	525	590	5.900	730
Forsmark 3	BWR	1050	670	640	6.800	850

* Reactor pressure vessel and internals not included.

It can be concluded from these data that the cost for dismantling a BWR is about 800 SEK/kW. For a PWR the cost is about 500 SEK/kW.

It shall be pointed out that the calculational method used is very rough and that the figures given only show the level of the dismantling costs. They do not take into account the following factors, which most probably lead to cost reductions:

Two or more plants on the same site could be dismantled in parallel.

The newer plants, Forsmark 1, 2 and 3 and Oskarshamn III have more space for dismantling and transportation. They also have more duplicated systems.

The project management, planning etc. could be made more efficiently, when dismantling a bigger plant.

It is also evident that the method of proportioning costs give better results when the same type of reactors are considered. Consequently the uncertainties are greater in the cost estimates for the three PWRs.

9 APPENDICES TO MAIN REPORT

LIST OF REFERENCES
(References 1 and 4 are presented in the Appendix section)

1 ASEA-ATOM PM TK 79-217
Rivning av svenska kärnkraftverk
(Dismantling of Swedish nuclear power plants)

2 ASEA-ATOM PM RD 79-489
Demontage of reaktortank och interna delar
(Dismantling of reactor vessel and internal components)
(In Swedish)

3 ASEA-ATOM PM RF 79-413
Aktivitetsmängder och strålningsnivåer
(Quantities of activity and radiation levels)
(In Swedish)

4 VBB Report 88435-000 19791005
Rivning av svenska kärnkraftverk
(Dismantling of Swedish nuclear power plants)

5 Barsebäck Station Technical Information
Description of one of the reference plants
(In Swedish)

6 Scandpower Report 2.34.06 19790117
Kjernekraftens kostnader
(Costs of nuclear power)
(In Swedish)

7 AIF/NESP-009 Atomic Industrial Forum Inc., Nov 1976
An engineering evaluation of nuclear power reactor decommissioning alternatives

8 NRC-BNWL, NUREG/CR-0130, June 1978
Technology, safety and cost of decommissioning a reference pressurized water reactor power station

9 Nuclear Engineering and Design vol. 45, 1978
Bardtenschlager et al
Decommissioning of light water nuclear power plants

10 IAEA-SM-234/2, November 1978
Essman et al
Provision for decommissioning of the German utilities for LWR power plants

11 T Milchert (Saltech) Report Prav 1.15, 1978
Transport av låg- och medelaktivt radioaktivt avfall till avfallslagret ALMA
(Transport of low- and medium-level radioactive waste to waste storage facility ALMA)
(In Swedish)

12 L Devell et al
Report Prav 1.31, 1980
Safety analysis of sea transportation of solidified reactor wastes

13 L Devell et al
Report Prav 1.29, 1980
Safety analysis of final storage for low- and medium level wastes

14 Personal communication
Sven-Gunnar Håkansson, Oskarshamn Station
Lars Venner, Barsebeck Station

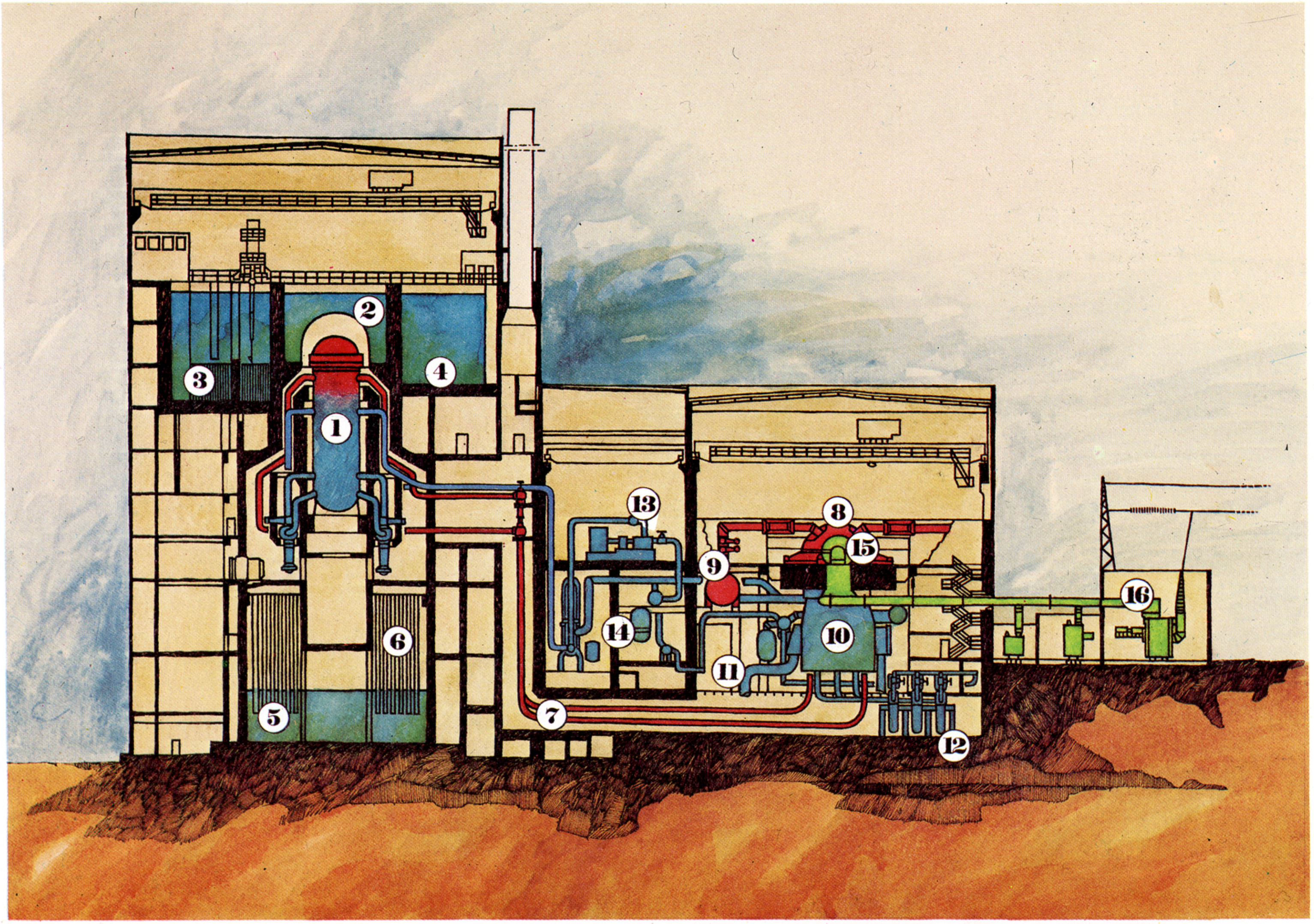
Aktivt material, placeras i **skärmad** transportbehållare — *Radioactive material, **shielded** transport container*

Aktivt material, placeras i **icke skärmad** transportbehållare — *Radioactive material, **non-shielded** transport container*

Icke aktivt material, ($<10^{-4} \mu Ci/cm^2$) (efter viss rengöring) — *Non-active material, ($<10^{-4} \mu Ci/cm^2$)*

Barsebeck nuclear power plant - Reactor and Turbine buildings

Barsebeck Nuclear Power Plant—Reactor and Turbine buildings.

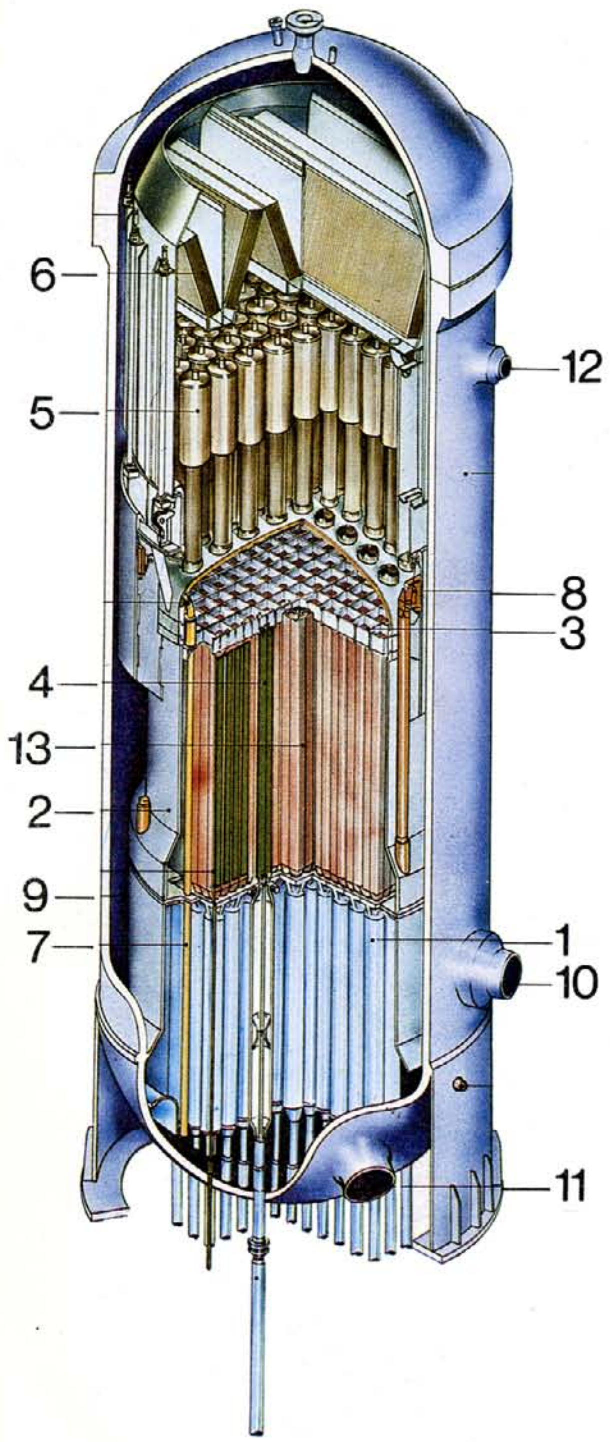


1 Reactor vessel
2 Reactor pool
3 Fuel storage pool
4 Storage pool internal parts
5 Condensation pool
6 Blow-down pipes
7 Main steam pipes
8 Turbine
9 Reheaters
10 Condenser
11 Cooling water
12 Condensate pumps
13 Feedwater pumps
14 Feedwater heaters
15 Generator
16 Main transformer

Appendix 9.3

Reactor vessel and internals

Reactor vessel and internals



1. Control rod quide tube
2. Moderator tank
3. Core grid
4. Control rod
5. Steam separator
6. Moisture separator
7. Core spray pipe
8. Feedwater mainfold
9. Downcomer
10. Outlet spigot for cooling water to the circulation pump
11. Inlet spigot for cooling water from the circulation pump
12. Steam outlet
13. Reactor core

System diagram - Activity classification

SYSTEM DIAGRAM – ACTIVITY CLASSIFICATION

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214	Steam separators
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312	Feed-water lines
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322	Containment vessel spray system
323	Low pressure coolant injection system
324	Pool water cooling and clean-up system
326	Pressure vessel head cooling system
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332	Condensate clean-up system with precoat filters
341	Off-gas delay system
342	Liquid waste system
351	Boron system
352	Controlled leakage drain system
353	Leakage control system
354	Hydraulic scram system

4 TURBINE PLANT

431	High pressure turbine
433	Low pressure turbine
452	Steam reheat system
454	Seal and leakage steam system
461	Condenser and vacuum system
462	Condensate system
463	Feed-water system
471	Generator cooling system
472	Auxiliary cooling water system
482	Leakage, drain and drying system

7 SERVICE SYSTEMS

711	Cooling water screening plant
712	Shut-down cooling water system
713	Normal operation cooling water system for priority demands
714	Normal operation cooling water system for non-priority demands
721	Shut-down secondary cooling system
723	Normal operation secondary cooling system for priority demands
731	Raw water treatment system
732	Water demineralization system
733	Fresh demineralized water distribution system
734	High pressure purge water system
741	Containment vessel gas treatment system
742	Reactor building ventilation system
754	Compressed nitrogen system

Appendix 1

ASEA-ATOM

Promemoria
Memorandum **PM**

TK 79-217 Rev 2

Distribution

Från/From	Datum/Date	Reg.	Page Sida 1

Författare/Author
Lars Nilsson

Granskad/Examined

Godkänd/Approved

Titel/Title

Dismantling of Swedish nuclear power plants

Sammanfattning/Abstract

CONTENTS

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1. Premises

General

A 590 MW ASEA-ATOM BWR, mainly Oskarshamn unit II, will serve as a reference plant, but its differences compared to Barsebeck unit 1 will also be studied. The results are to be applicable to other plants as well, where possible.

The plant is to be dismantled completely so that the site can be used for another purpose.

The station has been in operation for 40 years with an availability factor of 0.8. The dismantling work starts one year after shutdown, at which point spent fuel and normally replaceable radioactive equipment has been transported away.

It is assumed that the plant has functioned normally throughout its operational life without any incident involving the release of a large quantity of activity. Some operating leakage has been assumed, however, (see below).

The experience of the plant's operating and maintenance personnel shall be utilized for planning work as well as for supervision of the dismantling of equipment, especially during the early phases.

The study assumes that dismantling will be carried out using known techniques, even though better methods will undoubtedly be available when the time comes. Both personnel safety and protection against releases to the environment shall be taken into consideration in selecting working methods.

Inspection functions shall be equivalent to those used in nuclear power plant construction, where applicable.

Calculation of the activity inventory shall also take into account the results of foreign (mainly American) studies. Simple decontamination procedures shall be followed, such as washing with a high-pressure spray or removal of small concrete surfaces.

Surfaces with contamination less than

10^{-4} $\mu Ci/cm^2$ for β- and γ-radiation and

10^{-5} $\mu Ci/cm$ for α-radiation

shall be considered non-active.

Waste with surface contamination in excess of these values and waste with induced or absorbed activity in excess of 0.002 μCi/g shall be regarded as active waste.

Radioactive waste shall be transported to a central waste facility, Prav's ALMA. The transport packages shall conform to Prav's specifications, with internal dimensions 2.5 x 3.7 x 2.7 m.

The containers can be of two types: An unshielded container of steel with an unladen weight of 10 tonnes or a shielded container of concrete with an unladen weight of 52 tonnes. The total laden weight of the container may not exceed 100 tonnes. Material with a surface dose rate of up to 30 mrem/h can be transported in the unshielded container and material with up to 1 rem/h in the shielded container. These values are calculated so that the transport regulations of IAEA are complied with.

The possibilities of reusing components and materials shall normally not be credited to the project.

At the time of the dismantling work, there are no nuclear power units in operation on the site, so that the dismantling work can be carried out without taking such factors into consideration.

The cost calculation shall assume the cost level in mid-1979.

2. Extent of AA's share of the study

AA's share of the dismantling study includes:

- estimate of activity inventory for reactor vessel with internal components
- estimate of activity inventory for reactor's primary and auxiliary systems
- estimate of activity inventory for building components
- studies of methods and estimate of costs for dismantling of active parts of reactor and turbine plant
- estimate of costs and waste quantities for active plant components
- assessment of radiological impact
- proposal for a dismantling sequence and timetable

3 Activity quantities and radiation levels

3.1 Introduction

A detailed account of calculations and results concerning activity quantities and radiation levels is provided in ref. 1. A summary of the most important points follows below.

The plant's controlled area is assumed to have been kept relatively clean, i.e. activity dispersal has been limited to normal operating leakage. Incidents involving the release of large amounts of activity have not occurred during the operating period.

The plant is assumed to have suffered only moderate damage to its core during its operating life. In the following, it is assumed that such damages have been limited to 10% of the design fuel damage, i.e. 0.1% fuel failures.

3.2 Neutron-induced activity in and surface activity on reactor vessel and internal components

Activity calculations have been carried out using the computer program AKTGAMMA.

As regards the composition of the constituent structural materials, the goal has been to use as realistic values as possible. In most cases, the compositions used have been obtained from average values from a number of material certificates.

It is assumed that the materials have been irradiated for a total of 40 years, with 7 200 EFPH per year. The activity per gram of material after the last year's irradiation has been calculated for a number of different decay times up to 1 000 years. As an example, the activity per gram of core grid is reported in diagram 1. In addition to total activity as a function of decay time, the contributions from different nuclides are also presented.

As is evident from diagram 1, activity after one year of decay is dominated by Fe-55, Co-60 and Ni-63. The dominant gamma radiation source is Co-60, which thereby determines the radiation shielding requirement. After very long decay times (> 500 years), Ni-59 dominates the activity.

The amount of surface activity on the components that come into contact with the reactor water (known as "crud") is considerably more difficult to estimate. Determinations using the measuring instrument MADAC (Mobile Analyzer for Detection of Crud in piping) have given a value of about 10 mCi/m^2 Co-60 from measurements of pipelines in Oskarshamn II. After 40 years of operation and one year of shutdown, it is estimated conservatively that this figure will have increased to about 50 mCi/m^2 Co-60. As in the neutron-induced activity in structural materials, Co-60 is expected to be the dominant gamma radiation source in crud.

On the basis of recorded values for the material composition of the crud on the fuel cladding, and with the aid of the computer program AKTGAMMA, an estimate of the amount of other nuclides relative to Co-60 has been made. The resulting values for the surface contamination are presented in Table 1. In addition to the radioactive corrosion products Co-60, Ni-59, Ni-63 and Fe-55, a certain contribution from fission products has also been included. MADAC measurements of pipes and components in Oskarshamn 1 have shown that this contribution amounts to a maximum of 10% of the Co-60 activity.

CORE GRID
Material stainless steel SIS 2333, operating period 40 years

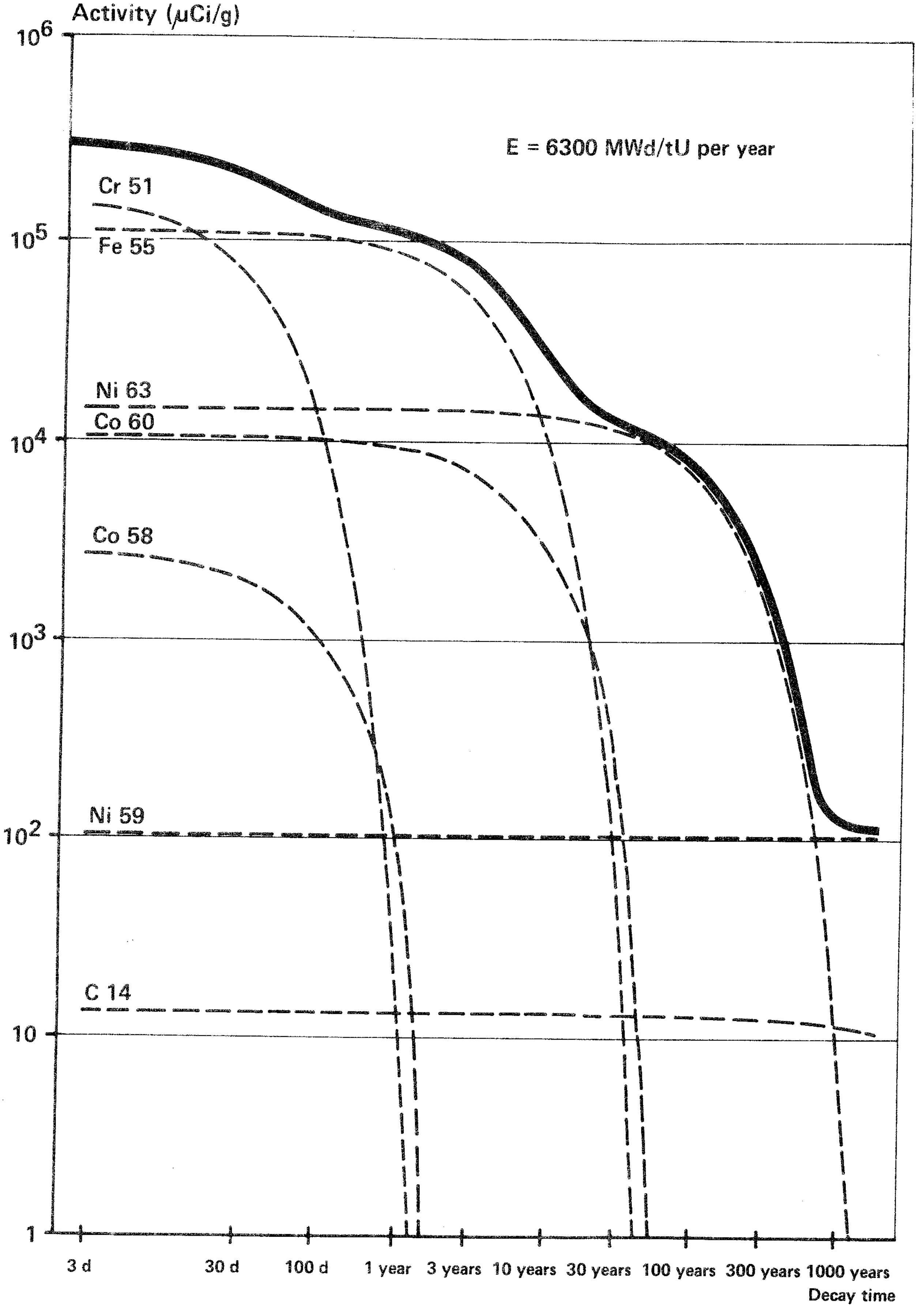


Table 1 - Surface activity on surfaces in contact with reactor water

Fe-55	50	mCi/m^2
Co-60	50	"
Ni-59	0.2	"
Ni-63	3	"
Fiss prod	5	"

Activity data for the reactor vessel with internal components are presented in Table 2. The specific activity (Ci/tonne Co-60 and Ci/tonne total activity) of each component is given.

As is evident from Table 2, the activity varies widely in different internal components, depending upon how close to the core they have been situated. The core grid, the moderator tank and the core spray risers have the greatest amount of activity, with about 10^4 Ci/tonne Co-60, which means radiation levels on the order of $>10^4$ rem/h in the vicinity of the components.

Table 2 - Neutron-induced activity in and surface activity (crud) on reactor vessel and internal components in Oskarshamn 2 after 40 years of operation

Component	Co-60 Ci/tonne	Total Ci/tonne
Steam dryer	3.0	6.4
Steam separators	2.4	5.1
Moderator tank head with core spray	14	150
Moderator tank	2.1(3)	2.4(4)
Core grid	9.2(3)	1.1(5)
Core spray risers	1.7(4)	1.9(5)
Control rod guide tubes	4.0	20
Water distribution baffle	3.6(-1)	7.8(-1)
Neutron detector guide tubes	2.9	15
Control rod drives	1.1(-1)	2.4(-1)
Neutron detector housings	4.6(-1)	1.0
Control rod drive housings	4(-2)	8.2(-2)
Feedwater spargers	1.4	4.7
Head cooling circuit	1.6	3.4
Reactor vessel (carbon steel + stainless steel cladding)	3.2(-1)	3.6
Reactor vessel head (carbon steel + stainless steel cladding)	2(-2)	4(-2)

3.3 Neutron-induced activity in biological shield

Neutron-induced activity in the concrete and reinforcement in the biological shield has been calculated using the computer program AKTGAMMA. The calculation method is the same as for the calculation of activity in internal components.

Normally, no analysis is made of the material composition of the reinforcing bars, which means that some uncertainty exists (especially for trace elements).

In order to obtain a reasonable estimate of the material composition in the concrete, three representative samples have been taken from the biological shields in Barsebeck, Forsmark and Olkiluoto. These samples have been analyzed at ASEA's laboratory with respect to a large number of elements.

Fig. 1 shows the part of the biological shield which, according to the premises in section 1, contains neutron-induced activity (>2 μCi/kg). The lined area contains about 500 tonnes of concrete and 33 tonnes of reinforcing bar. Other parts of the biological shield can be regarded as inactive to the extent that they are not contaminated.

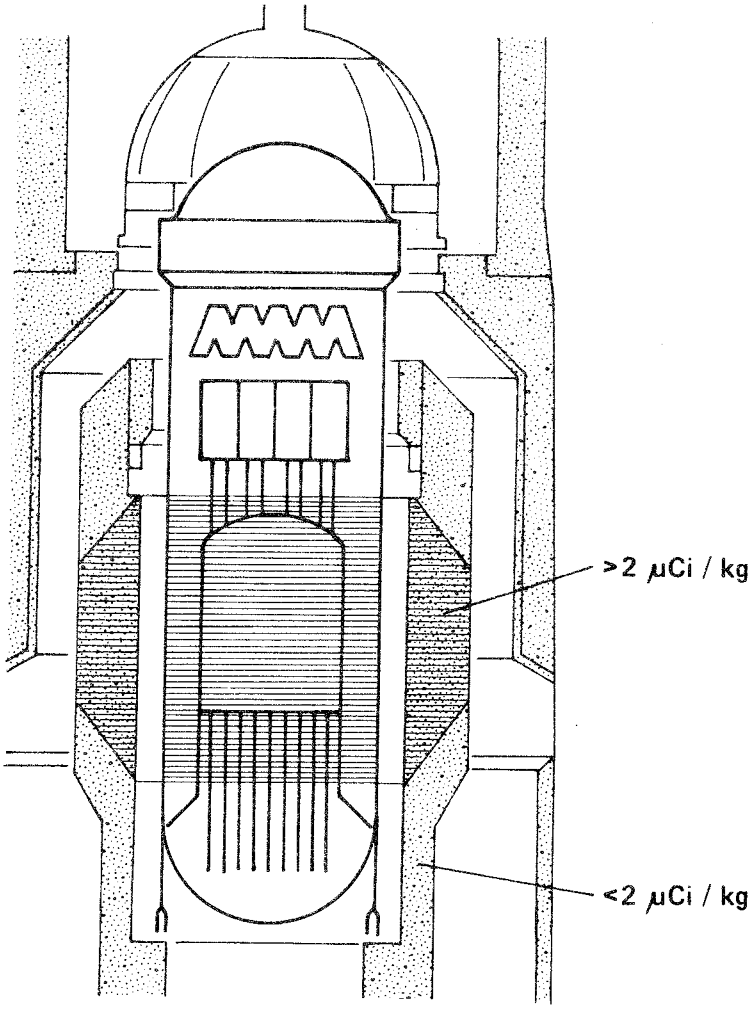


Fig. 1 Parts of the biological shield and reactor vessel with internal components containing neutron-induced activity greater than 2 µCi/kg.

Table 3 shows the activity contributions of different nuclides in the biological shield. The dominant nuclide in terms of activity is H-3. Other nuclides of importance are Fe-55, Co-60 and Ca-45. The dominant gamma radiation source is Co-60.

Table 3 - Neutron-induced activity in biological shield, decay time one year - approx. 500 tonnes of concrete and 33 tonnes of reinforcing bar.

Nuclide	$T_{1/2}$	Activity (Ci)
H-3	12.3 y	4.1(2)
C-14	5730 y	1.6(-2)
Ca-41	80000 y	3.2(-1)
Ca-45	162.7 d	1.3(1)
Mn-54	313 d	1.8(0)
Fe-55	2.7 y	2.0(2)
Co-60	5.26 y	2.1(1)
Ni-63	92 y	2.4(-1)
Total		6.4(2)

The radiation level on the inside of the biological shield is estimated at <100 mrem/h. Of the above 530 tonnes of concrete and reinforcing bars, approximately 30% has to be transported in shielded containers, while the rest can be transported in unshielded containers. Alternatively, unshielded transport containers can be used for all the concrete if the most active concrete scrap is diluted with less active concrete.

Owing to the very moderate radiation level, the dismantling work should be able to be carried out without special demands on radiation shielding. The risk of airborne activity is great, however, so measures must be taken to prevent the dispersal of radioactive dust.

3.4 Activity in service and process systems

The results of the above-mentioned MADAC measurements and of dose rate measurements have been used to estimate the activity level in the reactor station's different process systems. Experience shows that most of the contamination in process systems stems from radioactive corrosion products (crud).

More sophisticated system decontamination is not expected to be performed. Simpler decontamination such as washing with a high-pressure spray is expected to be carried out to some extent. It is assumed that a large portion of the turbine systems (condenser, condensate and feedwater systems) can be rendered inactive in this manner. Many of the reactor's cold process systems (e.g. 322, 323, 324 or 352) should be able to be decontaminated, but this has not been assumed.

In a few systems, fission products are expected to constitute the dominant activity. This applies especially to certain gas treatment systems. The delay tank in system 341 contains about 965 m^3 sand in which daughter products of radioactive noble gases are expected to accumulate. An estimate has been made of the activity inventory in the sand assuming 40 years of operation with 0.1% fuel damage and one year of decay. The resulting activity inventories are presented in Table 4. The nuclides Sr-90 and Cs-137 dominate. The activity concentration in the sand is low, so that the sand can be transported in a non-shielded transport container (after being packaged in e.g. a 200 litre metal drum). Furthermore, since most of the activity is at the bottom of the sand tank, it should be possible to classify the sand in the rest of the tank as inactive.

Table 4 - Activity inventory in sand from delay tank for active gases (total 965 m^3 sand)

Nuclide	$T_{1/2}$	Activity (Ci)
Rb-87	$5 \cdot 10^{10}$ y	1.0(-8)
Sr-90	28.9 y	4.6
Cs-135	$2.3 \cdot 10^{6}$ y	1.0(-3)
Cs-137	30.2 y	8.4
Total		1.3(1)

Appendix 1 presents the weights of the radioactive components in the station's process and service systems. The table indicates the portions of the systems that have to be transported in shielded or unshielded containers and the portions that constitute inactive waste.

3.5 Activity in concrete around fuel, reactor and condensation pools

The fuel, reactor and condensation pools are lined with stainless steel. Experience shows that this lining is not completely leakproof, so that radioactive water leaks out to the surrounding concrete. Measured values for the fuel and reactor pools in the Oskarshamn reactors vary within the inverval 1-10 l/h. The condensation pool is not expected to leak to a corresponding degree.

The leakage water penetrates the concrete after a period of time. The concrete, however, has proved to have very good filtering capacity, since samples of the water that has leaked through the concrete contain only negligible quantities of radioactivity.

An estimate has been made of expected activity inventory in the concrete, both outside the reactor/fuel pools and outside the condensation pool. It has been assumed that both types of pool leak 5 l/h and that this leakage has been going on throughout the life of the station (= 40 years). The activity content of the reactor, fuel and condensation pool water has been estimated on the basis of values measured in Oskarshamn 1.

Assuming complete filtration in the concrete, the activity inventories in the concrete after final storage shutdown have been calculated. The results are reported in Table 5.

Table 5 - Activity inventory in concrete outside of pools

Reactor/fuel pool

Nuclide	$T_{1/2}$	Activity (Ci)
Co-60	5.26 y	0.007
Sr-90	28.9 y	0.2
Cs-134	2.06 y	0.01
Cs-137	30.2 y	0.2

Condensation pool

Nuclide	$T_{1/2}$	Activity (Ci)
Co-60	5.26 y	0.07
Sr-90	28.9 y	0.5
Cs-134	2.06 y	0.04
Cs-137	30.2 y	0.5

As is evident from Table 5, the activity level in the concrete is relatively moderate. The activity is assumed to be concentrated to the first few centimetres outside the stainless steel lining and to a few large cracks in the concrete.

4 Dismantling methods

4.1 General

4.1.1 Initial assumptions

Before dismantling of the plant is begun, all fuel has been transferred from the reactor to the fuel pools and then transported away from the station.

The reactor and turbine systems have been emptied of their water content to the waste building for normal treatment. All consumable materials such as ion exchange resin and filter aid have been removed and disposed of in the normal manner.

Only the reactor pools and the reactor vessel are filled with water and the appurtenant pool water clean-up system is operative.

Other equipment that is normally replaced at regular intervals during the life of the station, such as control rod drives, control rods, core instrumentation, neutron sources etc. have been dismantled and disposed of in accordance with normal routines.

Power to all electrical appliances in the buildings or building sections in question has been cut off. Only the ventilation system and the floor drainage system are kept supplied with power.

4.1.2 Transport containers

The required number of transport containers has been estimated on the basis of ALMA's transportation system, with internal container dimensions (WxLxH) = 2.5 x 3.7 x 2.7 m.

Two types of container have been assumed:

- unshielded steel container with an unladen weight of 10 tonnes

- shielded concrete container, wall thickness 35 cm, with an unladen weight of 52 tonnes

Parts with surface dose rates of up to 30 mrem/h are transported in the unshielded container and up to 1 rem/h in the shielded container.

The laden weight of the container may not exceed 100 tonnes.

4.2 Reactor vessel with internal components

4.2.1 General

A detailed account of methods used in the dismantling of the reactor vessel with internal components is provided in ref. 2. A summary of the most important points follows below.

4.2.2 Dismantling procedure

As is noted in section 3, the activity in the internal components of the reactor vessel varies widely depending upon how near the core they have been situated. The core grid, moderator tank and core spray risers have the greatest activity, with radiation levels on the order of $>10^4$ rem/h near the components. These components must be cut up and packaged under about 2 m of water. Other internal components with considerably lower neutron-induced activity are also cut up under water in order to reduce the dose burden. But the depth of water coverage required is considerably lower. In addition, the components can be lifted up above the surface of the water for a short period of time during handling and turning operations.

The internal components that are made of stainless steel can be cut up under water by means of plasma cutting or arc sawing. These methods are described in ref. 1 and 2. Swedish experience has been gained in plasma cutting from e.g. the repair work on feedwater spargers in the reactor vessel at Oskarshamn 1.

The reactor vessel, which is made of carbon steel (130 mm with 3-5 mm stainless steel facing on the inside), can be cut up in air. The radiation level in the tank is moderate, between 1 and 10 rem/h. Before the reactor vessel is drained, it is vacuum-cleaned in order to remove traces of radioactive materials on the bottom of the vessel.

A number of methods can be used to cut up the reactor vessel:

- arc gouging and gas cutting, oxy-acetylene torch,
- plasma cutting and gas cutting, oxy-acetylene torch,
- grinding and gas cutting, oxy-acetylene torch,
- direct through-cutting with oxy-acetylene torch from the outside.

Oxygen gouging is used for the thick material in the vessel flange.

The reactor vessel is cut up from a radiation-shielded work platform located on the reactor vessel. The required thickness of the radiation shield is about 10 - 15 cm of steel.

The radiation protection is designed so that the personnel can occupy the platform continuously. Adjustment and inspection of cutting torches etc. is done through lead glass windows. Exhaust of dust and gases is arranged at each torch. The top of the platform is covered and provided with a special fresh air supply. The personnel on the platform should wear protective masks. In general, remote control should be employed wherever possible in order to minimize the dose burden on the personnel.

Cutting up of the reactor vessel with internal components is described in greater detail in ref. 3.

Only small quantities of airborne activity are expected to be generated by the cutting of active components under water. To some extent, the radioactivity is emitted with the aerosols that are formed in connection with plasma cutting under water, but the quantities are small and can easily be captured by means of a simple ventilation extractor above the surface of the water connected to the plant's filter system.

The problems associated with cutting in air are considerably greater. Attention must therefore be devoted to the question of ventilation in connection with cutting up of the reactor vessel in order to reduce activity dispersal.

Most of the reactor's internal components require more radiation protection than the 35 cm of concrete included in the shielded waste containers of the ALMA type. Packaging must take place under water. The ALMA containers are therefore furnished with inner containers that give extra radiation shielding and can be handled under water. Inner containers are also used when no extra radiation protection is required, in which case they can be made of steel. The inner containers are filled under water and then lifted up into the ALMA containers, which are standing on the floor of the reactor hall. In this way, external contamination of the ALMA containers with radioactive pool water is avoided.

4.2.3 Special equipment

The following special equipment is required:

- radiation-shielded work platform for cutting up the reactor vessel in air, equipped with cutting torches, hydraulic shears or cutting wheel, picking tools, high-pressure spray equipment, fresh air equipment etc.

- manipulators for cutting up the reactor's internal components under water, equipped with plasma cutting torches or arc saws.

- cutoff equipment for control rod drive housings etc. under water.
- lead box with manipulator for certain cutoff work in air.
- extra work platform above reactor and handling pools.
- radiation-shielded control cabin for overhead cranes.
- diverse lifting tools for underwater and above-water handling.
- inner containers of varying thickness for ALMA containers, incl. handling equipment.
- extraction equipment for airborne activity from plasma cutting, under and above water.
- high-pressure spray equipment.

To this list can be added various types of hand tools, which can become contaminated during the course of the work.

4.2.3 Transport containers

The following are required for the transport of the cut-up reactor vessel with its internal components:

- 19 unshielded steel containers
- 64 shielded concrete containers

of type ALMA. In addition:

- 34 extra inner containers

of steel or concrete for handling of internal components under water and, in some cases, as extra radiation protection for the ALMA containers.

4.3 Active systems and system components

4.3.1 Dismantling procedure

Dismantling of the radioactive systems and system components is done area-by-area to as great an extent as possible. In order to enhance accessibility and facilitiate the removal of the radioactive parts, it may be necessary to dismantle certain wall sections out to the surrounding corridor system and to dismantle equipment in the corridors in order to make room for electric truck transports within the station.

The cutting up of pipes and valves is based on the same methods and procedures as those that are used in the maintenance work at nuclear power plants today.

This is normally done with a pipe lathe or cold saw which can be applied quickly to the cutoff point and then operate without continuous supervision. In hard-to-reach spots, the work is done with a disc grinder.

Small-bore pipes are cut up with hydraulic shears.

Heavier units, for example large heat exchangers, ion exchange vessels etc., that cannot be put directly into waste containers are cut up into suitable pieces by means of plasma cutting.

Pipes, tubes and components in the active areas are cut up into as large pieces as possible in order to minimize the time that has to be spent by personnel in these areas, and thereby minimize the dose burden on the personnel. The pieces are then taken to a nearby area, where the pipes can be cut up into suitable lengths for the waste containers. The pieces are then transported by electric truck through the corridor and lift systems to the ground level of the hoist shaft, where the waste containers are filled.

The stainless steel lining of the pools in the reactor hall and the reactor containment is cut up with shears or a disc grinder. Radioactive material adjacent to the grouted-in support beams for the pool lining is chiselled off.

Plasma cutting is used for the radioactive parts of the turbine installation, especially the high-pressure turbine and the reheater.

The advantage of using a pipe lathe or cold saw to as great an extent as possible is that contamination of the area by airborne activity is avoided at the same time as the work can be done without continuous supervision.

When a disc grinder or plasma cutting device is used, the dispersal of radioactivity to adjacent areas or to the environment is prevented by the station's ordinary ventilation system, since the ventilation air from the areas containing radioactive systems is taken from surrounding inactive areas and is then exhausted to the stack without passing through other areas.

It is possible to run the ventilation air from the various radioactive system areas to filter units in system 341, the system for radioactive off-gases, where any airborne activity will be removed before the ventilation air is discharged to the chimney stack.

In isolated cases, for example if access openings have been made in the wall to surrounding corridors, provisional ventilation may be required around certain components in the form of plastic tents connected to provisional fans and filters or to the regular ventilation system.

The same procedure is used for cutting up the turbine plant's active components in order to prevent the dispersal of airborne activity to the turbine hall and the environment.

In order to further reduce the dispersal of airborne activity, all dismantled parts are immediately wrapped in plastic, all openings are sealed with plastic etc.

4.3.2 Special equipment

Special equipment includes:

- temporary radiation protection, for example lead box for ion exchanger work

- provisional fans and filters

- lifting equipment

- mechanical shearing and cutting equipment

- plasma and gas cutting equipment

- cold saws

- shearing tools

and similar items of equipment which can be expected to be contaminated during the course of the dismantling work.

4.3.3 Transport containers

65% has been assumed as a typical value for the degree of fill (in terms of volume) of the transport containers. Assuming this degree of fill, the container load will be as follows:

Pipe size, mm	Container load, tonnes
A200 (Ø 214 x 14.5)	18
A200 (Ø 205 x 2.5)	5
A125 (Ø 140 x 11)	27

Based on an estimated distribution of the different pipe sizes in the radioactive systems and system components, the mean load per waste container has been estimated to be 10 tonnes.

The following numbers of filled transport containers of type ALMA are obtained:

- 310 unshielded steel containers

- 60 shielded concrete containers

To this should be added 5 000 metal drums of 200 litres each for the sand in the delay tanks in system 341 - System for radioactive waste gases.

4.3.4 Provisional waste handling

In connection with the dismantling of radioactive equipment in the reactor and turbine buildings, all radioactive waste water from the systems and from the decontamination of walls and floors is delivered to the waste building for normal treatment and disposal.

Small amounts of radioactive liquid are also obtained from the dismantling of the waste building. This liquid must be treated in a provisional waste system consisting of filters of a type similar to those in the waste building.

5. Timetable

The timetable for dismantling of radioactive systems and system components is shown in Appendix 2. The timetable is based on 8-hour shifts, 5 working days a week.

The timetable assumes that the plant has been shut down approximately one year before the start of the dismantling work. During this time, all reactor fuel has been removed from the reactor and transported away from the plant, which enables the dismantling work to be conducted without any restrictions due to reactor safety considerations. The same standards with respect to dose burdens on working personnel and the environment prevail as during the operation of the plant.

It is assumed that all necessary dismantling permits have been obtained, plans and instructions have been drawn up, the entire station has been radiologically mapped and the necessary special equipment has been designed, manufactured and tested.

The critical path goes through the dismantling of the reactor vessel and internal components. Other activities, for example dismantling of reactor systems outside the containment and dismantling of radioactive systems in the turbine building, can be done in a shorter time than that indicated in the timetable by using more personnel per shift. This is not possible where the reactor is concerned, owing to the limited space in the reactor vessel and reactor pools.

The dismantling work is begun with removal of the internal components from the reactor vessel, after which they are cut up and the pieces are placed in transport containers. This is done under water in the reactor and handling pools.

At the same time, work is begun on dismantling the radioactive systems in the reactor building outside of the reactor containment, all except for system 324 - Cooling and clean-up system for fuel pool with necessary auxiliary equipment, which is required for maintaining and cleaning the water in the reactor and handling pools.

The dismantling work on the radioactive turbine systems can also start immediately and can be carried out independently of dismantling activities in other parts of the plant.

The dismantling work is started with decontamination and rinsing out of the systems with water. The waste is conducted to the waste system via existing drainage lines for treatment in accordance with normal operating routines.

When the internal components have been dismantled and transported out of the station, all pools as well as the reactor vessel are completely drained of water to the waste building.

Dismantling of the reactor vessel then starts parallel to dismantling of the reactor systems inside the reactor containment as well as the equipment in the reactor pools and the condensation pool.

When all radioactive equipment has been dismantled, all radioactive building components have been removed and all areas have been decontaminated and approved as being free from radioactivity, connecting drainage systems for radioactive water to the waste building and remaining ventilation systems for the areas in question are dismantled.

Last of all, the waste plant is dismantled. Small quantities of radioactive water from this dismantling work are treated in a provisional waste plant.

6. Personnel requirements

An estimate of the personnel requirement for the dismantling of active systems and system components and the packaging of the active components in containers of the ALMA type is presented below. The personnel requirement is divided between white-collar and blue-collar workers. Note that this does not include the services which are normally provided by the operator, such as security, housekeeping, radiation protection etc.

1. Planning of the dismantling work

This includes the preparatory planning of the dismantling work before the start of dismantling. Planning and follow-up during the course of the work are included in the estimated labour requirements for each part of the plant.

The estimated labour requirement is 35 man-months.

2. Technical documentation, instructions, safety analysis report

This includes preparation of the necessary technical documentation for the planning and execution of the dismantling work, preparation of instructions for the dismantling work, preparation of a safety analysis report, follow-up and reporting to safety authorities.

The estimated labour requirement is a total of 250 man-months.

3. Decontamination

Advanced decontamination procedures for radioactive systems and system components are not foreseen. Simpler decontamination, such as chipping-away of small contaminated concrete surfaces, washing with a high-pressure spray etc., is expected. Only the turbine with auxiliary systems, not including the high-pressure turbine with appurtenent systems and reheaters, are assumed to be decontaminated to an inactive level, see section 1. Premises for the study.

The required labour input for decontamination of the turbine with above-mentioned systems by means of high-pressure spraying, wiping with rags etc. is estimated to be about 30 man-months.

4. Dismantling of reactor vessel with internal components

The manpower required for dismantling the reactor vessel with internal components, control rod drive housings etc. is estimated at 290 man-months (blue-collar labour) plus 15% for overhead crane operators, stores personnel etc. The total blue-collar requirement is thus about 330 man-months.

The white-collar manpower requirement during the dismantling period is estimated to be about 120 man-months.

5. Dismantling of active systems and system components

In order to estimate the labour requirement for the dismantling of active systems and system components in the reactor and turbine section, the dismantling procedure for three typical systems has been studied in greater detail. Dismantling labour requirements for installation of the systems. These values are known for the various systems and system components.

The following systems were chosen:

- System 321 - Reactor shut-down cooling system. The system is a stainless steel high-pressure system situated partially outside and partially inside the reactor containment.

- System 322 - Containment vessel spray system. The system is a stainless steel low-pressure system situated outside the reactor containment.

- System 331 - Reactor water clean-up system. The system is a stainless steel high-pressure system situated outside the reactor containment.

The following results were obtained:

System	Installation kg/man-hour	Dismantling kg/man-hour	Manpower requirement % dismantling/installation
321	8.5	11	77
322	6.3	8	79
331	9.6	10.7	90

The manpower requirement for dismantling is estimated on these grounds to be about 70% of the installation requirement, figured as an average for the entire plant.

This requirement is then multiplied by a factor of 3 to adjust for the difference between work in contaminated and non-contaminated systems. This factor is based on experience from the maintenance work that is carried out annually by AA in already commissioned plants.

The total manpower requirement for dismantling a contaminated system is thus 0.7 x 3 $\sim$ 2 times the original installation requirement.

The material weights for these systems are estimated on the basis of existing documentation in the form of component specifications, installation drawings etc.

The weights of these systems are adjusted upwards by 30% as an allowance for small-bore pipes and insulation. 10% of the insulation is assumed to be contaminated due to leakage from packings and flange connections in components. The weights are then distributed between contaminated and non-contaminated components of each system, see Appendix 1, on the basis of activity estimates according to section 3 "Quantities and activity contents".

Weight data on the turbine section has been obtained from STAL-LAVAL.

In calculating the manpower requirement for dismantling of all contaminated systems and system components, the average value of the manpower requirements for the installation of the corresponding components was used: 10 kg/man-hour, reduced by a factor of 2 (see above), i.e. 5 kg/man-hour to adjust for the difference between work in active and inactive systems (see Appendix 1). The specified manpower requirement is therefore not exactly correct for each individual system, applying instead to all systems taken together.

The specified requirement includes dismantling of the systems, cutting up into suitable lengths for the transport containers, packing of the containers and transport of the containers out of the station.

Dismantling of active systems and system components, including packing in containers that are located outside the reactor building, thus requires a total of about 740 000 man-hours or 4 600 man-months of direct blue-collar labour.

Indirect blue-collar labour for stores personnel, crane operators etc. must be added to the above figure. Based on previous experience from similar installation work, the amount to be added is about 15%. The total blue-collar labour requirement is thus about 5 300 man-months.

The actual ratio between labour requirements for white-collar and blue-collar workers in the erection of Barsebeck 2, including personnel for both ASEA-ATOM and ASEA-ATOM's subcontractors, was 36%/64%. The corresponding ratio for dismantling is assumed to be 30%/70%. The white-collar labour requirement at the plant site will thus be about 2 270 man-months.

Note that this does not include the services that are normally provided by the operator, such as security, housekeeping, radiation protection etc.

6. Summary of personnel requirements

The total personnel requirements for the dismantling of active systems and system components are presented below

	White-collar man-months	Blue-collar man-months
Planning of dismantling work	35	-
Preparation of technical documentation etc.	250	-
Decontamination of turbine plant	-	30
Dismantling of reactor vessel, internal components	120	330
Dismantling of active systems and system components	2 270	5 300
Total manpower requirement	2 700	5 700

The chronological distribution of the labour force during the dismantling period is shown in Appendix 4.

7. Radiological impact

ASEA-ATOM has made a rough estimate of the collective dose as follows:

a) Reactor vessel with internal components

The labour requirement according to section 3 is 12 men, 5 days/week for two years, i.e. 1 080 man-weeks.

It is assumed that the men work about 6 h/day in a radioactive environment, broken down as follows:

1%	- special lifts, etc.	100 mrem/h
10%	- work near reactor vessel, transport of containers etc.	10 mrem/h
89%	- remote-controlled dismantling, work above pool, etc.	1 mrem/h

The collective dose is then 93 manrem, say 100 manrem. The individual dose is then about 4 rem/year. The permitted dose is 5 rem/year.

b) Active systems and system components

Labour requirements as per Appendix 1.

It is assumed that the men work about 50% of the time in a radioactive environment. The following doses are then obtained.

System	Man-hours	Man-hours / 2	Dose rate mrem/h	Collective dose manrem
243	30 000	15 000	1	15
244	20 000	10 000	1	10
245	2 000	1 000	1	1
253	1 000	500	2	1
311	27 680	13 840	1	14
312	7 260	3 630	10	36
313	49 140	24 570	50	1 230
314	9 340	4 670	1	4.5
316	70 000	35 000	1	35
321	16 740	8 370	50	420
322	16 740	8 370	1	8.5
323	24 940	12 470	1	12
324	6 400	3 200	3	10
326	960	480	50	24
331	27 440	13 720	50	690
332	42 000	21 000	1	21
341	2 800	1 400	3	4
342	32 400	16 200	1	16
343	16 000	8 000	1	8
344	420	210	1	0.5 (344–345)
345	490	245	1	
351	645	320	50	16
352	3 825	1 910	10	19
353	300	150	10	1.5
354	45 360	22 680	3	68
411, 412, 413, 414, 419, 432, 455	281 000	140 500	1	140
741	1 200	600	1	0.5
				2 805

Work at the highest radiation levels (i.e. around system 313 - Reactor coolant circulation system, 321 - Reactor shutdown cooling system, 331 - Reactor water clean-up system, 351 - Boron injection system) will not be done in practice as described above. By means of radiation protection measures (extra radiation shielding, remote control, dismantling of more radioactive components in each area to reduce radiation in the area before the other components are dismantled), it should be possible to reduce the doses by a factor of 5.

The collective dose will then be about 900 manrem.

c) Dismantling of active building components
Estimated at about 50 manrem.

d) Radiation protection etc.
Estimated at about 150 manrem.

The total collective dose will then be about 1 200 manrem.

8. Cost estimate

8.1 General

A summary of the costs reported in the previous section is presented below.

The cost level corresponds to the summer of 1979. Labour charges are calculated in accordance with prevailing rates for service and maintenace work on reactor plants, i.e.:

- blue-collar workers about SEK 21 000/man-month

- white-collar workers about SEK 29 000/man-month

A 25% contingency allowance for unforeseen costs is added to the reported total.

8.2 Reactor vessel with internal components

	SEK mill.	Total SEK mill.
Planning of dismantling work		
- White-collar employees	3.5	3.5
Dismantling of reactor vessel with internal components		
- White-collar employees	3.5	
- Blue-collar workers	9.5	38
- Special equipment	25	
Total		41.5
Plus 25% contingency		10
Total, approx.		50

8.3 Active systems and system components

	SEK mill.	Total SEK mill.
Planning of dismantling work		
- White-collar employees	1	1
Preparation of technical documentation etc.		
- White-collar employees	7	7
Decontamination of turbine plant		
- Blue-collar workers	0.5	0.5
Dismantling of active systems and system components		
- White-collar employees	66	
- Blue-collar workers	111	
- Special equipment	6	
- Provisional waste handling	5	188
Total		196.5
Plus 25% contingency		49
Total, approx.		245

9. Comparison between Barsebeck 1 and Oskarshamn 2

Barsebeck 1 and Oskarshamn 2 are nearly identical as regards the reactor and turbine systems.

The waste plants differ with regard to construction and design.

Since the dismantling cost for the waste building constitutes only a small portion of the total dismantling cost, between 5% and 10% according to Appendix 1, the reported total costs can be considered to apply with the same accuracy for both Barsebeck 1 and Oskarshamn 2.

10. References

Ref. 1 AA PM RF 79-413, KBS - Rivning av kärnkraftverk - Aktivitetsmängder och strålningsnivåer ("Dismantling of a nuclear power plant - Activity quantities and radiation levels")

Ref. 2 AA PM RD 79-489, Rev. 1 - Rivning av kärnkraftverk - Demontage av reaktortank med interna delar ("Dismantling of a nuclear power plant - Dismantling of reactor vessel with internal components")

INVESTIGATION PERTAINING TO DISMANTLING OF NUCLEAR POWER, dismanling of mechanical process systems

SYST.	SYSTEM'S MATERIAL WEIGHT IN KG TOTAL	OF WHICH RED X) % / KG	YELLOW X) % / KG	BLUE X) % / KG	DISMANTLING KG/MAN-HOUR YELLOW RED	BLUE	DISMANTLING NO. OF MAN-HOURS YELLOW RED	BLUE	NO. OF CONTAINERS RED	YELLOW	COMMENTS
243	150.000		100/150000		5		30.000			15	
244	100.000		100/100000		5		20.000			10	
245	10.000		100/10000		5		2.000			1	
253	5.000		100/5000		5		1.000			0,5	
311	184.500		75/138400	25/46100	5		27.680			14	
312	145.000	25/36300		75/108700	5		7.260		3,5		
313	273.000	90/245700		10/27300	5		49.140		24,5		
314	55.000		85/46700	15/8300	5		9.340			4,5	
316	350.000		100/350000		5		70.000			35	
321	93.000	90/83700		10/9300	5		16.740		8		
322	93.000		90/83700	10/9300	5		16.740			8	
323	138.500	20/27700	70/97000	10/13800	5		24.940		2,5	10	
324	40.000	60/24000	20/8000	20/8000	5		6.400		2,5	1	
326	6.000	80/4800		20/1200	5		960		0,5		
331	171.500	55/94300	25/42900	20/34300	5		27.440		9,5	4	
332	280.000		75/210000	25/70000	5		42.000			21	
341	20.000		70/14000	30/7000	5		2.800			1,5	
342	180.000	40/72000	50/90000	10/18000	5		32.400		7	9	
343	100.000		80/80000	20/20000	5		16.000				
SUB-TOTAL	2.394.500						402.840		58	142,5	

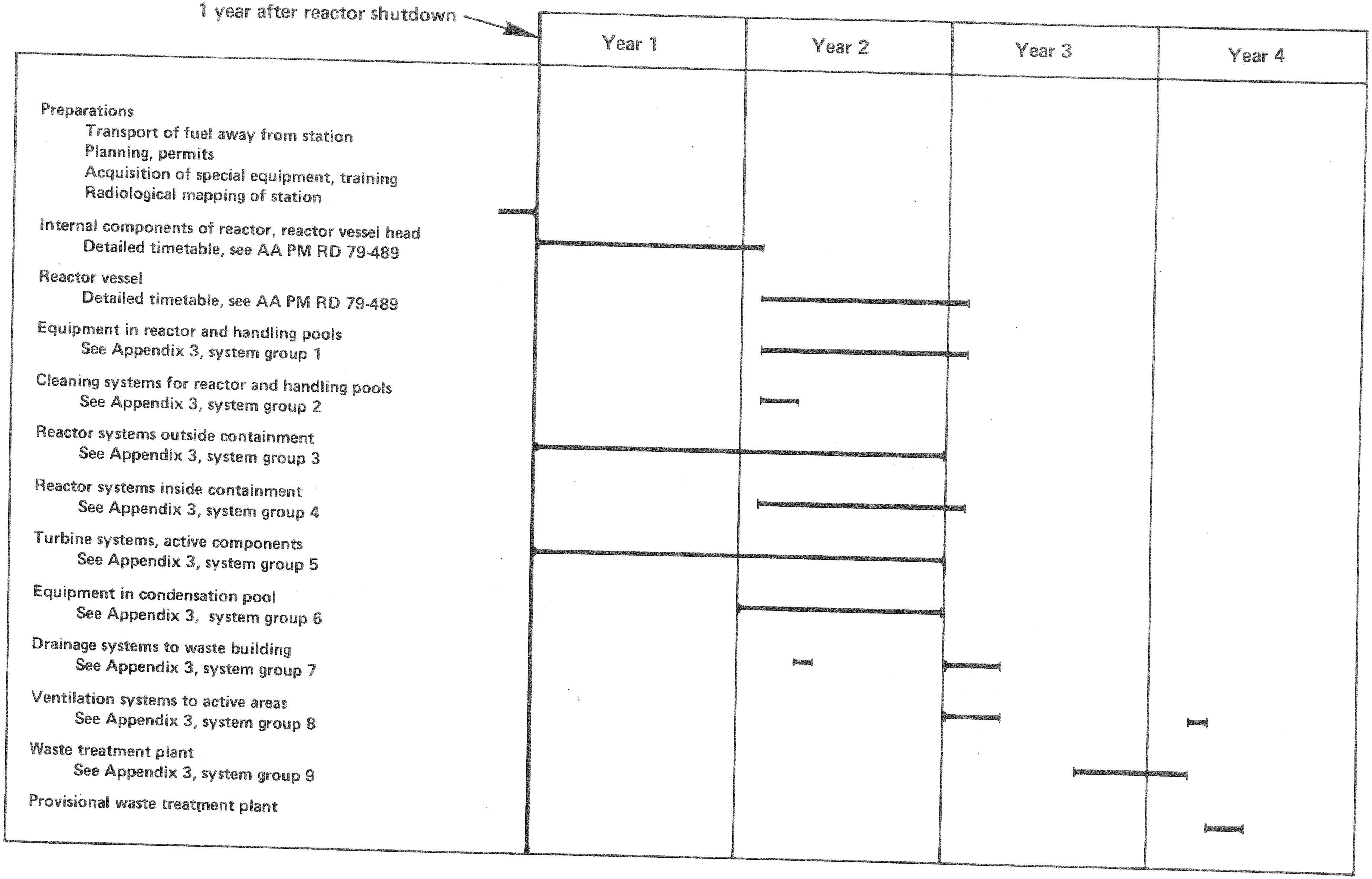
Red = active waste, transported in shielded concrete container
Yellow = active waste, transported in unshielded steel container
Blue = inactive waste

INVESTIGATION PERTAINING TO DISMANTLING OF NUCLEAR POWER, dismanling of mechanical process systems

SYST.	SYSTEM'S MATERIAL WEIGHT IN KG TOTAL	OF WHICH RED X) % / KG	OF WHICH YELLOW X) % / KG	OF WHICH BLUE X) % / KG	DISMANTLING KG/MAN-HOUR YELLOW RED	DISMANTLING KG/MAN-HOUR BLUE	DISMANTLING NO. OF MAN-HOURS YELLOW RED	DISMANTLING NO. OF MAN-HOURS BLUE	NO. OF CONTAINERS RED	NO. OF CONTAINERS YELLOW	COMMENTS
TRPT	2.394.500						402.840		58	142,5	
344	3.000		70/2100	30/900	5		420				
345	24.500		10/2450	90/22050	5		490				
351	21.500	15/3225		85/18275	5		645		0,5		
352	22.500	85/19125		15/3375	5		3.825		2		
353	2.500	60/1500		40/1000	5		300		0,5		
354	324.000		70/226800	30/97200	5		45.360			22,5	
411	650.000		30/195000	70/455000	5		39.000			20	
412	1.000.000		60/600000	40/400000	5		120.000			60	
413	850.000		40/340000	60/510000	5		68.000			34	
414	300.000		70/210000	30/90000	5		42.000			21	
419	50.000		10/5000	90/45000	5		1.000			0,5	
432	100.000		50/50000	50/50000	5		10.000			5	
441	500.000	10/500000	90/450000	100/500000							
442	500.000	10/500000	90/450000	100/500000							
455	50.000		10/5000	90/45000	5		1.000			0,5	
741	30.000		50/15000	50/15000	5		3.000			1,5	
433	20.000		30/6000	70/14000	5		1.200			0,5	
TOTAL	6.842.500						739.080		61	308	

Red = active waste, transported in shielded concrete container
Yellow = active waste, transported in unshielded steel container
Blue = inactive waste

TIMETABLE FOR DISMANTLING OF ACTIVE SYSTEMS AND COMPONENTS



Classification of active systems and system components into groups for dismantling of nuclear power plants

Group 1. Equipment in reactor pools

Pool lining
243
244
245
254

Group 2. Cleaning systems for reactor pools

324
733, partially
751, partially

Group 3. Reactor systems outside containment

321, outside containment
322, outside containment, partially
323, outside containment
324, partially
331
354, outside containment

Group 4. Reactor systems inside containment

311, inside containment
312, inside containment
313
314, partially
321, inside containment
323, inside containment
326
327, inside containment
351, inside containment
353
354, inside containment

Group 5. Active turbine systems

311, inside turbine building
312, inside turbine building, partially
332, partially
341, partially
411, partially
412
413, partially
414, partially
419, partially
432, partially
455, partially

Group 6. Equipment in containment pool

Pool lining
314, partially
316
322, partially
323, partially

Group 7. Drainage systems to waste building

322, outside containment, partially
324, partially
345, partially
352

Group 8. Active ventilation equipment

341, partially
722, partially

Group 9. Waste systems

342
343

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111 Plant site
112 Cooling water channels
113 Dams and dredged cooling water channels
114 Culverts and dikes
116 Wells and raw water supply systems
117 Roads and parking areas
118 Harbour
119 Navigational channels

12 Main buildings I
121 Reactor building
122 Turbine building
123 Condensate clean-up system building
124 Auxiliary systems buildings
125 Entrance building
126 Control building
127 Diesel buildings
128 Waste building
129 Active workshop building

13 Main buildings II
131 Auxiliary cooling water building
132 High voltage switchgear building
133 Generator switching device building
134 Transformer buildings
135 Water treatment building
136 Cooling water screening plant building
137 Turbine cooling water systems building
138 Boiler building
139 Sanitary sewage treatment building

14 Secondary buildings and mechanical equipment
141 Meteorology tower
142 High voltage switchyard structural equipment
143 Lightning protection equipment
144 Main stack
145 Other stacks and gas release points
146 Administration building
147 Garage
148 Storage and workshop buildings
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151 Containment vessel
152 Containment vessel internals
153 Reactor pools and fuel pools
156 Containment vessel access penetrations
157 Containment vessel pipe penetrations

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17 Radiation shielding

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211 Reactor pressure vessel
212 Core support components
213 Core water supply components
214 Steam separators
215 Steam dryer
216 Reactor instruments mechanical equipment
217 Start-up neutron sources
218 Surveillance test equipment
219 Fuel boxes

22 Control rods and control rod drives
221 Control rod drives
222 Control rods

23 Handling equipment
231 Reactor service bridge
232 Control rod drive replacement equipment
233 Core instruments replacement equipment
235 Handling equipment for reactor vessel cover and containment dome
236 Handling equipment for reactor internals
237 Recirculation pump handling equipment

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243 Fuel pool equipment
244 Reactor pool equipment
249 Other equipment in reactor service room

25 Service equipment
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253 Fuel service equipment
254 Failed fuel locating equipment
256 In-service inspection equipment for reactor pressure vessel

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263 Spare fuel, replacement fuel
267 Core design
269 Special start-up instruments

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341 Off-gas delay system
342 Liquid waste system
343 Solid waste system
345 Controlled area floor drain system
348 Recombiner system
349 Off-gas filter system

35 Other reactor process systems
351 Boron system
352 Controlled leakage drain system
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403 Turbine
405 Generator
406 Rotating excitation system
407 Generator voltage regulator

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412 Lubrication and jacking oil system
416 Seal oil system

42 Steam systems
421 Turbine plant main steam system
422 Steam reheat system
423 Steam extraction system
424 Seal and leakage steam system

43 Turbine building service systems
431 Turbine building air cooling system
433 Turbine building floor drain system
434 Fire fighting water system for turbine building
435 Turbine building sprinkler system
436 Other fire fighting systems for turbine building
437 Turbine building tap water system
438 Turbine building lighting system

44 Cooling systems
441 Main cooling water system
442 Auxiliary cooling water system
443 Closed circuit cooling water system
445 Generator cooling system

45 Governing oil system and turbine governor
452 Governing oil system
456 Turbine governor

46 Condensate and feed-water systems
461 Condenser and vacuum system
462 Condensate system
463 Turbine plant feed-water system
464 Make-up water system

47 Service systems - steam and water
472 Leakage, drain and drying system
473 Seal water system
474 Service water system
477 Turbine plant sampling system

48 Service systems - gas
481 Hydrogen and carbon dioxide system
485 Turbine plant service and instrument air system

49 Turbine plant electrical systems
491 Turbine plant control room equipment
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531 Neutron flux measurements
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536 Reactor instrumentation
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538 Reactor pressure control

54 Process control
541 Process measurements
542 Process control
543 Valve operation
544 Other process operation
546 Room monitoring
547 Other process monitoring

55 Radiation monitoring
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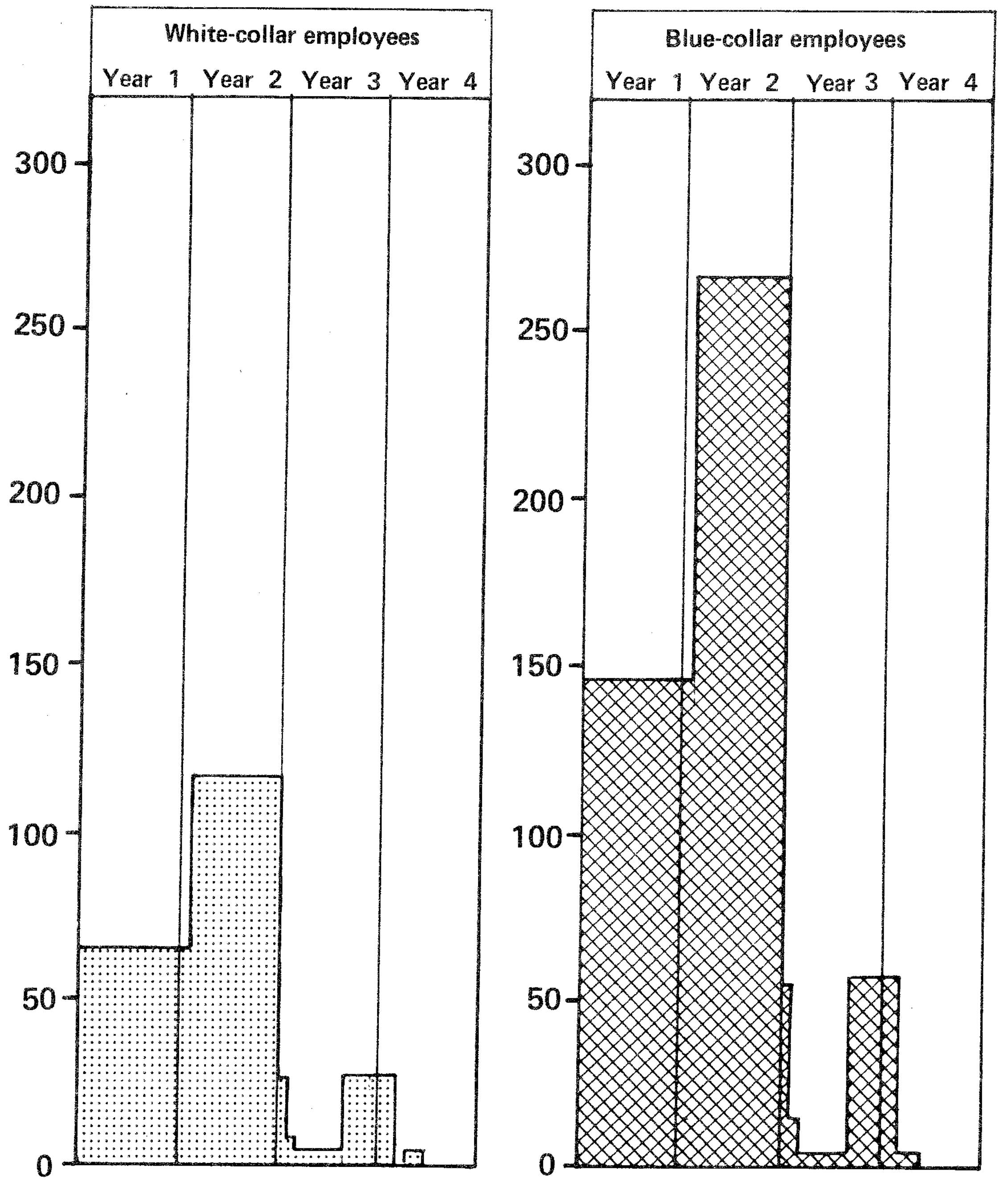
ASEA-ATOM

CALCULATED LABOUR FORCE FOR DISMANTLING OF ACTIVE SYSTEMS



Appendix 2

DISMANTLING OF SWEDISH NUCLEAR POWER PLANTS

VBB Report 88435-00 19791005
Arne Göransson

CONTENTS

ASEA-ATOM and VBB (Consulting Engineers) have been jointly contracted by KBS (The Nuclear Fuel Safety Project) to carry out a study of suitable procedures to be used in a future dismantling of Swedish nuclear power plants and to estimate the time and costs required for this.

1. Premises

1.1 General

A 590 MW ASEA-ATOM BWR, mainly Oskarshamn unit II, will serve as a reference plant, but its differences compared to Barsebeck unit 1 will also be studied. The results are to be applicable to other plants as well, where possible.

The plant is to be dismantled completely so that the site can be used for another purpose.

The station has been in operation for 40 years with an availability factor of 0.8. The dismantling work starts one year after shutdown, at which point spent fuel and normally replaceable radioactive equipment has been transported away.

It is assumed that the plant has functioned normally throughout its operational life without any incident involving the release of a large quantity of activity. Some operating leakage has been assumed, however, (see below).

The experience of the plant's operating and maintenance personnel shall be utilized for planning work as well as for supervision of the dismantling of equipment, especially during the early phases.

The study assumes that dismantling will be carried out using known techniques, even though better methods will undoubtedly be available when the time comes. Both personnel safety and protection against releases to the environment shall be taken into consideration in selecting working methods.

Inspection functions shall be equivalent to those used in nuclear power plant construction, where applicable.

Calculation of the activity inventory shall also take into account the results of foreign (mainly American) studies. Simple decontamination procedures shall be followed, such as washing with a high-pressure spray or removal of small concrete surfaces.

Surfaces with contamination less than

$10^{-4}\mu Ci/cm^2$ for β- and γ-radiation and

$10^{-5}\mu Ci/cm^2$ for α-radiation

shall be considered non-active.

Waste with surface contamination in excess of these values and waste with induced or absorbed activity in excess of 0.002 μCi/g shall be regarded as active waste.

Radioactive waste shall be transported to a central waste facility, Prav's ALMA. The transport packages shall conform to Prav's specifications, with internal dimensions 2.5 x 3.7 x 2.7 m.

The containers can be of two types: An unshielded container of steel with an unladen weight of 10 tonnes or a shielded container of concrete with an unladen weight of 52 tonnes. The total laden weight of the container may not exceed 100 tonnes. Material with a surface dose rate of up to 30 mrem/h can be transported in the unshielded container and material with up to 1 rem/h in the shielded container. These values are calculated so that the transport regulations of IAEA are complied with.

The possibilities of reusing components and materials shall normally not be credited to the project.

At the time of the dismantling work, there are no nuclear power units in operation on the site, so that the dismantling work can be carried out without taking such factors into consideration.

The cost calculation shall assume the cost level in mid-1979.

1.2 Inactive systems

In general, inactive or decontaminated components that have been dismantled are deposited outside the power station, from where further transportation is paid for by their scrap value.

Process equipment and the like:

Pipes, valves, hangers, brackets, pumps, equipment in pump sites, turbine control and lubrication systems, cooling systems, monitoring equipment and all associated or similar components are dismantled into suitable pieces and transported out of the building.

Smaller parts can be allowed to accompany the building materials down into the ground or to a landfill site. The same applies to installed heating, ventilation and plumbing equipment.

Electrical equipment:

All low-voltage cables etc. will be left in place. Either their scrap value will pay for their dismantling and transport or they will be allowed to accompany the building waste.

ASEA-ATOM's part of the study describes the dismantling of all other electrical equipment, including generator and transformers.

Other equipment:

When they are no longer needed, overhead cranes and lifts will be dismantled and removed.

Fire protection equipment can be dismantled without cost. The same applies to workshop and laboratory equipment, communications equipment and the like.

1.3 Buildings

All demolition and dismantling of buildings will be done using currently known and proven technique, although better and cheaper methods will most probably be available at the time of dismantling.

Radioactive sections are to be packaged for transport to ALMA, see above. But the costs of transport and final storage are not to be included in this part of the study.

According to an estimate made together with the operator and ASEA-ATOM, the following building components shall be considered to be radioactively contaminated and not reasonably cleanable:

1) The concrete barrel immediately surrounding the reactor vessel to a depth of slightly more than 1.0 m and a height of about 7.0 m.

2) In the fuel, reactor and condensation pools to a depth of 5 cm in the concrete inside the stainless steel lining, over the entire surfaces. In addition, cracks in the concrete have led to contamination of an additional 5 m^3 of concrete.

3) In pump pits for radioactive waste water, the concrete has been contaminated to a depth of 10 cm. Cracks in the structures have also led to the contamination of an additional 1 m^3 of concrete.

4) In areas belonging to category C_1 and C_2, the floors are contaminated to a depth of 1-2 cm on 10% and 1% of the total surface area, respectively. The category designations are those used by ASEA-ATOM and mean: C_1 = process areas with hot, unfiltered reactor water and, C_2 = other process areas where there is a risk of airborne activity.

5) During the course of the dismantling work, a certain section of the yard has been contaminated by spillage, giving rise to about 10 m^3 of waste.

All steel building structures within active areas, such as floor gratings, beams and the like, can be decontaminated.

Inactive building components will be demolished in the most appropriate and economical manner. Concrete structures deeper than 1 m below the surface of the ground can be left in place if they do not obstruct backfilling of the foundation. The uppermost 30 cm are to be filled with natural material and surfaced with topsoil.

All civilian engineering structures on the site are to be removed, with the exception of the gas turbine plant, outgoing power lines, harbour facilities and shelters.

2. Extent of VBB's share

VBB's share comprises two main types of work: firstly inactive systems (with the exception of electrical systems) and secondly, buildings and site restoration.

Inactive systems also include systems that have become inactive after decontamination. The studied systems and their most important components are described under 3.1 below.

VBB reports on the demolishing of both active and inactive buildings. Those parts that are to be regarded as active are specified in chapter 1.3 above. In addition, the earthmoving and other ground and foundation work required around the station in order to restore the site so that it can be used freely for other purposes is assessed.

Several large contracting companies and some specialist firms have been consulted in order to obtain their viewpoints on suitable dismantling methods and associated costs, see list of references.

3. Dismantling methods

3.1 Inactive systems

As regards normal, uncontaminated pipes and valves as well as low-voltage cables, it is assumed that these items can either be dismantled and taken away by a scrap dealer or that they will accompany the building waste. Whichever alternative is chosen, they will be disposed of free of cost. For the sake of comparison, the costs for the dismantling of electrical equipment including electrical cubicles, cables, cable trays and troughs, transformers, diesel generators, batteries, busbars and converters have been calculated to be SEK 1.0 - 1.5 million.

The basic principle for other equipment is that the components are taken apart, either at the joints or by means of gas cutting, into pieces of suitable size for existing lifting equipment and transport routes, after which the pieces are deposited on piles on the yard outside the building. The cost of further transport away from the site is not included.

With respect to items 2 - 7 below, the equipment must be cleaned prior to dismantling so that it is completely inactive. The cost of such decontamination is reported by ASEA-ATOM. Certain components can be difficult to decontaminate, however, and must therefore be treated as active material.

For the purposes of the cost estimate, dismantling of the following systems has been subjected to closer study:

1) Service platforms for reactor
2) Low-pressure turbine
3) Condenser
4) Preheaters
5) Feedwater system
6) Condensate clean-up plant
7) Condensate pumps
8) Screening plant
9) Cooling systems
10) Waterworks and demineralization plant
11) Fans
12) Compressor plant
13) Overhead cranes
14) Lifts
15) Fire protection

3.2 Methods for demolishing buildings

Several different methods that may be used to demolish heavy concrete structures are described in brief below.

1) Hole drilling and hydraulic splitting. This can be done either with large core-drilled holes and powerful hydraulic equipment or with small holes and small hydraulic cylinders. An example of the first method is "Hydrocrack", for which 160 mm holes are required. The second method is exemplified by Atlas Copco's "Darda" with 45 mm holes. The first method has been assumed here, since it creates larger cracks, which is valuable in reinforced structures.

2) Seam drilling with large-diameter holes. The method consists of slits made with closely spaced diamond-drilled holes about 150 mm in diameter.

3) Thermic lance. This consists of a tube containing specially alloyed metal wires that burn in gas at such a high temperature that the flame melts both concrete and steel. The lance makes an approximately 50 mm large hole through one metre of concrete in about 5 minutes, and a series of adjacent holes are made in order to split the concrete. Theoretically, this method works better the more the concrete is reinforced.

4) Sawing with diamond blades. The method is suitable at a sawing depth of up to 30 - 40 cm, although considerably deeper cuts can be made under certain conditions.

5) Removal of surface layer by means of chipping. Only used for radioactively contaminated surfaces, which means that all dust etc. must be collected. Thin layers (a couple of centimetres) are removed using a pneumatic chipping machine fitted with a dust extractor. A hydraulic machine can be used in place of a pneumatic machine to reduce dust formation. If the surface layer to be removed is thicker, for example if it extends inside the reinforcement, the work can be facilitated by sawing the surface into squares to the desired depth prior to chipping.

6) Removal of surface layer without chipping. In, for example, the condensation pool, where the concrete surface must be removed and the sealing lining is 20 cm below the surface, it can be easier to remove all concrete down to the lining. The concrete is sawn down to the lining and holes are drilled for hydraulic cylinders, by means of which the concrete is sheared off.

Another way to break off a concrete surface without creating a great deal of dust is to drill small holes at intervals of about 20 - 25 cm and insert expanders in the holes. These expanders have an edge around their circumference at a suitable depth, which slices off the concrete around the hole when the expanders are forced to expand by means of a hydraulic cylinder.

An interesting way to cause spalling of the surface would be to heat the surface and then cool it, causing the concrete in the surface to crack loose, generally down to the reinforcing bar. Since little experience has been gained with such a method, and even less is known of its costs, it has not been taken into consideration.

7) Blasting. Only used for inactive structures. Skillfully executed blasting can give very good results.

8) Slit blasting. Done with two parallel rows of holes, c/c spacing around 20 cm, in a zig-zag pattern. With normally reinforced structures and reasonable wall thicknesses, the concrete between the holes can be "blown away", creating a slit in the concrete structure. After the reinforcing bar has been cut off, the concrete can then be lifted off in blocks.

3.3 Active building components

After all equipment (with a few special exceptions), both active and inactive, has been removed, the demolishing of radioactively contaminated building structures in the reactor, turbine and waste buildings is commenced.

As long as demolishing work with active building components is in progress, the building must be kept tightly sealed. Ventilation systems and filters must be functional and augmented with extra capacity where required.

As was mentioned under the chapter "Premises", active building parts shall be packaged in standardized containers after dismantling for transport to the ALMA waste facility. In connection with dismantling and other handling, special arrangements must be made to prevent radioactively contaminated dust or gases from being released to the environment. In order to protect against dust, workers must wear face masks or similar respiratory protection.

The reactor building is the time-determinant building. In the first place, it contains the most difficult systems from the viewpoint of dismantling, which means that the start of demolition of its structures will be delayed, and in the second place it has much larger volumes of radioactively contaminated building materials than other buildings. For this reason, only the reactor building is dealt with in detail here.

The largest and most contaminated portion is the biological shield immediately surrounding the reactor vessel. (Shown as item 1 in Appendix 1.) This shield is not so active that special radiation shielding is required in connection with its dismantling, but since there is a risk of dust, the work should be done from the outside, where the concrete is virtually inactive. The concrete, which is not particularly heavily reinforced here, is split up into large blocks, mainly by means of hole drilling and splitting with hydraulic cylinders in the holes. Alternative methods, though somewhat more expensive, are cutting with a thermic lance or seam drilling by means of core boreholes. The uppermost part, which is not contaminated, is cut down and taken away in as large pieces (up to 60 tons) as space and lifting equipment permit. The active portions, between levels 118.0 and 125.5, are divided into 18 blocks of a size which fits the transport containers and a weight of around 32 tonnes, plus wedge-shaped sections for the lower parts.

Dismantling of the lining in the fuel pools is described by ASEA-ATOM. After removal, contaminated concrete inside the lining and along cracks in the concrete in the bottom or the side walls is chipped away. (Item 2.) In order to facilitate the chipping work, slits are made using circular saws. All dust arising from this work must be collected. A suitable method is to equip the machines with dust extractors.

After the stainless steel lining in the condensation pool has been removed, the contaminated concrete behind it is removed in a similar manner. (Item 3.) On the cylindrical wall, it is assumed that the entire 20 cm concrete layer inside the sealing liner generally has to be removed. This is done by making core boreholes at a c/c spacing of around 1.0 m and sawing vertical slits through the holes. The concrete is then broken loose from the lining by means of jacks. The material is hoisted up through holes made in the circular floor slab at +106.0.

While the above-described work is proceeding, concrete surfaces that have become contaminated, mainly floors, are decontaminated by removing the surface layer of concrete. It is assumed that this 1 - 2 cm thick layer will be chipped away using a pneumatic or hydraulic machine, after which the waste will be collected and disposed of. Other methods that cause less contamination should be explored, for example shearing off the surface layer using expanders or spalling it off by means of heating and cooling.

In pump pits for radioactive water, 10 cm of the concrete surface must be removed. Concrete and reinforcement are sawn up in squares, approximately 40 cm large, which are then sheared off. It should usually be feasible to remove all of the concrete down to the rock.

Surface layers of contaminated concrete in the turbine and waste buildings are removed in a similar manner.

All radioactively contaminated concrete (broken off in the manner described above) is collected and transported for packing into transport containers. This work is done on the 106 level, right next to the lift shaft. Each container holds a quantity of loosely packed concrete waste equivalent to 14 - 18 m^3 solid concrete. A total of 30 transport containers are required for all contaminated concrete.

3.4 Other building components

Completely inactive buildings are dismantled in the manner which is found to be easiest and at the same time cheapest. The roof structure can generally be lifted off in sections using a mobile crane. The concrete framework can be blasted into suitably sized pieces and according to a plan so that the materials fall down into the "basement". Intermediate floors underground must also be blasted so that the foundation can be backfilled completely.

After all contaminated building structures have been taken away or decontaminated, the reactor, turbine and waste buildings can also be torn down in the conventional manner. The buildings do not have to be kept tightly sealed any longer. Ventilation systems and filters are the first to be dismantled.

In the reactor containment, the demolition work starts with the slabs at +98.5 and +106.0. (Item 4.) They are taken down by drilling and splitting, followed by careful blasting. The rubble is allowed to fall to the bottom. The eight columns underneath the central portion (item 5) are then blasted, causing the remaining portions to collapse. Standing portions, especially the heavily reinforced HC wall, may require supplementary blasting and cutting of the reinforcing bars in order to bring down the entire structure under +105 and obtain a good degree of compaction.

While this work is being done, demolition of walls and bottoms of the fuel pools (item 6), which are heavily reinforced, is begun. This is done by blasting slits through the walls, forming concrete blocks of approximately 30 tons. After the reinforcing bar has been cut off, the blocks are lifted by the overhead crane and taken to the turbine building to be deposited in its deep parts. An alternative method, which is somewhat more expensive but disturbs the other work less, is to divide the walls into blocks by drilling and splitting.

As soon as possible, the floor slabs in the reactor building that are not needed as working platforms or for stability are taken down. (Item 7.) This is done by drilling and splitting as well as by blasting. Interior walls that are not necessary for the stability of the exterior walls are blasted. At the same time, the main overhead crane and the roof are dismantled. (Item 8.)

At this point, all other buildings except the waste building have been levelled to the ground, see below. The main ventilation stack (item 9) is blasted and allowed to fall over the remains of the turbine building. The reactor building's exterior walls down to +126 and all floor structures remaining above this level are then blasted so that the rubble for the most part falls down inside and just outside the building. (Item 10.)

The outer walls of the reactor containment are then blasted from the top in approximately 4 m high stages. (Item 11.) These walls, which are heavily reinforced with both ordinary reinforcing bars and tendon cables and contain a 5 mm sealing liner, will probably be the most difficult part of the dismantling work. They can be blasted in a number of ways, for example by slit blasting to moderately sized blocks or by drilling vertically immediately outside the sealing liner, causing this liner and the thinner inner concrete to fall down into the pit, and finally shattering the outer barrel by means of centrally placed vertical charges. Parallel with this and in stages, surrounding parts of the reactor building are blasted from the inside outward. (Item 12.) All of this is done down to +105, whereby at the end certain materials will have to be transported to other parts of the power station where the foundations have not been completely filled up. With some slight heaping of the filling materials, none of the rubble will have to be transported to landfill sites outside the area.

Other buildings are demolished mainly by blasting the concrete structures, basically in the same manner as described above. In the turbine building, certain contaminated floor surfaces must first be chipped off. In the case of certain massive concrete structures, especially the base slab for the main machinery in the turbine building, the columns are blasted away after any underlying heavy walls have been cleaned away, after which the entire structure falls down below the ground surface.

In general, all blasting work must be carried out with the greatest care and under the supervision of specialists. A structural designer familiar with the construction must follow the work continuously.

After each major blasting round, the results shall be inspected, obstructing reinforcing bar and other steel parts cut off and any necessary secondary blasting work done. The work must aim at making sure that the materials are stable after blasting and that the cavities under the future surface of the ground are filled to as great a degree as possible.

Other buildings within the station grounds, such as the waterworks and tanks, warehouse, workshop and garage, are torn down in the simplest manner possible. At the water intake, the screens are removed and the concrete structure is blasted down to 2 m below the water surface. All openings of rock tunnels for supply and waste water are backfilled with demolition rubble.

After concluded dismantling, the station site must be levelled and covered with a layer of natural material. Absolute flatness should not be striven for; some parts can be allowed to remain raised in the form of soft mounds. The site for the machinery station can be given an elevation of up to 1.0 m above the surrounding ground, which also ensures that unavoidable subsidence of the filler materials will not be noticed. 25 cm fine sand and 5 cm topsoil can be chosen as the natural material on the surface. Before this is deposited, however, the blasting rubble must first be compacted, for example by means of repeated passes with heavy bulldozers.

4. Timetable

During the plant's last year of operation, the planning work for the dismantling is begun. This is done by the station's operating personnel, with specialists in various areas being brought in as needed.

After plant shutdown, it will be about a year before any real dismantling activities can get under way. During this period, the fuel has time to cool and be transported away, along with the control rods etc.

Most of those parts of the dismantling work which it is VBB's responsibility to study and which are described here cannot be done until ASEA-ATOM has completed its part of the work. The timetable presented in Appendix 2 has therefore been drawn up by ASEA-ATOM and VBB together.

Where uncertainty has existed with regard to the dismantling method or its capacity, sufficient time has been alloted to be on the safe side. For those parts studied by VBB, single-shift work has been assumed all the way through. A reasonably uniform level of employemnt has also been striven for. The total dismantling time is about 4½ years. The critical path goes through the reactor building the whole time.

5. Personnel requirements

The general planning of the dismantling of the plant is done by the ordinary operating personnel, mainly during the year between reactor shutdown and the start of the dismantling work. Since this planning mainly concerns the active components, this personnel requirement has been included in ASEA-ATOM's part of the study. Only the personnel requirement for the dismantling of inactive systems (not including electrical systems) and of buildings has been included here.

5.1 Dismantling of inactive systems

This work is done for the most part immediately after the systems studied by ASEA-ATOM have been dismantled or after contaminated concrete has been removed. The largest component is the low-pressure turbine with condenser. After the turbine has been decontaminated, the turbine and the condenser are dismantled during the first half of the third dismantling year. Approximately 15 men are required for this work.

To as great an extent as possible, the rest of the dismantling work should be scheduled for the period prior to or following dismantling of the turbine. With good planning, the manpower requirement should be relatively stable and as shown in Appendix 3.

Most of the work will be done in the third year. The largest work force is 20 and the total labour requirement comes to 230 man-months. An additional 25 man-months should be added for planning and central management.

5.2 Demolishing of buildings

The largest manpower requirement is about 40 men and will occur during part of the third and fourth year. Some of these people will come from special firms contracted to carry out certain parts of the dismantling work.

If a reasonable attempt is made to stabilize the labour requirement, the total manpower curve should have roughly the appearance shown in Appendix 3.

The total is approximately 850 man-months. This figure includes local supervision, but an extra allowance should be added for planning and central management, say 60 man-months.

6. Cost estimate

All of the costs specified below are calculated to include all secondary costs associated with the work in the form of supervision, social security contributions, industrial safety arrangements, sheds, machines, scaffoldings, electric power, transportation etc. Prices of main items are also estimated to cover associated but not specified detail jobs. In addition, the costs have purposely been calculated somewhat on the high side.

Finally, a percentage contingency allowance for "unforeseen" expenses has been added to each subsection in order to cover numerous unspecified jobs of minor importance and to provide a cushion against cost increases in view of the fact that this type of work has never been done on such a large scale, and finally as an allowance for the uncertainty stemming from the short time available for the study. The contingency allowance is on the order of 20 - 30%.

The building quantities on which the cost calculation is based have been taken from Oskarshamn unit II. The borderline between OI and OII has been chosen on the general drawings. The waste building has been included in its entirety, however. Half of the dismantling cost has been included for the water intake, water treatment plant, workshop, warehouse and garage.

All costs relate to the price level as of mid-1979.

6.1 Inactive systems

The following has been drawn up in agreement with the description in chapter 3.1. The costs are specified in somewhat greater detail in Appendix 4.

		SEK thousands
1)	Service platform for reactor	30
2)	Low-pressure turbine	900
3)	Condenser	1 550
4)	Preheaters	120
5)	Feedwater system	70
6)	Condensate clean-up plant	90
7)	Condensate pumps	30
8)	Screening plant	70
9)	Cooling systems	90

		SEK thousands
10)	Waterworks, demineralization plant	50
13 14	Overhead cranes, lifts	160
11-12 16-18	Diverse minor plants	165
Allowance for unforeseen costs under 6.1		875
	Total	4 200

6.2 Active building components

The following cost itemization is specified in Appendix 6. Certain typical unit prices for the dismantling work that have been used in the calculation are shown by Appendix 5.

		SEK thousands
1)	Reactor containment with pools	5 290
2)	Reactor building	115
3)	Turbine building	105
4)	Waste building	40
5)	Contaminated material outside station	10
Allowance for unforeseen costs under 6.2		1 680
	Total	7 240

6.3 Other building components

The following cost itemization is specified in Appendix 6. Certain typical unit prices for the dismantling work that have been used in the calculation are shown by Appendix 5.

		SEK thousands
1)	Reactor containment with pools	6 485
2)	Reactor building	8 775
3)	Turbine building	11 335
4)	Electrical building	2 270
5)	Office building	655
6)	Waste building	2 815
7)	Stand-by power building	450
8)	Screening plant building	355
9)	Transformer box	255
10)	Active workshop	420
11)	Water intake	450
12)	Waterworks	285
13)	Workshop, warehouse, garage	420
14)	Site restoration, levelling and grading	220
Allowance for unforeseen costs under 6.3		8 710
	Total	43 900

6.4 Cost itemization

Even though each cost item is meant to cover all secondary costs associated with this work, a certain fixed cost must be allocated for the contractor's establishment on the site. It is estimated that about SEK 2.5 million will be required for this.

The total cost for those parts of the study which lie within VBB's area of responsibility is itemized below. To this must be added the cost for dismantling active components and electrical systems, as calculated by ASEA-ATOM.

		SEK millions
-	Establishment cost	2.5
-	Dismantling of inactive systems	4.2
-	Demolishing of active building components	7.3
-	Demolishing of inactive building components	43.9
	Total	57.9

7. Barsebeck 1 in comparison with Oskarshamn II

The Barsebeck unit 1 has the same electric capacity as Oskarshamn II. The nuclear steam supply system is virtually identical and the layout of the reactor building is also the same.

What mainly distinguishes the plants is the foundation method and foundation depth. This latter factor applies especially to the reactor building.

A comparison between the turbine buildings shows that the turbine building at Barsebeck has a larger volume. Certain auxiliary systems have been designed differently at the two plants. For example, the pump and heat exchanger at B1 are located in the workshop building, but in the screening plant building at Oskarshamn II. Furthermore, the workshop building at Barsebeck 1, which is integral with the machine station, also serves Barsebeck 2, while the corresponding functions at Oskarshamn II are located in a separate building. The personnel and office building at Barsebeck 1 has a considerably larger volume than the equivalent building at Oskarshamn II. The same applies to the electrical building.

At Barsebeck, the screening plant buildings are separate, while they are integral with the power stations at Oskarshamn.

The underground portion is much smaller at Barsebeck 1 than at Oskarshamn II, which leaves less space for demolition rubble. At Barsebeck, a portion of this rubble can be deposited in the concrete tunnels for coolant water, after the roof has been blasted down. But around 25 000 m^3 of demolition rubble must be hauled away to an external landfill site.

When the calculated dismantling costs are compared, it is found that the quantity of concrete to be torn down is approximately 25% greater at Barsebeck than at Oskarshamn II, mainly due to the fact that a relatively larger portion of the buildings is located above ground, and to the fact that many of the buildings are larger. Other dismantling quantities are also generally somewhat larger. The result is that the cost for dismantling the buildings at Barsebeck 1 is around SEK 8.5 million higher than the cost calculated for Oskarshamn II.

Furthermore, the dismantling work for Barsebeck 1 will probably take a couple of months longer.

Stockholm, 5 October 1979
VBB

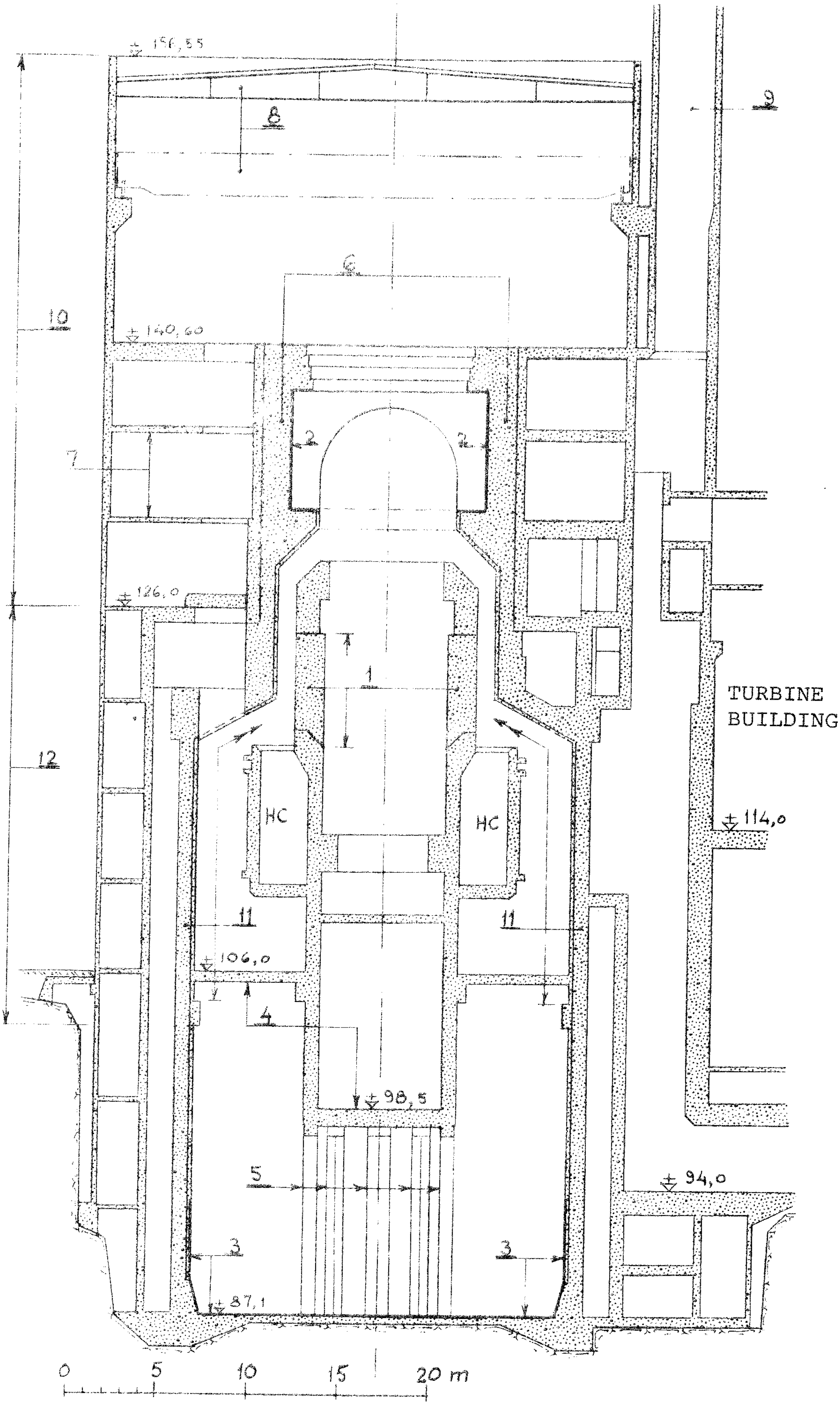
Arne Göransson

List of references

During the course of the study, we have consulted representatives of the following companies:

Armerad Betong - Vägförbättringar
Stabilator
Skånska Cementgjuteriet
Hålmetoder
Nordisk Kartro
Nitro-Consult
Stal-Laval

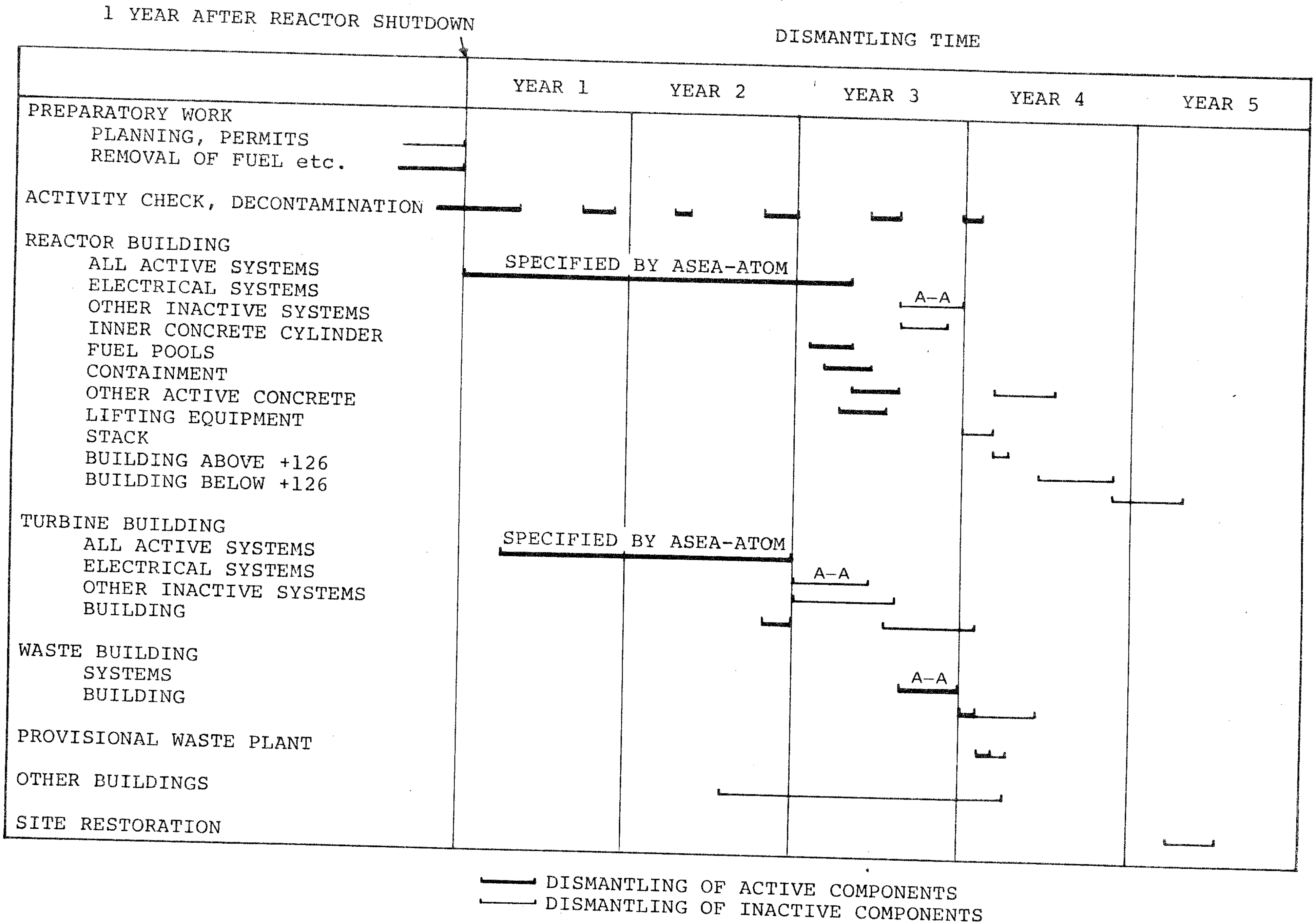
Appendix 1
1979-10-05



OSKARSHAMN UNIT II
REACTOR BUILDING,
WORKING PLAN

DISMANTLING OF NUCLEAR POWER PLANT

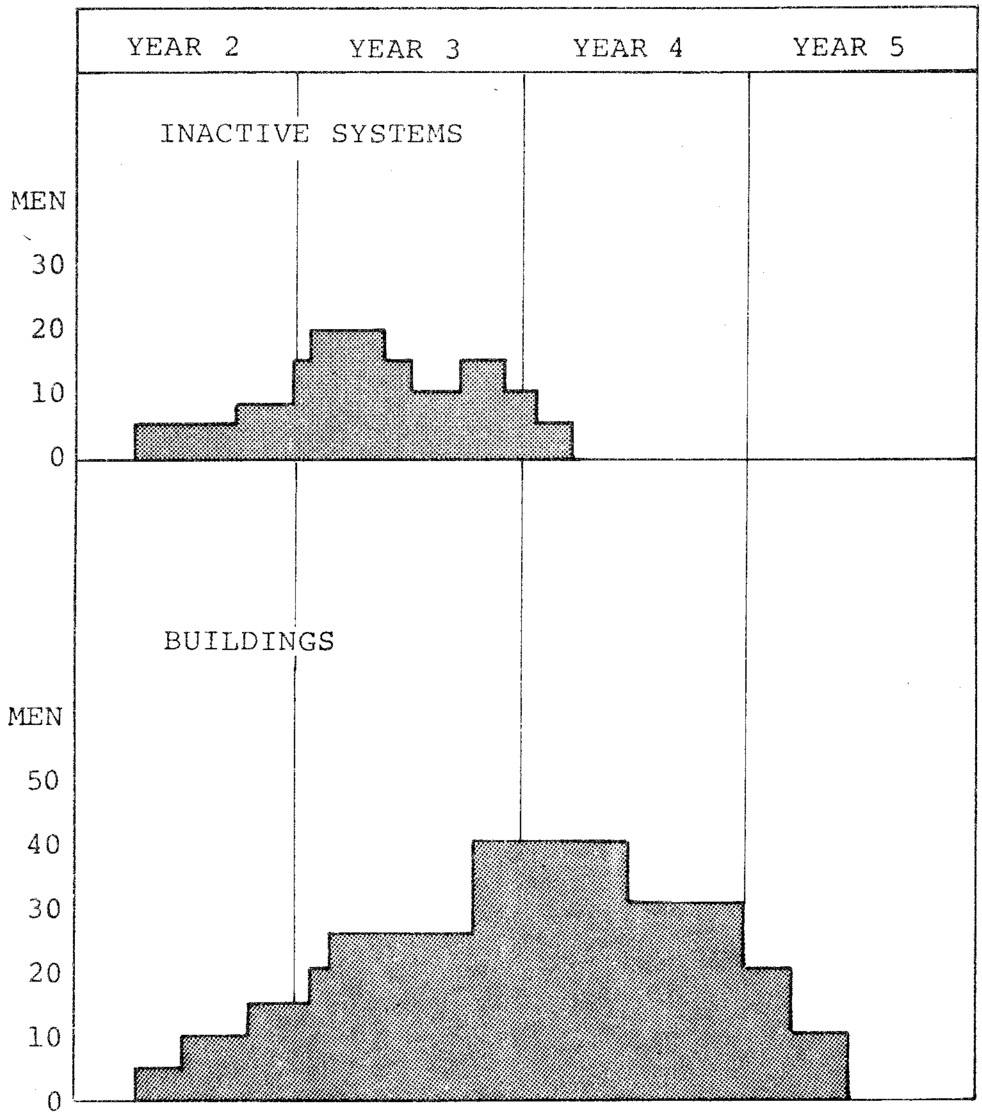
88435-000



Appendix 2
1979-10-02

DISMANTLING OF NUCLEAR POWER PLANT

ESTIMATED LABOUR FORCE FOR DISMANTLING OF:



Inactive buildings
Cost estimate

		SEK thousands
1)	Service platform for reactor	
	- Dismantling and removal	30
2)	Low-pressure turbine	
	- Turbine (3 turbine housings) incl. pillow blocks: dismantling, some cutting-up and removal, total	900
3)	Condenser	
	- Cutting-up and removal	1 400
	- Steam pipes, as above	50
	- Taprogge system, as above	100
4)	Preheaters (main part)	
	- Removal of:	
	- High-pressure preheater	40
	- Low-pressure preheater, incl. partitioning	80
5)	Feedwater system	
	- Removal of pumps	30
	- Removal of other parts	40
6)	Condensate clean-up plant (main part)	
	- Removal of tanks	50
	- Removal of filters etc.	40
7)	Condensate pumps (main part)	
	- Removal	30
8)	Screening	
	- Removal of	
	- Basket belt strainers	40
	- Screens with rakes	10
	- Rest, incl. overhead crane	20
9)	Cooling systems	
	- Removal of	
	- Main cooling water pumps	30
	- Steel tubes	40
	- Auxiliary cooling water pumps	20

		SEK thousands
10)	Waterworks and demineralization plant	
	- Removal of all equipment	50
11)	Fans	
	- Removal	15
12)	Compressor plant	
	- Dismantling	15
13)	Overhead cranes	
	- Removal, dismantling and partitioning	120
14)	Lifts	
	- Removal	40
15)	Fire protection equipment	0
16)	Workshop and warehouse	
	- Removal of equipment	10
17)	Water intake	
	- Removal of screens etc.	25
18)	Removal of diverse unspecified minor components in different buildings	100
Allowance for unforeseen costs		875
	Total	4 200

88435-000
Dismantling of Swedish
nuclear power plants

Typical demolition prices

Gross prices, incl. general equipment, scaffoldings etc.

Radioactively contaminated concrete

Removal of surface layer:

Chipping or equivalent, 1 cm	SEK	450/m^2
Chipping or equivalent to reinforcement		600/m^2
Sawing and chipping, 10 cm		1 700/m^2
Removal to sealing liner, 20 cm		1 400/m^2

Breakup of heavily reinforced concrete:

Seam drilling		4 400/m^2
Drilling and splitting		3 500/m^2
Thermic lance		3 800/m^2

Demolition of thick concrete structures:

Breakup into large blocks and loading into containers		12 000-14 000/m^3
Removal of limited sections		15 000/m^3

Inactive concrete

Demolition by means of blasting,
incl. compaction or loading:

Thick, heavily reinforced structures		1 000/m^3
Medium-thick structures		700/m^3
Thin structures		600/m^3

Transport of demolition rubble		50/m^3
Slit blasting in metre-thick heavily reinforced concrete		900/m
Sawing, 30-40 cm concrete		800/m

Other building work

Dismantling of steel frame		400/ton
Dismantling of steel floor structure		75/m^2
Dismantling of roof, excl. main beams		100/m^2
Dismantling of lightweight concrete walls and ceiling		60/m^2
Dismantling of warehouse etc. (building volume)		30/m^3
Filling with 25 cm fine sand and topsoil		15/m^2

Demolition of buildings
Cost estimate

Certain typical unit prices that are used in the calculations are shown by Appendix 5.

Costs in SEK thousands:		Active parts	Inactive parts
1)	Reactor containment with pools		
	- Walls toward reactor vessel	3 120	
	- Behind steel lining in condensation pool	634	
	- Behind steel lining in other pools	1 510	
	- Floors in C_1 areas	24	
	- Other concrete structures		6 419
	- Steel structures		66
TOTAL		5 288	6 485
2)	Reactor building		
	- Floors in C_1 area	29	
	- Floors in C_2 area	3	
	- In pump pit	84	
	- Other concrete structures		8 336
	- Steel structures		103
	- Roof		136
	- Stack		200
TOTAL		116	8 775
3)	Turbine building		
	- Floors in C_2 areas	37	
	- In pump pits	69	
	- Other structures		11 005
	- Steel structures		73
	- Roof		257
TOTAL		106	11 335
4)	Electrical building		
	- Concrete structures		2 153
	- Lightweight concrete walls etc.		117
TOTAL		0	2 270

		Active parts	Inactive parts
5)	Office building		
	- Concrete structures		581
	- Lightweight concrete walls etc.		74
TOTAL		0	655
6)	Waste building		
	- Floors in C_2 areas	7	
	- In pump pit	33	
	- Other concrete structures		2 570
	- Steel structures		14
	- Lightweight concrete walls and floor structures		231
TOTAL		40	2 815
7)	Stand-by power building		
	- Concrete structures		441
	- Lightweight concrete walls		9
TOTAL		0	450
8)	Screening plant building		
	- Concrete structures		262
	- Rest		93
TOTAL		0	355
9)	Transformer box		
	- Concrete structures		231
	- Rest		24
TOTAL		0	255
10)	Radioactive workshop		
	- Concrete structures		356
	- Lightweight concrete walls, steel floor structures		64
TOTAL		0	420

		Active parts	Inactive parts
11)	Water intake (half the cost)		
	- Concrete structures		450
TOTAL		0	450
12)	Waterworks (half the cost)		
	- Concrete structures		275
	- Rest		10
TOTAL		0	285
13)	Workshop, warehouse, garage (half the cost)		
	- Concrete foundation		135
	- Superstructure		285
TOTAL		0	420
14)	Site restoration, levelling and grading etc.		
	- 10 m^3 radioactively contaminated material	10	
	- Other ground restoration work		220
TOTAL		10	220
Together:		5 560	35 190
Allowance for unforeseen costs:		1 680	8 710
GRAND TOTAL		7 240	43 900

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