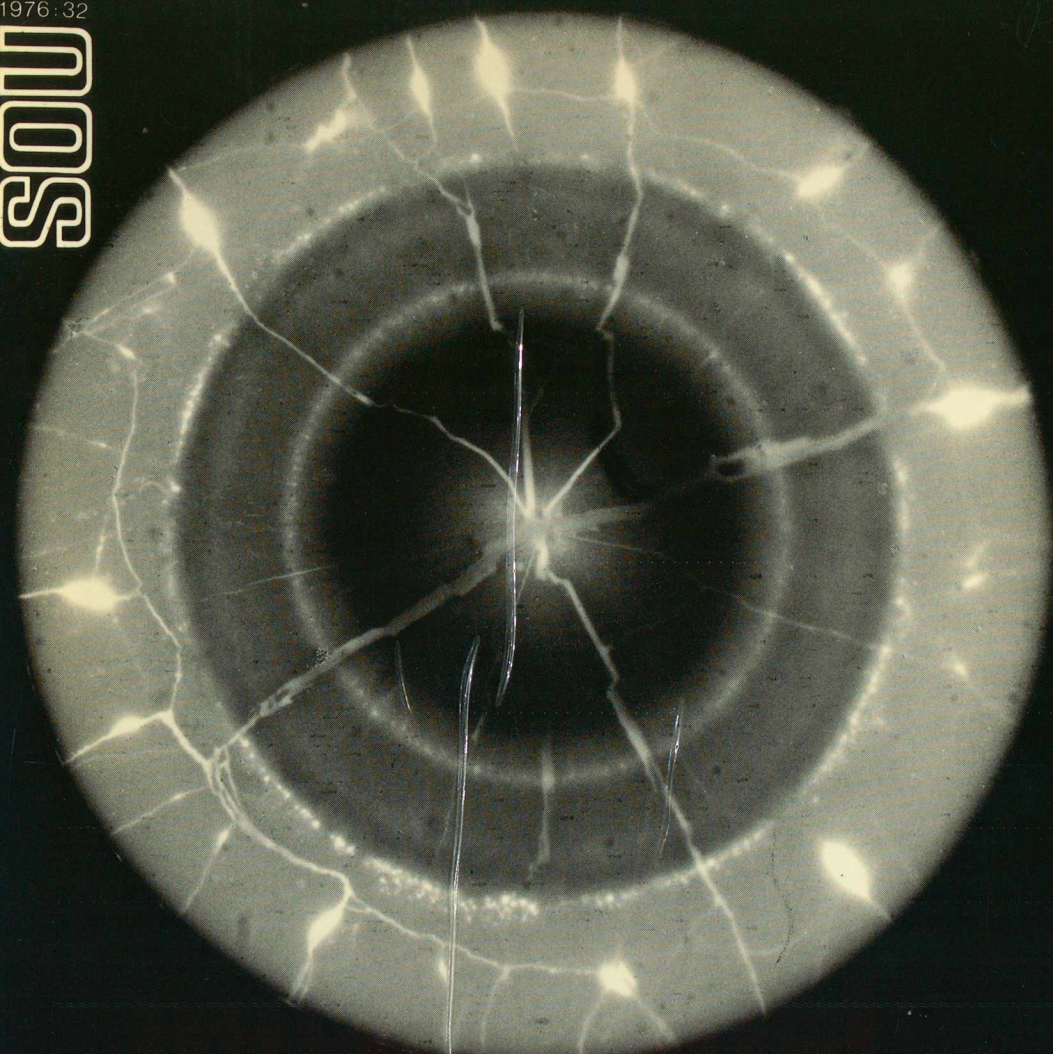


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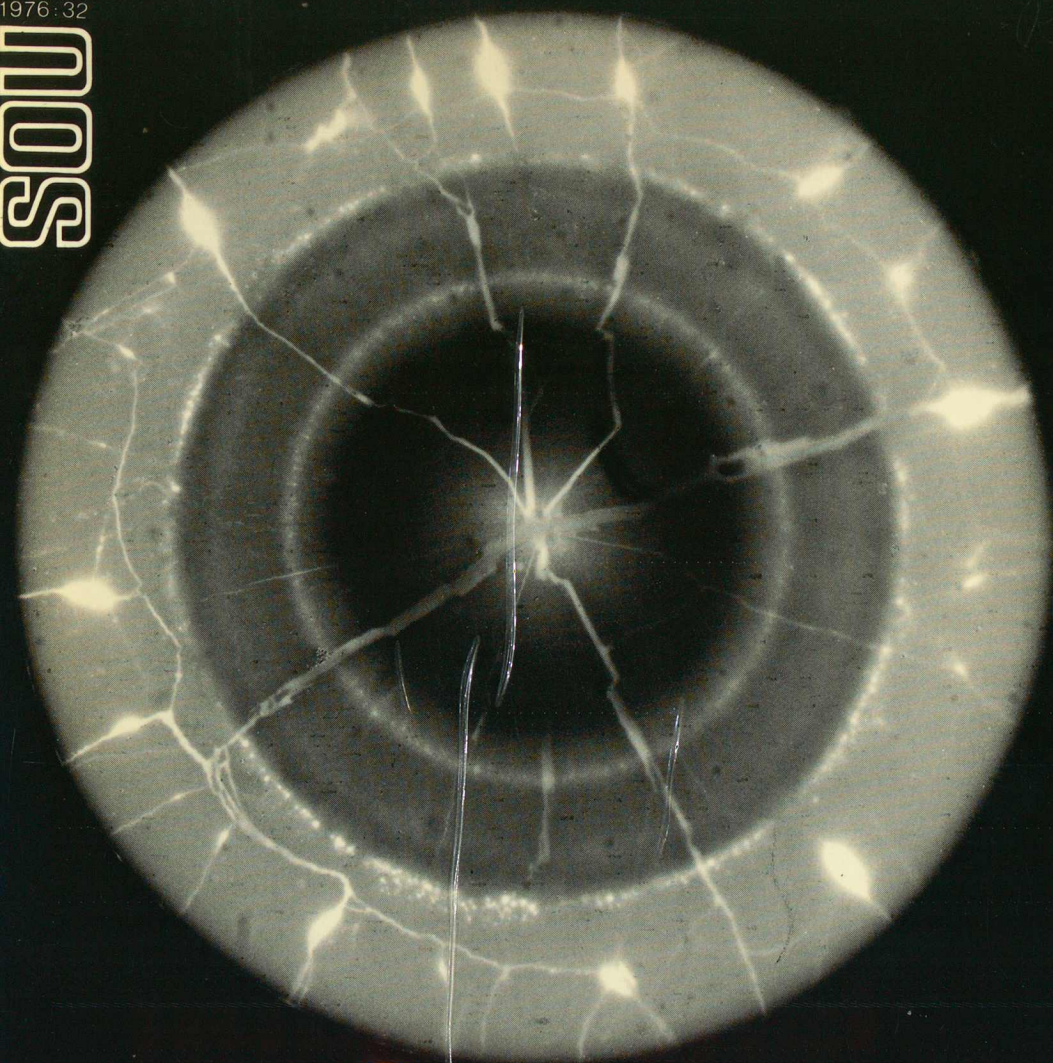
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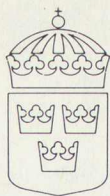


Spent nuclear fuel and radioactive waste

A summary of a report given by
the Swedish government committee
on radioactive waste

UTREDNINGEN om radioaktivt avfall

23
2



Statens offentliga utredningar
1976:32
Industridepartementet

Spent nuclear fuel and radioactive waste

A summary of a report given by
the Swedish government committee
on radioactive waste

Stockholm 1976

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Malmö Sweden 1976

Cover cross section of an irradiated uranium
oxide pellet.

Picture from AB Atomenergi.

To the Minister of Industry

Pursuant to the Royal Commission of 28 December 1972, the Minister of Industry appointed on 25 April 1973 a Committee of seven members under the chairmanship of County Governor Gösta Netzén, with the aim of investigating the problem of handling high-level radioactive waste from nuclear power plants. Two additional members were named on 28 December. The Committee was instructed to analyse various matters which are of importance to the Swedish preparedness in this field. In additional directives of 10 May 1974, the Minister of Industry extended the terms of reference of the investigation to embrace matters concerned with the handling and storage of low-level and medium-level radioactive waste. The members assumed the name of the Swedish Government Committee on Radioactive Waste, abridged to the Aka Committee.

Earlier, we submitted a situation report dealing with high-level radioactive waste from nuclear power plants (Ds I 1974:6) and a situation report dealing with low-level and medium-level waste (Ds I 1975:8). We hereby submit our main report which is divided up into two parts. Part I (SOU 1976:30) contains the summary, an outline of the investigation work and background material, and various considerations and proposals. Part II (SOU 1976:31) contains a collection of facts for the background to our opinions and proposals. The reports of certain experts are submitted concurrently as appendices to the report. (SOU 1976:41).

We wish to extend our thanks to the concerned authorities, organizations and companies, in Sweden and abroad, which have supplied the Committee with valuable material.

This report, SOU 1976:32, is an English-language summary of the investigation and corresponds to the Swedish-language summary, published as SOU 1976:30. Chapters 2 and 3 in the Swedish report, SOU 1976:30, also contain parts which were not translated to English. Examples are, how the Committee's work was performed, visits abroad and projections of nuclear energy in different countries.

The Committee is unanimous in its proposals. Special statements have been issued by two of the members – Einar Larsson and John Takman.

Malmö, 26 April, 1976

Gösta Netzén

Jan Bergqvist

John Takman

Nils Erik Wååg

Einar Larsson

Arne Westlin

Rune Ångström

Lars-Gunnar Larsson

Anders Wijkman

/Philip Moding

Hans Fransson

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Abstract

On May 19th 1976 the Swedish Government Committee on Radioactive Waste ("the Aka Committee") submitted its final report to the Government. The report gives a broad picture of the present situation with the general conclusion that today's technique offers satisfactory possibilities for the management of spent fuel and radioactive waste but that large efforts are needed in Sweden to complete the fuel cycle in a satisfactory way. The necessary program is outlined here including proposals for organization, financing, the role of the authorities, and law amendments.

All the five political parties in Parliament were represented among the Committee members, which also included scientists from the fields of radiobiology and industrial safety. The experts of the Committee represented the fields of geology, nuclear technology and physics, radiation protection, biology and environmental protection.

Summary

The following summary gives a brief outline of the questions which the Committee had to deal with according to its instructions, as well as the proposed solutions which it arrived at.

Instructions

1. Analyse the technical, economical and safety problems connected with reprocessing and storage of radioactive waste as well as with transport of radioactive material.

2. Indicate appropriate methods for handling radioactive waste in Sweden considering the preconditions of the country.

3. Study possible coordination of low- and medium-level radioactive waste management with that of high-level waste.

Proposals

To a great extent basic material was presented in preliminary reports published in 1974 and 1975. Part II offers a more comprehensive review of this material. Supplements will contain special material.

According to the findings of the Committee, glass or ceramic solidification of high-level radioactive waste is the best method so far available. Terminal storage of radioactive waste should be effected in bedrock. The geological survey carried out by SGU shows that Sweden's bedrock which has been stable for millions of years offers suitable storage conditions. As shipping by rail or boat gives many safety advantages it is recommended that radioactive waste which demands heavy, shielded containers be, whenever possible, shipped by rail or boat.

A central storage site for low- and medium-level radioactive waste should be established. To this site waste from research, industry

Instructions

4. Study the possibilities for constructing a Swedish reprocessing plant taking into account a possible joint siting with a nuclear power plant and a radioactive waste storage facility.

Proposals

and the medical field requiring long term storage as well as waste from reactor operation can be transferred. Low- and medium-level waste should not be buried in the ground; like high-level radioactive waste it should be stored in bedrock. The terminal storage site for low- and medium-level waste should be coordinated with storage facilities for high-level waste and projected concurrently.

Plans for a Swedish reprocessing plant with a capacity of 800 metric tons a year should be made as soon as possible in order for the plant to be completed by the beginning of the 1990's. It is estimated it will employ almost 1 000 people. A precondition for reprocessing should be the requirement that the extracted plutonium be converted to new fuel and recycled to the reactors as soon as possible. Any decision to construct a reprocessing plant should include a plutonium fuel fabrication plant as well.

Siting studies initiated by the Committee show that it is possible to site a reprocessing plant at a number of places in the Country. Primarily a possible joint site at Forsmark or Simpvärp should be investigated further. In the preparation for a possible future fifth nuclear power plant site, the site selected should, if possible, fulfill also the demands for a reprocessing plant and a terminal storage facility. Detailed geological studies of suitable locations for terminal storage should be started at an early date, primarily near Forsmark and Simpvärp. Alternative

Instructions

5. Consider the need for Swedish R & D in the area of radioactive waste and propose general guidelines for this work.

Proposals

sites should also be surveyed. A regional, Nordic solution to questions of reprocessing and terminal storage is of advantage and desirable from many points of view.

Though we primarily recommend reprocessing of Swedish spent fuel, further studies should be carried out to clarify the conditions for a non-reprocessing scheme. We feel that a technique can be developed for sending spent fuel directly to terminal storage. A decisive disadvantage of such a scheme is that the energy resources in the uranium and plutonium contained in the spent fuel would be wasted. Of advantage is that the plutonium is not separated and available in a pure state. This alternative of non-processing likewise permits the continued use of nuclear energy.

Our recommendation for a Swedish reprocessing plant implies that R & D in the reprocessing field should be increased as soon as possible. Efforts should include as well solidification processes for liquid high-level waste, primarily by vitrification methods. The geological work already started by SGU should continue and be expanded. We also envisage the need for significant R & D work on the manufacture and use of plutonium enriched fuel.

We wish to stress the importance of such R & D work being performed as is required as a basis for the approvals and control of the Nuclear Power Inspectorate (SKI) and the Institute of Radiation Protection (SSI) through the employment of the research bodies of these authorities.

Instructions

6. Examine the possibilities of international and in particular Nordic cooperation in the area of radioactive waste.

7. Consider forms for the organization of waste management under the precondition that the government will manage terminal waste storage operation.

Proposals

Considering the extensive R & D in progress in this field in foreign countries and in international organizations, Sweden should actively participate in the international cooperation. In particular, possibilities of practically oriented Nordic cooperation should be exploited.

The primary responsibility for the management of radioactive wastes rests with the organization from which the waste originates. Terminal storage operations demand far-reaching public surveillance and control. We therefore propose a special Government organization for all long-term management of radioactive waste and associated work, in particular the conduct of connected R & D. Furthermore, a special unit within the Nuclear Power Inspectorate should be set up for the inspection and control functions in the areas of nuclear fuel and radioactive waste. The unit should also be responsible for safety-related R & D work in the waste area. We propose that a reorganized Swedish Nuclear Fuel Supply Company should assume the responsibility for continued studies and plans for a Swedish reprocessing plant, a central stockpile of spent fuel and a spent nuclear fuel transport system. A special group should be organized for this purpose within the company which will, under the supervision of the Nuclear Fuel Supply Co, be responsible for directing and executing necessary developmental work for the reprocessing plant and for the transport of spent nuclear fuel. If a Swedish reprocessing plant is to

Instructions

8. Propose methods of financing the treatment, transport and storage of radioactive waste as well as R & D programs under the precondition that all cost should be borne by the waste producer.

9. Grossly estimate the size of investments necessary for appro-

Proposals

be built, we recommend the creation of a Government owned or a Government controlled corporation for this purpose.

The Radioactive Waste Program Advisory Board should be disbanded as of July 1, 1977 and its duties taken over by the previously suggested bodies. It is of utmost importance that future organizational changes should aim at a unified planning and a consolidated responsibility for the management of spent nuclear fuel and radioactive waste.

The electric power utilities should meet all expenses related to the management and storage of spent nuclear fuel and radioactive waste. In our opinion, costs incurred by the organizations and costs for development work proposed by the Committee should also be included. In their cost calculations the power utilities should furthermore incorporate future costs of reprocessing and terminal storage already at the time when the nuclear fuel is being used for power production. We recommend an amount corresponding to these charges being reserved in the utilities' annual accounts and transferred to a special fund from which the costs will be covered when they appear later on. In the meantime, the fund should form part of the companies' working capital. Preliminary estimates show that 0.5 öre (0.005 Sw.Cr.) per kilowatt-hour is sufficient to cover the remaining costs of nuclear power production.

In view of the demand for appropriate Swedish preparedness

Instructions

priate Swedish reprocessing and waste preparedness.

Proposals

in this field, it is our opinion that already initiated pilot studies for a Swedish reprocessing plant should continue and plans laid as soon as possible. According to information at present available, investment costs for a complete Swedish reprocessing plant with associated facilities having a capacity of 800 metric tons of uranium per year are estimated at 4 000 million Sw.Cr. Annual operating costs are estimated at about 850 million Sw.Cr. Investment costs for terminal storage of non-reprocessed spent fuel are estimated to equal about half of the amount for combined reprocessing and storage.

We propose that an approved, technical description of the planning of any future decommissioning should constitute a precondition for the licensing of nuclear facilities. The Nuclear Power Inspectorate should be the responsible authority to ensure that nuclear installations are constructed in such a way that a future decommissioning can be carried out in a satisfactory manner from technical and safety points of view.

10. Amend legislation.

We propose paragraph 2 of the present Atomic Energy Act to be amended in the following way, "... or installations for the treatment and storage of radioactive waste which originates from the use of nuclear fuel or treatment of spent nuclear fuel".

2 Commissions of enquiry in the Swedish administrative system

In the Swedish administrative system an important part is played by Commissions of enquiry. Whenever a reform is considered – whether involving legislation, administration or general policy – it is considered normal to appoint an ad hoc committee. The composition of this body will vary with the nature of the enquiry to be pursued. A commission whose report will have political implications will normally include representatives of the major political parties. This is the case in the Aka Committee where all the five parties in the Parliament are represented. In some cases, the commissions are confined to members of Parliament and in fact work not only as investigating bodies but also as negotiating bodies, i.e. the report will contain a negotiated agreement (or disagreement) between the political parties. On more technical matters the membership may be limited to civil servants and other experts. Usually, however, a commission is composed of a mixture of all these elements, that is members of Parliament, civil servants, experts and representatives of interested bodies (e.g. trade and industry, trade unions, etc.). The following list shows the composition of the Aka Committee.

The work of the commission is regulated by instructions issued by the Government. These directives give the detailed background to the required study and indicate the main lines of investigation to be pursued. Sometimes fairly firm directives are given and the task of the commission is then to create the administrative and legal framework necessary for their implementation. The commissions or their secretariats often include civil servants from the interested Ministries. Thus, the work of a commission will be closely followed by the Ministry concerned.

This system means that most of the basic studies which in other countries are performed within the administration itself, are in Sweden carried out by special bodies. This also helps to keep the Ministries down to a reasonable size.

When the commission's work is completed, its report is circulated for comment (*remiss*) to Agencies and private organizations concerned. This report from the Aka Committee is now circulated in this way and the comments will arrive in October 1976. The comments which the Government then receives are often lengthy documents analysing the

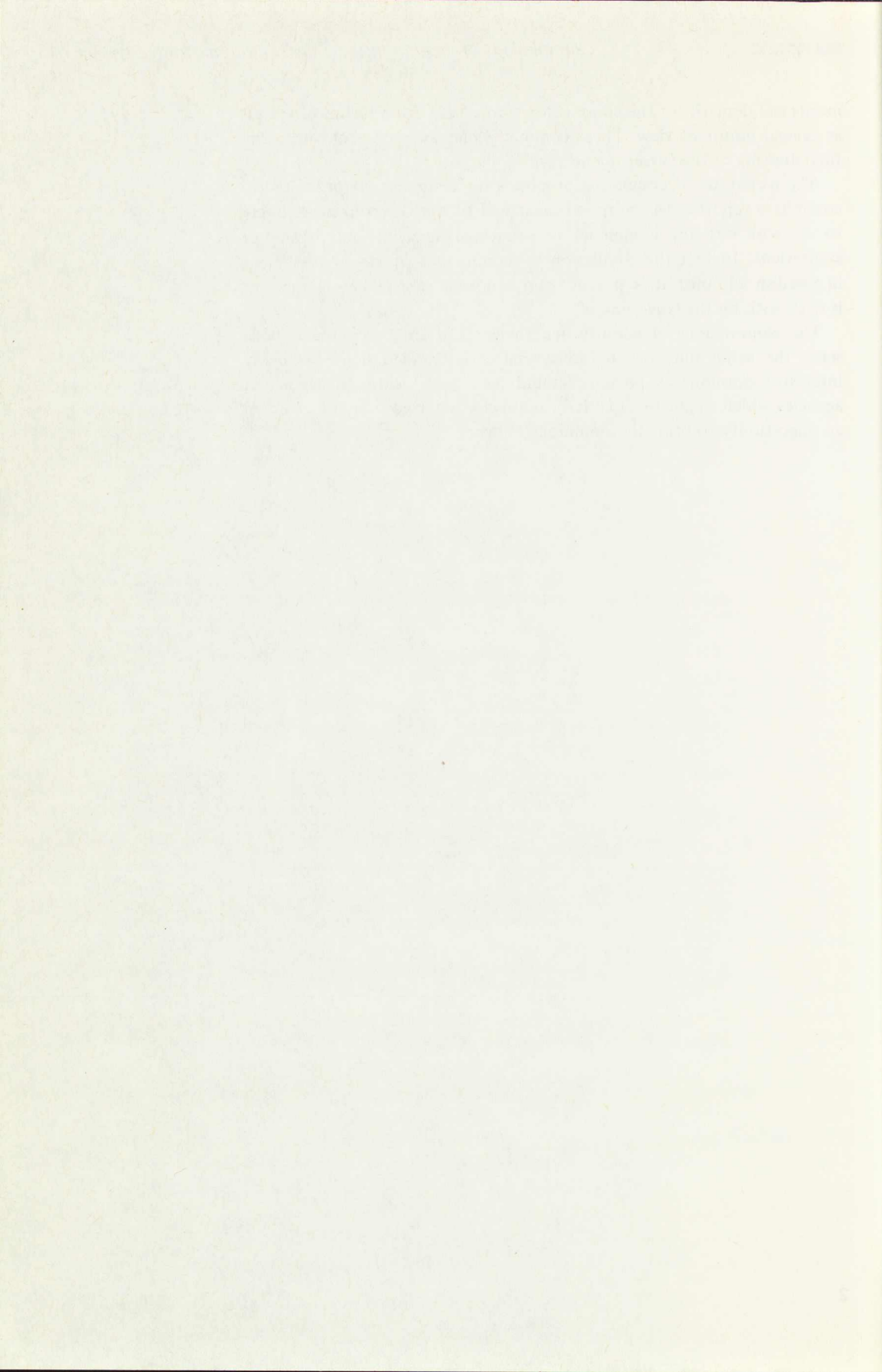
COMPOSITION OF THE AKA COMMITTEE

Name	Organization	Position in the Aka Committee
Gösta Netzén, Governor	The Aka Committee	Chairman
Jan Bergqvist, M.P. (The Social Democratic Party)	The Swedish Parliament	Member
Einar Larsson, M.P. (The Centre Party)	The Swedish Parliament	Member
John Takman, M.P. (The Communist Party)	The Swedish Parliament	Member
Anders Wijkman, M.P. (The Conservative Party)	The Swedish Parliament	Member
Nils Erik Wååg, M.P. (The Social Democratic Party)	The Swedish Parliament	Member
Rune Ångström, M.P. (The Liberal Party)	The Swedish Parliament	Member
Lars-Gunnar Larsson Professor	The Department of Radiotherapy, University Hospital, Umeå	Member
Arne Westlin Head of Department	The National Board of Occupational Safety and Health	Member
Gunnar Ekevärn Director-General	The Geological Survey of Sweden (SGU)	Expert
Leif Hjärne Master of Science	The Aka Committee	Expert
Åke Hultgren Doctor	The Swedish Atomic Energy Co, (AB Atomenergi)	Expert
Alf Larsson Master of Science (Engin.), adviser	The Ministry of Industry	Expert
Bo Lindell Professor	The National Institute of Radiation Protection (SSI)	Expert
Lennart Lindgren Head of Section	The Ministry of Agriculture	Expert
Bertil Mandahl Manager Protection Technology	OKG Co	Expert
Erik Svenke Managing Director	The Swedish Nuclear Fuel Supply Co (SKBF)	Expert
Philip Moding Director of Planning	The Aka Committee	Secretary
Hans Fransson Head of Section	The Aka Committee	Dep. Secretary

merits and demerits of the commission's proposals, from technical as well as general points of view. These comments play an important role in the final drafting of the Government's proposals.

The technique of circulating proposals for comment is not limited to committee reports. Any proposal presented to the Government is likely to be sent out for comments to interested agencies and private organizations. In fact the circulation for comment is an essential element in Swedish administrative practice and is normal routine before a matter is dealt with by the Government.

The commissions of enquiry and the circulation for comment both serve the same purpose. Before a matter is decided upon, as many interested opinions as possible should have been heard. In particular, agencies which might be directly or indirectly involved should be offered an opportunity to bring their opinions to bear.



3 Background

3.1 The development of nuclear power in Sweden

In the middle of the 1950's the Government laid down the guiding principles for Sweden's future activities within the nuclear energy sector. The prerequisites for the introduction of nuclear power were considered favourable. Sweden had large uranium deposits as well as a technically highly developed industry. At the time, the Country still had rather large untapped hydro-electric power resources. They were, however, expected to be almost fully exploited during the 1970's. Furthermore, Sweden lacked coal and oil. Nuclear power was considered to be a good alternative at the time when the hydro-power resources would be fully utilized. AB Atomenergi began its activities as far back as 1947. The power utilities and the manufacturing industry played an active role early in the Swedish nuclear energy program.

A research reactor near the Institute of Technology in Stockholm was taken into operation in 1954. Experimental uranium ore mining was carried out at Kvarntorp in Närke and a small uranium plant was built at Ranstad in Västergötland. The large Swedish uranium deposits as well as other factors made it natural for Sweden for a long time to concentrate on developing a heavy water reactor which could utilize natural uranium. From 1964 to 1974, a heavy water reactor was in operation at Ågesta outside of Stockholm. It generated electric power as well as heat and functioned as an important demonstration plant.

The development of the light water reactor abroad as well as certain difficulties in developing a Swedish heavy water reactor, led to a reorientation of the Swedish program in the 1960's. In 1965 the ASEA company was awarded the order for a light water reactor to the Country's first major light water reactor plant at Simpsvarp near Oskarshamn. Further orders followed in 1968. That year ASEA and the Government signed an agreement on cooperation in the nuclear energy field, and this led to the formation of AB Asea-Atom. The water cooled light water reactor which Asea-Atom now markets was developed without licensing agreement with any large foreign reactor manufacturer.

In a statement issued in 1962 covering expected electrical energy

consumption during the 1970's, The Central Operating Management, CDL, a joint organization of major Swedish power producers, estimated that by the second half of the 1970's, most of the needed additional electric power demand would be supplied by nuclear energy. Ten years' later, in 1972, CDL issued a study on the expansion of nuclear power which showed that eleven nuclear power plants supplying a total of 8,260 MW would be in operation by 1980.

Following a parliamentary decision in 1972, the Swedish Nuclear Fuel Supply Company, SKBF, was created with Statens vattenfallsverk (The State Power Board), Sydsvenska Kraft AB (South Swedish Power Co.) and Oskarshamns Kraftgrupp AB (OKG Co.) as part owners. The duties of SKBF are to supply nuclear fuel, reprocessing services etc. The operating costs of the company are met by the partners and Parliament approved a state guarantee.

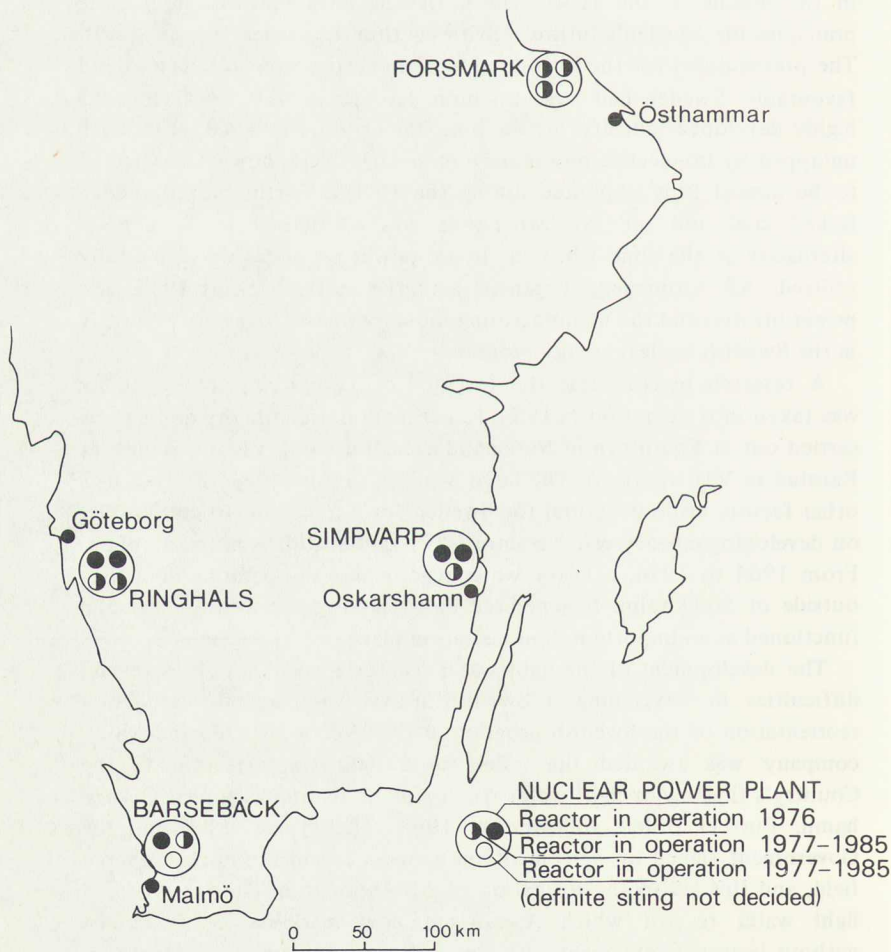


Figure 3.1 Licensed reactor units at the Country's four nuclear power plants

Aka 1976-04-04

Table 3.1 Licensed nuclear power installation program in Sweden

Installation	Owner	Commercial operation	Type	Net output MW
Oskarshamn 1 (Simpvarp)	OKG ¹	1972	BWR	450
Oskarshamn 2	OKG	1974	BWR	580
Oskarshamn 3 ²	OKG	1982/83	BWR	1060
Ringhals 1	Vattenfall	1976	BWR	760
Ringhals 2	Vattenfall	1975	PWR	820
Ringhals 3	Vattenfall	1977/78	PWR	915
Ringhals 4	Vattenfall	1979	PWR	915
Barsebäck 1	Sydskraft	1975	BWR	580
Barsebäck 2 ⁵	Sydskraft	1977	BWR	580
Barsebäck 3	Sydskraft	—	Undecided	—
Forsmark 1	FKA ³	1978	BWR	900
Forsmark 2	FKA	1980	BWR	900
Forsmark 3 ⁴	FKA	1982/83	BWR	1000
Forsmark 4 ⁵	FKA	—	—	900

¹ Oskarshamns Kraftgrupp AB (OKG) of which South Swedish Power Co. holds the largest percentage of the shares, i. e. 35 %.

² Licensed in 1974. Unit ordered in May 1976 (Åsea-Atom).

³ Forsmarks Kraftgrupp AB of which the Swedish State Power Board owns 75 %.

⁴ Licensed in May 1976.

⁵ Barsebäck and Forsmark are alternative sites for the thirteenth unit.

In 1973 Parliament decided that no decision to build additional reactors beyond the first eleven would be taken before a new comprehensive basis for decisions was presented to Parliament. This was to include i. a. research findings, development trends and safety considerations.

In 1975, Parliament considered the Government's bill on energy conservation etc. which mainly contained guidelines for Sweden's energy policy through 1985. Parliament approved a continued nuclear power expansion by two reactor units. A principal point for the planning was that no new sites were to be opened. Planning for the new units should primarily be concentrated on an extension at Forsmark. However, the thirteenth unit may be placed at Barsebäck. Parliament is expected to take up the question of long range energy policy in 1978. Government and Parliament anticipate a more conclusive basis for a decision on the future energy policy to be available at that time. Results of investigations in progress of further experience from the nuclear power plants now in operation and the effects of certain energy conservation measures are awaited.

The approved nuclear power expansion program comprises thirteen units at four sites. At full power, their combined net output will amount to 10.000 MW. Five units totalling 3.190 MW are now in operation while the remaining eight units are in various stages of building, design and planning, table 3.1 and figure 3.1.

Through the State Power Board, the Government accounts for more than half of the approved nuclear power expansion.

AB Asea-Atom in Västerås is supplying all of the boiling water reactors. The three pressurized water reactors at Ringhals were delivered by Westinghouse.

Nuclear power supplied about 14 % of the Country's total electrical energy production in 1975. According to bill 1975:30 it is estimated that electricity consumption will increase by 6 % per year in the next decade. This is a total increase from 80 TWh in 1975 to 159 TWh in 1985. This increase will be covered by an expanded nuclear power program which by the end of the period is estimated to supply about 40 % of the electricity produced.

3.2 The nuclear fuel cycle

A nuclear power plant often consists of several reactor units. The principal components of a single unit are the reactor and the turbine. Nuclear reactions take place in the reactor fuel whereby heat is produced. The heat is transferred to water which is converted to steam to drive the turbine. The turbine turns the generator which produces electricity.

The nuclear fuel cycle constitutes the entire range of processes to which the fuel is subjected from ore mining to terminal storage of the radioactive waste in bedrock. Figure 3.2 shows the cycle in simplified form.

Uranium ore is mined and uranium is extracted from the ore in a uranium mill. Natural uranium contains about 0.7 % of the fissile isotope uranium-235 and 99.3 % non-fissile uranium-238. To be of use in a light water reactor the content of uranium-235 must be increased to 2–3 %. This is achieved in an enrichment plant. The enriched uranium in the form of uranium dioxide is the raw material for the fabrication of fuel elements. In the fuel element plant uranium dioxide is sintered into small cylinders called fuel pellets which are charged into long metal tubes. A number of these tubes are assembled to form a fuel element. The elements are charged to a reactor to obtain heat through nuclear fission.

When a uranium-235 atom is split and releases energy, two to three free neutrons are formed. The new atoms created through fission, also known as fission products, can be of various types. Up to 250–300 nuclides of different elements are produced, and nearly all of these are radioactive. Some of the neutrons are being absorbed by the uranium-238. In this way isotopes heavier than uranium, known as transuranics are created. The most important of these is plutonium. Figure 3.3 provides a schematic illustration of the fission process, how plutonium is formed and its subsequent fission.

The fuel elements remain in the reactor for three to five years before having to be discharged and replaced with fresh fuel. The spent fuel contains large amounts of radioactive substances. Assuming that the

tubes which surround the fuel have not begun to leak, all the fission products and transuranics will stay in the fuel together with the remaining uranium. Approximately 3 % of the contents of the spent fuel consists of fission products. Uranium constitutes about 96 percent and plutonium about 1 percent of the spent fuel.

Until March 1, 1976, the five reactors now in operation have together produced about 20,000 million kWh. Table 3.2 gives detailed performance data for the five units.

After reenrichment the uranium as well as the plutonium can be reused as fuel. Spent nuclear fuel should therefore not be considered as radioactive waste. The fission products in the fuel generate large quantities of heat when the fuel is discharged from the reactor. One day after the discharge from the reactor the heat production in the fuel is reduced to one-tenth and after three months, to one-hundredth.

Figure 3.2 The nuclear fuel cycle

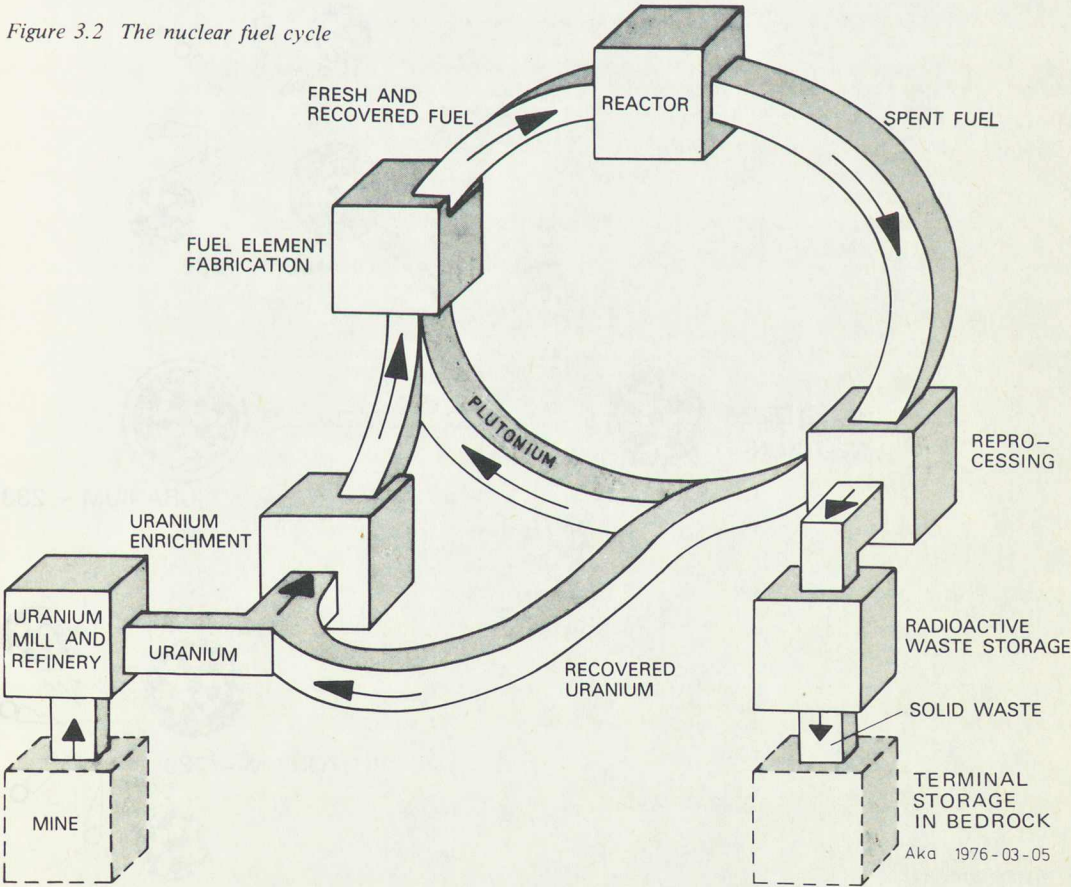
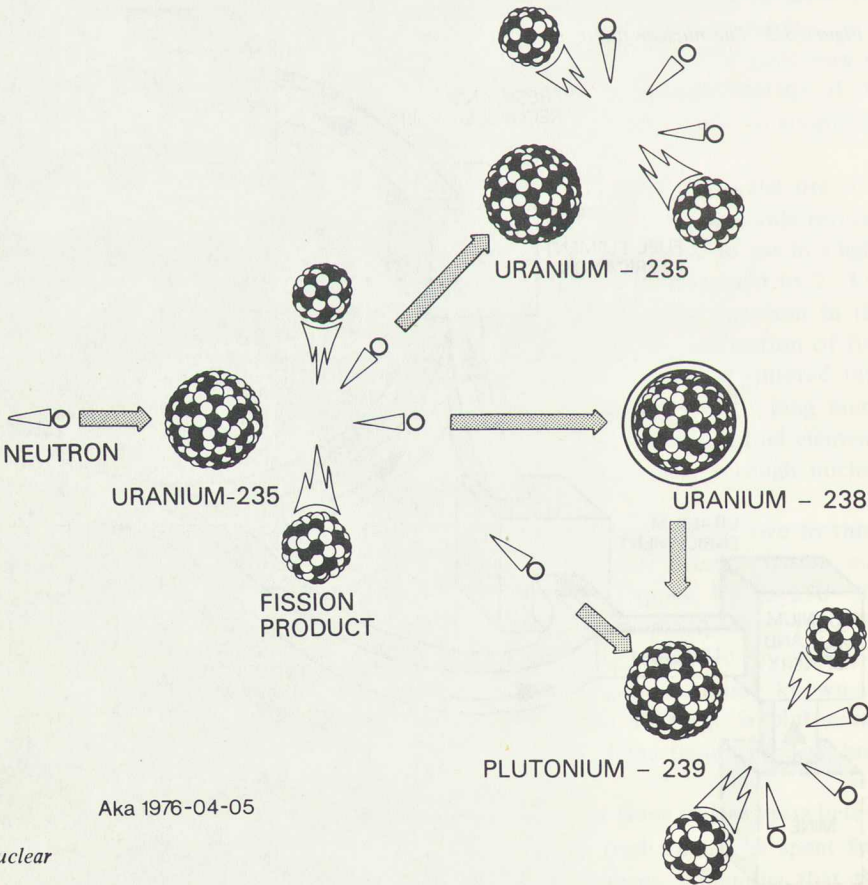


Table 3.2 Performance data as of March 1, 1976 for Swedish nuclear reactor units

	Operating time with generator connected to the grid, hours	Gross electricity production, GWh	Approximate burnup, MWd per ton uranium	
			Average	Max.
Oskarshamn 1	19 873	8 276	10 600	20 000
Oskarshamn 2	7 928	4 172	6 100	10 000
Ringhals 1	4 740	2 100	2 580	4 600
Ringhals 2	6 060	3 635	6 400	11 500
Barsebäck 1	4 650	2 420	3 760	6 700

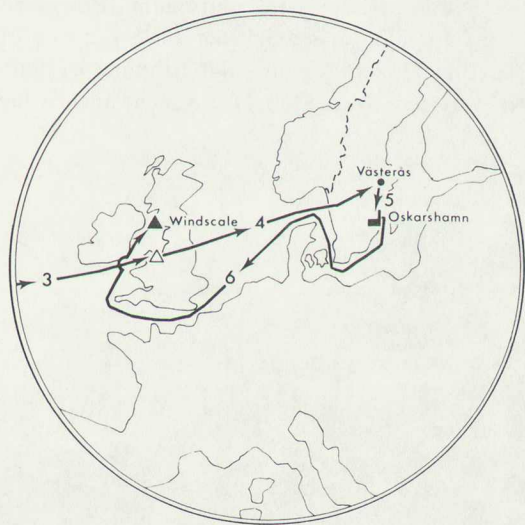
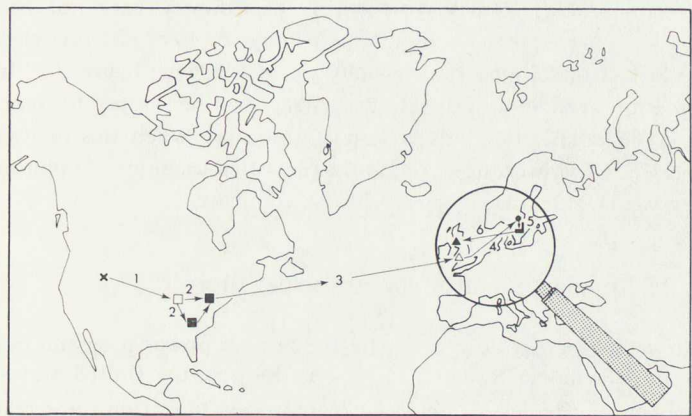
Nuclear power plant
Reactor in operation in 1976
Reactor in operation in 1977–1985
Reactor in operation in 1977–1985
(Definite siting not decided)



Aka 1976-04-05

Figure 3.3 The nuclear fission process

The spent nuclear fuel is deposited in a deep water pool adjacent to the reactor and is usually kept there for at least one year. It is then transferred in heavy, radiation shielded, shock-resistant containers to a plant for fuel reprocessing or to a special storage facility for spent fuel. In the reprocessing plant the remaining uranium and the newly formed plutonium are separated from the fission products which comprise the



Installations

- × Mine
- Conversion of uranium concentrate to UF_6
- Enrichment plant
- △ Conversion of UF_6 to UO_2
- Fuel element fabrication
- ▣ Nuclear power plant
- ▲ Reprocessing plant

Transports

- 1. Uranium concentrate
- 2. Natural UF_6
- 3. Enriched UF_6
- 4. Enriched UO_2
- 5. Fresh fuel
- 6. Spent fuel

Figure 3.4 Fuel path for the first reactor, Oskarshamnsverket 1, at Simpvarp, north of Oskarshamn

high-level radioactive waste. The high-level radioactive waste is stored close to the reprocessing plant, at first in liquid form. Subsequently, the waste is solidified for terminal storage.

Figure 3.4 shows the fuel path for the Country's first large reactor, Oskarshamn 1, at Simpvarp north of Oskarshamn, which has been in operation since 1972.

During 1974 and 1975, 96 fuel elements were discharged from Oskarshamn 1 and in 1976, an additional 115 elements will be discharged from this reactor. Other reactors in the Country have not been in operation long enough to require refuelling. In 1975, 24 fuel elements were sent from Simpvarp to Windscale in England, figure 3.5. In the summer of 1976 an additional 72 elements will be shipped for reprocessing in Windscale. It is not certain at this stage when this fuel will be processed. OKG may sell or retain the recovered uranium and plutonium. The waste is taken care of by the British company.

3.3 The management of spent nuclear fuel

Light water reactors now dominate the nuclear power programs in most countries, including Sweden. In Western Europe, the United States, the Soviet and Japan, plans are afoot to reprocess fuel from these reactors and to recycle the uranium and plutonium. However, the present situation in the United States is somewhat unclear in view of factors such as regulations for the reprocessing and handling of plutonium being revised. A recovery of fissile material from spent nuclear fuel reduces the



Figure 3.5 Loading of spent fuel at Simpvarp's port in 1975

need for natural uranium and therefore leads to better energy conservation. Reprocessing also makes it possible to treat and store the high-level radioactive waste in a more satisfactory way than direct terminal storage of the spent nuclear fuel.

If the fast breeder reactor becomes accepted and commercially available, the reprocessing of its fuel will constitute a necessary prerequisite for its function. In the fast reactor, uranium-238 is gradually converted to fissile plutonium-239 which after reprocessing is reused in new fuel. It is estimated that, by this method, 70–75 % of the uranium can be utilized, as compared to only 1–2 % in the light water reactor. Spent fuel from the core of the fast reactor will have three times as high a burn-up as the fuel used in the light water reactor which adds to the demands on transport and reprocessing. Because of the higher plutonium content, the reprocessing of fuel from these reactors is more complex than the reprocessing of plutonium enriched fuel for light water reactors. Industrial experience from fuel reprocessing and the recycle of plutonium for fuelling light water reactors is therefore considered to be imperative for industry in order to establish a corresponding operation for the fast reactor fuel supply.

The delays of recent years and the rapidly rising costs for expansion of the reprocessing industry has increased interest on the possibility of refraining from reprocessing. The consequences of such a course of action have therefore begun to be studied in the United States, Canada and Sweden. The aim is to obtain a more precise basis for assessing the motives for and against reprocessing, from technical, economic and safety considerations.

The cost calculations carried out by the Committee for reprocessing and non-reprocessing schemes are compiled in chapter 3.1.2.

3.3.1 *Reprocessing*

During reprocessing the uranium, plutonium, high-level waste and the cladding waste are separated from each other. The uranium is re-enriched and recycled.

Since a long time uranium from the spent fuel from research reactors containing highly enriched uranium has been recovered. The incentive is one of economy, since the contents of uranium-235 in this particular spent fuel is still very high, 60–70 % for the R 2-reactor at Studsvik as compared to about 90 % in fresh fuel. In the case of light water reactor fuel, the economics of reprocessing are dependent on the cost of reprocessing and the value of the recovered uranium and plutonium. The price of natural uranium is also an important factor.

Plutonium can partially replace low enriched uranium as fuel for light water reactors and thus reduce the requirement for natural uranium as well as for enrichment. Industrial methods for the enrichment of power reactor fuel with plutonium have been developed up to large-scale production. There are two plants in Belgium and the Federal Republic of Germany each with an annual production capacity of 40 metric tons of

plutonium enriched oxide fuel. Small amounts of plutonium fuel have also been produced at Studsvik. The production cost is estimated to be 15–30 % higher than for uranium fuel without plutonium. Plutonium fuel has been tested on a large scale and to high burn-up in power reactors in among other places, the United States and the German Federal Republic. Also in Sweden plutonium enriched test elements have been charged to the Ågesta reactor and Oskarshamn 1.

A recycle of uranium as well as plutonium in new reactor fuel for light water reactors is estimated to save 15–20 % of the enrichment work and 30–35 % of the requirement of natural uranium for the fuel supply of the reactors.

Methods have been developed to transfer the high-level radioactive waste to solid form, including glass vitrification. Principal solutions have also been developed for terminal storage of waste in bedrock. These methods of storing waste are now under comprehensive development in many nations, among these, Sweden.

Transports of spent nuclear fuel and plutonium are subject to rigorous rules and control by competent authorities. This also applies to the construction and operation of reprocessing plants.

3.3.2 *Non-reprocessing*

If the decision is made not to plan for immediate reprocessing of the spent fuel there are basically two alternatives available. The one involves terminal storage in a state in which reprocessing is impossible in the future, while the other involves storage in such a way that the spent fuel can be reprocessed at a later date. In both cases the management is considered to be technically advanced. The alternative of terminal storage of spent fuel can be expected to imply opening of the fuel, breaking it down into smaller parts and moulding it in some metallic material, for instance, which conductively removes the heat and makes possible terminal storage in bedrock in a manner similar to that for high-level radioactive waste. However, terminal storage of spent fuel places greater demands due to factors such as risk of criticality in the presence of plutonium. In certain stages the treatment technique corresponds to ordinary reprocessing. If the possibility of future reprocessing is to be retained, the problem of long-term safe storage of spent fuel will have to be solved.

Non-reprocessing offers certain advantages from the point of view of control, primarily as regards the plutonium. For clandestine groups for example, it is almost impossible to retrieve plutonium from fuel which is not reprocessed. The risk of plutonium being used for nuclear explosions is thus much less when the plutonium is bound in spent fuel than when pure plutonium is stored.

An analysis of the overall risk in the management chain from reprocessing, through recycle to terminal storage, is in progress within the Swedish research program.

3.3.3 The development of the reprocessing industry

A technique for the reprocessing of irradiated nuclear fuel was first developed in the beginning of the 1940's. The main purpose was then solely to obtain plutonium for the production of nuclear weapons. A number of plants were built for this purpose. e. g. in the United States. After separation of the plutonium, the uranium was left together with fission products as waste. The relatively low concentration of radioactive fission products facilitated the development of this new technique.

From the beginning of the 1950's up to about 1970, a number of reactor types were developed. The two versions of the light water reactor i.e. the boiling water and pressurized water reactors, finally became predominant at the time of the commercial breakthrough of nuclear power. Essential factors for the supply of fuel during this period were the procurement of natural uranium, enrichment services and fuel fabrication. When the military demand for highly enriched uranium and plutonium was essentially met around 1960, a substantial excess capacity for uranium mining and milling as well as enrichment emerged leading to low prices. The situation was similar in the reprocessing industry. The reuse of uranium and plutonium in new fuel was considered to become profitable as soon as the recovery of plutonium was established on an industrial scale. The management of the high-level waste from reprocessing was entirely the responsibility of the reprocessing industry. In this saturated market for all essential services in the nuclear fuel cycle it was not considered necessary for the power utilities and authorities to engage in securing adequate capacity for reprocessing and waste management.

Even in the beginning of the 1970's competition in selling reprocessing services was stiff between the government financed reprocessing companies British Nuclear Fuels Ltd, BNFL, Windscale, England and Commissariat à l'Energie Atomique, CEA, France on the one hand and the European company Eurochemic with its pilot plant at Mol, Belgium on the other.

Together with 12 other nations, Sweden participated in a technically successful development project at Eurochemic. To secure coordination and to avoid the risk of excess capacity in the reprocessing field, the British BNFL, the French CEA and the West German KEWA merged in October 1971 to create United Reprocessors GmbH (URG). Sweden and the other European nations were left out.

3.3.4 Present situation of the European reprocessing industry

Since 1971, only United Reprocessors GmbH offers contracts for reprocessing in Western Europe. The Western European need for reprocessing should therefore be related to the present and planned capacity at URG. Even assuming that the planned expansion of the reprocessing installations at La Hague, France (figure 3.6) and at Windscale, England will be taken into service according to plan, a reprocessing bottleneck situation will occur around 1978/79. This

shortage of capacity will worsen during the 1980's, until a planned, but as yet undecided West German plant with a yearly capacity of 1500 metric tons of uranium is expected to be in operation. However the effects of this imbalance can be accepted temporarily without any major inconvenience by the extension of storage pools for spent nuclear fuel.

The possibilities of storing Swedish spent fuel at both Windscale and La Hague are limited. Expansion is in progress at Windscale for storing an additional 600 metric tons of spent fuel by 1976, but URG is negotiating a contract with Japan for accepting 700–800 metric tons a year from 1977 to 1983. La Hague has a storage pool system with a capacity of 250 metric tons, but it is already filled. By 1978 La Hague is estimated to have an additional capacity of 500 metric tons in a larger storage pool system. The planned large West German reprocessing plant is expected to have a capacity for stockpiling 3.600 metric tons of spent fuel.

Reprocessing metallic fuel and other low burn-up fuel no longer present any difficult technical problems. These fuel types have been reprocessed for a long time in England, France and the United States. On the other hand, the high burn-up nuclear fuel from light water reactors has appeared to be more difficult to reprocess. In England, France and the United States, it has therefore proved necessary to replan and to modify buildings, processes, equipment etc. This has caused appreciable

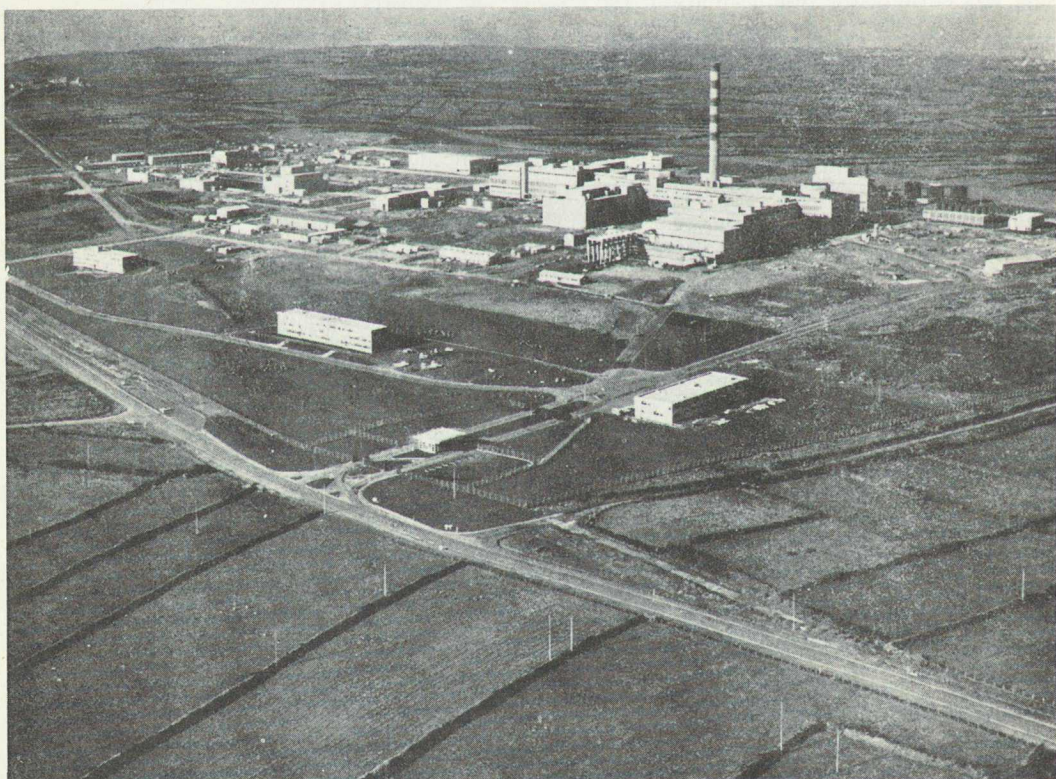


Figure 3.6 *The reprocessing plant at La Hague, France*

delays. The recently feared excess capacity of reprocessing services in Western Europe has changed to the opposite. Furthermore, as a consequence of the increases in crude oil prices the expansion of nuclear energy has been accelerated in many countries.

It is as yet unclear when the reprocessing of spent high burn-up fuel can start up in Great Britain. The erection of a new facility at Windscale for 1 000 metric tons per year is planned at present. The domestic British need for reprocessing her own high burn-up fuel will be moderate still in the beginning of the 1980's as Great Britain at present has different reactors and different types of fuel.

In the present situation, United Reprocessors has given notice of a temporary halt in receiving additional fuel for reprocessing which will be removed from reactors between 1977 and 1979. It must also be considered improbable that URG can undertake reprocessing of all spent fuel in Europe after 1985-86. The consequences are that other European countries with large nuclear power programs should consider what measures are necessary to handle spent nuclear fuel which is discharged after 1985. If present plans for reprocessing materialize, the accumulated stock of non-reprocessed fuel may reach 7 000-8 000 metric tons by the end of the 1980's.

3.3.5 *The management of Swedish spent nuclear fuel*

Difficulties in clarifying the actual conditions for the contracts for reprocessing which URG is now offering can be expected to continue for a long time to come. The difficulties are to a large extent connected with the performance of the plants at Windscale and La Hague.

The Soviet Union is expected to begin large-scale reprocessing of high burn-up oxide fuel during the 1980's. The Russian capacity is estimated to satisfy the East European demands. In all probability, capacity will not be available for reprocessing Swedish nuclear fuel neither in the Soviet Union nor in the United States in the near future. As many other nuclear power countries, Sweden must therefore increase her own storage capacity for spent fuel. This can be accommodated by suitable distribution of the enlargement of storage pools at power stations and at a central stockpile.

Oskarshamnsverkets Kraftgrupp (OKG) has secured contracts for reprocessing with BNFL, covering the requirements of OKG until 1980. However, Vattenfall and Sydkraft have as yet not acquired, any contracts for the nuclear fuel which will be discharged from the reactors at Ringhals, Forsmark and Barsebäck. In the report issued in the summer of 1974 the Committee felt that the Swedish power utilities would have the possibility of utilizing the capacity at plants in England and France during the 1970's. Negotiations on new contracts are now underway between URG and SKBF.

3.4 Reprocessing in Sweden

3.4.1 *Preparedness*

In the instructions to the Committee in 1972, the Minister of Industry noted that a more restrictive attitude abroad toward reprocessing spent Swedish nuclear fuel could not be completely precluded in the long run. The Committee should therefore study the prerequisites for a reprocessing plant and storage facility in Sweden. The Committee has studied the technical, economic, safety and time related consequences which this would involve. A more detailed account is given in part II of this report.

According to our studies it takes 10–13 years after decision to erect a reprocessing plant and to attain full-capacity operation.

This period of time would be allocated as follows

- | | |
|--|---------|
| – Preparatory studies and site investigations | 4 years |
| – Design, building work, installation of equipment | 7 years |
| – Successive commissioning | 2 years |

If experience in this field can be obtained from countries which have constructed and operate plants of this kind, the time spent on preparatory studies can be considerably shortened. Such countries can base their planning on experience from the operation of large plants, pilot plants and research and development work. A Swedish reprocessing plant will therefore be likely to require at least 13 years from the decision to initiate a pilot study to full commercial operation. This implies that it could be in operation in the beginning of the 1990's at the earliest.

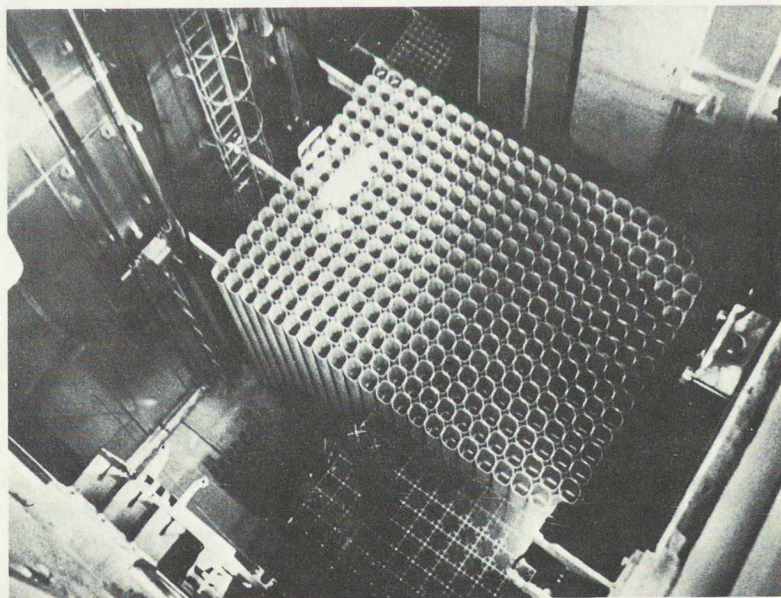


Figure 3.7 Storage pool for spent nuclear fuel at a reactor

Several factors influence the capacity which should be chosen for a Swedish reprocessing plant, including:

- The number of reactors to be served and thus the annual discharge of spent fuel
- The starting time for operation
- The expected amount of spent fuel already stored at the beginning of operation
- Economic and technical factors
- Cooperation with other countries

The capacity of the plants now being planned in western Europe, the United States, the Soviet Union and Japan is reported to be 3–5 metric tons of uranium per day. The operation time is estimated at 200–300 days a year and this corresponds to 600–1500 metric tons per year. However it is as yet uncertain how large a percentage of the annual capacity can be utilized in reality. For this reason, considerable excess capacity is incorporated, often, in the form of additional, parallel process lines. This arrangement allows a certain rate of production to be maintained even if one line should become inoperative. For technical and safety reasons, it may thus be advantageous to design certain parts of the process as parallel units. This approach offers ample scope for expanding the capacity in stages by planned extensions, without the need for shutting down the plant. The capacity of the plant is thus rendered flexible.

The size of a plant and above all, the degree to which it is utilized, plays a large role in the economy of reprocessing. Reprocessing in a plant with a capacity below 600–800 metric tons of uranium per year is considerably more expensive than in a larger plant. On the other hand, the economic advantages offered by very large plants must be weighed against the different problems which they give rise to.

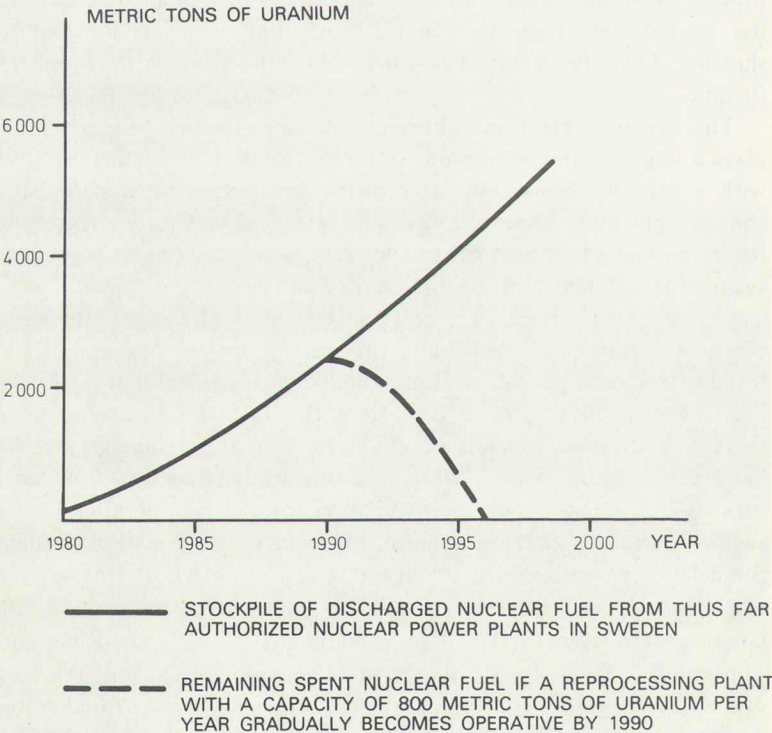
The write-off time of a reprocessing plant is often taken to be 15 years. However, the actual useful life may be longer. Assuming that a Swedish installation is gradually commissioned in 1990 it will by 2005 have handled all fuel discharged from the 13 authorized reactors an average reprocessing capacity of 470 metric tons of uranium per year will be required. From 1980 to 2005, it is estimated that about 7 000 metric tons of uranium will be discharged from the reactors. Reprocessing at such low capacity is uneconomical. Inadequate margin will be available for delayed commissioning or breakdown. The choice of a capacity of 600–800 metric tons of uranium a year offers more favourable conditions. A plant designed for 800 metric tons a year offers good opportunities for reducing the stockpile of spent fuel in 6–7 years and can simultaneously reprocess the spent fuel discharged from reactors during this period, (figure 3.8). On the other hand, the size of a plant may prove to be too large once the existing stockpile has been reprocessed. This might be a reason for the plant to consist of two separate process lines for perhaps 400 metric tons per year each. Other

factors which must be taken into consideration are possible new Swedish nuclear power units after 1985 and the possible need for capacity for reprocessing fuel primarily from the other Nordic countries.

3.4.2 Siting

Through an ad hoc working group the Committee has studied existing and planned foreign reprocessing plants in order to improve knowledge of how a Swedish reprocessing plant should be sited. The study was given the form of a special assignment to Vattenbyggnadsbyrån, VBB. The group consulted on a continuous basis with the Committee. The plants studied were Marcoule and La Hague in France, Windscale in England, Eurochemic in Belgium and West Valley, Barnwell and Morris in the United States.

On the basis of experience gained by the group in connection with detailed studies of foreign plants as well as earlier Swedish experience it arrived at the tentative application of the following conditions for choosing a site for a Swedish reprocessing plant. These conditions were approved by the Committee.



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Figure 3.8 The development of spent nuclear fuel from Swedish reactors

- The plant should have a surface area of at least 2 square kilometers. As it probably will be used for a long time, the site must offer good opportunities for future buildings and reconstruction of old ones
- The demands applicable to the siting of a nuclear power plant with respect to environmental safety can essentially also guide the choice of a site for a reprocessing plant
- The area should have suitable ground water conditions and drainage of water within the area taking into account the risk of the spreading of radioactivity
- The climatic conditions in the area should be such as to provide sufficient dilution of released radioactive gases
- The site should be chosen so that it is assumed to be as free as possible from natural disasters and other events which might damage the installations
- Fresh water must be available. The amounts required is estimated to about 100 m³/h
- The requirement for cooling water is about 4 000 m³/h. This demand can be substantially reduced if air cooling is employed to a larger extent. If a natural reservoir does not already exist, such a reservoir should be possible to build
- It should be possible to regularly transport loads of 100 tons to and from the site, primarily by ship or rail. The site should be close to a railway line and roads capable of carrying heavy traffic, and close to a port
- It should be possible to place certain parts of the installation underground in rock
- Suitable bedrock at the site offers the opportunity for a joint location for a reprocessing plant and a terminal storage facility for waste. In this way, long waste transports are avoided
- A reprocessing plant will most probably be followed by other nuclear activity such as plutonium fuel fabrication. Ample margies for land and fresh water should therefore be available
- The demands of the authorities on permissible radiation doses and industrial safety conditions must be satisfied
- The demands according to national planning in the use of land as well as regional policy must be met
- Civil defence aspects as well as security against theft, terrorism and sabotage must be considered

The group has also consulted a West German working group on these aspects. For the most part, the West German and Swedish group agreed on the demands. The differences mostly concerned the geology where West Germany will probably demand salt bed under the reprocessing plant for terminal storage of the waste. The Swedish conditions include demands for suitable rock in the plant area and suitable primary rock for storage at or in the vicinity of the area. Our demands on rock coverage for certain parts of the installation are also more far-reaching than existing demands abroad.

After defining in relative detail the conditions for siting which should be satisfied for a possible Swedish reprocessing plant, the group attempted to establish possible sites for such a plant within the Country. The group considered the entire country which was divided into five regions. In each region, places or areas were sought where the defined conditions could be satisfied.

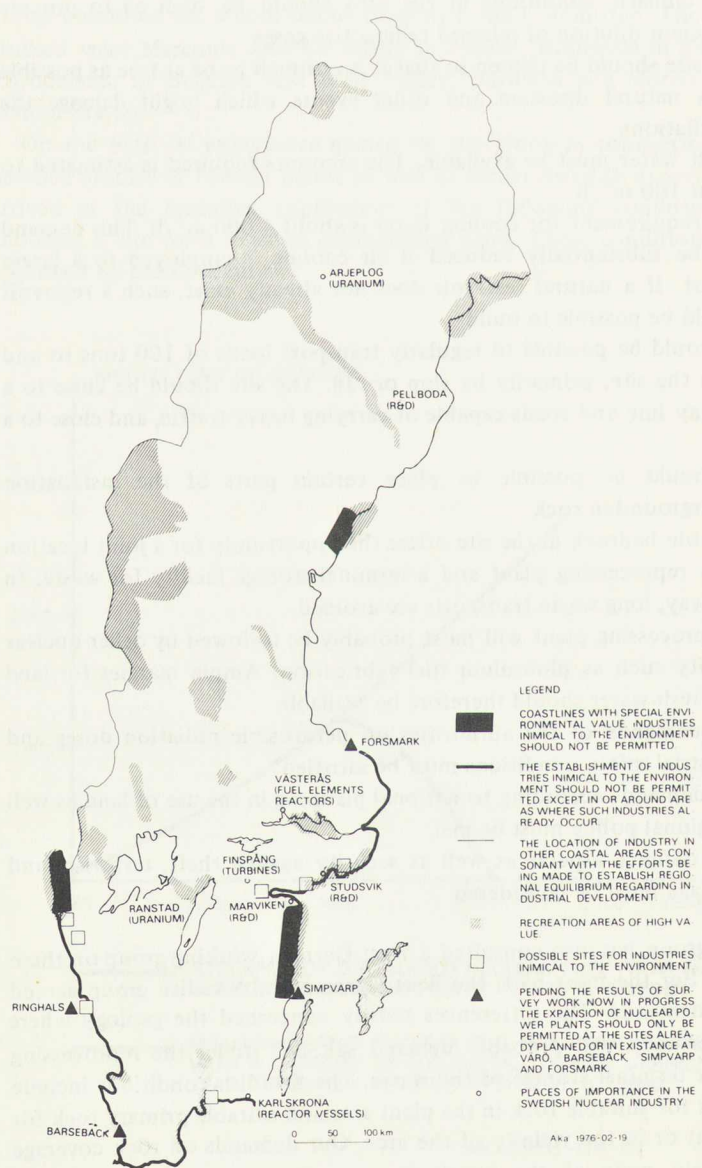


Figure 3.9 Nuclear facilities and the national planning

Against the background of the study, the Committee concluded that many sites fulfill the conditions. The studies show that it should even be possible to site a plant in the interior of the Country. The question of a large storage facility for spent fuel can also affect the choice of a site for a possible plant.

The guidelines included in the national physical planning, figure 3.9, imply that industrial activities likely to disturb the environment are not permitted in intact coastal regions. On highly exploited coast such activities are permissible only close to existing industry.

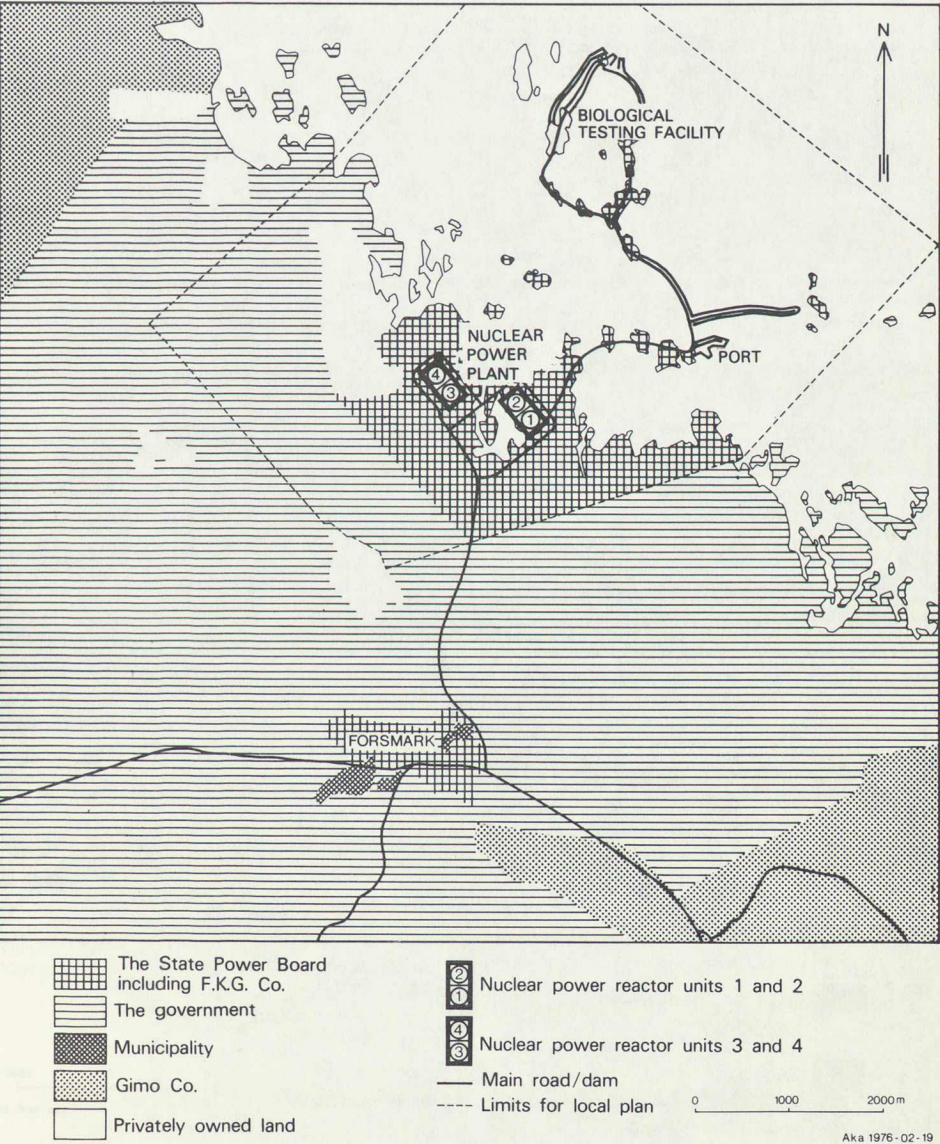


Fig. 3.10 Land owners 1976 in the Forsmark area

According to these guidelines, it is more suitable to site industries of this type along remaining coasts. A reprocessing plant is estimated to engage about 1000 employees and is therefore also important from a regional policy standpoint.

According to its instructions the Committee should observe the

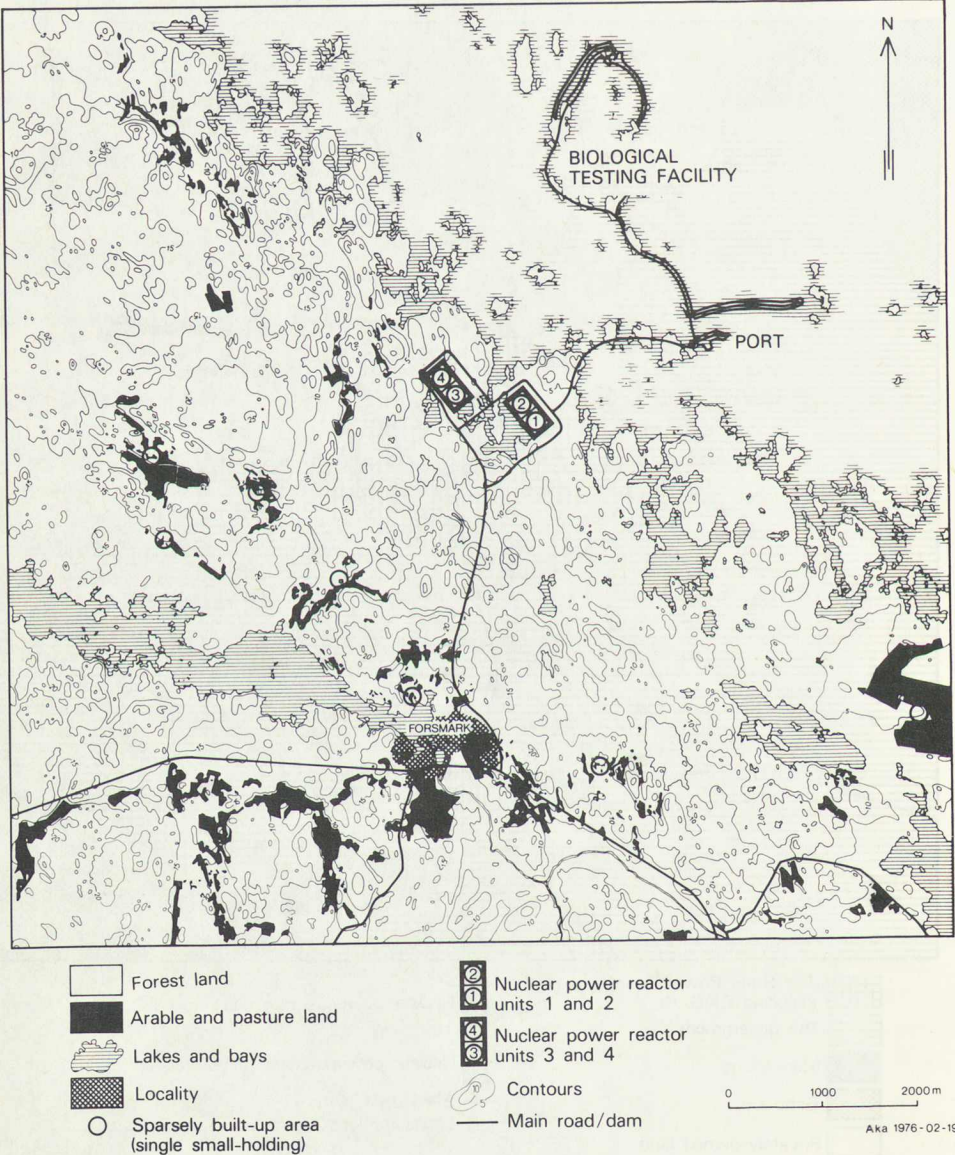


Figure 3.11 Land use and topography 1976 in the Forsmark area

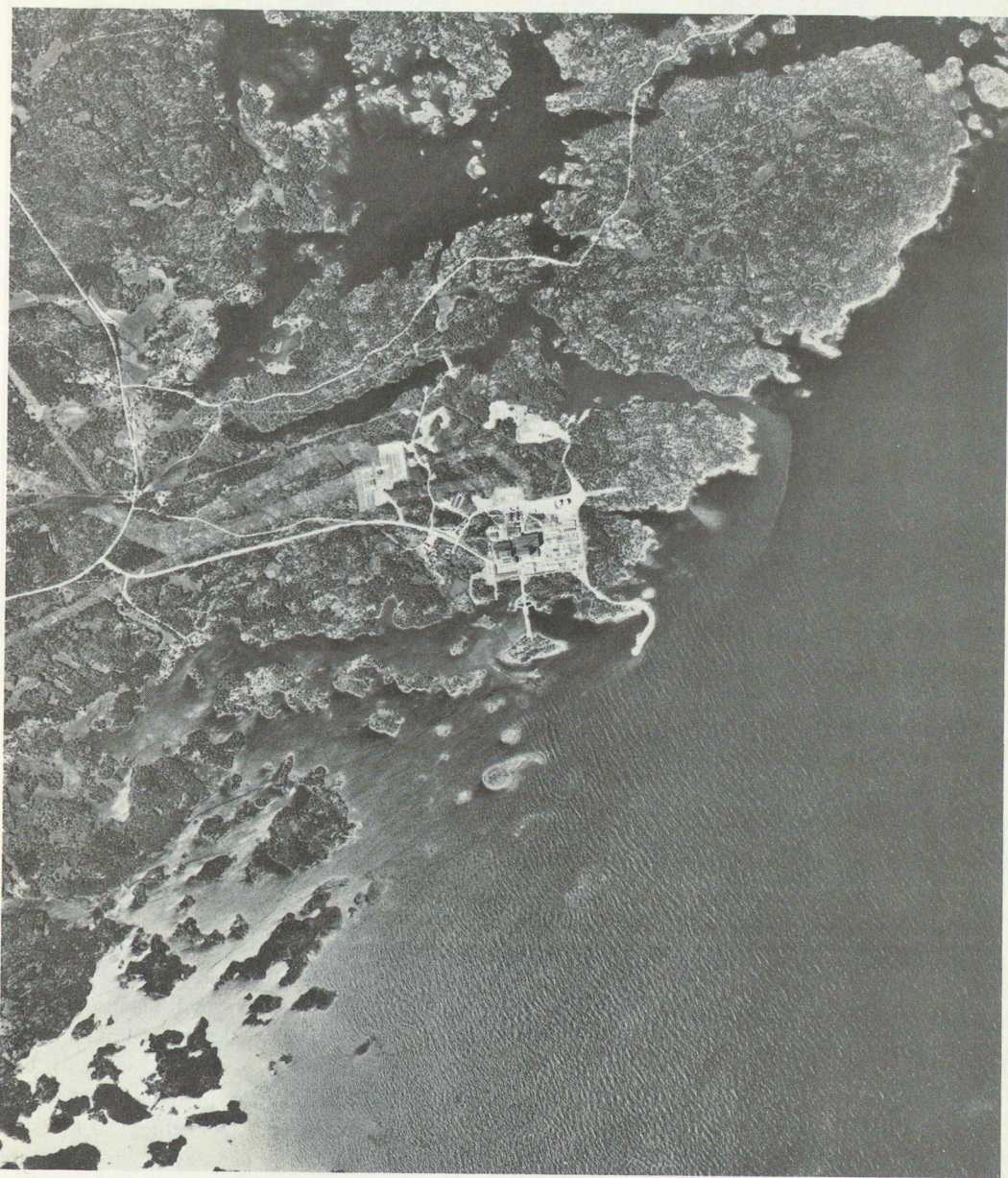


Figure 3.12. Aerial photo of the Simpvärp area, Oskarshamn. The Geographical Survey Office of Sweden 1973. Approved for reproduction and distribution by the National Land Survey of Sweden 1976-03-30

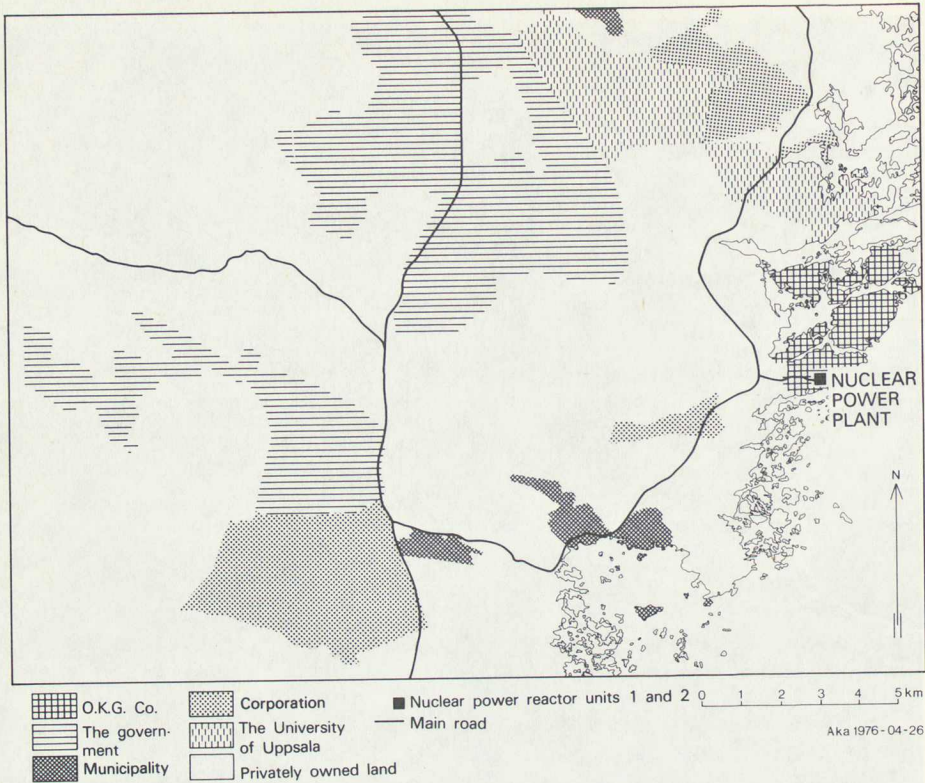


Figure 3.13 Land owners 1976 in the Simpvärp area

national planning policy guidelines and examine the possibility of joint siting of the reprocessing plant at one of the four nuclear power plants in the Country. Of these, the nuclear power stations at Forsmark and Simpvärp offer better conditions for joint siting than those at Barsebäck and Ringhals. The result of our studies of the present land ownership situation and land utilization around the power stations at Forsmark and Simpvärp are shown in figures 3.10–3.13. As shown on the maps, both of these plants are located in sparsely populated woodlands. The government's ownership of land at Forsmark is large. The geological investigations which the Committee initiated through SGU in this area will also provide further information on the possibilities of terminal storage at or near both these places as well. In connection with preparations for a possible fifth nuclear power plant in the country, it should further be possible to choose a site where the demands for the siting of a reprocessing plant and a facility for terminal storage can also be met.

3.5 Nuclear Weapons and the Control of Fissile Material

To be able to construct an atomic bomb of fission type it is necessary to have access to fissile materials such as uranium-235 or plutonium. When nuclei from these materials split during absorption of neutrons, further neutrons are emitted which can hit new fissile nuclei and further increase the neutron population. If the amount of uranium or plutonium available is small most of the neutrons formed will be lost without being absorbed by other fissile nuclei. Larger amounts of material and higher density increase the probability for the neutrons to be absorbed by the uranium or plutonium nuclei. At a certain size, the critical size, the number of fissions per second will become constant. One has then just barely achieved a chain reaction and a constant energy generation. This is the principle of a nuclear reactor. If the uranium or plutonium material is spherically shaped and not surrounded by other materials, the critical mass for pure metallic uranium-235 is about 50 kg. For weapon grade plutonium, i. e. almost pure metallic plutonium-239, the critical mass is about 15 kg.

The design of an atomic bomb is based on the principle of using an explosive to very quickly combine parts of fissile material, each of the parts having a mass below the critical mass although the parts combined are above the critical mass. One then obtains a supercritical mass for which the energy production is not constant but increases rapidly. A nuclear explosion will then occur. Although the principle of the atomic bomb is simple the technical problems of its construction are very large. The materials in the bomb must be very pure and the engineering precision of the system must be very high.

A hydrogen bomb is based on the principle of fusion of hydrogen nuclei, whereby large quantities of energy are released. To start the reaction, the hydrogen must be heated to a very high temperature. This can be accomplished by an atomic bomb of the fission type which, analogous to conventional explosives, acts as a primer cap. The hydrogen isotope tritium is most probably used in the hydrogen bombs made so far. Tritium is produced in a nuclear reactor by irradiating rods containing lithium. The construction of a hydrogen bomb also requires advanced technology and materials which do not occur in civilian nuclear power generation.

Uranium-235, uranium-233 and plutonium can be applied as materials for atomic bombs. Uranium-235 is the material which is easiest to obtain, as it exists in a concentration of 0,7 % in natural uranium. To be useful as a material for an A-bomb, it must be enriched to over 50 % of uranium-235. The material which is used for the production of weapons is highly enriched and contains at least 93 % uranium-235. As a comparison, the enriched uranium for fuelling light water reactors has a uranium-235 content of 2–3 %. Such a low concentration cannot produce a nuclear explosion and a nuclear reactor cannot explode like an atomic bomb.

Highly enriched uranium is not used in power reactors. It has,

however, a limited use in certain research reactors. The fuel elements for the research reactor R 2 at Studsvik are made of highly enriched uranium.

Isotope enrichment of uranium is a technically complicated and expensive process. The enriched uranium so far produced has for the most part been made in diffusion plants which were erected at an early stage by the nuclear weapons powers for the production of enriched uranium for their nuclear weapons programme. Since military requirements have now largely been met, the plants have a large surplus capacity. This is especially the case for the plants in the United States. They are therefore used to enrich uranium for civilian nuclear power reactors, inside as well as outside the United States.

In recent years, the Netherlands and Great Britain have erected plants for isotope enrichment according to the gas centrifuge method. Economical production according to this method does not require as large installations as the diffusion method. This increases the possibilities for smaller nations to build their own plants which then can enrich uranium for civilian as well as military purposes.

Recently the laser method has been suggested as a new means for enrichment. A comprehensive effort to develop this method is now being made by the major powers. Even smaller nations, such as Israel, make concentrated efforts to develop the laser technique. Finally, it is in this context important to mention that the so-called nozzle process, developed in West Germany, was sold to Brazil during 1975.

Development work in the field of enrichment has so far been shrouded in great secrecy. Even assuming that those countries which now know the methods of enrichment will continue to keep their progress secret, it is realistic to suppose that even less-developed countries will eventually master the technique of uranium enrichment.

All Swedish power reactors require enriched uranium for their operation. However, other types of reactors can be fuelled with natural uranium, e. g. the British and French Magnox reactors, which are gas-cooled, graphite moderated reactors. Natural uranium is also employed in the Canadian Candu reactors which are moderated and cooled with heavy water.

Weapon grade plutonium is produced through uranium being irradiated in a reactor. After irradiation, the fuel must be reprocessed for separation of the plutonium. The reprocessing is based on principally well-known chemical processes.

The prerequisites for weapon grade plutonium production are access to natural or enriched uranium, a plant for manufacturing fuel elements, a nuclear reactor, a reprocessing facility and certain final stages for purifying plutonium and converting it to metallic form.

The third possible material, uranium-233, has so far only been produced in small quantities, mostly for research purposes. The raw material is thorium. Certain reactor types, e. g. the gas-cooled, high temperature reactor, can be operated with a fuel which initially consists of highly-enriched uranium or plutonium as well as thorium. During

irradiation uranium-233 is formed which after separation can be recycled to the reactor and replace uranium-235 or plutonium. The technique for reprocessing thorium fuel from high temperature reactors is not yet developed and tested on a commercial scale. Since the introduction of this reactor type in the United States by Gulf-General Atomics has largely failed, it will be quite some time before large quantities of uranium-233 are available. The properties of the material for use in nuclear weapons are not particularly well known outside the nuclear powers.

Uranium and plutonium bombs differ radically in design. This is due primarily to the difference in velocity with which the parts must be combined. A higher velocity is needed for a plutonium bomb than for a uranium bomb. For a uranium bomb, a sufficient velocity can be achieved in a high-speed gun. A plutonium bomb, on the contrary, requires an advanced explosion technique for its detonation.

An efficient plutonium bomb must contain a high amount of the isotope plutonium-239 and no more than a few percent of plutonium-240. To achieve this, the uranium must be irradiated for a short time only in a reactor. Because of the low burn-up required the fuel elements in a reactor for nuclear weapon production may be simple as they are not subject to the same stress as power reactor fuel.

Power reactors on the other hand need an expensive fuel element construction designed for high burn-up which implies long time irradiation. They are therefore unsuitable for the production of weapon grade plutonium. However, it is in principle, technically possible to modify the operation of power reactors so that they can be used to produce weapon grade plutonium. The plutonium which is produced in Swedish power reactors contains as much as 25 to 30 % of plutonium-240. Such plutonium can only be utilized in weak and probably unreliable nuclear charges of highly questionable military value. It is, however, technically and economically more practical to use research reactors or reactors specially constructed for production of weapon grade plutonium than to use expensive power reactors for this purpose.

If reactors fuelled with natural uranium, as the Canadian type reactors, are used for power generation, it should theoretically be sufficient for a nation to acquire facilities for the production of fuel elements and the reprocessing of irradiated fuel elements in order to make fissile material for nuclear weapons. An actual example of a country which can apply this procedure is India. However, the plutonium which India used for the nuclear charge which she exploded was produced in a research reactor. The National Defence Research Institute (FOA) in a report issued in 1974 presented an examination of the risks of clandestine production of nuclear weapons. In its report FOA asserted that anyone who wishes to produce nuclear charges secretly must have access to both qualified personnel and fissile material. A technically less developed nation lacking its own nuclear power program cannot satisfy any of these requirements. Through recruitment and procurement abroad, such a country can probably satisfy the prerequisites for a few

individual charges, only useful for terrorist acts. The cost which would not exceed 10 million Sw. Cr. would be no obstacle. This is the most likely alternative of all the possible ways to produce an illegal nuclear charge, according to the report.

According to FOA, the demands on the clandestine group would involve enormous difficulties. First of all, it would be very difficult to recruit about 50 people in secrecy, 10 or so of whom would have to be specialists in the field, and to conduct several years of necessary development work.

These problems, combined with the high expenses involved, make it unlikely that clandestine groups would attempt to develop nuclear charges. At any rate, they can attain their goals through the use of conventional methods which are quicker, simpler and cheaper.

Against this background, we feel that a greater threat than the risk of secretly produced nuclear charges would be a theft of existing nuclear weapons from any of the nuclear powers.

The expansion of nuclear power throughout the world might imply an increased risk of spreading of nuclear weapons. This was understood at a very early stage. The "Atoms for Peace" program, started in the United States in 1955, included the demand that American inspection personnel would be permitted to control that fissile material supplied by the United States would be used solely for peaceful purposes.

The founding of the United Nations International Atomic Energy Agency, (IAEA), in 1957, established an organization which could perform the important inspection and control function. The Non-Proliferation Treaty (NPT) was agreed upon in connection with the General Conference on Disarmament in Geneva in 1968. The treaty came into force in 1970 and was ratified by Sweden in the same year. It has so far been signed by nearly a hundred nations. A number of important countries, including the two nuclear weapon states France and the People's Republic of China, and furthermore India, who recently detonated a nuclear charge and thus displayed its ability to produce nuclear weapons, have not ratified the treaty. Other nations, including Argentina, Brazil, Egypt, Israel, Pakistan, Spain and the Union of South Africa, all of which have nuclear capabilities, have not yet become parties to the treaty.

The treaty contains, first of all, a declaration by the non-nuclear powers to refrain from acquiring nuclear weapons. The nuclear powers undertake not to aid any non-nuclear power in achieving nuclear weapon capabilities.

According to the treaty signatories agree to conclude an agreement with IAEA on the control of fissile material. However, the nuclear powers are not bound by this clause. Nevertheless, the United States and Great Britain have voluntarily agreed to waive this clause with respect to their civilian nuclear programmes. These voluntary inspections have not yet been established. The main principle of the agreement is a control of the member's accounting of fissile material. The control is combined with spot checks. The purpose behind the control is to detect if any

fissile material is being diverted so that it may be used for nuclear explosions. In principle, this implies a control of the entire nuclear industry of those states, parties to the treaty, which have concluded the prescribed control agreement with the IAEA.

NPT states have further agreed to demand Agency Control as a condition for export to non-nuclear powers outside the NPT. This export related inspection is connected to the actual project and thus provides incomplete control of the importing states nuclear activities..

As a corollary to the treaty NPT states, including Sweden, which supply nuclear equipment and installations, have declared that the equipment and the installations will only be delivered on the condition that fissile material which is processed or used in the equipment or the installations. Furthermore, this control would also include certain of industrial nations, certain NPT members, and France, declared that they would require IAEA control when exporting nuclear equipment or installations. Furthermore, this control would also include certain installations. Furthermore, this control would also include certain from previously supplied equipment. As of March 1976, Sweden has decided to adopt similar procedures.

In 1970 the IAEA convened a committee to frame in detail the control regulations. All IAEA members were given the opportunity to participate in the committee. Their efforts resulted in a model agreement which, together with the nation-oriented and plant oriented regulations, comprises the foundation for the control which the Agency performs in many countries. In 1975, Sweden concluded an agreement with the IAEA on control of fissile material in accordance with the NPT stipulations. This agreement superseded an earlier tripartite agreement between Sweden, the United States and the IAEA on the control and inspection of fissile material.

3.6 The medical, research and industrial uses of radioactive material

Radioactive nuclides have long been used in the medical field for diagnosis and treatment of diseases. They are used in industry in many ways, such as gamma radiography, tracer studies and in various equipment such as level indicators and area weight monitors. Radioactive nuclides have made possible much of the progress in chemical, biological and medical research during the past three decades.

3.6.1 *Medical use of radioactive nuclides*

Unsealed radioactive substances can be administered orally or through injection for treatment of patients. Iodine-131 is often used for treatment of thyroid diseases and phosphorous-32 for certain blood diseases. More rarely radioactive substances are injected in the pleurae,

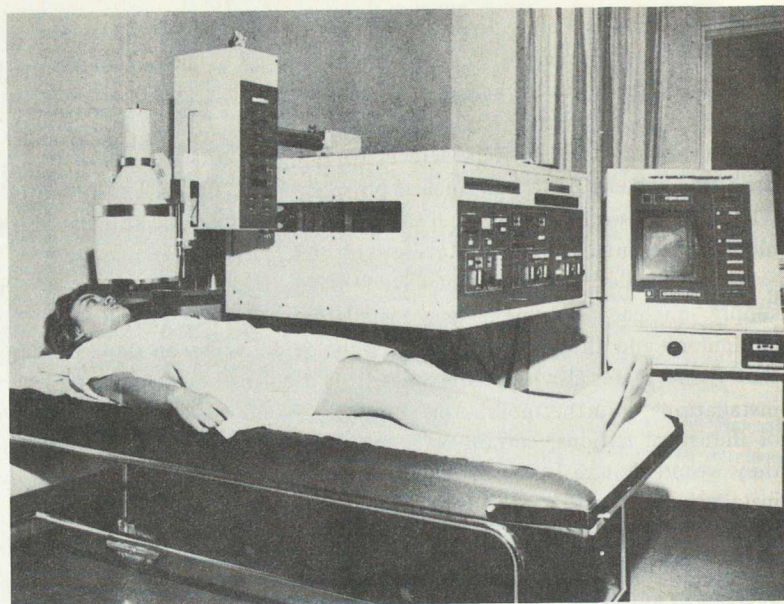


Figure 3.14. External measurement of radionuclide administered to a patient for diagnostic purposes. Malmö Hospital

abdominal cavity or in tumour tissue. About 3 000 treatments a year are performed in Sweden with unsealed radioactive nuclides. Most of these refer to treatment of goitre with iodine-131. The radionuclides used have a short half-life and the waste problem is thus relatively small.

Sealed radioactive substances contained in applicators are used as radiation sources for treatment of malignant tumors. Cobalt-60 dominates and about 100 000 treatments a year are given with cobalt-60 in Sweden. When the activity has decreased below a certain level the source is exchanged. The old sources are either returned to their supplier, usually abroad, or sent to AB Atomenergi in Studsvik.

Unsealed radioactive substances are also used as trace elements to study organs such as the thyroid gland, liver, kidneys, heart, lungs etc. The patient is given a specially chosen labelled substance which can later be traced by external measurements or by measurement of the radioactivity in various body fluids. More than 100 000 of this type of examinations are performed each year.

In another type of examination which has lately come into very widespread use, the radioactive isotope is merely used as a test tube reagent. Usually, iodine-125, tritium, or carbon-14 are used. About half a million of these tests are performed each year in Sweden.

The diagnostic use of unsealed radioactive radionuclides presents relatively small waste problems as they are either short-lived or are used in very small activities.

The National Institute of Radiation Protection receives information from the importers and the Customs authority on the import and sale of radioactive isotopes within the country. A few, short-lived nuclides are responsible for most of the activity. Most of the radioactivity disappears through decay while in use or in storage within the hospitals.

3.6.2 Research and education

Radioactive substances are used at many research centers and laboratories. Apart from tritium and carbon-14, mainly short-lived substances are used.

At the Department of Nuclear Chemistry at Chalmers University of Technology, Gothenburg, research is carried out using long-lived radioactive nuclides, mostly thorium and plutonium. The Department of Chemical Technology at the Royal Institute of Technology, Stockholm, has a program for chemical uranium. Studies on the radioecology of actinides are being carried out at the Swedish College of Agriculture, Uppsala.

The only laboratories where larger amounts of radioactivity can be handled, are at Studsvik. AB Atomenergi has i. a. well equipped laboratories for the examination of irradiated test fuel. In recent years, the nuclear research at AB Atomenergi has been concentrated on nuclear fuel, construction material and safety.

3.6.3 Industry

Industry mainly utilizes sealed radioactive substances for gamma radiography. Unsealed substances are used as tracers. Radionuclides are also used in smoke detectors, level indicators, density monitors and area weight measurement. The strongest radioactive sources in industry exists at two facilities for sterilising medical instruments. Sources which have been exchanged due to physical decay give rise to radioactive waste in this field.

3.7 The concept of radioactive waste

Radioactive waste originates from all stages of the nuclear fuel cycle as well as at hospitals, in industrial operations, and in research centers which use radioactive substances. The structure and characteristics of radioactive waste vary depending upon its origin.

High-level radioactive waste consists predominantly of fission products which are separated in the reprocessing of spent nuclear fuel. Its activity is high enough to require artificial cooling besides radiation shielding for safe storage. Because of its radioactivity, it must be kept separate from the biosphere for a long period of time.

Medium-level radioactive waste must also be shielded to make safe handling feasible, but need not be cooled. Low-level radioactive waste can be handled and stored in simple packages without additional special protection. The nuclide contents and radioactivity concentration in certain cases also necessitate long term storage of low- and medium-level waste until the level of activity has decreased sufficiently so that the waste can be considered inactive.

A special group consists of waste containing transuranium nuclides such as plutonium, americium and curium. This group is often referred to as plutonium waste, transuranium waste or alpha active waste.

It is difficult to define clearly the various types of radioactive waste. The terminology is subject for discussion in international working groups. The problem is that not only the level of activity determines the risks caused by the waste. Physical and chemical states, as well as the physical and biological half-life affect, possible contamination of the environment and must also be taken into account. All of these factors are important in waste management considerations.

3.8 The management of radioactive waste

3.8.1 *Radioactive waste from nuclear power*

Even in the first stage of the nuclear fuel cycle, large amounts of low-level waste are produced. In uranium production from shale of the type found at Ranstad, the leached shale as well as the sludge produced in neutralization of the acidic leach solutions demand particular attention. In fuel production, uranium from defective pellets and waste material from grinding is reused. The amount of waste is thus negligible.

Nuclear fission in the reactor gives rise to various radioactive fission products in the fuel. A number of nuclides are produced through neutron absorption in the construction materials and coolant. If fuel elements are damaged during operation primary volatile elements such as the noble gases, iodine and cesium may leak to the cooling water. The circulation of the coolant spreads radioactivity to those reactor systems by having direct contact with the reactor core.

During reactor operation, radioactive waste is obtained from filtering the various fluids used in the clean-up process. Important waste forms are ion exchange resins, filters and evaporation concentrates. Radioactive material which leaks from the fuel is partly gaseous or gasborne and must be treated to reduce or prevent radioactive material from spreading to the environment. The normal procedure is to lead the gas to decay tanks and subsequently filter the gas. Waste is then mainly obtained in the form of spent filters.

The reactor core includes control rods, detectors and neutron sources for monitoring and supervising the fission process. These are consumable items which must be replaced. They are then highly radioactive. Other forms of solid waste are components which have been removed in conjunction with repairs.

The operation of a nuclear power plant gives rise to other forms of waste such as plastic, insulation, rags, coveralls, paper, scaffolding and scrap metal. As they are used in areas where radioactive material is present, they are considered radioactive, although they are most often completely inactive.

If a reactor is permanently shut down, the fuel elements are first removed. Solid radioactive waste is produced during disassembly. The highest levels occur in the reactor containment. The total amount of radioactive material will vary to a great extent depending on the design and construction, how successful the cleaning has been and how

contaminated the concrete portions have become. The amount of medium-level waste occurring after shut-down of a large reactor is estimated to be between 4 000 and 5 000 metric tons. The amount of low-level waste is greater. According to American estimates, the costs of a complete decommissioning of any large nuclear installation would be very high.

High-level radioactive waste

During operation, fission products and transuranium elements, such as plutonium, are formed (figure 3.3).

Many fission products are highly radioactive, but decay gradually like the transuranics to form stable elements. During decay several kinds of radiation is emitted. The rate of decay is different for different nuclides. The half-life of the fission products varies from fractions of a second to millions of years in a few cases. Their physical properties differ. A few fission products such as xenon and krypton are gaseous while others, e. g. iodine, are liquid. However, most of them are solids.

The chemical and physical properties of the fission products and the transuranic elements, their radiation characteristics and the radiation hazard for human beings determine the ways in which the spent fuel can be handled. It is of the utmost importance to shield against gamma rays with lead or concrete or by submersion in water-filled storage pools. The radiation from high-level radioactive waste also generates heat which must be removed.

In reprocessing, the fuel element cladding and other material are removed and the uranium dioxide is dissolved in boiling nitric acid. Uranium, plutonium and fission products are then separated by a series of chemical processes.

The high-level waste is separated in the form of a solution which is concentrated as much as possible for storage at the reprocessing plant in cooled stainless steel tanks.

The high-level waste contains fission products, small amounts of uranium and plutonium and other transuranic elements. The radiation is initially very intense and a large amount of heat is generated which puts great demands on the shielding and cooling. As the short-lived fission products decay, the need for cooling is reduced.

After some 10 years the radiation is dominated by the long lived strontium-90 and cesium-37 having half-lives of 29 and 30 years, respectively. Using present reprocessing technique the waste contains about 0,5 % of the original amount of plutonium. Other transuranic elements, such as neptunium, americium and curium, produced in the fuel are also present in the waste. Certain nuclides are extremely long-lived such as neptunium-237 with a half-life of more than 2 million years and plutonium-242 with a half-life of 380 000 years. This is why the high-level waste must be kept out of contact with the biosphere for a very long time.

The intention is to solidify liquid high-level waste after a suitable

cooling period. In solidification, the aim is to obtain a product with good chemical resistance. Most of all it should be insoluble in water. At the same time it should be capable of withstanding the heat emitted by fission products and the stresses of handling and transport. At present, glass vitrification is considered to yield the most stable product for long-term storage, and experiments are being conducted on glass of various compositions.

The vitrification of high-level waste is being developed on an experimental scale in the United States, France, Great Britain, Federal Republic of Germany, the Soviet Union and India. In the vitrification process the high-level waste is concentrated by evaporation and calcined. It is then heated to 1 000–1 200°C after the addition of glass forming substances. The resulting glass melt is poured into containers which then must be kept in a cooled and controlled storage facility.

Low-level and medium-level radioactive waste

Low-level and medium-level radioactive waste from nuclear power plants and other facilities in the nuclear fuel cycle is usually treated in order to reduce its volume. The waste is contained in different ways depending on its level of radioactivity. Low-level waste is packed in plastic sacks or metal drums. Ion exchange resins and evaporation concentrates are incorporated in concrete or asphalt after which they are stored in special facilities. An alternative to immediate incorporation of medium-level waste is storage in tanks.

Components exchanged from systems which are in direct contact with the reactor core are stored according to their level of radioactivity. Spent core components are at present stored under water in the fuel storage pools.

Filters and ion exchange resins as well as evaporator concentrates are usually incorporated in inert solid material such as concrete or asphalt but the method can also be applied to metallic waste. A third method utilizing plastic for incorporation is in the course of development. The incorporation of waste often causes increase in weight and volume.

Special facilities for treating and storing radioactive waste are built at the nuclear power plants. At the present time, waste in any significant quantity is stored in Sweden only at the Oskarshamn nuclear power plant.

The methods which have so far been applied in the processing of radioactive waste are partly designed to permit the waste products to be either dumped at sea or buried in the ground. Since 1972, Swedish law in practice prohibits dumping at sea. Waste must therefore be stored on land but there are as yet no facilities for terminal storage of waste. In the meantime, waste is being temporarily stored at the nuclear power plants and at the waste facilities at Studsvik.

When reprocessing spent nuclear fuel, also low- and medium-level waste is produced. A rough estimate shows that the reprocessing of fuel from one year of reactor operation produces as much low-level and

medium-level waste as that produced at the reactor site. This refers to waste such as ion exchange resins, evaporator concentrates as well as trash and similar waste.

The low- and medium-level waste volumes produced throughout the nuclear fuel cycle are much greater than the high-level waste volumes, see table 3.3. The level of activity is, however, very low and because of the composition of the nuclides the time necessary for waste to become inactive is short. One exception is the alpha active waste which mainly originates in the reprocessing of spent nuclear fuel and in the handling of plutonium.

Intensive development work is in progress throughout the world to find methods to reduce the volume of radioactive waste. In the case of ion exchange resins, extensive regeneration or scrubbing are possible alternatives. Combustion and pyrolysis are other possibilities. After such treatment the radioactive residues must be contained in a way suitable for terminal storage. The concentrates can be evaporated further to a dry state and incorporated. The volume of both the ion-exchange resins and the concentrates can be reduced to one-tenth by these methods.

Trash and similar waste can be sorted and burned. After incorporation of the radioactive waste residue, the remaining volume in this case is then also about 10 %. It is, however, uncertain whether this is possible for the corresponding waste from a reprocessing plant which has a different nuclide content. The volume of waste from a reprocessing plant is therefore estimated to reach about 20 % of the original volume. The volume of core components, cladding waste and shrouding tubes can be reduced to about half of its original volume by compression.

Table 3.3 shows the total volume of radioactive waste within the entire nuclear fuel cycle, obtained before and after waste processing from one year of operation of a 900 MWe reactor. This also includes the waste produced in the reprocessing of the spent fuel. As shown by the table, operation of a 900 MWe reactor for a year yields 2–3 m³ of solid high-level radioactive waste. The figures of volumes for post treatment

Table 3.3 Radioactive waste from the nuclear fuel cycle for one year of operation of a 900 MWe reactor.

Type of waste	Volume	
	Before treat- ment, m ³	After treat- ment, m ³
High-level	17	3
Medium-level		
Cladding waste	11	2
Ion exchange resins and evaporator concentrates	90	9
Core components, shrouding tubes and metallic waste	100	50
Low-level		
Trash and similar waste	800	120

waste volumes refer to the waste in its final state prior to terminal storage. Waste from uranium mining and milling is not included.

3.8.2 *Waste from non-nuclear activities*

The use of radioactive material outside the nuclear fuel cycle utilizes or produces nuclides, partly with other characteristics than nuclides originating from the nuclear fuel cycle. These are often radionuclides with very short half-lives so no great waste problems arise. Some radionuclides, however, involve waste which requires long term storage. An example is cobalt-60 which is used in stationary equipment.

In total, less waste is produced than in the nuclear fuel cycle. A rough estimate shows that such non-nuclear activity in Sweden yearly gives rise to about as much waste as a large nuclear power reactor unit. Minor proportions of this waste requires storage for hundreds of years.

Trash and similar waste cause normally no problems from the radiation protection point of view and can be handled just like non-radioactive or very low-level waste. Short half-lives may permit the same handling procedures as for ordinary trash. One exception is the research at Studsvik. The extensive activities there produces wastes of the same kind as those at a nuclear power plant. Experiments at Studsvik on spent fuel and plutonium also involve very long-lived waste.

Calibration sources and spent industrial research and medical sources are examples of stationary radiation sources with radioactivity greater than 1 microcurie. The activity can vary from a few microcuries up to several kilocuries depending on the field of application.

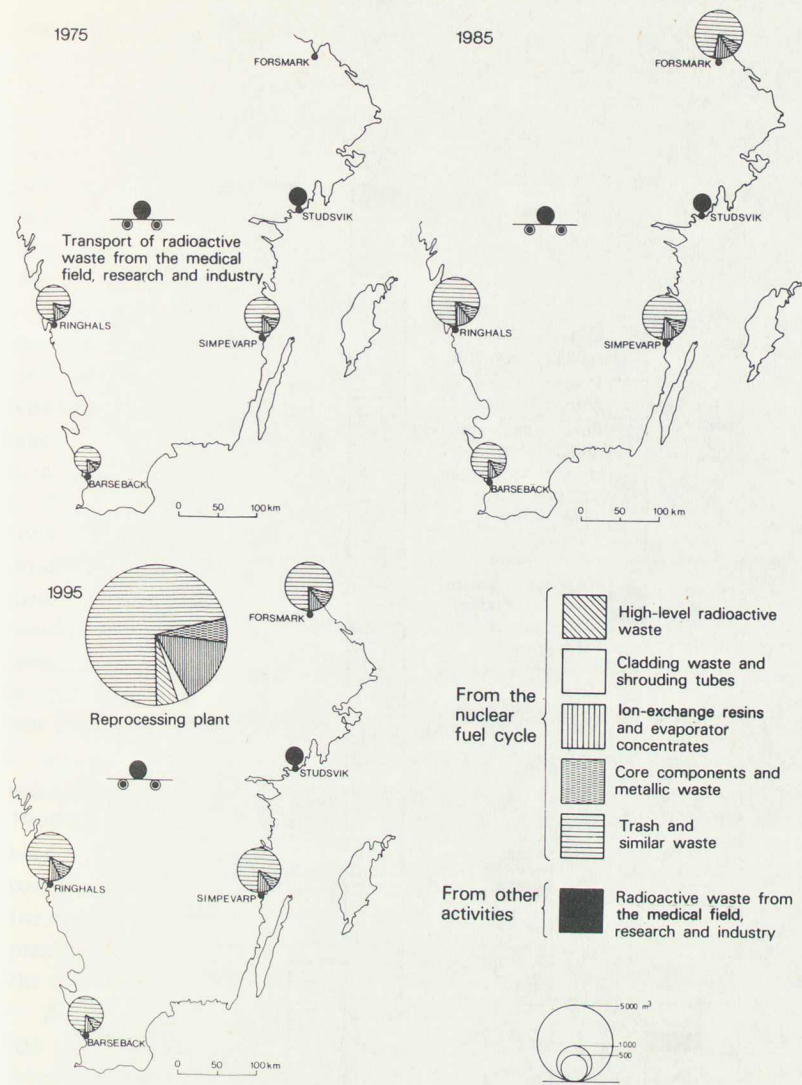
When the high-level sources are replaced, the old ones are taken care of by the supplier and in some cases are returned to the foreign manufacturer. However, facilities are available at AB Atomenergi, Studsvik, for storage of such compounds.

Fairly large amounts of radioactive waste are produced at Studsvik. The Studsvik plant includes a system for collecting, treating and storing such waste. Facilities are also available for receiving waste from other activities in the country such as hospitals, industry and other research centres.

3.8.3 *Future volumes of radioactive waste in Sweden*

A total of about 500 m³ of radioactive waste is treated at Studsvik each year. About half of this arises from the activities at Studsvik. The other half is sent there from hospitals, research centres, and industry. AB Atomenergi estimates that its own waste volumes will remain constant during the next few years. The future waste from the other sectors will depend on what regulations will come into force as regards the management of such waste.

Up to the 1990's it is estimated that only reactor waste will be produced. High-level waste is obtained only if a Swedish reprocessing plant is taken into operation which is expected around 1990 at the



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Figure 3.15 Future volumes of radioactive waste in Sweden

earliest. High-level waste from Swedish spent fuel reprocessed abroad may also be returned to Sweden, but not before about 1990.

Figure 3.15 shows total volumes of waste for the years 1975, 1985 and 1995 from the 13 Swedish reactors licensed so far, from a possible Swedish reprocessing plant and from the non-nuclear sector. Estimates have also been made to determine the total volumes for these years, before and after treatment. These estimates are shown in figure 3.16.

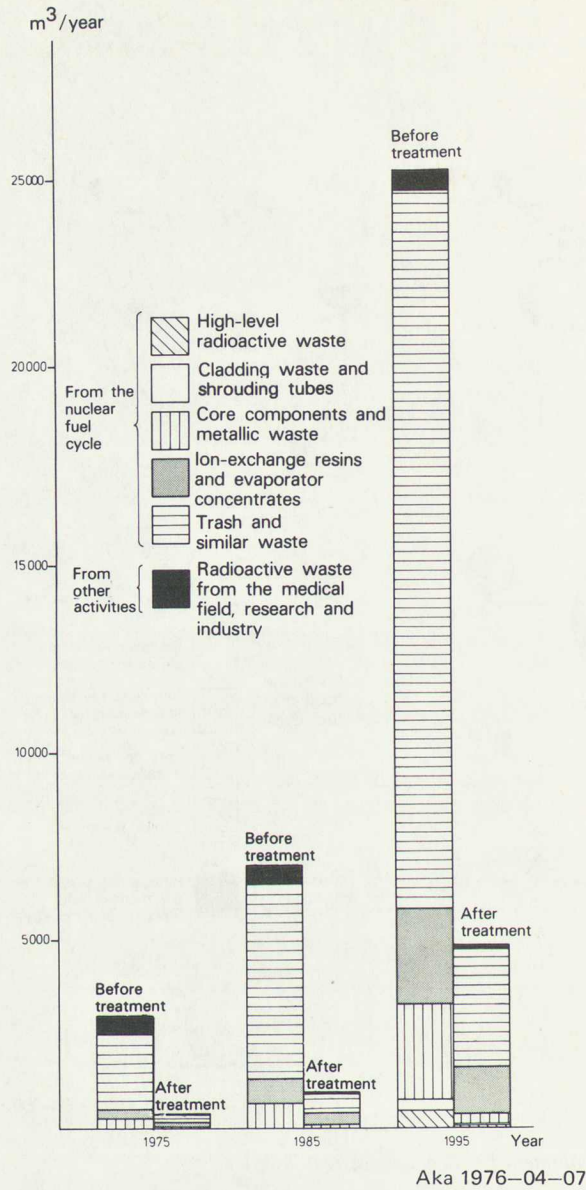


Figure 3.16 Future volumes of radioactive waste before and after treatment

3.9 Possibilities for terminal storage of radioactive waste in Sweden's bedrock

Certain elements in the radioactive waste will continue to emit ionizing radiation even after thousands of years which is beyond the scope of human planning but short in comparison with the age of the bedrock. Since the 1950's it has been considered feasible to store waste in bedrock

long enough for the radiation to become negligible. Such storage would require neither surveillance nor cooling and it will thus not become a burden on future generations.

The first solution considered was storage in salt free from ground water. Large amounts of low- and medium-level waste are stored in an old salt mine in Asse, Federal Republic of Germany, where preparations also have been made for pilot work with vitrified high-level waste. Investigations are in progress elsewhere on the possibility to store high-level waste in thick clay strata.

Burial of low-level radioactive waste is practiced in some parts of the world. The Committee members have visited a number of these facilities in i. a. the Soviet Union, France and the United States. The conditions for burial are less favourable in Sweden because the soil cover above the bedrock is very thin in most places. The burial of waste containing long-lived nuclides is considered inadvisable.

In many countries including Canada, Great Britain and France, there is now an interest in storing high-level waste in bedrock similar to that found in Sweden. It is now believed that many different forms of bedrock may offer suitable conditions for terminal storage of high-level waste and other radioactive waste which requires long-term storage. Of particular interest to Sweden is the extensive bedrock investigation program in progress in Canada. Some cooperation in this field between our two countries has therefore been initiated.

As far as Sweden is concerned, the need for terminal storage of solidified high-level waste in bedrock may be imminent sometime in the 1990's when our first spent fuel has been reprocessed and the waste has been allowed to cool for about ten years. The Committee has commissioned the Geological Survey of Sweden to investigate conditions for terminal storage. Such a storage in Swedish bedrock can be based mainly on already existing techniques and it is simple when compared to the reprocessing technique.

The long term safety depends decisively on bedrock conditions and the possibility to clarify these conditions. Calculations made by AB Atomenergi have shown that satisfactory heat conduction can be provided in bedrock. It is also evident that adequate protection from spreading radioactivity due to accidents, acts of war, theft and sabotage is also provided if the waste is stored in bedrock.

As far as long-term natural processes are concerned, it has been established that the bedrock area of Sweden has been stable for hundreds of millions of years and that it lies outside the earth's deformation and volcanic belts. The average erosion has been less than 5 meters per million years. Renewed deformation of the bedrock which could cause radical erosion threatening a terminal storage facility in bedrock would presuppose a change in the deformation pattern of the earth in less than 100 000 years or at a maximum, one million years. Such changes require about one hundred times longer periods. It can thus be considered impossible that waste from a facility in bedrock could be spread due to either bedrock deformation or extreme general erosion.

The same applies basically to earthquakes. Storage facilities in Swedish bedrock can be sited in such a way that damage due to possible earthquakes can be avoided.

The stability of bedrock sites are totally independent of unexpected changes at ground level over the long waste storage periods. Even a new ice age with glaciers eroding away man-made structures and soil, a tropical age with associated melting of ice caps causing the sea-level to rise 60 meters, or a future world war annihilating our technical civilization will not alter the conditions in the deep bedrock terminal storage facility to any appreciable degree. This stability will provide the necessary precondition for terminal storage in bedrock free from surveillance.

The Committee's preliminary report issued in 1974 (DsI 1974:6) assessed favourably the possibilities of terminal storage of high-level radioactive waste in bedrock without risk of activity spreading via ground water. It was considered urgent, however, that more information be acquired to back up this judgement by surveying selected sites and that long-term ground water observation be carried out at an early stage. Considering this situation, a further recommendation was that the waste facilities be sited in dry bedrock in an area with small differences in the topography and remote from any major water-courses. This recommendation was designed to avoid the risk of local erosion. From the general geological and conservation points of view, it was recommended to site any terminal storage facility in some very common type of rock, which completely lacks intrinsic value. This would prevent any further mining operation which could threaten the storage facility.

The elements contained in the waste which are of interest in considering ground water are strontium, cesium and transuranics, primarily plutonium. As far as strontium and cesium in vitrified waste are concerned, the amount of ground water present in normal rock is too small to cause any significant spreading while these elements are radioactive. In the case of transuranium elements, no observations are available concerning the long-term effects of ground water as these substances do not normally occur in nature. Investigations into the presence of transuranium elements in ground water and the surroundings of buried low-level waste have been started in the United States. These studies will soon provide important information in this area. The transuranium elements are very similar chemically to the so-called lanthanides (rare earth elements) and uranium which already offers some possibility of judging the role of ground water by comparison.

The average content of lanthanides present in granite rock is 300 g per ton, and the presence of lanthanide-bearing minerals is fairly common. These minerals are not generally affected by weathering but on the rare occasions when weathering was nevertheless observed, the lanthanides were found to have re-precipitated in the immediate vicinity of the minerals. Extreme weathering of granite to china-clay caused a certain release of lanthanides although they are again precipitated along the flow path of the water. The reported contents in ground water are low, i. e.

2–60 mg per ton, as in surface water. In Sweden, where bedrock mostly consists of granite, surface water tests have shown a content of 0.2 mg lanthanum per ton (about 1.2 mg of lanthanid per ton). If lanthanides can be assumed to behave like the transuranics the risk of spreading by water is negligible.

The behaviour of uranium is more complex. Under oxidizing conditions it is dissolved in nature by carbonated ground water forming uranyl carbonate complexes. When reducing conditions again occur, the uranium precipitates and becomes very immobile. This sometimes leads to extensive migration of the uranium in the water cycle and can even cause the formation of large uranium ore deposits. Future waste will originate from nuclear fuel that has passed several cycles. Further studies on the spread of transuranium elements from a terminal storage facility in bedrock are therefore warranted.

Of particular interest here is the uranium mine at Oklo in Gabon. Research results show that 1.5 metric tons of plutonium which were formed during a natural chain reaction about 1 800 million years ago decayed completely without any spreading. In this case both the uranium and plutonium remained stable in the same location under the same conditions for more than two million years, i. e. the time necessary for the amount of plutonium formed to fully decay.

The conclusion of these comparisons is that if the transuranium elements behave similarly to the lanthanides, their spreading in ground water will be negligible while more extensive spreading can be expected if they are similar to uranium and if the waste is exposed to large ground water flow under oxidizing conditions. The spread is limited in a small flow of water and no spread with ground water takes place under reducing conditions. Reducing conditions are predominant deep below the water table, and a storage facility can be designed to retain such conditions for very long time.

The precipitation water flows through bedrock above the water table. Extreme oxidizing conditions are then dominant. In good, i. e. uncracked, rock the water table is high. If it is more than 50 meters below the rock surface the rock can be assumed to be porous. As a result it is difficult to find space available for a storage facility above the water table. Such a facility would furthermore require protection from and drainage of surface water and it would probably be difficult to guarantee satisfactory conditions for a storage installation having in mind the long storage time involved. Storage facilities built above the water table are inadvisable, especially in view of possible climatic changes during the time of storage which could lead to higher and changing water table. Deep below the water table the water flow is very small. The stability of the rock provides essentially stable conditions during the storage period. It is therefore possible to assess the expected amount of water and provide effective protection against waste spread with the ground water.

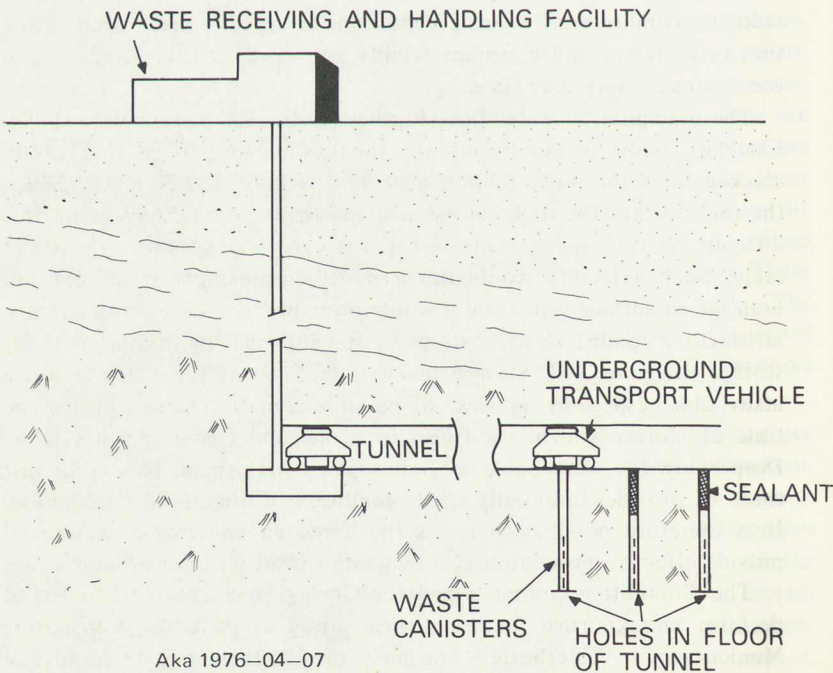
The Committee commissioned the Geological Survey of Sweden to perform an extensive methodological study at Pellboda, Robertsfors Municipality in Västerbotten. The gneiss present there is representative in

many respects of many gneiss areas in the Country. The results of this study are presented in a special supplement to this report. They show that a technique is available today to locate uncracked, groundwater-free rock even if it is covered by soil, and to map cracked zones in order to avoid these since they may contain ground water.

Other studies which are now under preparation will analyse the ground water flow and contents as well as the degree of insolubility of vitrified waste, the stability of various solidified products, and the possibility of using clay to catch any dissolved waste elements. The results are expected to provide the basic information necessary to assess the safety provided by the different methods in preventing the spread of waste.

Part II of the report deals further with a postulated future facility in Swedish bedrock. It should be emphasized that the design is based on technique now known and available. Extensive development work is being carried out throughout the world and even better methods can be expected. It will later on be possible to compare the safety conditions and costs of new methods with the storage methods shown in the chapters mentioned.

The study which SGU performed for the Committee showed that the storage of vitrified high-level radioactive waste in bedrock is a method which for all practical purposes can utilize present-day techniques of mining, rock drilling, rock sealing, spent nuclear fuel reprocessing, vitrification, and incorporation of waste. By this method, the



impermeability of the rock, the insolubility of the vitrified waste and a watertight, stable incapsulation within the rock afford triple protection against waste spread via groundwater.

Further protection can be provided by surrounding each waste cylinder with a layer of ion-absorbing clay. Beyond this excellent natural protection against the waste reaching ground level is obtained by the long dwell of the ground water in the rock and the natural absorption processes. These factors cannot as yet be fully assessed. However, ample possibilities are available for the inspection of the waste as well as its surroundings. Geological experts consider it highly probable that waste stored in bedrock by the method described above will not come in contact with the groundwater even within 100 000 years.

3.10 Radiation protection, environmental protection and safety

3.10.1 *Radiation and its effects*

Almost everything in our environment, including our own body, contains radioactive elements which emit ionizing radiation. The most common radioactive nuclides in the biosphere are potassium-40, radium-226 and short-lived daughter-products of radium, such as the radioactive noble gas radon-222.

Knowledge of the natural radiation to which mankind is exposed as well as of its variations are important in judging radiation risks. Man, as well as DNA, have continually existed in the natural radiation environment which must thus be considered natural from the radiation risk point of view. Similar, it is reasonable to assume that small amounts of additional radiation which are considerably less than the natural variations in the background radiation will not cause any noticeable changes in the overall pattern of risk to which the individual is exposed. The dominant natural radiation sources in our environment are

- uranium and thorium, including daughter products in the ground and in building material 50 mrad per year
- cosmic rays from the sun and the space 30 mrad per year
- potassium -40 in the human body 20 mrad per year

In total, natural radiation sources give us an average dose of about 100 mrad per year. However, the variations are wide, and the dose depends on the type of bedrock, altitude and latitude. Apart from cosmic rays, the external radiation dose in wooden houses is 15–20 mrad per year, and in concrete buildings 20–100 mrad per year. In some lightweight concrete buildings, it may approach 250 mrad per year. Even within a home, the annual dose rate can differ by tens of mrad from room to room.

In addition to radiation doses from natural radiation sources, mankind is exposed to varying doses from man-made sources. Among these, medical devices for radiation treatment and diagnosis dominate.

In radiation treatment, malignant tumours are given concentrated doses of several thousands rads in a limited part of the body. Such doses would prove lethal if applied to the whole body, but by concentrating the irradiation the tumours can be reduced or will disappear entirely. Healthy tissue in the immediate vicinity of the tumour will be damaged, but only temporarily.

The collective dose to the bone marrow and the gonads due to diagnostic x-ray examination is 1 million manrad per year. This is an average of 120 mrad for each individual per year and is about equal to the natural dose. Exceptional, complex x-ray examinations performed only on seriously ill patients can give radiation doses which by far exceed the average.

Radioactive substances are also used for radiation treatment and diagnosis. The most common nuclides in use are iodine-131, technetium-99 m and xenon-133. During such examinations, the dose received by the bone marrow and the gonads is often within the limits of ordinary radiography, but individual organs may be subjected to higher doses. The radiation dose received by the thyroid gland in the most common examinations is normally about 15 000 mrad, and during thyroid scanning with iodine-131 about 75 000 mrad.

Persons employed in radiation work often receive an average dose of a few hundreds mrem per year. Current regulations limit the yearly dose to a maximum of 5 000 mrem. International experience shows that reprocessing plant and nuclear power station personnel receive about one fifth of this. At the plant in Simpsvarp, the average dose for 1975 was 218 mrem.

Radiation doses can be caused either by external sources or internally by radioactive material which enters the body with water, food or with the air we breathe.

The radiation risk connected with plutonium, for example, depends mainly on how the radioactive material enters the body, primarily by ingestion or inhalation. Absorption in the gastro-intestinal tract is low. Small amounts of ingested plutonium are accumulated in the bone for decades before any damage becomes noticeable. Inhalation is much more dangerous than ingestion.

The fact that ionizing radiation can cause serious acute injury has been known since the turn of the century. It is only during the past thirty years that we have begun to notice genetic damage and cancerogeneous effects. Valuable reports in this field have been issued by the International Commission on Radiological Protection, the United Nations Scientific Committee on the Effects of Atomic Radiation and the American Academy of Science. The damage from ionizing radiation is divided into cell destruction which destroys tissue and causes damage to organs, cancerogenic effects, hereditary damage and embryo development impairment.

In order to comprehend the risk to biological life caused by radioactive waste it is important to know which isotopes are present, their half-lives, their radiation characteristics and their path through nature. Some isotopes can remain radioactive for a long time while others will decay to form safe substances after a few months or years.

Every step in waste processing must be planned to provide maximum protection for man and his environment. If radioactive isotopes are released into the environment, they can be spread and enriched by the food chain. The steps taken to protect man as an individual should also afford protection to other forms of life as species.

Radiation from radioactive decay is invisible and is unnoticed by the person affected by it. Only special instruments can detect radioactivity. Decay produces various types of radiation. Radium, uranium and most transuranic elements emit alpha radiation. Some transuranium elements emit neutrons, fission products emit beta and often also gamma radiation. Decay may be complex, sometimes occurring in stages.

Alpha radiation has a very short range. It is unable to penetrate the human skin, for instance. In order for alpha radiation to be dangerous, alpha emitting substances must enter the body, e.g. by inhalation. The most important substances in this category are radium and some of its daughter products as well as plutonium.

Beta radiation has a longer range. It can penetrate the skin and affect its lower layers. The main risk from beta-active elements is their entering the body by ingestion or inhalation. Some beta-active elements, primarily strontium-90, accumulate in the bone where their radiation can damage cells in the bone and the bone marrow.

Gamma rays, which are similar to X-rays, have a greater range and higher penetrating ability. Gamma rays from external sources can therefore affect internal organs.

Our knowledge of radiation damage is derived from the results of large radiation doses from the atomic bombs in Japan and from medical radiation treatment. Small doses cannot cause serious injuries but could cause leukemia and cancer at a later date. Scientists are uncertain of the effects of small doses. However, they are convinced that the effects, if any, are very small. The possibility of a threshold, below which radiation is not dangerous, is yet to be established. The problem is that the small doses in question cannot lead to a sufficient number of cancer cases to be identifiable against the random variation, in the naturally occurring cancer cases, as long as the dose is about as large as the background radiation from natural sources. However, as far as radiation protection is concerned, the risk of cancer is considered to be directly proportional to the dose, without any threshold dose.

Since 1928, the International Commission on Radiological Protection has published protection recommendations which are applied by nearly all countries. The basic ICRP recommendations are presented in ICRP Publication 9 (1965) and imply that

— unnecessary radiation sources and irradiation should be avoided.

- the use of radiation must be assessed in relation to the benefits in each individual case.
- all doses must be kept as low as is reasonably achievable, economic and social considerations taken into account.
- no doses should exceed the recommended limits.

The ICRP recommendations and dose limits were initially applicable only to persons occupationally exposed to radiation. The limits are,

- 5000 mrem per year for whole-body radiation, the gonads and the bone marrow being considered critical.
- 30 000 mrem per year for the thyroid gland and essentially also for bone tissue
- 15 000 mrem per year for other internal organs.

Since 1956 the ICRP has recommended that the dose for individual members of the public be kept below 10 % of the above limits, excluding natural background radiation and medical exposures.

To estimate future radiation doses as the result of current activities, some new concepts have been introduced. One of these is the dose commitment, which is defined as the sum of all future yearly doses which a given group receives on an average. This group can be as large as the world's entire population or as small as a group of employees, and the members of the group may change from year to year. Another new concept is the collective dose, which is the product of the number of persons exposed and their average dose.

For a given number of exposed individuals, the expected amount of future damage is directly proportional to the collective dose or, more precisely, to the dose commitment. The latter may therefore be considered an indicator of future damage.

The dose commitment makes it possible to predict the consequences for every release of radioactive substances, where consideration is given not merely to the immediate effects. By calculating the global collective dose commitment, disregarding geographical limits, an indication of the total damage caused by any given release can be derived, regardless of where the damage will occur.

The institutes of radiation protection in Denmark, Finland, Iceland, Norway and Sweden cooperate on the principles for reducing the environmental releases of radioactive substances. During 1974, common recommendations were adopted. The question has been the subject of panel discussions and seminars organized by the International Atomic Energy Agency, the World Health Organization and the Nuclear Energy Agency of the Organization for Economic Cooperation and Development.

At the National Swedish Institute of Radiation Protection, work is being carried out to draw up radiation protection guidelines for the activities covered by the Radiation Protection Act. A step in this work is the proposed legislation on the releases of radioactive substances from nuclear power plants with light water reactors suggested by the Institute early in 1975.

3.10.2 Occupational safety

Occupational safety plays a major role in the design and operation of nuclear facilities. This involves machinery, pressure vessels and other equipment, chemicals, work premises, underground facilities, ventilation, ergonomics as well as employee protection against fire and explosion. Three authorities, i. e. the National Swedish Board of Occupational Safety and Health, the Nuclear Power Inspectorate and the National Institute of Radiation Protection together have the responsibility for the safety of workers in the nuclear field in Sweden. Important factors are on-site safety work and the employee's role in it which affect working conditions. Employees have representation in the National Swedish Board of Occupational Safety and Health and the Labour Inspectorate. In effect, the Radiation Protection Act is also an industrial safety act. Society's interest in matters dealing with occupational safety have grown, at the same time as the number of places of employment where radiation protection is required have increased. Cooperation among the occupational safety and radiation protection agencies has been intensified in recent years. As radiation risks are often connected with other hazards, this cooperation is of great importance.

3.10.3 Environmental factors

Radioactive nuclides released to the environment are spread throughout the ecological system and can reach the human being through various routes. In order to judge the possible effects, it is important to chart these migration routes. This science is called radioecology.

The radioecology section of the National Swedish Environment Protection Board is cooperating with the Institute of Radiation Protection on radioecological water matters. Efforts are now focused on nuclear power plants in which the environment is observed during a number of years before start of plant operation. After beginning of operations, studies are made on the uptake and enrichment in, for example, sediments, vegetation, river bed organisms and in various organs of fish and shell fish of ecological and economic significance. Also of importance is the discharge of heated cooling water which can affect the biological system in the vicinity of the plant.

At the nuclear power plant in Forsmark, a biotest facility is under construction, with about one square kilometre of moated water through which cooling water from the plant must flow. The installation will provide good opportunities for detailed analyses of the effects on the biological system.

In connection with radioactive fallout from nuclear tests, the Research Institute of National Defence performed extensive land ecological investigations of the spreading in nature of various radioactive nuclides. The results of these investigations and supplementary work being carried out at AB Atomenergi, The University of Lund and the Agricultural College can be utilized to assess the possible radioecological effects of the spread

of radioactivity from nuclear installations, such as nuclear power plants and reprocessing facilities.

3.10.4 *Sabotage, theft, terrorism*

In the current debate about the peaceful uses of nuclear energy, the risks of radioactive releases are often regarded as a main issue. Above all, the risks during accidental conditions, materials, breakdown, or lack of knowledge or far-sightedness on the part of designers and operating personnel have been debated so far. In recent years, the possible threat of intentional actions to cause radioactive releases has received more attention. This is where sabotage, theft and terrorism are the focus of attention. These risks have existed since the atomic age began but it is only recently it has become necessary to seriously deal with the problems.

Terrorism in several forms has existed since a long time and has been used as a threat. It was often limited to national issues and its effects were seldom felt in large geographic areas. Sweden has long been spared from serious acts of international terrorism.

Terrorism has spread markedly throughout the world in recent years and can present itself over the whole world. It is difficult to judge the risks of some international terrorist organization using nuclear energy to attain its goals. However, the threat of such acts can not be discounted. The major risks are the threat of using explosives or sabotage against a nuclear power station to spread radioactivity, and the theft of strategic fissile material to construct nuclear weapons.

The Swedish nuclear programme is still in its initial stages. Experience is so far lacking regarding e. g. the results of protection against sabotage, theft, and terrorism.

The physical protection is not especially dependent on the type of plant or object which is to be protected. The general knowledge and experience from existing security operations at Swedish industries among them the power industry and the National Police Board provide a good foundation to build on. As it is also possible to utilize the experience gained abroad, there are good preconditions to master this kind of security problems at nuclear power plants.

The Nuclear Power Inspectorate is authorized to control that the physical protection at nuclear power plants is appropriate.

3.10.5 *Acts of war*

In order to judge the aspects of acts of war, the Swedish Defence Staff was asked to present its views. The Swedish Defence Staff raises no objections to existing or planned nuclear power plants. However, as the power generation is concentrated to a limited number of sites, the risk is incurred of an invader attacking these sites to interrupt the power supply. This may also be designed as an attempt to spread radioactivity. Appropriate siting and certain security and emergency measures should

reduce the effects, as any radiation spread would be limited to a relatively small area.

From the defence standpoint, nuclear facilities should be sited in the interior of the country. If sited along the coast, strategic areas should be avoided. It might be necessary to site certain activity in rock to provide protection from acts of war.

During a state of war, transports of fissile material may be subject to attack and should be avoided. The time prior to a conflict should be utilized to limit the risks associated with the handling of spent nuclear fuel.

Certain protective steps should be taken, if possible, prior to any expected conflict. Storage pools at power plants should be emptied and fuel elements removed to storage installations which are safe against acts of war. A transport organization with an excess capacity of transport containers should be built up for this purpose. Provision should be made for the shut-down of surface facilities and the removal of nuclear materials. The wartime risk of transporting solid high-level radioactive waste is comparable to spent fuel transport and should be avoided.

3.11 Research and development

Within the individual nuclear energy countries as well as international nuclear energy organizations, R&D into a reliable method for handling management and storage of waste and spent fuel has noticeably increased. The reason is partly the increased demand for evidence of acceptable safe management of waste and fuel and partly the markedly increased final stage costs of the nuclear fuel cycle.

A more detailed account of the current foreign waste R&D is presented in part II of the Committee report. The efforts cover processes and systems to solidify liquid waste to a stable form suitable for terminal storage. Geological development work to design rock underground storage facilities is an important phase of the work being carried out. International organizations are cooperating to disseminate research findings and to draw up uniform regulations for management and storage. Among the organizations in which Sweden is active are the International Atomic Energy Agency, the Nuclear Energy Agency of the Organization for Economic Cooperation and Development, the United Nations Scientific Committee on the Effects of Atomic Radiation and the International Energy Agency. Nordic cooperation is directed through Nordic Contact Organization for Atomic Energy Matters (NKA).

3.11.1 *Swedish work*

In 1972, a delegation was set up for research into safety and environment matters associated with nuclear energy. The terms of reference of the delegation were to plan and lead the development of reactor (primarily light water reactor) safety and the effect on the environment by radioactive releases. The treatment and storage of

high-level radioactive waste from reprocessing spent nuclear fuel was not part of the delegation's work. Vattenfall, OKG and Sydkraft assumed financial responsibility for the development project during 1973 and 1974 within a budget of Sw.Cr. 12 Million. A further Sw. Cr. 8 Million was placed at the delegation's disposal for work started in 1975.

For development work on low-level and medium-level radioactive waste, the delegation granted Sw.Cr. 1 Million. The project has mainly been concerned with questions surrounding reactor operation, such as the handling of semi-liquid waste and the problems associated with highly radioactive used core components. Other projects cover incineration facilities, the possibility of burying radioactive waste, and the development of methods of measurement for determining the radioactive content of solid low-level waste. A number of these items are the subject of Nordic cooperation.

Projects costing Sw.Cr. 2.5 Million have been sub-contracted to AB Atomenergi, the Research Institute of National Defense and the Agricultural College to study the radioecological risks from radioactive waste and plutonium.

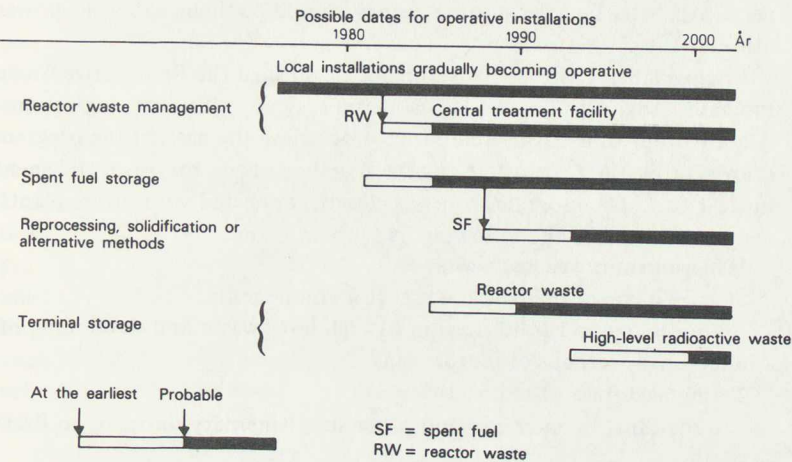
According to a Government decision published in December 1975, the delegation was to cease its activities by the end of that year and the responsibilities were simultaneously transferred to the National Nuclear Power Inspectorate and the National Swedish Board for Energy Source Development. The National Nuclear Power Inspectorate took over the responsibility for the treatment of radioactive waste, while the National Swedish Board for Energy Source Development assumed the responsibility for the effect of nuclear energy on the environment in anticipation of an awaited reorganization of the National Institute of Radiation Protection. According to legislation (Bill 1975/76:123) this area will come under the jurisdiction of the Institute by 1 July 1976. A preliminary budget of Sw. Cr. 2 Million has been proposed for the 1977 fiscal year for the research of radiation protection.

To ensure an immediate start on R&D on high-level radioactive waste, the power utilities are financing such activities at AB Atomenergi through their company, the Swedish Nuclear Fuel Supply Company. The program began in March 1975 and includes study of methods for classifying and treating high-level waste from reprocessing as well as risk evaluation analyses of various steps in its transport, treatment and storage.

AB Atomenergi is making certain contributions in the field through government grants. Several of its personnel have been stationed at Eurochemic to follow operations there. The Technical Development Council (AFR) have financed waste research at the Technical Institutes in Stockholm, Gothenburg and at the University of Lund. The efforts concern the development of partly new methods for treatment and incorporation of high-level waste. AFR finances research on radiobiology, radioecology and radiation protection at various Swedish research centres.

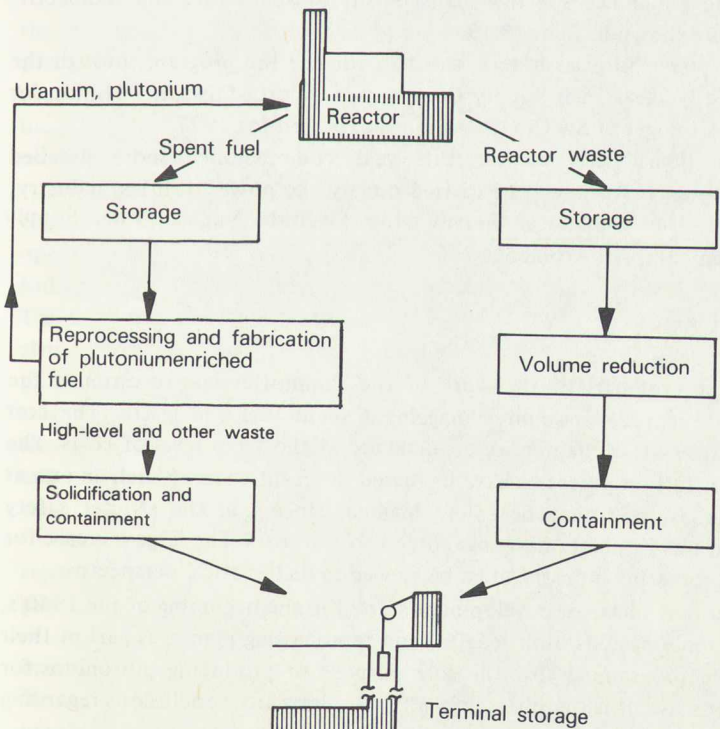
In the autumn of 1975, on behalf of the Aka Committee, AB

Atomenergi and the Swedish Nuclear Fuel Supply Company, drew up a common proposal for continued R&D on radioactive waste from nuclear power. The proposal was considered at Committee meetings held in September and October 1975. Further inclusion of radioecological matters is also expected. The proposal was submitted to the Minister of Industry emphasizing the importance of maintaining continuity of the



Aka 1976-04-05

Figure 3.18 Proposed time schedule for R&D-work on spent fuel and reactor waste



Aka 1976-04-08

Figure 3.19 Guidelines for the management of spent fuel and reactor waste

current development work. We recommended the formation of an agency or board to be responsible for guiding and following up necessary development in the field.

The proposed agency began operating on a temporary basis in lieu of the expected long term organization based on further Committee suggestions. The agency should be totally independent of the utility companies but should, at the same time, cooperate intimately with them. All costs incurred by the agency should be financed by the power utilities.

In November 1975 the Government established the Radioactive Waste Program Advisory Board. Its guidelines agree with our suggestions. Among other things, the Board is to proceed on the basis of the program drawn up by the Committee for the handling of reactor waste and spent nuclear fuel. The program, which is closely connected with future plants, can be divided into the following five sub-programs.

- Management of reactor waste
- Storage of spent fuel and used reactor components
- Reprocessing and solidification of high-level waste and developing of alternative methods of reprocessing
- Terminal storage of radioactive waste
- International cooperation and other supplementary duties of an R&D nature

The schedule for the technical sub-program is presented in figure 3.18, and the guidelines for the management of spent fuel and radioactive waste are shown in figure 3.19.

The power utilities have decided to finance the program through the Swedish Nuclear Fuel Supply Company at a cost of Sw.Cr. 9 Million for 1976. A budget of Sw.Cr. 12 Million is expected for 1977.

The Board has so far this year commissioned more detailed sub-programs. Work will be carried out by the power utilities, industry, the Swedish Geological Survey, the Swedish Nuclear Fuel Supply Company and AB Atomenergi.

3.12 Costs

An important part of the work of the Committee was to estimate the costs of reprocessing and management spent fuel and waste. The cost estimates in this chapter were calculated at the 1976 level of costs. The costs of certain processes have increased in recent years to such an extent that inflation cannot be solely blamed, since i. a. the stricter safety precautions in plants have also added to the costs. The large increase for the reprocessing industry must be viewed in its historical perspective.

The first phase of development started in the beginning of the 1940's, when some nations built reactors and reprocessing plants, as part of their defence programme, for the sole purpose of producing plutonium for weapons use. It is therefore impossible to draw any conclusions regarding the costs involved for modern civilian plants.

The second phase began in the middle of the 1950's with civilian

nuclear power reactors. The chief aim was the economical production of electric power. A high burn-up of the fuel was sought. Reprocessing came second, since the price of uranium was low. In Europe, the government-owned military plants were adapted to treat spent high burn-up oxide fuel from power reactors. A number of pilot plants were built by individual countries or as cooperative efforts, such as Eurochemic, for example.

In the United States, the NFS plant attempted commercial reprocessing of oxide fuel. The price agreed upon was unrealistically low, as the plants were subsidized by government. The processes were also not complete, as waste management was not taken into account.

In the beginning of the 1970's, the situation of excess to reprocessing capacity was reversed. A number of factors were responsible. NFS in the United States was temporarily shut down, to allow for reconstruction in order to attain a higher capacity. A technical mishap caused a drop in production at Windscale. At the Midwest Fuel Recovery Plant, their unique reprocessing method failed to work. In Europe, the decision to shut down Eurochemic was taken, as its low capacity was considered uneconomical. During this period, it also became apparent that certain sub-processes had to be modified to make possible routine reprocessing of spent high burn-up fuel at sufficient capacity.

For the last few years, a fourth phase is discernible. In this phase, reprocessing is considered as a method of treating spent nuclear fuel prior to satisfactory terminal storage of radioactive waste. Reprocessing must therefore be considered as a consequential activity of nuclear energy production without purely economic considerations of the recycle of uranium and plutonium. It is also considered natural that all costs incurred throughout the nuclear fuel cycle should be included in the price of nuclear energy paid by the consumer.

There are many reasons why a reprocessing facility planned today will cost far more than those built in the early years. To ensure safe operation, regulations have become increasingly strict. In licensing today's installations, more far-reaching guarantees for safety are required. These include the demands for reduced radioactive waste emission to the atmosphere and water, safer storage of liquid waste and increased protection from external hazards such as hurricanes, plane crashes or sabotage. The demands for control and accounting of fissile material are also stricter. Clear guidelines for terminal storage of waste do not exist, and this means that temporary waste stockpiles must be built up and maintained.

Also the increased use of high burn-up fuel has increased the reprocessing costs. It is primarily the highly radioactive portions of the process, the chopping of fuel elements, the dissolution and the first stage of extraction, which have demanded modification. Even though automated chopping equipment is available on the market today, maintenance is complicated. By duplicating the chopping machines and providing excess capacity, ample production capacity will be maintained, even if part of the system should break down. For the same reason, other

highly radioactive stages of the process are backed by parallel equipment with excess capacity. The increased amount of plutonium present in high burn-up fuel places greater demands on the processes and the equipment. The large-scale handling of plutonium has proved to be more expensive than expected.

The ever-increasing costs are in no small measure due to the enormous delays in the expansion of reprocessing plants. In addition to the increased capital costs, large expenses have also been incurred for temporary storage pools to be used until a reprocessing plant is operative. This is the situation in Sweden as well.

The reprocessing industry has no firm basis for its cost calculations, as there is no commercial installation in operation as yet. The cost of reprocessing and associated activities can only be roughly estimated today. The bases of waste management cost calculations are uncertain, and this stage will require practical testing and above all the establishment of standards.

Part II of this report provides particulars of the expected costs of planned and already constructed plants in a number of countries.

The investments for the latest of these installations are of most interest as these installations include more complete activities. The plant at Barnwell in US for 1 500 tons of uranium is predicted to cost U. S. dollar 500–600 million. The more comprehensive KEWA plant in the planning stage in the Federal Republic of Germany with the same capacity is expected to cost DM 2 500 million.

Using figures available today, the investments for a complete Swedish reprocessing plant with a capacity of 800 metric tons per year is estimated to be Sw. Cr. 4 000 million divided in the following items.

– Additional spent fuel storage pools	Sw.Cr. 400 million
– Reprocessing plant and transport system	Sw.Cr. 3000 million
– Supplementary final waste treatment facilities	Sw.Cr. 100 million
– Terminal storage facility for radioactive waste	Sw.Cr. 500 million

The expenditures for such a system are estimated at about Sw. Cr. 850 million per year, including capital and operating costs, including also the control of fissile material and any future decommissioning. The system operating at full capacity, can reprocess 800 tonnes of spent fuel per year. This works out at Sw. Cr. 1 060 per kilogramme of uranium. This amount of fuel has produced about 185 000 million kWh, which corresponds to a reprocessing cost of 0.46 öre per kWh. The value of the recovered uranium and plutonium has not been included. According to West German estimates from January 1976, this value should be about Sw. Cr. 915 per kilogramme of uranium in the spent fuel. This figure is based on the saving of uranium ore equaling Sw. Cr. 815 and a gain in enrichment work by the use of plutonium of Sw. Cr. 390 per kilogramme of uranium. An amount of Sw. Cr. 290 per kilogramme must be deducted to cover the added expenses for fabrication of plutonium enriched fuel elements, as compared to ordinary enriched uranium. The net savings for 800 metric tons is Sw. Cr. 730 million per year, which is very close to the annual cost of reprocessing.

Possible alternatives to reprocessing spent nuclear fuel will also demand their share of costs. As neither the methods nor the techniques have been developed these costs are difficult to estimate.

It may be assumed that a terminal storage system for spent fuel without reprocessing will hardly be developed earlier than present planned methods for high-level radioactive waste and waste containing transuranium elements. These methods will probably come into use around 1995. Provided that the problem of terminal storage of non-reprocessed spent fuel is solved, the costs of the necessary installations can be roughly estimated to between Sw. Cr. 1 700 and Sw. Cr. 2 400 million. This sum can be divided as follows:

– Extra storage pools for spent fuel (approx. 3500 metric tons of uranium from 13 reactors in 1995) and transport system	Sw.Cr. 900 million
– Facility for solidification of fuel elements and treatment of reactor waste	Sw.Cr. 300–1000 million
– Terminal storage facility for solidified fuel elements and other waste	Sw.Cr. 500 million

An installation for terminal storage of non-reprocessed spent fuel would cost roughly half of what a combined reprocessing and terminal storage system would cost.

Figure 3.20 contains a German survey of the cost development for the important stages of the nuclear fuel cycle for a light water reactor at two separate dates. During the past three years, the cost of fuel has increased as a proportion of the total production cost of electric power from 0.88 to 2.74 öre/kWh. The major parts of fuel supply cost are still the purchase of natural uranium and enrichment. Reprocessing costs have also increased as the system for reprocessing has become more comprehensive and the costs are more realistically calculated. Also the future cost of reprocessing is expected to represent only a small part of the total cost of the fuel supply for nuclear power.

The estimates are based on the cost information for the various parts of the fuel cycle as shown in table 3.4.

The number of employees at previously planned reprocessing plants have varied from 250 to 400. Higher estimates are made today, e. g. 1 000 employees at the West German KEWA plant. A Swedish plant should require at least 700–800 employees for all stages in a complete plant. A large number of people will be indirectly affected by this operation. A small number of highly qualified personnel will be required at the plant, while most of the employees will receive on-the-job training. During construction, the number of construction workers needed will be roughly equal to the number required to build a nuclear power reactor. However, the construction time will be longer than that required for a reactor.

¹ Rate of exchange
1976–06–23. Sw.Cr. 100
= US dollar 22,40 = DM 58.

Table 3.4 The costs of various stages of the nuclear fuel cycle in 1973 and 1976 according to a Survey in Federal Republic of Germany

	Sw.Cr. per kg of uranium	
	1973	1976
Natural uranium	71	354
Enrichment	144	405
Fuel element production	425	578
Reprocessing	272	>850

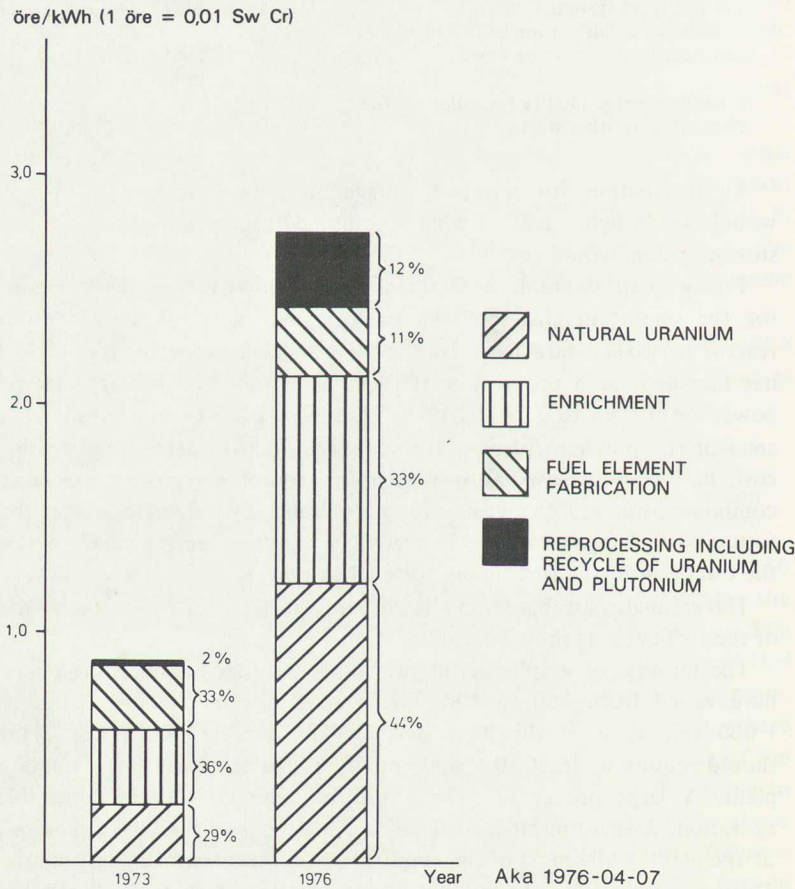


Figure 3.20 Fuel supply costs for light water reactors in 1973 and 1976 according to a German survey

3.13 Swedish authorities and legislation

The Ministry of Industry is responsible for matters pertaining to energy supply. In matters involving the international control of fissile material, the Ministry of Foreign Affairs plays a central role. The Swedish Nuclear Power Inspectorate (SKI) deals with safety matters in nuclear energy. SKI is the central administrative authority in accordance with the Atomic Energy Act and the Atomic Liability Act and its duties are to:

- As supervisory authority act in accordance with the Atomic Energy Act
- As central administrative authority, follow the development in the field of nuclear energy and, in particular, matters related to safety
- Fulfill its duties according to the regulations in accordance with the Atomic Liability Act
- Fulfill the duties connected with the control of nuclear materials and, in particular, of special nuclear materials in conformity with Sweden's international obligations
- Determine the need for research and development in the field of safety at nuclear installations and during the transport of fissile material, and take initiative on research and development of the safety of nuclear installations for which licenses have been granted or applied, provided that this duty is not under the jurisdiction of another authority

The main goal of the Nuclear Power Inspectorate is to promote technical safety at nuclear energy installations and in the handling of fissile material. The Inspectorate's activities are financed by levies on the nuclear power companies. The levies are expected to cover fully the expenses of the Inspectorate.

Included in a Government license for a nuclear power reactor is the requirement that the Nuclear Power Inspectorate should direct the conditions for design, construction and operation which are necessary for safety. Licensing of a nuclear energy installation is also subject to conditions in the Radiation Protection Act, the Environment Protection Act and the Building Legislation.

Nuclear energy safety matters in the field of radiation protection are dealt with by the National Institute of Radiation Protection (SSI) which has been transferred to the Ministry of Agriculture on the 1 January 1976. According to the Radiation Protection Act the Institute of Radiation Protection is the authority responsible for matters concerning radiation protection. In this capacity the institute is the central administrative authority for matters concerning protection from ionizing radiation.

The Institute of Radiation Protection is required by law to obtain detailed information on the risks associated with ionizing radiation and to follow carefully the developments in the fields of radiation biology and radiophysics. It is also the duty of the Institute to pursue research which is necessary for its operation and to coordinate various radiation

protection interests in Sweden. The Institute should furthermore disseminate information on the dangers and disadvantages of ionizing radiation.

In 1974, the Government directed the Agency for Administrative Development to reorganize the Institute of Radiation Protection and its duties. An added directive issued in 1975 included also the field of the use of non-ionizing radiation.

According to legislation (Government bill 1975/76:123) the Institute of Radiation Protection is partly reorganized and given added resources. Special funds have been allocated for research in the field of radiation protection. The changes are completed by the end of fiscal year 1975/76.

An advisory research body is to be included in the Institute's organizational make-up. Its duties will be to develop research programs, evaluate projects, and otherwise plan and follow up the research for which the Institute is responsible.

It is suggested that radiation protection research connected with the operation of nuclear power plants be financed through levies on the nuclear energy companies similar to the safety research on reactors. Other radiation protection research funds should come from the Government budget.

Radiation protection legislation regulates protection from ionizing radiation for radiological work. The Occupational Safety Act by which the National Board of Occupational Safety and Health exercises supervision, is applicable to activities covered by the Radiation Protection Act only to the extent of injury caused by other than ionizing radiation.

The Radiation Protection Act can be considered as part of the occupational safety legislation. Close cooperation is therefore practiced between the Institute of Radiation Protection and the National Board of Occupational Safety and Health, above all in the question of the rules and regulations of the two authorities for safety precautions for employees. Close cooperation with the Nuclear Power Inspectorate is maintained in matters of design demands on nuclear power plants.

The radiation protection should be considered a prerequisite for a good occupational environment, just as protection from heat, noise and stress. The Occupational Environment Committee has covered these matters in its report.

4 Considerations and proposals

4.1 General

The Committee has set up certain goals for the aims of its work as well as for the formulations of considerations and proposals. One is the principal requirement that all stages in the management of spent nuclear fuel and radioactive waste be designed with due consideration to protecting man and his environment now and in the future. This goal, just as the demand that safety matters concerning handling, transport and storage must be awarded the highest priority was stated in the first preliminary report, issued by the Committee.

The Committee's duty has not been to develop a new technique. Its responsibility has primarily been to study and consider the possibilities which present techniques offer and from that reference point, present concrete proposals adapted to conditions prevailing in Sweden.

Against this background and guided by experience from abroad, we have attempted to show, as thoroughly as possible, how the techniques available at the start of the investigation have been developed and improved. This account shows that already present technology provides satisfactory possibilities of handling and storing spent nuclear fuel and radioactive waste. The current broad world-wide research and development will further increase knowledge and thereby handling safety. In some sectors where the available material has been difficult to evaluate or insufficient, special investigations have been carried out. One such sector covers the handling and use of plutonium from high burn-up spent nuclear fuel. In particular the Committee has studied the possibilities of recycling plutonium to light water reactors.

The composition of the waste is another important field within which we performed our own investigations. A detailed knowledge of the composition is a prerequisite for proposals on handling and storing radioactive waste. Furthermore, the Committee has taken the initiative on extensive geological studies of the possibilities to terminally store highly active waste in bedrock. Measurement methods have therefore been tested in a gneiss deposit area in Västerbotten.

It has not been part of the Committee's work to compare health and

environmental risks involved in the handling and storage of spent nuclear fuel and radioactive waste with the corresponding risks from other forms of energy production. The Government has, however, appointed a special Committee to shed light on health and environmental risks involved with different methods of energy production, including nuclear power. The risk comparisons which will make up part of this work will be completed by the summer of 1977.

4.2 The management of spent nuclear fuel

4.2.1 *Storage of spent nuclear fuel*

The present insufficient reprocessing capacity is causing nuclear energy countries to investigate the need for storage facilities for spent nuclear fuel. At our request, the nuclear power utilities in 1975 provided information on available and planned space for spent fuel storage. The Swedish Nuclear Fuel Supply Company, SKBF, gave an account of the current situation at the beginning of 1976. The account shows that the conditions for storage vary from one power plant to the next. Common for Swedish nuclear power plants is that reactor storage pools are large enough to contain the entire reactor core if it for any reason must be discharged, as well as one to three year's discharge of spent fuel. One year's discharge corresponds to 20–30 % of the core. Beyond this the power utilities have certain capabilities to meet the increased storage needs through the use of modest investments.

If they utilize these possibilities and if spent nuclear fuel in the future cannot be sent for reprocessing abroad, the storage pools at the nuclear power plants will be filled by the beginning of the 1980's. Hence, the storage facilities are inadequate, particularly since present storage facilities abroad are nearly filled.

We feel that a central Swedish spent nuclear fuel storage facility is required. This central facility should be operative by 1982 at the latest and should be planned so that it can be built in stages. Construction time including planning and equipping is considered by the Swedish Nuclear Fuel Supply Company to be about three years. The Company has performed a study on spent nuclear fuel storage in the United States. This study and information obtained by the Committee in connection with visits at American, Russian and Swedish nuclear power plants as well as research findings at Studsvik show that spent nuclear fuel can be safely kept in storage pools for at least ten to fifteen years using present techniques.

In our opinion the possibilities of siting a central storage installation at an existing nuclear power plant site, primarily Forsmark or Simsvärp should be investigated. The basis for a final decision is now being worked out within the Radioactive Waste Program Advisory Board, which was established in 1976 and is continuing the work initiated by the Aka Committee.

4.2.2 *Transporting spent fuel*

In our opinion the Swedish power utilities should ensure the availability of a spent nuclear fuel transport system as soon as possible. Flasks are necessary for shipments between nuclear power plants and reprocessing plants, within the power plants themselves, and between power plants and a central spent nuclear fuel storage facility.

Since 1973, one company in Western Europe, the Nuclear Transport Limited, NTL, specializes on the transport of nuclear fuel. The company NTL is owned by British, French and West German interests and has almost a monopoly on spent nuclear fuel transports in Western Europe.

According to our findings, there will soon be a shortage of transport flasks in Europe. The Swedish Nuclear Fuel Supply Company estimates that it takes 2–3 years to manufacture a flask. The larger ones cost about 7 million Sw.Cr. To begin construction quickly in Sweden, access to drawings, patents and various licenses is required.

Many countries including the United States and Federal Republic of Germany, plan to avoid highway transports of spent nuclear fuel. The Soviet Union ships mostly by rail at present. Vehicles and loads are very heavy and can weigh over 100 metric tons. Transporting by ship or rail offers a number of safety advantages. Against this background, we recommend that Swedish spent nuclear fuel and such radioactive waste which requires heavy radiation shielding, be shipped by rail or sea.

Several authorities are involved in the sea transport of spent nuclear fuel, including the Nuclear Power Inspectorate, The Institute of Radiation Protection, the National Administration of Shipping and Navigation and the respective County Administration. We feel that it is important that the actions taken by various authorities in connection with transports be coordinated as far as possible.

4.3 The reprocessing of spent nuclear fuel

The fuel discharged from reactors contains uranium, plutonium and fission products. An important point of reference for the Committee has been to regard spent nuclear fuel as an energy resource and not as waste. The recycling of used uranium and plutonium offers better conservation of the earth's energy resources.

Against this background, we recommend as a first alternative program which aims at reprocessing spent fuel from Swedish nuclear power plants and that the recovered uranium and plutonium be reused as fuel. However, reprocessing is not an absolute necessity for nuclear power in Sweden. Its economics depends partly on factors such as the price of uranium. We have therefore also considered the case that the spent fuel is merely considered as waste. This implies that the energy contents of the used uranium and plutonium are not put to use.

4.3.1 *Reprocessing in Sweden*

So far it has been the intention of the Swedish nuclear power utilities to have their spent nuclear fuel reprocessed abroad. It is uncertain at present to what extent the conditions exist for purchasing reprocessing services in Western Europe for the next few decades. It is probably not possible at present either to obtain contracts for reprocessing services in the United States, the Soviet Union or Japan, all of which construct or plan for high burn-up light water reactor fuel reprocessing plants. The total capacity of current expansion is considered insufficient for a considerable time ahead.

Against this background, the Committee must consider the alternative that as far as the management of spent fuel is concerned, we cannot expect any reprocessing abroad for a long time. As mentioned earlier, it takes 10–13 years from pilot studies on a reprocessing plant to full capacity operation. This means that the earliest date when a Swedish plant would be operational is sometime around 1990. In view of the demands for a satisfactory Swedish preparedness to manage spent nuclear fuel, we feel that the pilot studies which have begun should be continued so that initial planning of a Swedish reprocessing plant can be started immediately. This preproject is estimated to take about 4 years. At the time of a final decision in the beginning of the 1980's, experience from a few years of commercial scale operation of reprocessing plants abroad should be available. In addition, results will then be available from the extensive R & D work now being pursued in many countries and also from Swedish R & D proposed by the Committee.

The Committee has investigated the conditions for siting a reprocessing plant in Sweden. The study shows that it is possible to site such an installation at various locations in the Country, on the coast as well as in the inland. Certain factors, primarily transport considerations, speak for coastal siting. A prerequisite is that the municipal authorities involved will approve the siting. As a primary alternative the Committee recommends that a siting of a reprocessing plant together with the nuclear power plants at Forsmark or Simpsvarp should be investigated. This recommendation, in our opinion, agrees with the guidelines in the national planning and regional policy (Government Bill 1972:111). In December 1972 the Swedish Parliament made some important decisions concerning the Government's proposal for regional development and management of land and water resources in Sweden, see figure 3.9.

In connection with preparations for a possible fifth nuclear power plant in Sweden, a site should, if possible, be chosen which will fulfill also the requirements for siting a reprocessing plant and a terminal storage facility.

The eventual capacity of a Swedish reprocessing plant should be determined by the yearly discharge of fuel and by the size of the existing spent fuel stockpile at the time when the reprocessing plant becomes operative.

During the 1980's, spent nuclear fuel will have to be stored within

the country. The size of this stockpile will depend on how much of the fuel that can be shipped abroad. If all spent nuclear fuel must be stored from 1980 onwards, nearly 3 000 metric tons of spent fuel will be accumulated in storage pools by 1990. Of further importance will be the possible installation of additional reactors beyond the 13 already authorized by Government and Parliament. It should be established whether the plant should have capacity for the reprocessing also of certain amounts of foreign spent nuclear fuel, primarily fuel from the Nordic countries. The Committee report deals with the matter of a Nordic spent nuclear fuel reprocessing plant in chapter 4.5.

As shown in chapter 3.4, there are a number of reasons why a Swedish plant should have a capacity of 800 metric tons per year, preferably divided into two separate process lines of 400 tons each. A plant of this size which is gradually taken into operation from 1990 will during the second half of the 1990's have reprocessed all fuel discharged from the Swedish reactors.

It has turned out to be very difficult to estimate the cost of a Swedish reprocessing plant. The information available from abroad and from earlier Swedish pilot projects, has proved to be insufficient in this context. Only a new preproject directly adapted to Swedish conditions can provide the necessary basis. In chapter 3.13 and in part II of the report, the costs for the handling of spent nuclear fuel, reprocessing, waste treatment and terminal storage are estimated at about 0.5 öre per kWh for nuclear power production. The value of recovered uranium and plutonium is not included in these calculations.

4.3.2 Alternative methods of treating spent nuclear fuel

One alternative to reprocessing is to treat spent fuel as waste and reclaim neither the remaining uranium nor the plutonium. In this case the energy resource which the spent fuel represents is not utilized. Detailed studies on the possibility of direct terminal storage of spent nuclear fuel have not been carried out anywhere in the world. As the necessary technique is as yet not developed, it is impossible to estimate costs in the usual way. According to West German information indirect comparisons with the costs of reprocessing point to a cost level which is about half that of reprocessing. Even if we primarily recommend reprocessing of Swedish spent nuclear fuel, we recommend that studies should begin to clarify more closely the conditions for non-reprocessing. These studies should in the first place be aimed at following foreign developments. It is the Committee's judgement that a method for direct terminal storage of spent fuel can be developed. A decided disadvantage of this alternative is that the energy resources of the spent fuel are not utilized. One advantage is that the plutonium will not be separated and available in a pure state. Also this alternative of non-reprocessing makes possible the continued use of nuclear power.

4.4 The management and use of plutonium

4.4.1 *Nuclear power plants*

By 1985, a total of about 17 metric tons of plutonium is estimated to have been formed in fuel used in Swedish nuclear power plants. According to plans plutonium separated in reprocessing will be reused in new fuel. The technique of manufacturing plutonium enriched light water reactor fuel is being tested on a large scale i.a. in Belgium and West Germany. Also AB Atomenergi in Studsvik has produced plutonium fuel. Plutonium enriched fuel elements have been inserted in one of the reactors at Simpsvarp, Oskarshamn. The Ågesta reactor also utilized plutonium fuel for a long period. However, experience from the production and use of fuel containing reactor plutonium (plutonium with high plutonium-240 and plutonium-241 contents) is so far limited.

The Committee wishes to emphasize that our recommendation in favour of the reprocessing alternative is subject to the condition that the plutonium which occurs in a pure state as a result of reprocessing be converted to new fuel as soon as possible and be recycled to the reactors. Only in this way a large stockpile of pure plutonium can be avoided.

Hence, we recommend that any decision on a Swedish reprocessing plant also should include a facility for the production of plutonium enriched fuel. To avoid additional transports, this installation should be adjacent to the reprocessing plant but does not necessarily have to be an integral part of it.

Oskarshamns Kraftgrupp AB, OKG, has a contract for reprocessing abroad of 140 metric tons of spent nuclear fuel from reactors 1 and 2 at Simpsvarp which covers its needs until 1980. The Swedish Nuclear Fuel Supply Company is planning to obtain contracts for the 1970's for spent fuel from the other power plants and is also investigating alternatives for the 1980's. It is exceedingly important that the utilities will account for how the plutonium received from reprocessing will be utilized when they are concluding reprocessing contracts.

4.4.2 *The control of fissile material*

By signing the Non-Proliferation Treaty, Sweden has clearly shown its willingness to prevent fissile material from being used for military purpose. As a result of this, Sweden has adopted strict export control not only of fissile material but also of certain nuclear equipment. In March 1976, the Government declared that it will apply export control also to nuclear technology within some particularly sensitive areas.

The Committee has performed certain studies on the risk of theft of fissile material. As far as the enriched uranium used as fuel in the research reactor R2 is concerned, the Committee has observed that security precautions for handling, transport and storage have recently been considerably tightened.

At present there are only very small amounts of pure plutonium in the Country. The plutonium produced in reactor fuel is inaccessible as long as

it exists together with large amounts of radioactive fission products. In the future, we assume that the fuel will be reprocessed and that plutonium will be handled on a large scale in our Country as well. If the plutonium is reused in new fuel immediately after reprocessing, the risks of theft, terror and sabotage are reduced. We should attempt to minimize the number of plutonium transports as far as possible as the risk of theft is considered to be greater during transport. This is important reason for our recommendation of a joint siting of a reprocessing plant and a plutonium fuel facility. Possible intermediate stores of plutonium should also be located there.

4.5 Terminal storage of radioactive waste

Terminal storage of radioactive waste in bedrock is aimed at isolating the waste in such a way that surveillance will not be required during the long period of time necessary to render it harmless. The most important requirement is that the waste should not be able to spread to the biosphere through natural processes, accidents or acts of war.

Techniques of storing high-level radioactive waste which are now being developed in many countries are based on the solidification of liquid high-level radioactive waste. We consider that as far as Sweden is concerned vitrification to glass or ceramics is the best method so far developed. Installations for vitrification are commercially available from France. Long term safety for the terminal storage of containers of vitrified high-level radioactive waste is dependent upon bedrock conditions and the possibilities of ascertaining these. The Geological Survey of Sweden was asked by the Committee to examine sites in various parts of the country. They found that many sites may satisfy the stipulated criteria. Before a final decision on sites for terminal storage, further geological investigations must be carried out, including drilling, test shafts and extensive ground water investigations.

The geological studies so far, made by the Geological Survey of Sweden, show that Sweden with its stable bedrock which has been inactive for millions of years offers favourable geological conditions for terminal storage of high-level radioactive waste.

In letters from the Committee to the Ministry of Industry in 1975 concerning the proposed Radioactive Waste Program Advisory Board we have underlined the importance of a continuation of the geological investigation and work already initiated by the Committee.

Against the background of present contracts for reprocessing Swedish fuel abroad, we consider that high-level radioactive waste resulting from reprocessing may be returned to Sweden in 1990, at the earliest, for terminal storage. Planning should be directed toward an installation for the terminal storage of high-level radioactive waste operative at that date. The installation should be constructed in stages and designed so as to allow storage of all high-level radioactive waste from reprocessed Swedish nuclear fuel. Chapter 4.6 covers the question of storing low-and medium-level radioactive waste. Preferable, high-level radioactive waste

should be stored close to a Swedish reprocessing plant. We therefore propose an immediate start of detailed geological studies of suitable sites primarily near Forsmark and Simpsvarp. Other locations should also be studied in order to obtain alternative sites.

Proposals have been made in the Nordic Contact Organization for Atomic Energy Matters and the Nordic Council to investigate the possibility of Nordic cooperation on the handling and storing of radioactive waste. Unofficially, similar suggestions have been made on the occasions of the Committee's visits to other Nordic countries. The proposals follow the principle guidelines for regional fuel cycle centers presented by the International Atomic Energy Agency. In our opinion a Nordic regional solution seems appropriate and desirable from many points of view.

4.6 The management and storage of low- and medium-level radioactive waste

Low- and medium-level waste is produced in many activities connected with the use of radioactive material at nuclear power plants, research institutes and hospitals. A detailed description is presented in chapter 3.8 part I and chapter 9 in part II.

Some of the methods used so far to treat radioactive waste were designed to enable the waste to be dumped at sea or buried in the ground. Sweden has ratified the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter, (London Convention). Since 1972, Swedish legislation prohibits the dumping of any waste at sea. Many countries including the Nordic ones have introduced similar laws. Therefore, the Nordic countries must store radioactive waste on land.

According to the present plans of the power utilities, on-site storage capacity for low- and medium-level radioactive waste from nuclear power plant operation must correspond to at least five years of operation. Thus the utilities presume that after a certain storage time the reactor waste will be moved to a new site.

In accordance with the present planning by the utilities the Committee recommends that it should be possible to store reactor waste at the nuclear power plants for at least five years. This recommendation agrees with the proposed guidelines for the management of radioactive waste issued by the National Swedish Institute of Radiation Protection (SSI:1972-012). We propose that a central storage site for low- and medium-level waste be established and that waste from nuclear power plants be shipped to that site. The joint location of this installation with a central installation for storing spent nuclear fuel and a reprocessing plant should be investigated as a first choice. Consequently, Forsmark and Simpsvarp would be the main alternatives. A possible new site of a nuclear power plant may also be considered.

Low- and medium-level waste requiring long term storage should be stored in bedrock similarly to high-level waste. The terminal storage site for low- and medium-level waste should be coordinated with storage facilities for high-level waste and designed concurrently.

AB Atomenergi in Studsvik has a special organization for the management and storage of radioactive waste from its own operations. In addition waste from hospitals and research institutes requiring long term storage is also handled at Studsvik. This activity should in our opinion continue for the time being. On longer terms, it should be coordinated with the activities at the central storage installation for low- and medium-level waste.

The Committee has become aware of the fact that the waste facility at Studsvik will need some modifications and should be enlarged to correspond to the demands now being placed on this kind of installations. We recommend therefore, that extended investments in the waste handling installations at Studsvik will be made gradually. Geological studies started at Studsvik should continue, partly in order to explore the possibilities of a temporary storage for a 20–30 years period and partly to explore the possibilities for terminal storage of the waste being treated at the site.

Many countries having deep strata of soil on top of the rock have more suitable conditions than Sweden for low-level waste burial. With few exceptions, Sweden has only a thin earth layer above the bedrock. Because of this and in view of the climate and groundwater conditions, the Committee considers that ground burial of radioactive waste should not be practiced in Sweden. However, Swedish licensing authorities may decide upon exceptions of this rule e. g. for certain short-lived waste. For waste which contains long-lived elements, burial in the Swedish soil is unsuited.

The reprocessing of spent nuclear fuel will lead to significant amounts of low-level and medium-level radioactive waste. The Committee is therefore of the opinion that a treatment and storage installation should be sited in the vicinity of a possible Swedish reprocessing plant. The terminal storage of low- and medium-level waste can thus be coordinated with the terminal storage of high-level waste.

In the near future shipments of low- and medium-level waste will increase considerably. It is important that these shipments can be carried out under adequate safety conditions. Considering the relatively large number of shipments, we propose that a special transport system for this type of waste be developed. According to the Committee's opinion, rail and ship should be utilized as far as possible for heavy radioactive waste transportation.

The waste management at Studsvik comprises radioactive waste from the development work of AB Atomenergi as well as waste from non-nuclear activities at and outside Studsvik.

4.7 Decommissioning of nuclear facilities

In our comments on the report of the Urban Siting Committee we concluded that the questions of decommissioning of reactors at the end of their life, after about 30–40 years of operation, should be considered at an early stage. In a number of countries research is now being planned to clarify conditions for necessary steps in decommissioning. The matter has been discussed at an expert meeting organized by the IAEA in 1975 with Swedish participation. Decommissioning of nuclear installations will in the future produce radioactive waste which will be difficult to manage. We therefore stress the importance of this matter. In our opinion the following criteria should be met in the decommissioning of nuclear plants

- the decommissioning should be performed with satisfactory protection for man and his environment
- the plant should be left in such a state that surveillance will not be required after 50 years since shut-down and in such a way as to facilitate the use of the site for other purposes.
- the radioactive waste should be managed in a way acceptable to the supervising authorities.

A plan for decommissioning prepared today can only partly foresee future technical possibilities for demolishing and dismantling the heavy structures which make up a nuclear power plant, in order to facilitate a future decommissioning. Certain steps should, however, be taken already during the design and construction phase. We therefore suggest that an acceptable, technical description of the planning of any future decommissioning should constitute a precondition for the licensing of nuclear facilities. This plan should be based on available technology. It should be the responsibility of the licensing authority to ensure that nuclear installations are constructed in such a way that a future decommissioning can be carried out in a satisfactory manner from technical and safety points of view.

4.8 Research and development

The proposals which the Committee has presented on the management of spent nuclear fuel and radioactive waste require an extensive research and development program for its implementation. Within the framework of such a program, significant contributions are needed in many fields including:

- The management of low- and medium-level radioactive waste from nuclear power plants
- The construction and operation of facilities for the temporary storage of spent nuclear fuel and radioactive waste
- The construction and operation of a reprocessing plant

- Facilities for treatment and temporary storage of high level radioactive waste
- The terminal storage of radioactive waste
- The handling and recycling of plutonium to nuclear power reactors

The present management of reactor waste at the Swedish nuclear power plants is not well adapted to the type of terminal storage which we recommend. The main principle in the process should be segregation of the radioactive waste according to its halflife, activity and elemental content. The volume of the reactor wastes must be reduced in order not to occupy too much storage space. Methods of compacting waste are well established. To make possible later transfer to a central storage site, the waste must be given a suitable form. Two methods are in use today, incorporation in concrete and in asphalt. These methods need to be supplemented by other techniques and to be adapted to the requirements of transportation and central storage.

The Committee is of the opinion that it is as yet unclear which method is most suitable for treating waste from ion-exchange filters at nuclear power plants and other facilities. Swedish development efforts in this area should continue and concentrate on problems related to storage at a central site and later terminal storage in bedrock.

Development work is being carried out at AB Atomenergi to design suitable equipment for incinerating combustible low-level radioactive waste. The Committee considers that this development of suitable incineration equipment is important and should be continued. Apart from Studsvik, the method should be suitable for use for example at a central facility for low-level and medium-level waste.

Further methods should be developed for the treatment of evaporator concentrates of radioactive solutions.

The Committee has already touched upon the question of a transport system for spent fuel and radioactive waste. We foresee the need for a relatively extensive investigation into a suitable design of a transport system. The scope of this investigation will largely depend on which methods, design, equipment and vehicles can be purchased abroad.

A preproject for a central spent fuel facility has begun through the Radioactive Waste Program Advisory Board. This installation may demand certain development work which is beyond the purely planning work.

Prior to any decision on constructing a Swedish reprocessing plant, a detailed preproject is required. In view of the significant difficulty associated with the project, extensive research and development are required to ensure a successful technical realization. In the past details of reprocessing techniques were readily available. Most of the results of foreign plants were published or were obtainable through direct contacts. To prevent the spread of nuclear weapons, secrecy in the field of reprocessing has been significantly greater in the recent years.

Research and development on reprocessing should primarily be aimed at producing the basis necessary for a decision for the construction of a plant. As soon as a pilot project group for a reprocessing plant has been

formed, it should be instructed to guide the reprocessing research and development. Coordination with the construction work will thus be ensured.

Research and development on reprocessing should also include work on liquid radioactive waste solidification processes. The R & D should be concentrated on vitrification methods. This work has already been started. This should be supplemented by more fundamental work so that the best possible basis for a decision will be available by the end of the 1980's when a method will have to be decided upon. The project group should also guide this part of research and development.

The Committee has contracted some tasks to the Geological Survey of Sweden, SGU, to i. a. consider the suitability of Swedish bedrock for terminal storage of radioactive waste. This assessment forms an important background to our proposals on bedrock storage. In our estimation, a Swedish installation for terminal storage in bedrock may be necessary by 1990 at the earliest. However, radioactive waste from a Swedish reprocessing plant will probably not require terminal storage before 1995. The work made by SGU should be continued and extended. As is evident from our proposals, a special organization will be established for the development, construction and operation of a terminal storage facility.

The work which the Radioactive Waste Program Advisory Board commissioned the Geological Survey of Sweden to conduct should be directed by the new waste organization in the future. We consider it imperative that R & D on treatment and storage of waste be coordinated with work in the field of reprocessing.

For reasons mentioned earlier a plant for the production of plutonium enriched fuel should be adjacent to any Swedish reprocessing plant. We have not considered the questions of ownership and management of such a plant. By its nature, it is closely connected to the present field of activity of Asea-Atom. The power utilities should bear the responsibility for creating the conditions for the establishment of the plant.

The technology for manufacturing plutonium enriched fuel can probably partly be acquired abroad. The general knowledge of processing technique which Asea-Atom and AB Atomenergi possess, should provide an adequate basis for domestic production. A pilot plant may be necessary. However, significant research and development in this field is required. It should be coordinated with development work now being conducted at AB Atomenergi.

In the opinion of the Committee, it is also necessary to carry out R & D work on alpha active waste which is produced in various processes, primarily in handling plutonium. Extensive efforts are being made abroad on the development of processes for handling this type of waste. The proposed waste organization should manage the necessary Swedish R & D in this area.

Responding to a proposal from the Committee, the Government set up the Radioactive Waste Program Advisory Board in 1975, as a provisional step in anticipation of the Committee's final recommenda-

tion. Its duties are to continue development work initiated by the Committee in the fields of waste management and reprocessing. R & D should now be concentrated on the facilities which we have proposed and be part of the planning. For this reason, we propose that the Advisory Board be disbanded by the 1 July 1977 and that the organizations mentioned assume its duties. This means that management will then in the future be led by the power utilities, the suggested reprocessing group and the new waste organization.

The construction and operation of plants for spent fuel and waste which result from the program mentioned previously require permits from the appropriate supervising authorities. To a certain degree the proposed R & D program can also be of value for these authorities decision making process.

We wish to stress the importance of the Nuclear Power Inspectorate and the National Institute of Radiation Protection, through their research committees, ensuring that the necessary R & D efforts will be made.

The National Institute of Radiation Protection, through its research Committee, will direct R & D work contributions in the fields of radiation protection and radioecology. The Nuclear Power Inspectorate will for its new responsibilities require a program oriented toward rules and standards for processes and installations. The safety authorities require standards for the design of storage facilities and for suitable methods of storing radioactive waste, rules for packaging and transporting spent fuel and radioactive waste as well as rules for the handling of alpha-active waste.

Considering the extensive R & D within the reprocessing and waste fields which is being carried out abroad as well as in international organizations, Sweden should actively take part in international cooperative efforts. In particular, the possibility of practically oriented Nordic cooperation should be utilized.

4.9 Organization, financing and legislation

4.9.1 Organization

The responsibility for management of radioactive waste rests primarily with the company or institution from which the waste originates. Most of the waste is produced at nuclear power plants and the installations of AB Atomenergi. Smaller amounts are produced at hospitals, industry, etc.

The Committee's instructions specify that the state should have the duty of managing activity involved with the terminal storage of high-level radioactive waste. In our opinion these activities require far-reaching public control.

Regarding the organizational form for the future handling of radioactive waste in Sweden, we have primarily taken into account that some of this waste must be stored for long periods of time and special requirements therefore be made in the terminal storage facilities.

The Committee proposed the formation of a special state organization which will manage all long-term handling of radioactive waste and associated activities. A special organizational committee should i.a. be entrusted with specifying these duties.

We furthermore regard it important that the state organization which we recommend assumes a responsibility at an early stage for duties of immediate interest. As presented in chapter 4.8, the organization should lead certain development efforts in the field of waste. This includes geological investigation into the storage of radioactive waste in bedrock.

Our deliberations have also led to our proposing the formation of a special unit at the Nuclear Power Inspectorate to assume responsibility for safety-oriented development work needed for the Inspectorate's control of the handling and storage of spent nuclear fuel and radioactive waste. A special section of the research committee should be formed for these duties.

We propose that the Swedish Nuclear Fuel Supply Company, SKBF, reorganized after certain organizational studies of the company have been carried out, should be given the responsibility of continued pilot studies and the preprojecting of a Swedish reprocessing plant. A special group within SKBF should also have the responsibility of directing and carrying out the necessary development work for a reprocessing plant and for the transportation of spent nuclear fuel.

If a Swedish reprocessing plant is to be built, we recommend that a government owned or government controlled corporation be organized for the purpose. This corporation should also come under the jurisdiction of the Nuclear Power Inspectorate.

The storage of spent fuel at nuclear power plants should continue to be the responsibility of the power utilities.

Furthermore, we have found that a central storage facility for temporary storage (10–15 years) of spent fuel is required, pending a decision on future handling and treatment of spent fuel either abroad or at a possible Swedish reprocessing plant. The responsibility of the planning and construction of this storage installation should rest with the nuclear power utilities through SKBF under the supervision of the Inspectorate's suggested new unit. Considering these new responsibilities for SKBF, we propose the board of the company to be increased to 6 members. Of this total, the Government should appoint the chairman and two additional members.

The Radioactive Waste Program Advisory Board should be disbanded as of July 1, 1977 and its duties be taken over by the previously suggested bodies. It is of the utmost importance that future organizational changes should be aimed at unified planning and integrated responsibility for the management of spent nuclear fuel and radioactive waste.

4.9.2 *Financing*

The generation of electrical energy, whether by coal, oil, or nuclear fuel causes heat emission and produces wastes in various forms. Fossil fuelled power stations produce large amounts of waste which are released into the environment resulting in regional and global effects. This refers to dust, ashes, sulphur compounds, heavy metals, etc. Increased work to reduce these emissions increase the cost of generating electricity. During operation of nuclear power plants radioactive waste is produced and must be taken care of. The costs of an environmentally satisfactory handling of waste has not yet fully burdened the three forms of power generation. Our Committee has according to its instructions examined waste costs caused by nuclear power and their financing.

It is assumed that the power utilities shall cover all expenses connected with the management and storage of spent nuclear fuel and radioactive waste. In our opinion, the costs for the organizations and the development work which we proposed earlier are included in this commitment.

The electric power utilities should meet all expenses related to the management and storage of spent nuclear fuel and radioactive waste. In our opinion, costs incurred by the organizations and cost for development work proposed by our Committee, should be included. In their cost calculations the power utilities should also include the future costs of reprocessing and terminal storage at the time when nuclear fuel is being used for power production. We recommend that a sum corresponding to these charges should be reserved in the utilities' yearly account and transferred to a special fund from which the costs will be covered when they appear later on. In the meantime, the fund may form part of the companies working capital.

Another possibility is for the state to levy a charge on energy delivered from nuclear power stations and thereby assume the responsibility of further handling of spent nuclear fuel. The charge should be set so as to correspond to the future estimated costs of waste handling. The charges should be credited to a special state equalization fund for the residual costs of nuclear power. Development work in the fields of reprocessing and waste handling could also be financed through this fund. Based on very preliminary estimates, a charge of up to 0.5 öre (0.005 Sw. Cr.) per kWh levied on nuclear electrical energy should be sufficient to cover the residual costs involved, including the costs for handling of reactor waste. However, in our opinion the costs of handling reactor wastes should be covered by fees associated with the volume of wastes and their activity levels. In this way, an incentive is provided for reducing the amount of waste. Corresponding residual costs for electrical energy from coal and oil fuel have not been analysed by the Committee.

4.9.3 *Legislation*

The Committee has examined the legislation covering the handling of spent nuclear fuel and radioactive waste. In our opinion the responsibilities of the supervising authority, the Nuclear Power Inspectorate, are not evident, from the Atomic Energy Act. We, therefore, purpose that paragraph 2 in the present Atomic Energy Act be altered in the following way:

Present wording

In the absence of authorisation by the Government or an authority appointed by the Government, it is prohibited to construct, possess or operate an atomic reactor, or a plan for processing of substance or compound referred to in paragraph 1.

Proposed wording

We propose the following amendment to the present wording in paragraph 2.

"or plants for processing and storing radioactive waste produced during the utilization of nuclear fuel or in processing spent nuclear fuel".

In our examination of the Atomic Energy, Atomic Liability, Radiation Protection Acts, we have found that the wording in these acts in many cases is often difficult to interpret and should be reviewed. It is important to clarify and modernize these laws, above all the Atomic Energy Act. The expression "Atomic" for instance should consistently be altered to "Nuclear".

Additional statements

I. By *Einar Larsson*

The terms of reference of the Swedish Government Committee on Radioactive Waste were primarily to present proposals for the handling of spent nuclear fuel and radioactive waste generated by the Swedish nuclear power plants. The duties of the Committee were merely to study and assess the opportunities provided by present-day techniques, rather than developing a new technique. In its work, the Committee has avoided, as far as possible, presenting proposals of such a nature that a decision concerning the handling of spent nuclear fuel and radioactive waste is delayed to an indeterminate date in the future. The work of the Committee has instead been concentrated to finding quickly proposals which are attainable at the present level of technology.

In my opinion, the report of the Committee contains extensive factual information, which cannot be regarded as an opinion, concerning further extension of nuclear power. In addition, I consider that excessively high risks are still involved in the handling of high-level radioactive waste. In view of the problems associated with waste, the Committee should therefore also have adopted an attitude as to whether or not operation of the present five reactors should continue. But the basis for the investigation work was to submit proposals on how the waste from the 13 reactors already authorized is to be handled in the safest possible manner.

According to its directives, the Committee was not entrusted with carrying a complete risk analysis for the whole of the nuclear fuel cycle, including transport, and this I consider to be unsatisfactory. An analysis of this type would have formed a valuable basis in other connections for a meaningful comparison with other alternatives, with a view to safeguarding the uninterrupted availability of electrical energy in the future.

II. By *John Takman*

According to its directives, the terms of reference of the Aka Committee were to "make a survey of the technical, economic and safety problems associated with the reprocessing of nuclear fuel as well as the subsequent

treatment and storage of the high-level radioactive waste, including transport, on the basis of the information available today". According to the new directives, the terms of reference of the Committee were extended to "also consider matters dealing with the handling and storage of low-level and intermediate-level waste, including such waste which does not originate from nuclear power stations".

This survey of the whole field was well justified. Even though the risk of ionizing radiation were known almost since the discovery of X-rays by Röntgen in 1895 and the safety regulations have been stricter and generally observed more faithfully than in any other sector of environment protection and industrial safety for the past fifty years, shortcomings still existed in the handling of waste.

Ever since 1895, nuclear energy has been an invaluable instrument for research, investigation and treatment in almost all modern fields of natural science and technology, including medicine, agriculture and industry. It is used in various forms for curing cancer, improving the yield of seed grain, combating insect pests, detecting art forgeries, checking the quality of machine components, etc. Even though the quantities of waste from all of these activities and the volumes of low-level and intermediate-level radioactive waste from nuclear power stations are small in comparison with the enormous volume of other waste in a modern industrial society, they represent a difficult problem which can be significantly reduced by sorting, volume reduction (by means such as pressing and pyrolysis) and final storage under more acceptable conditions than hitherto.

During the course of the investigation work, I have had the opportunity to study waste treatment in France, the U.S.A., the U.S.S.R. and Sweden, and to discuss current shortcomings and planned improvements with a large number of experts in these countries. My critical views have been taken into account in the continued work.

On the other hand, it is a shortcoming that, in some respects, the Committee has not been given any opportunity whatever and, in other cases, has been given insufficient opportunity to deal with the overshadowing military problems, comprising the safety problems (including the problem of waste) associated with the actual production of nuclear weapons which is largely excluded from public insight, and concerning the risks of nuclear weapons tests still being pursued and the risks associated with the many thousands of hydrogen bombs, nuclear warheads ready for instant use, etc. scattered throughout the world. Congressional Committee hearings in the U.S.A. in 1974 confirmed suspicions that theft of atomic bombs from military stockpiles, sabotage of military nuclear weapons stockpiles and "the human factor", not least in the form of habitual marihuana-smoking military police and artillerymen at nuclear weapon bases in West Germany, are realistic, hair-raising risks.

A nuclear energy discussion which entirely ignores this problem serves intentionally or unintentionally the purpose of distracting attention from the incomparably most urgent current duty of examining how the arms race can be stopped in the field of strategic weapons, and thus taking the first step on the path of disarmament.

In spite of its limitations, the 1963 partial agreement between the U.S.A and the U.S.S.R. on stopping nuclear weapons tests in the atmosphere had an importance which extremely few people in our own country and other parts of the world ever mention or even know. Tables and graphs produced by research stations in about 30 countries in the northern hemisphere, including Sweden, Norway, Denmark and Finland, and at least 10 stations in the southern hemisphere have shown that strontium-90 and cesium-137 – two of the most dangerous, long-lived fission products from atmosphere nuclear weapons tests – are found in almost all water and foodstuff samples examined since 1957. These fission products occurred in much increased quantities after the large test series in 1958, 1961 and 1962. After the agreement came into force, the curve began to decline, with new peaks in the northern hemisphere only following the Chinese atmosphere nuclear weapon tests, and in the the southern hemisphere following the French nuclear weapon tests (on the Mururoa atoll).

Radioactivity is measured in picocurie – the smallest unit. The measuring instruments are exceptionally sensitive. But the fact that measurable quantities of strontium-90 and cesium-137 were present and are still present in every litre of milk throughout the world since 1957 should at least provide food for thought or be mentioned occasionally in the public discussion. But these facts appear to be entirely uninteresting to the mass media. The following news item appeared below a single-column heading on page 13 in the Swedish newspaper Dagens Nyheter of the 14 February 1976: "The latest atomic bomb explosion in China took place above ground at a low height and with a relatively small explosive power. The bomb was exploded on the 23rd of January and the radioactivity has been measured in the eastern parts of central and southern Sweden from the 7 to the 8 February".

In civilian connections, small local incidents without any consequences whatsoever for the environment or the population are blown up to firstpage news.

It is easy to visualize what a nuclear war would entail for the whole of the world, even in the unlikely event of hostilities being confined to a few countries. As long as the US bases in Western Europe alone have a stockpile of 7 000 warheads ready for almost instant use, there is every reason to bear in mind the comment in the 1974 SIPRI Yearbook that "there is the great and ever present danger that nuclear war will come about by accident, miscalculation or madness" (page 70).

From the very first meeting of the Aka Committee which I attended, I have insisted on nuclear energy for peaceful applications being viewed in the perspective of the very serious negligence which has come to light from the nuclear armaments production, the uncontrolled and global emission of radioactive matter which has occurred and, to a smaller extent, still occurs as a result of atmospheric nuclear weapon tests and the enormous stockpiles of hydrogen bombs and nuclear weapons ready for instant use at a very large number of places throughout the world.

I am aware of the fact that the directives and the resources of the

Committee have restricted the scope of the investigation. At the same time, I deplore that no overall picture has emerged and that the incomparably more serious aspects of nuclear energy, particularly the arms race in strategic weapons, have not been thoroughly examined. This overall picture is indispensable for a purposeful and constructive discussion on the peaceful uses of nuclear energy, and to initiating a broad and effective campaign against the arms race.

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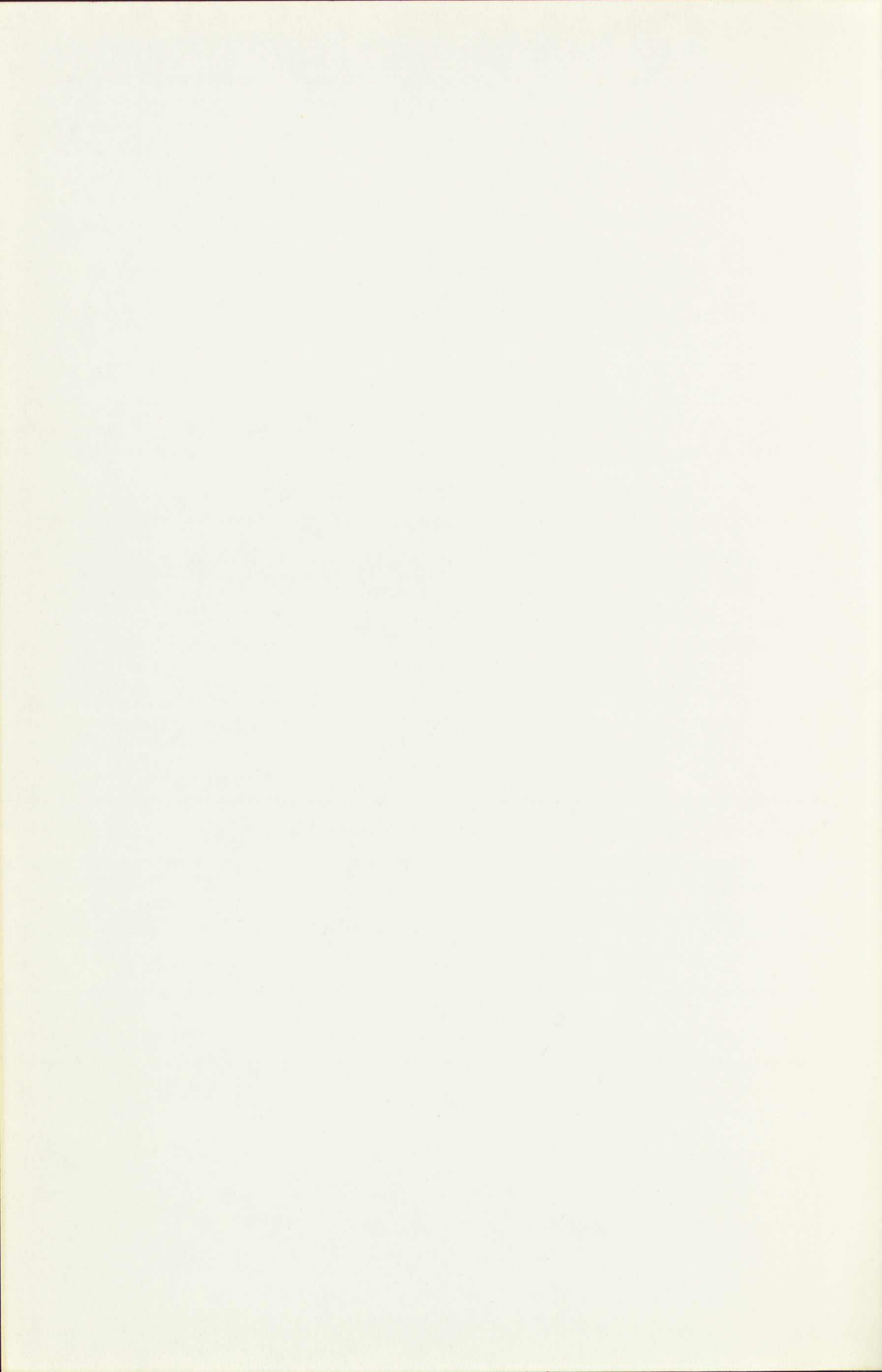
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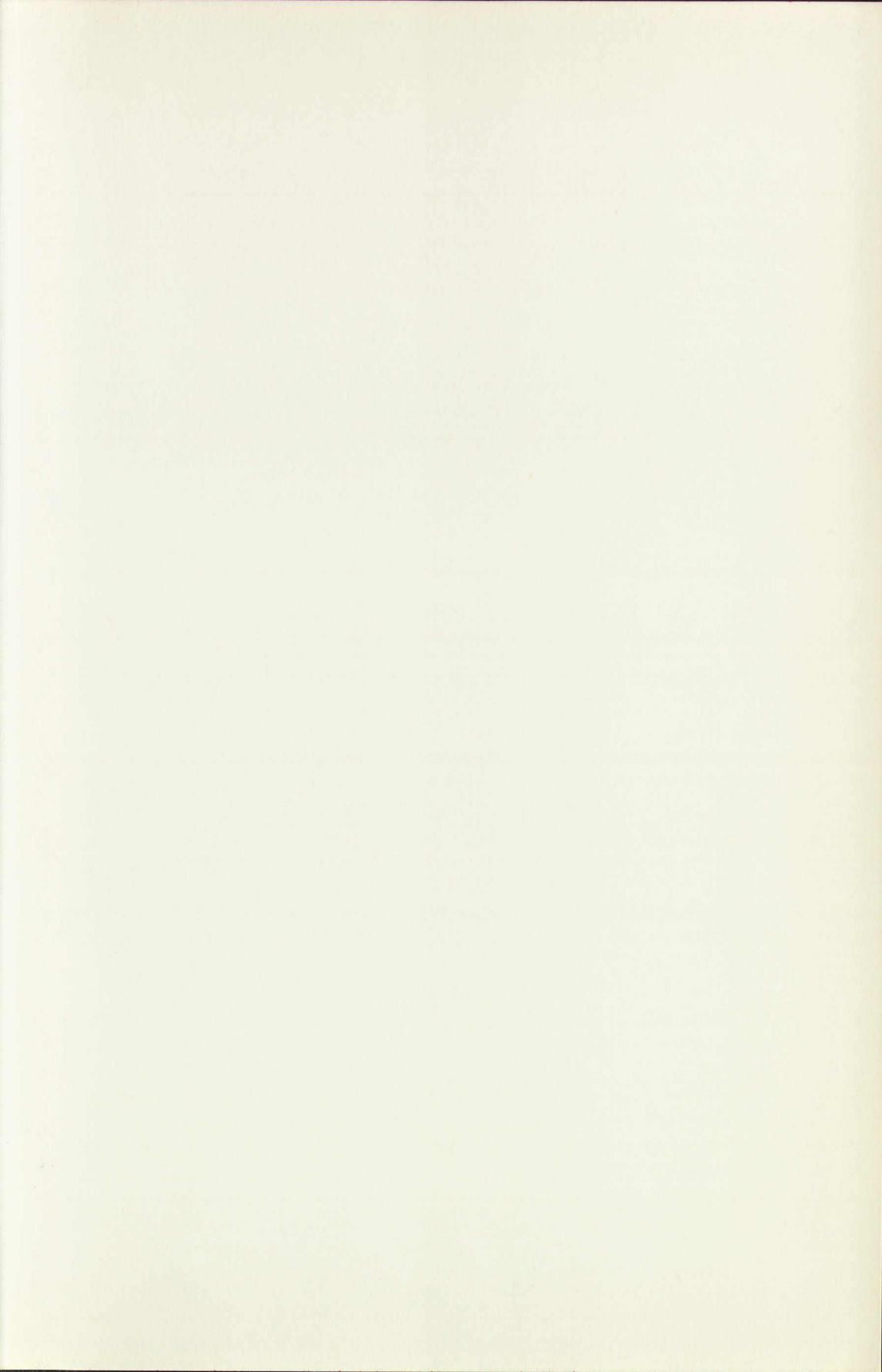
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