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Research

Nuclear Weapons Research in Sweden

The Co-operation between Civilian and Military Research, 1947 - 1972

Dr Thomas Jonter

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SKI's perspective

Background

In the year 1998 Sweden, together with the rest of the states in the European Union and Euratom signed the Additional Protocol to the Safeguard Agreement with the International Atomic Energy Agency, IAEA. The Additional Protocol gives the Agency extended complimentary access to areas and buildings and rights to take environmental samples within a state. The process of ratification is going on with the intention that the protocol should be implemented simultaneously in all member states. In ratifying the agreement in May 2000, Sweden changed its Act on Nuclear Activities and passed a new law regarding inspections. The present estimate is that the protocol could be implemented in the beginning of 2003 after ratification in all EU member states.

Aim

When the Additional Protocol is implemented, Sweden is to be "mapped" by the IAEA, scrutinising all nuclear activities, present as well as future plans. In the light of this, SKI has chosen to go one step further, letting Dr Thomas Jonter of the Department of History at Uppsala University investigate Sweden's past activities in the area of nuclear weapons research in a political perspective. Dr Jonter has previously studied the Swedish National Defence Research Institute's (FOA) activities in this area up until 1972. This report deals with the civilian research programme and its links to the military plans to produce nuclear weapons.

Since Sweden had plans in the nuclear weapons area it is important to show to the IAEA that all such activities have stopped. This is the main objective with this report.

Results

Dr Jonter has made a survey of available sources in the archives at Studsvik and FOI, where the records of the AB Atomenergi company are stored. Furthermore, he has conducted interviews with key people involved in the research. The survey has a political and structural character rather than technical and the conclusions and views put forward in this report are his own and is not necessarily the view of SKI. SKI's conclusion from this report is that the issue of Sweden's nuclear ambitions is thoroughly elucidated showing that Sweden's research in the area is ended.

Continued efforts in this area of research

Dr Jonter will, financed by SKI, describe how this investigation has been conducted and develop a model that IAEA and other countries can use when investigating a states' historical nuclear ambitions.

Effect on SKI's activities

This report will be added to the Swedish State Declaration according to the Additional Protocol. With this research done, SKI is able to show that Sweden's ambitions in the field of producing nuclear weapons research is over.

Project information

Dr Kåre Jansson has been responsible for the project at SKI.

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Other projects: SKI Report 99:21 – Sverige, USA och kärnenergin, Framväxten av en svensk kärnämneskontroll 1945-1995, Thomas Jonter, May 1999, (Sweden, USA and nuclear energy. The emergence of Swedish Nuclear Materials Control 1945-1995). SKI Report 01:05 – Försvarets forskningsanstalt och planerna på svenska kärnvapen, Thomas Jonter, March 2001 translated to SKI Report 01:33 – Sweden and the Bomb. The Swedish Plans to Acquire Nuclear Weapons, 1945-1972, Thomas Jonter, September 2001.

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Contents

Acknowledgements

This study was carried out as part of a project at the Swedish Nuclear Power Inspectorate (Statens Kärnkraftinspektion, SKI), begun in 1998, to make a historical review of Swedish nuclear weapons research during the period 1945-2000.

This is the third report of three. The first report mainly analyses Swedish-American nuclear energy collaboration between 1945 and 1995. The report also contains a list of archives with documentation of nuclear material management in Sweden, the growth of international inspections and the legislation that has applied in the nuclear energy field since 1945. The second report investigates the Swedish National Defence Research Establishment (FOA) and plans to acquire nuclear weapons, 1945-1972.[1]

Several persons have read and commented this text. First and foremost, I am indebted to the individuals I have interviewed in order to carry out this report: Bo Aler, Erik Haeffner, Eric Hellstrand, Åke Hultgren, Hilding Mogard, Bengt Pershagen, Jan Rydberg and Carl Gustaf Österlundh. They have not only given me time to make the interviews, but have also shared their experience with me.

The comments of emeritus professor Nils Göran Sjöstrand, at the Department of Reactor Physics at Chalmers University of Technology have in many respects shed light on many technical misunderstandings in the first draft. Alvar Östman, former nuclear engineer at AB Atomenergi, Morten Bremer Maerli at the Norwegian Institute of International Affairs and Jan Prawitz at the Swedish Foreign Policy Institute, has also read and commented on the text.

At the Swedish Nuclear Power Inspectorate (SKI) and the especially at the Office of Nuclear Non-Proliferation several staff members have been consulted. Among them I am especially thankful for the advice and help given by Göran Dahlin, Monika Eiborn, Lars Hildingsson, Kåre Jansson and Stig Wingefors.

Finally I would like to express my gratitude to SKI who financially supported this project and at the same time emphasise that the conclusions of this report are mine only.

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[1] Jonter, Thomas, *Sverige, USA och kärnenergin. Framväxten av en svensk kärnämneskontroll 1945-1995* (Sweden, the USA and nuclear energy. The emergence of Swedish nuclear materials control 1945-1995), SKI Report 99:21; *Försvarets forskningsanstalt och planerna på svenska kärnvapen*, SKI Report 01:5, translated to *Sweden and the Bomb. The Swedish Plans to acquire Nuclear Weapons, 1945-1972*, SKI Report 01:33.

Summary

The Swedish nuclear weapons research began as early as 1945, shortly after the first atomic bombs fell over Japan. The assignment to look into the new weapon of mass destruction went to the Swedish National Defence Research Establishment (FOA). Admittedly, the main aim of the research initiated at that time was to find out how Sweden could best protect itself against a nuclear weapon attack. However, from the outset FOA was interested in investigating the possibilities of manufacturing what was then called an atomic bomb.

A co-operation between FOA and AB Atomenergi (AE), which was created in 1947 in order to be responsible for the industrial development of civilian nuclear energy, was initiated. AE made several technical investigations within this co-operation regarding choice of reactors and preconditions for a production of weapons-grade plutonium.

The first purpose of this report is therefore to investigate how this co-operation emerged and what consequences it had for the project to produce basic information for the Swedish manufacture of nuclear weapons.

In general terms, the finding of this report is that FOA was responsible for the overall nuclear weapons research. For this reason, FOA was in charge of the construction of the nuclear device and the studies of its effects.

Additionally, AE should deliver basic information of a possible production of weapons-grade plutonium and investigate the possibilities of a production or a procurement of inspection-free heavy water (i.e. without inspections by the supplying country). AE should also build a reprocessing plant and manufacture fuel elements to be used in the reactors for a production of weapons-grade plutonium.

Furthermore, it is important to emphasise that both FOA and AE conducted plutonium research. The reason why FOA conducted this research was that the plutonium had to be in metallic form in order to be used in a nuclear weapons device. Therefore, FOA carried out research with the purpose of producing metallic plutonium. Simultaneously, AE developed methods to separate plutonium from uranium (reprocessing) in order to be used as fuels in the reactors (plutonium recycling). This procedure would imply a better use of the natural uranium.

Between 1949 and up to 1968, when the Swedish government signed the Non-Proliferation Treaty (NPT), four main investigations regarding the technical conditions for a manufacture of nuclear weapons were made (1953, 1955, 1957 and 1965). AE prepared several reports within the framework of this FOA research. It was mainly assignments, which dealt with reactor technique, production of plutonium and procurement of heavy water.

The second purpose is to account for the reactors and other facilities where nuclear materials activities (especially with plutonium, U-235 and heavy water) have taken place. The results of this investigation are given in appendix 2.

The third purpose is to investigate how much plutonium, U-235 and heavy water AE had at its disposal during the period 1945-1972. The results of this investigation are given in appendix 1.

Appendix 4 contains a general model of how the historical review of Sweden's non-proliferation policy of nuclear weapons was carried out. This model has been created in order to serve as a guide for other states' efforts to make similar surveys.

Sammanfattning

Den svenska kärnvapenforskningen kom igång redan 1945, strax efter att de första atombomberna föll över Japan. Det var det nybildade Försvarets forskningsanstalt (FOA) som fick uppdraget av överbefälhavaren att ta fram kunskaper om det nya massförstörelsevapnet. I det uppdraget låg också att i bred mening undersöka möjligheterna av att tillverka, som det kallades på den tiden, atombomber. FOA inledde ett samarbete med AB Atomenergi (AE) som bildades 1947 och som hade till uppgift att ansvara för den civila kärnenergiutvecklingen. AE gjorde flera tekniska utredningar om val av reaktorer och förutsättningarna för en framställning av plutonium av vapenkvalitet för FOA:s räkning.

Det första syftet med denna rapport är därför att undersöka hur detta samarbete växte fram och vilka konsekvenser detta fick för projektet att få fram underlag för en svensk tillverkning av kärnvapen.

Generellt kan man säga att FOA skulle komma att ansvara för den övergripande kärnvapenforskningen. Det innebar att FOA höll i själva konstruktionsarbetet för själva laddningen och studierna över dess verkan.

AE i sin tur skulle ta fram underlag för en eventuell framställning av plutonium av vapenkvalitet och undersöka möjligheterna att anskaffa inspektionsfritt tungt vatten. AE skulle även bygga en upparbetningsanläggning och tillverka bränsleelementen vilka kunde i användas reaktorerna för en produktion av de erforderliga mängderna plutonium av vapenkvalitet.

Dessutom är det också viktigt att framhålla att både FOA och AE bedrev plutoniumforskning. FOA:s forskning syftade till att ta fram plutonium i metallisk form för att det skulle kunna användas i en kärnvapenladdning.

AE:s plutoniumverksamhet hade som målsättning att utveckla metoder för att separera plutonium från uran (upparbetning). Det separerade plutoniet kan efter denna process användas som bränsle i reaktorerna (plutoniumåterföring). Detta innebär att uranråvaran utnyttjas bättre.

Mellan 1949 och 1968, då Sverige undertecknade avtalet om icke-spridning av kärnvapen, gjordes fyra stora FOA-utredningar om förutsättningarna för en kärnvapenproduktion (1953, 1955, 1957 och 1965). AE producerade flera omfattande rapporter inom ramen för dessa FOA-utredningar. Det rörde sig främst om tekniska underlag som hade med reaktorteknik, plutoniumproduktion och anskaffning av tungt vatten att göra.

Det andra syftet är att redovisa AE:s reaktorer och anläggningar där verksamhet med kärnämnen (i synnerhet plutonium och U-235) ägt rum. Resultaten för denna undersökning redovisas i bilaga 2.

Det tredje syftet är att redovisa för AE:s innehav av plutonium, U-235 och tungt vatten under perioden 1947-1972. Resultaten för denna undersökning redovisas i bilaga 1.

I bilaga 4 finns en text som innehåller en generell modell över hur den historiska kartläggningen genomfördes av Sveriges icke-spridnings politik. Modellen har skapats för att kunna användas som allmän vägledning för andra staters ansträngningar att göra liknande kartläggningar.

1. The aims of the report and the issues it deals with

The Swedish nuclear weapons research begun as early as 1945, shortly after the first atomic bombs fell over Japan. The assignment to look into the new weapon of mass destruction went to the Swedish National Defence Research Establishment (FOA). Admittedly, the main aim of the research initiated at that time was to find out how Sweden could best protect itself against a nuclear weapon attack. However, from the outset FOA was interested in investigating the possibilities of manufacturing what was then called an atomic bomb.

A co-operation between FOA and AB Atomenergi (AE), which was created in 1947 in order to be responsible for the industrial development of civilian nuclear energy, was initiated. AE made several technical investigations within this co-operation regarding choice of reactors and the preconditions for a production of weapons-grade plutonium.

AE was four-sevenths government owned. The rest of the shareholdings were split between 24 different Swedish companies belonging mainly to the energy, mining, steel, and engineering industries.[2]

One of the first more important tasks was to acquire and extract uranium. To extract uranium from primarily kolm-type shales was the basis of the plan for self-sufficiency that Sweden early on decided to fulfil. To reach self-sufficiency in the nuclear energy supply was an obvious aim for Swedish politicians and researchers shortly after the Second World War. For this reason, Sweden chose a technology where the reactors could be loaded with natural uranium to be used without preceding enrichment. Several studies had concluded that Sweden owned rich uranium deposits in the central part of the country. Consequently a reactor technology was chosen where heavy water could be used as moderator.

To import enriched uranium to be used in a light water technology was considered out of the question. The reason for this was that the Great powers, especially the United States at that time, had a very restrictive nuclear energy policy towards other countries. To build a Swedish enrichment plant was out of the question due to both technical and economic reasons.[3] Certainly it was possible to enrich the domestic uranium, but it was at that time regarded as both a costly and technically complicated process.[4]

The Swedish nuclear energy programme was called “the Swedish way”. Despite this name, the choice was nevertheless a rather common reactor solution in the 1950’s. If there were any unique part of the Swedish programme, the fact was that if anything, Sweden was considered to have one of the largest uranium deposits in the Western

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2 Lindström, Stefan, *I hela nationens tacksamhet. Svensk forskningspolitik på atomenergiområdet 1945-1956.* Dissertation, Stockholm 1991, p. 92.

3 *Svensk atomenergipolitik. Motiv och riktlinjer för statens insatser på atomenergiområdet 1947-1970.* Industridepartementet 1970, p. 6. See also, Jonter 1999, pp. 15-16.

4 The general picture of how such a process would be carried out were known at that time, but not the technology in details, according to Carl Gustaf Österlundh. Interview with Carl Göran Österlundh, 16 November 2001

world.[5] This opportunity constituted the foremost prerequisite to reach self-sufficiency in the nuclear energy field.

The civil nuclear energy programme should be designed in such a way that it could include a Swedish manufacture of nuclear weapons, if the Swedish parliament took a decision in favour of such an alternative. With a certain technique – which implies frequent changes of fuel batches – even weapons-grade plutonium could be obtained combined with energy production for civilian purposes.

A co-operation between FOA and AE was established in order to work out technical and economic estimates for such a production.[6]

Even though the contours of this co-operation are known, the picture is far from clear. It is elucidated what the main tasks for AE were within this co-operation up to 1968 when these plans were abandoned in the light of the fact that Sweden signed the NPT.[7] However, the previous studies have not analysed in detail what AE actually did for FOA and what amounts of nuclear materials AE used in the research.

The first purpose of this report is therefore to investigate how this co-operation emerged and what consequences it had for the project to produce basic information for the Swedish manufacture of nuclear weapons.

The second purpose is to account for the reactors and other facilities where nuclear materials activities (especially with plutonium, U-235 and heavy water) have taken place.

The third purpose is to investigate how much plutonium, U-235 and heavy water AE had at its disposal during the period 1945-1972.

In order to be able to carry out this study, the following questions will be posed:

1. How did the co-operation with FOA emerge and how was it regulated?
2. What sort of tasks did AE fulfil for FOA in order to deliver basic information about the Swedish manufacture of nuclear weapons?
3. What role should AE play within the framework of the possible manufacture of nuclear weapons?
4. With which companies and research institutions did AE collaborate in order to obtain technical information on which to base the development of nuclear weapons? What was the purpose of this collaboration and what was achieved?
5. What reactors, facilities and laboratories did AE have at its disposal where nuclear materials activities (especially with plutonium, U-235 and heavy water) took place? Where are/were these located? (See appendix 2 for a list of these facilities.)
6. What amounts of plutonium, U-235 and heavy water did AE have at its disposal in the period of 1945-1972? What happened to the nuclear materials and the heavy water after it was used? (See appendix 1).

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5 Skogmar, Gunnar, *De nya malmfälten. Det svenska uranet och inledningen till efterkrigstidens neutralitetspolitik*, Research programme Sverige under kalla kriget, Arbetsrapport nr 3, 1997.

6 Jonter 2001; see also *Svensk kärnvapenforskning 1945-1972*. Stockholm 1987.

7 Prawitz, Jan, *From Nuclear Option to Non-Nuclear Promotion: The Sweden Case*. Research Report from the Swedish Institute of International Affairs, Stockholm 1995, pp. 19-20; see also Dassen van, Lars*, Sweden and the Making of Nuclear Non-Proliferation: From Indecision to Assertiveness*. SKI Report 98:16.

1.1. Method

I have had full access to the archives at Studsvik AB (formerly AB Atomenergi), which means both the central archives and the Board of the Directors archives. These archives are not open sources, but Studsvik AB has given me permission to use their archives in order to carry out this study. According to the NPT the member states in IAEA are obliged to control that such information are not proliferated.

Additionally, documents from the FOI's (former FOA's) archives have been used. The referred FOA documents are declassified (if not otherwise is stated).

Despite this access the documentation is not complete. Not everything, especially concerning the development of the co-operation between FOA and AE has been documented or saved as reports and protocols.

It is, however, possible to describe the co-operation in broad terms given the existing documents. Furthermore, the published literature which deals with AB Atomenergi and its activities have been of much help in making this description more consistent.

In addition, I have interviewed eight people who have been involved in this co-operation at AE: former managing director Bo Aler[8], department heads Erik Haeffner, Eric Hellstrand, Bengt Pershagen and Carl Gustaf Österlundh, and chief engineer Hilding Mogard and the manager for the Plutonium Fuel Section Åke Hultgren. An interview has also been conducted with the emeritus professor Jan Rydberg, who was involved in the co-operation between AE and FOA in the plutonium research field during the 1950's up to 1963.

These individuals have read a first draft of report based on an analysis of the found documents. Thereafter I have interviewed them individually and listened to their version of what took place concerning the co-operation.

Concerning the investigation of how much nuclear materials and heavy water AE had at its disposal, the register of the Office of Nuclear Non-Proliferation at SKI has been used, "Sammanställning av uppgifter om transporter av kärnämnen till och från Sverige åren 1955-1979" (Compilation of information about transports of nuclear materials to and from Sweden between 1955 and 1979). A complementary comparison concerning AE's disposal of nuclear materials and heavy water has been undertaken based on a report by Åke Hultgren, "Upparbetning av Ågestabränslet 1969" (The Reprocessing of Ågesta fuel 1969, non published SKI report) and the working papers of the SKI deputy head of the Office of Nuclear Non-Proliferation Göran Dahlin.

1.2. Previous research

The history of the Swedish heavy water technology has not yet been written. Admittedly the issue has been touched upon in several books and articles.[9]

Furthermore, aspects of heavy water technology are included in different histories of companies, as, for example, in Jan Glete's history of the Swedish company ASEA.[10]

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8 Bo Aler was administrative manager 1957-1963, Administrative director 1964-1966, managing director 1970-1978.

9 See for example, Leijonhufvud, Sigfrid, *(parantes?. En historia om svensk kärnkraft*. Västerås 1994; Lundgren, Lars, *Energipolitik i Sverige 1890-1975*. Stockholm 1978.

However, an extended analysis of the nuclear power in Sweden has still not seen the light of day. Neither have the activities of AB Atomenergi been the subject for a thorough study. The political scientist Stefan Lindström has, however, analysed the prelude to "the Swedish way" up to 1956, when the nuclear energy programme was launched.[11] The reactor physicist Karl-Erik Larsson has also published an extended essay, which deals with the history of Swedish nuclear power energy. The essay is not based on an extended use of sources, on the whole the text is more to be considered as a first sketch of the emergence of nuclear power energy. The essay presents, however, an ingenious first draft to be followed by continued research.[12]

The former managing director of AE, Harry Brynielsson, has dealt with the heavy water reactors, which were built, in the framework of the Swedish nuclear energy programme in an article in *Daedalus*.[13]

Shortly before this report was about to be published, a study by Wilhelm Agrell was released which in parts deals with the co-operation between FOA and AE. Agrell touches upon several issues that I investigate in my report. In his study, Agrell has not used the archives at AE (Studvik AB), but has nonetheless been able to analyse this co-operation. The main aim in the Agrell study is to analyse the Swedish nuclear weapons issue in an overview perspective, where the political and military aspects are included in the analysis. My report is focused on the technical preparations, and goes more into details concerning the co-operation between the two parties and its consequences for the plans to manufacture nuclear weapons.[14]

The role of AE is also the matter in several studies, which are mainly focused on the political aspects of Swedish nuclear energy development. Among others, the analyses of the sociologist Per Lindquist and the political scientist Anki Schagerholm, are worth mentioning.[15]

Former employees at AE, the chemists Åke Hultgren and Carl Gustaf Österlundh present an overview of the Swedish reprocessing of spent nuclear fuel in a report entitled *Reprocessing in Sweden: History and Perspective*. The report deals with the activities at AE in order to produce plutonium to be used as nuclear fuels in the reactors.[16]

Erik Strandell has written about AE's uranium production, especially at the Ranstad plant. In two thorough studies, Strandell gives a detailed description of the development of the methods used in the uranium extraction.[17] Thomas Jonter has also touched upon

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10 Glete, Jan, *ASEA under hundra år 1883-1983.* ASEA 1983.

11 Lindström 1991.

12 Larsson, Karl-Erik, "Kärnkraftens historia i Sverige", *Kosmos* 1987.

13 Brynielsson, Harry, "Utvecklingen av svenska tungvattenreaktorer 1950-1970". *Daedalus* 1989/90.

14 Agrell, Wilhelm, *Svenska förintelsevapen. Utveckling av kemiska och nukleära stridsmedel 1928-70.* Lund 2002.

15 Lindqvist, Per, *Det klyvbara ämnet. Diskursiva ordningar i svensk kärnkraftspolitik 1972-1980.* Lund 1997; Schagerholm, Anki, *För het att hantera: Kärnkraftsfrågan i svensk politik 1945-1980*. Göteborg 1993.

16 Hultgren, Åke & Österlund, Carl-Gustav, *Reprocessing in Sweden: History and Perspective*. SKN Report 38, 1990.

17 Strandell, Erik, *Uran ur skiffer: Ranstadsverket: 40 års utveckling av processer för utvinning av uran ur mellansvenska alun skiffrar*, part 1 and 2. 1998.

AE's activities, mainly in a SKI report, which investigates the nuclear energy co-operation between the United States and Sweden during the cold war.[18]

1.3. Periods to be studied

The first period studied is 1947 to 1955. I have set the end at 1955, since this year the first "Atoms for Peace"-conference was held in Geneva, which meant a step forward for the global nuclear energy development. "Atoms for Peace" was the United States nuclear energy support programme for friendly nations and was a part of the cold war game between the superpowers. As a result, technical information concerning the nuclear energy was declassified in the United States, which helped Sweden and other states to develop their research.

The next period 1956 to 1959 has been chosen as in 1956 the Swedish parliament decided to launch a nuclear energy programme in order to build five to six reactor facilities in ten years. The reason for choosing 1959 as the final year of this phase has to do with the fact that the committee group of the Social Democratic party council issued a report in December of that year which was highly influential on the nature of protection research.

The third period from 1960 to 1967 is a natural choice since it was during those years that the nuclear weapons issue was finally settled.

Finally, the period from 1968 to 1972 was chosen because Sweden signed the NPT in August 1968. After this, FOA's more construction-oriented nuclear weapons research was phased out. In this context it can be of interest to study the impact it had on the co-operation between FOA and AE.

In 1972 a tripartite agreement was signed by Sweden, USA and IAEA in order to regulate the international control of the Swedish nuclear energy facilities. Before 1972, the United States Atomic Energy Commission (USAEC) conducted inspections of Swedish facilities in order to check that nuclear materials imported from the United States were not for the production of nuclear weapons. Even though the Swedish government ratified the NPT in 1970, the safeguards system of IAEA was not implemented in its entirety until 1975.[19]

From 1972 onwards, it is taken for granted that the IAEA is informed about what is happening in the nuclear energy field in Sweden.

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[18] Jonter, Thomas, *Sverige, USA och kärnenergin. Framväxten av en svensk kärnämneskontroll 1945-1995*. SKI Report 99:21.

[19] Ibid., pp. 28-29.

2. AB Atomenergi – a brief history 1947-1972

This concise exposé of AB Atomenergi's history is only included in order to serve as a background to understand the co-operation between FOA and AE. Several aspects of AE's activities and relation to other actors have been, if not totally excluded, at least dampened down. For instance, this account does not deal with the competition between AE and other companies in the nuclear energy field.

In *Svensk atomenergipolitik* 1970, the Minister of Industry Krister Wickman states three main reasons why the Swedish nuclear energy programme was initiated.

Firstly, this was due to the fact that the overall aim was to reach self-sufficiency in the nuclear power field. Investing in water power and oil only would be too risky. It was considered that it would take too long to develop the waterpower. Moreover, to be dependent on oil import could be a hazardous policy, which the Suez crisis of 1956 had shown in a dramatic way. In comparison, nuclear energy seemed to be a much more attractive alternative, particularly since Sweden had rich uranium deposits. Secondly, there was an industrial-political reason as well; to create a vital domestic industry in an important future energy sector. Thirdly, it was considered that only the government could bear the investment costs in such a planned large nuclear energy programme.[20]

AE should be responsible for the civilian nuclear development while FOA should be in charge of the military aspects of this new technology. The division of responsibilities that was made did not mean to draw a clear line between civilian and military activities. The division of work was rather made in order to economize on the limited resources of the country. According to Stefan Lindström, it is correct to talk about an extended division of work between FOA, AE and Atomkommittén (AK, the Atomic Committee, an advisory committee of experts which was founded in 1945 to serve the government with advice concerning the use of nuclear energy) at that time.[21]

AE's two main tasks were to initiate research in physics and chemistry and to start uranium production. The department of chemistry at FOA, had already started a research project with the purpose of developing methods for extracting uranium. At FOA, analysis of different uranium precipitates was conducted under the leadership of Roland Rynninger.[22]

This research activity was in fact taken over by AE at the end of the 1940's. As early as 1945, the Geological Survey of Sweden (SGU) had compiled a list of possible sources of uranium in Sweden. AE did not start from zero, when the young chemist Erik Svenke was employed to carry the uranium issue further. As a result of these endeavours, a uranium extraction pilot plant was set up in Kvarntorp in 1953.[23]

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20 *Svensk atomenergipolitik. Motiv och riktlinjer för statens insatser på atomenergiområdet 1947-1970.* Industridepartementet 1970, pp. 5-6.

21 Lindström 1991, pp 92-93.

22 Interview with Professor Emeritus Jan Rydberg, 8 November 2001.

23 Larsson 1987, pp. 129-130, see also *Svensk atomenergipolitik*, pp. 17-18.

2.1. R 1 – Sweden's first reactor is started

In 1954, Sweden's first reactor R 1 went into operation located at the Royal Institute of Technology in Stockholm. The reactor was not, however, loaded with uranium produced in Sweden as such a production had not yet been started. For this reason, AE borrowed three tonnes of uranium from the French Commissariat á l'Energie Atomique (CEA). It was decided that the reactor should be moderated with heavy water (five tonnes were imported from Norway) even if graphite was considered to be a technical possibility. The choice of heavy water was natural because this particular technology demanded less amounts of uranium.[24]

The head of the physics department, Sigvard Eklund, was in charge of the reactor project. Eklund used his international network contacts, particularly the French, in the planning and construction of R 1. The American reactor CP 3 in Chicago served as a model for the first reactor. R 1 was built 15 metres down in a rock cavern, and eventually had an output of 1 MW.[25]

R 1 was mainly a training facility. On the basis of the results from the measurements and experiments conducted in the reactor, the research could take a step forward. For instance, the researchers were occupied with studies of different materials behaviour under neutron radiation and cross-section measurements of uranium. Such information was of great value for both AE's and FOA's estimates of different reactions.

The techniques of refining U3O8 and of producing UO2 and metallic uranium were developed as well at Lövholmsvägen south of Stockholm.[26]

In 1953 another facility was erected in the same rock cavern as R 1, ZEBRA (Zero Energy Bare Reactor Assembly). This facility was used for investigations of configuration of uranium rods in reactor cores, which were of importance for the design of the heavy water reactor system.[27]

2.2. The construction of R 2 and nuclear energy co-operation with the United States

The "Atoms for Peace"-programme was decisive for the choice of the next reactor, R 2. This reactor was built at Studsvik close to Nyköping in 1959. R 2 was a material testing reactor. This alternative was not previously possible because of lack of enriched uranium. However, after the Geneva conference in 1955, it was possible to buy both enriched uranium and complete reactor systems from the United States at favourable prices.

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24 Svensk atomenergipolitik 1970, pp. 17-18; Larsson p. 131. Erik Svenke has discussed different methods to produce uranium and the Swedish uranium policy, in a lecture with the title "Svensk uranhistoria" (Swedish history of uranium) at the Technical Museum in Stockholm, November 14 2000. See also Strandell 1998.

25 Interview with Bengt Pershagen, 16 November 2000. About the construction of R 1, see Eklund, Sigvard, "Den första svenska atomreaktorn", *Kosmos* 1954: 32.

26 Gelin, Ragnar, Mogard, Hilding och Nelson, Bengt, "Refining of Uraniun Concentrate and Production of Uranium Oxide and Metal". Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva 1958.

27 Brynielsson 1989, p. 208.

An extended co-operation agreement was signed between the United States and Sweden on 18 January 1956 within the framework of the "Atoms for Peace"-programme. The agreement enabled Sweden to purchase enriched uranium and heavy water to be used for research purposes.

The agreements contained a matter of course condition; the receiving state promised not to use the nuclear material for a manufacture of nuclear weapons or to export it to other nations to be used for this purpose.[28]

The "Atoms for Peace"-program was a part of the cold war game between the superpowers. The restrictive American policy had nevertheless not been able to prevent the Soviet Union to acquire nuclear weapons. It was now considered that a more open and helpful attitude to other nation's developments of their civilian nuclear energy could better serve US interests. By and large, this policy was considered to be more effective in terms of controlling and supervising that the received nuclear materials and devices were not used for military purposes by the co-operative state.[29]

In April 1958, the USAEC declared that the government of the United States was willing to contribute $ 350 000 in order to build R 2 at Studsvik.[30]

R 2 became a bigger and more powerful reactor than R 1 with a thermal output of 50 MW. The reactor was mainly used for materials testing for the future reactor development in Sweden. For instance, studies were made of how to design fuel rods to be used in the planned nuclear power programme.[31]

2.3. R 3 – The Ågesta Nuclear Power Station

The nuclear energy programme of 1956 planned to build 5 to 6 nuclear power stations up to 1965. In fact one of these nuclear power stations was already in the process of concrete design when the programme was written, R 3 at Ågesta south of Stockholm. The reactor facility was constructed for a combined heat and electricity production. AE and Stockholms Elverk (The municipal authority of Stockholm responsible for electricity production) signed an agreement regarding the use of the Ågesta Nuclear Power Station for distant heat production to Farsta, a suburb of Stockholm.

The reactor was based on heavy water technology and loaded with natural uranium in the form of oxide as fuel.[32] The fuel elements were produced by AE in two periods, consisting of 18,5 tonnes of uranium sintered oxide pellets canned in tight fitting Zircaloy tube claddings.[33] (For details of the reactor data, see appendix 2).

AE was not alone on the nuclear reactor market in Sweden. As a consequence of the Geneva conference in 1955, the private industry started to show interest in what was considered as a future business with splendid opportunities. For this reason a

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28 About the Swedish-American nuclear energy co-operation, see Jonter, Thomas, *Sverige, USA och kärnenergin. Framväxten av en svensk kärnämneskontroll 1945-1995*. SKI Report 99:21.

29 Jonter 1999, pp. 20-21.

30 Jonter 1999, p. 26.

31 Interview with Bengt Pershagen och Carl Gustaf Österlundh, 5 October 2001. About the construction of R 2, see Larsson 1987, p. 138.

32 *Svensk atomenergipolitik*, pp. 29-31.

33 Brynielsson, p. 209. About the fuel, see Mogard, Hilding och Nelson, Bengt, "Fuel Elements in Sweden". *Nuclear Engineering*, November 1961.

consortium for nuclear power co-operation (Krångede AB & CO, AKK) was created by several Swedish companies just two months after the Geneva conference. Other bigger Swedish companies, such as ASEA and Vattenfall, were planning their own nuclear power projects.

However, the first over-optimistic prognoses made shortly after the "Atoms for Peace" programme was launched were changed after a couple of years. When it was realised that reactor developments required enormous investments, the interest faded.

As an example, when Vattenfall came to the conclusion that the planned district heating plant Adam in Västerås would cost much more than was previously estimated, the company asked the government for extra funds. The government rejected the request. Furthermore, the government decided to combine R 3 and Adam in one project. ASEA, who became the main contractor for the reactor, also took part in the negotiations.[34]

Finally, the Ågesta Nuclear Power Station went into operation on 17 July 1963. The reactor was a prototype facility with a thermal output of 65 MW, from which 55 MW was used as distant heating of Farsta and 10 MW for electricity generation. In 1965 the operation was taken over by Vattenfall. In the end, the Ågesta Nuclear Power Station was closed down in 1974 for economic reasons.[35] Another important reason for abandoning the reactor was new safety demands, which in turn would have necessitated costly renovations.[36]

The reactor was not furnished with devices for on-load refueling to enable frequent fuel changes under operation, which was one of the conditions for a production of weapons-grade plutonium.

Neither did the Ågesta Nuclear Power Station become an important power producer. Despite this, the white book *Svensk atomenergipolitik* considers that the most important aim was fulfilled: to gain the necessary experience for industrial reactor manufacture, reactor operation and fuel element production for the benefit of the continued nuclear energy development.[37]

2.4. The uranium plant at Ranstad

The decision in 1956 to develop an independent Swedish reactor system, was built upon the fact that self-sufficiency could be reached in terms of uranium, heavy water and plutonium.[38]

Concerning the uranium production, AE's pilot plant at Kvarntorp, which went into operation in 1953, had shown that such a project could be run on an industrial scale. In 1957, AE decided to build a larger industrial uranium plant with a capacity of 120

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[34] *Svensk atomenergipolitik*, p. 30.

[35] Brynielsson, p. 211. See also "The Ågesta Nuclear Power Station. A Staff Report by AB Atomenergi". Edited by B McHugh. Stockholm 1964.

[36] Letter from Professor Emeritus Nils Göran Sjöstrand to Thomas Jonter, 15 June 2001. Sjöstrand was a member of the board for Reaktorförläggningskommittén at that time and he remembers well the discussions in connection with the closing down of the reactor.

[37] *Svensk atomenergipolitik*, pp. 29-31.

[38] Ibid., p. 32.

tonnes a year. Furthermore, the uranium plant should be located at Ranstad where the total deposit was estimated to about 300 000 tonnes.[39]

When the United States drastically lowered the prices of uranium at the end of the 1950's, it was no longer self-evident to start Swedish domestic production.

An investigation was made in 1959 in order to tackle the uranium issue. The investigation, made by the AK's successor the Delegation of Atomic Energy Issues (DFA), came to the conclusion that a Swedish production of uranium was estimated to cost 70 % more than if uranium was imported from the United States. AE stressed that the Swedish need of natural uranium could be satisfied by import if Sweden was ready to accept submission to foreign or international control. The experts in DFA who represented the private industry were in favour of an import of uranium even though it would imply restrictions in the form of foreign inspections.

Despite the conclusion of the study, a majority of the members of DFA recommended that the Ranstad project should be continued with regard to the aspect of self-sufficiency.[40]

In 1965, the construction work was done. The conditions for the "Swedish way" had by now, however, dramatically changed. The industry's interest in light water technology, and the fact that the price of enriched uranium had dropped even further, finally closed the door to domestic production.

Another complication occurred in 1966 when the United States and Sweden signed an extended agreement of co-operation. As a consequence, the United States guaranteed to deliver uranium to Sweden until 1996. The estimated amount of uranium was enough to load the first six nuclear power reactors. In return, Sweden pledged that the received nuclear materials should be used only for peaceful purposes.[41]

The extended plans to make Ranstad an important uranium plant came to nothing. The operation would, however, continue during the 1970's due to the fact that the Swedish companies Boliden and LKAB became joint-owners of the uranium plant.[42]

At Ranstad about 213 tonnes of uranium were produced.[43] Their interest was to combine uranium milling with production of other valuable metals such as vanadium and molybdenum.[44]

2.5 The Plans for a Swedish reprocessing facility are abandoned

The other two parts of the 1956 nuclear power programme for self-sufficiency – a heavy water plant and a reprocessing facility – were not completed. A pilot plant for heavy

39 Interview with Åke Hultgren, 1 November 2001.

40 Jonter 1999, p. 23; *Svensk atomenergipolitik*, p. 32; Larsson 1987, p. 145. AK's responsibility was split in two functions: DFA was in charge of the control and deliverance of licence in the nuclear energy field, meanwhile Statens råd för atomforskning was responsible for basic research. DFA was transformed to SKI in 1974.

41 Jonter 1999, p. 29-30.

42 Interview with Bo Aler, 19 February 2002, Se also "Ranstad" in the Swedish National Encyclopaedia.

43 See "Ranstadsverket" by professor emeritus Nils Göran Sjöstrand in the Swedish National Encyclopaedia. See also Hultgren, Åke and Olsson, Gunnar, Uranium Recovery in Sweden. History and Perspective, SKB 93-42.

44 Interview with Stig Wingefors, 17 May 2002.

water production was built at Kvarntorp. The project was, however, abandoned in 1961. For this reason, the necessary heavy water for Ågesta and Marviken was imported from the United States and Norway.

Furthermore, the plant for reprocessing which was planned to be constructed at Sannäs on the west coast of Sweden at the beginning of the1960's was also abandoned.

The reason for this was that it had been shown that the facility had to be dimensioned for a large output in order to be profitable. As a result, the reprocessing plant would go into operation at the earliest in the 1970's.[45]

When an international market for reprocessing services started to grow, the need for a Swedish plant disappeared.[46]

2.6 R 4 – the Marviken Nuclear power Station

Notwithstanding that Ågesta went out of operation in 1974, the project was, however, considered rewarding because necessary experience was gained for the continued reactor development. On the contrary, the second Swedish nuclear power reactor, R 4 at Marviken close to Norrköping, was built but did not go into operation. The project became a complicated business which, after several steps of remodelling, was abandoned in 1970. As a consequence, the heavy water programme went into the grave.

Why then was Marviken constructed? The Swedish heavy water programme was not expected to be a competitive power-supplier until reactor plants with an output of 400 MW or more could go into operation. A medium size reactor was needed between Ågesta and such a larger reactor power station. As early as 1955, both AE and Vattenfall had their own plans for a medium size nuclear power reactor.[47]

For the fiscal year 1957/58, Vattenfall requested appropriation to start its heavy water reactor project by the name Eva. The request was not accepted. The minister of trade maintained that the time was not ripe for the next step. Instead a continued co-operation between AE and Vattenfall regarding a joint project was recommended. For this reason, an agreement was closed in 1957 between AE and Vattenfall in order to build a nuclear reactor by the name R4/Eva. AE should be in charge of the reactor construction while Vattenfall was to be responsible for the power station. The following year the private industry became involved as well. ASEA and NOHAB were contracted in order to take part in the manufacture of the reactor.[48]

At first AE chose a pressurised heavy water reactor (PHWR). Moreover, it was decided that the reactor should be designed in order to enable on-load refueling. With such an arrangement a higher burn up was possible and the cost of the fuel cycle could be lowered.[49]

The Marviken power station was planned to go into operation in 1963. However, when the prices dropped and the supply of oil increased in the beginning of 1960's, the need

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45 Interview with Carl Gustaf Österlundh, 5 October and 16 November 2001. See also Larsson 1987, pp. 33-34.

46 Interview with Bo Aler, 19 February 2002.

47 Brynielsson, p. 213.

48 *Svensk atomenergipolitik,* pp 37-38.

49 Ibid., pp. 41-49.

for a Swedish nuclear power station was not considered as urgent as before. Therefore more time for construction plans was gained and the building of the reactor could be postponed until 1968.

The remodelling of R 4 was a matter of intense internal debate during these years. Mainly two issues were discussed: boiling and superheating. A boiling heavy water reactor (BHWR) did not have to be provided with costly heat exchangers as in a pressurised reactor. Moreover, if the issue on nuclear superheating could be solved, which implied operation in higher temperatures to a higher output, much would be gained.[50]

In 1962, the PHWR model was abandoned in favour of a BHWR. For this reason, AE, ASEA and Vattenfall should together work out a project plan by the name K 200 concerning such a reactor system in the end of 1962. Furthermore, it was decided that the reactor should have an output of 400 MWe.[51]

Superheating was still the main problem. If enriched uranium was used with a special canning system, superheating could be reached without safety problems. The parliament had, however, decided that the reactor should be run with natural uranium. AE considered that it was too risky to fulfil "the Swedish way" from this point of view.

In 1964, Vattenfall recommended that the idea of superheating should be abandoned, and that the best alternative was to invest in a heavy water boiling reactor of simple construction.

Consequently, a decision was taken to go over to a BHWR the same year. However, the interest in designing the Marviken facility in order to enable operation with superheating still prevailed. Expensive equipment for such an arrangement had already been purchased and thus blocked the possibility of changing the construction plans.

In July 1964, ASEA was contracted to deliver the BHWR. The following year the order was complemented with devices for superheating and with a control system including an integrated computer for registration and control AE should construct the reactor part while ASEA should deliver it, and Vattenfall was to be in charge of the power station.

AE manufactured the fuel, which was supplied as 4,5 metres long rods canned in Zircaloy claddings. Furthermore, 40 tonnes enriched uranium with 1-2 % U-235 had been ordered from the United Kingdom Atomic Energy Authority (UKAEA) in 1964. The Zircaloy canning tubes were produced by the company Sandviken. Moreover, 180 tonnes of heavy water had been imported from the United States.[52] (For details of the Marviken facility, see appendix 2).

In 1965, an agreement between AE and ASEA was signed which meant that ASEA should deliver a heavy water reactor. In the same year, the first Swedish order was made of a commercial power reactor station based on light water technology. ASEA should manufacture a light water reactor with an output of 400 MW to Oskarshamn 1 belonging to the Oskarshamnsverkens Kraftgrupp AB (a private consortium).

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[50] Brynielsson, p. 214.

[51] *Svensk atomenergipolitik,* p. 44.

[52] Brynielsson, p. 222.

The following year the Swedish government signed an agreement with the United States concerning a purchase of enriched uranium. The agreement should be in force for 30 years and accordingly it worked up to 1996.[53]

In 1968, ASEA and Vattenfall ordered the first light water reactor to Ringhals power station. During the summer that year, AE's design and nuclear fuels departments were united with the nuclear power department of ASEA. The new company ASEA-ATOM was 50 % government owned, but ASEA had a casting vote. The company should be a part of the ASEA group.[54]

The reactor orders for Oskarshamn 1 and Ringhals were transferred to the new company. The reactor delivery to Marviken, which was considered to be a development project, was not, however, transferred to the new company. The newly founded company's field of action implied that Swedish nuclear energy had by now changed its direction to industrial development.

From then on, it was obvious that the light water technology was to dominate the future of the Swedish nuclear power energy. In spite of this, the government was of the opinion that Marviken should be continued due to the goal of self-sufficiency.

During the year of 1969, the problems increased. Several reports from different countries came to the conclusion that a superheating system would only give marginal improvements.

In addition, when the superheating arrangement at Marviken was considered to be insufficient for safety reasons, a decision was taken to abandon this system.

Nevertheless, it was shown that the arrangement for superheating could not be changed unless a costly renovation was conducted. The renovation was calculated to cost 40 million Swedish crowns and imply a delay of a couple of years. In May of 1970, the Marviken project was discontinued.[55]

Why did Marviken not go into operation? There were several reasons for this.

Firstly, the light water technology had its major breakthrough in the United States during the installation of the R 4 facility. The light water technology could be put on the market as an economically favourable and reliable reactor system compared to the heavy water system.

Secondly, the further lowering of the prices of enriched uranium in the United States reduced the fuel costs for a light water facility.[56]

Thirdly, the safety aspect was an important reason for abandoning the project. It was mainly the superheating technology, which created the most serious safety problem. In particular, the superheating could lead to corrosion of the fuel elements.[57]

Furthermore, there was also a risk that it would be difficult to control the power of the reactor.[58]

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[53] Jonter 1999, pp. 29-30.

[54] *Svensk atomenergipolitik,* p. 61.

[55] Brynielsson, pp. 223-224.

[56] This reason was the most important, according to Bo Aler. Interview with Bo Aler, 18 January 2002.

[57] Interview with Erik Haeffner, 29 September and 22 November 2001.

[58] Interview with Bengt Pershagen, 10 April 2002.

The heavy water and the fuel elements were sold. The facility was later on used for experimental studies in safety issues. Several countries, among others France, West Germany and the United States, participated in different experiments in order to analyse conceivable accidents simulated in the reactor vessel during the period 1972 to 1985.[59]

AE continued to be a state-owned company and diversified its activities during 1970's to include other parts of energy technology. The research was mainly focused on fuel operation limits. Some of this work has been carried out in an international co-operation since 1970's, and is still continuing.[60]

In 1970, the heavy water technology was finally abandoned.

Were AE's achievements in the heavy water field wasted energy? Not at all considering that much of the expertise, experience and technology could be used by the light water system that by now had taken over. In the words of Karl-Erik Larsson: "The light water technology got off to a flying start".[61]

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59 Brynielsson, p. 225-226. Interview with Bo Aler, 18 January 2002.

60 Interview with Bo Aler, 10 April 2002. A good example of what was carried out during this time, see Hilding Mogard, 16 October 2001. See also, Mogard, Hilding (AE) och Aas, Steinar (IFE) and Junkrans, Sigvard (AA), "Power Increases and Fuel Defection". Proceedings of United Nations Fourth International Conference on Peaceful Uses of Atomic Energy, vol 10, Geneva 1971.

61 Larsson 1987, p. 151.

3. The interlude: 1947-1955

The white book "Svensk atomenergipolitik" which was published in 1970 consists of 215 pages including appendixes. Only 16 lines deal with the plans to manufacture nuclear weapons and then in very general terms expressed in the preface by the minister of industry, Krister Wickman:

"Finally, I will touch upon a further aspect, namely the connection between the civilian nuclear energy programme and a possible Swedish manufacture of nuclear weapons. The final decision on the nuclear energy programme was based on purely civilian motives. While the nuclear weapons issue was most controversial at the end of 1950's, the political support for the nuclear energy programme was total.

At the same time, it is obvious that the government's policy of freedom of action for a later decision on procuring nuclear weapons implied a certain industrial capacity in the country. If a minimum of freedom of action was to have any real meaning, it was necessary that we could produce uranium, build reactors and were able to produce plutonium. These aspects were, however, included in the civilian programme and the potentially military use was more or less considered as a by-product. Moreover, the nuclear weapons issue lost its importance in the beginning of the 1960's. Since the ratification of the Non-Proliferation of Nuclear Weapons Treaty in 1970 Sweden has formally refrained from acquiring such weapons, and by the same token we have accepted international control of our nuclear energy programme."[62]

What is said in the preface by Krister Wickman is certainly true. Some parts necessary for military weapons manufacture were included in the Swedish civilian programme. Despite this, only 16 lines in a white book may seem too brief in the context of the conducted extensive research for the purpose of producing basic information for a possible manufacture of nuclear weapons. A reason for this is maybe that when "Svensk Atomenergipolitk" was written, most of the research concerning nuclear weapons was under secrecy. On the other hand, it would not have been a violation of the secrecy laws if the white book had dealt with the co-operation with FOA in a short overview.

Whatever the reason not to deal with the co-operation between AE and FOA in the white book, the previous official silence around the Swedish plans to acquire nuclear weapons has caused speculations in the media. For example, the Swedish journalist Christer Larsson has stated in a multi-part report in the journal Ny Teknik, that the civilian nuclear energy programme was designed in order to suit the military aims to produce nuclear weapons.[63]

As a result of the articles, the government appointed a one-man commission under the leadership of Olof Forssberg, at that time Head of the Legal Secretariat at the Department of Defence. The commission rejects Larsson's interpretation on practically every point, particularly the one concerning the co-operation between FOA and AE. According to Forssberg, the situation was the reverse to what Larsson has maintained. The commission concludes that it is more correct to say that the civilian programme

[62] *Svensk atomenergipolitik*, p. 8.

[63] Larsson, Christer, "Historien om en svensk atombomb", *Ny Teknik* 1985-86.

took priority and the military plans had to adapt to the requirements of the civilian programme.[64]

In view of this debate, an important purpose of this report is to investigate how far the co-operation between FOA and AE went.

In this chapter, the co-operation between the two parties is analysed from the foundation of AB Atomenergi from 1947 up to 1955 when the researchers at the company were able to produce the first gram quantities of plutonium.

3.1. The co-operation is initiated

During the spring and autumn of 1948, a close collaboration began to develop between FOA and AE. The idea was to co-ordinate the relatively scarce research resources that existed in Sweden. By and large, the co-operation at that time was about to plan for the future research, which had not yet been started in concrete terms. In fact, it is not correct to talk about an operating research and development activity at AE before 1950.[65]

The heads of departments 1 and 2 at FOA worked out a common basis that would be used in the negotiations with AE about future work at the beginning of 1949. The starting point for FOA was that collaboration should be aimed at the design and effect of nuclear weapons, regardless of whether or not the government and parliament decided on production. The basis states that, as well as such research providing opportunities for protection against nuclear weapons, it could also yield knowledge that could be used in civilian nuclear energy development.[66]

AE was in principle of the same opinion as FOA on the question of how collaboration between them should develop. For example, it was decided that FOA would hand over to AE research results and apparatus that could be used for the extraction of uranium. FOA had already conducted such a research activity since 1945.[67]

One of AE's first and important tasks was to get uranium production started. The low-content shales at Kvarntorp, which contained uranium, should be utilised for this purpose. It was considered that this extraction process could be done in close proximity to the oil extraction from the shales that was already taking place. An outline agreement had already been drawn up with Svenska Skifferolje AB concerning prospecting for and extraction of uranium at the plant at Kvarntorp.

A pilot plant for the extraction of kolm-type shales had, in fact, already been built at FOA and it was transferred to AE in the end of the 1940's in connection with a delivery of research results and apparatus.[68] The pilot plant had been set up in a factory at Vinterviken outside Stockholm. The plan was to build a larger extraction plant later, on the basis of the results obtained.[69]

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64 Forssberg, Olof, *Svensk kärnvapenforskning 1945-1972*, Stockholm 1987.

65 Interview with Bengt Pershagen, 5 October 2001.

66 Swedish National Defence Research Institute, Secretariat, Outgoing documents 1949 B IV, Volume 5, H 37:1 (appendix).

67 Interview with Professor Emeritus Jan Rydberg, 8 November 2001.

68 Idem.

69 Swedish National Defence Research Institute, 13 June 1949, "Redogörelse över verksamheten inom Aktiebolaget Atomenergi under 1948 och program för bolagets fortsatta arbete", H 4012-2091.

In addition, AE had initiated negotiations with Svenska Grafitaktiebolaget in Trollhättan in order to set up a pilot production of graphite. The material graphite was eventually planned to be used as reflector material in a heavy water reactor. A testing deliverance had been done with satisfying results, and an order for a further 9-10 tonnes would probably be carried out in the close future, according to a report from February 1949.[70]

Finally, on 28 December 1949 a more extensive collaboration agreement was signed for continued research and development work between FOA and AE. In general terms, the agreement meant that FOA would conduct research of importance for the defence of Sweden whilst AE would conduct research into the use of nuclear energy for industrial purposes. The parties agreed to conduct their work in "close and confidential collaboration".[71] FOA would give AE its research results as far as possible without conflict with military secrecy. AE undertook to keep FOA informed of the experience gained and the research results achieved in their own activity. In a serious military situation, AE would make its resources available to FOA. Both would carry out mutual research assignments for payment. Part of FOA's research into the civilian use of nuclear energy would be transferred to AE. Accordingly, some of FOA's physicists and chemists were also hired by AE, as was equipment that was thought to be more useful in the newly formed company. [72]

In fact, a majority of the nuclear physicists at FOA was hired by AE in July of 1950.[73]

The government approved the agreement on 22 September 1950.[74]

It is worth mentioning that it was not only a one way process in terms of FOA requesting AE for certain research tasks. For instance, FOA conducted several consultant tasks for AE at the end of the 1940's, mainly concerning uranium production from shales.[75]

In general terms, FOA should be responsible for the overall nuclear weapons research. For this reason, FOA was in charge of the construction of the nuclear device and the studies of its effects.

Additionally, AE should deliver basic information of a possible production of weapons-grade plutonium and investigate the possibilities of production or procurement of inspection-free heavy water (i. e without inspections by the supplying country). AE should also build a reprocessing plant and manufacture fuel elements to be used in the reactors for a production of weapons-grade plutonium.

It is important to stress that AE intended to perform this even though Sweden decided *not* to manufacture nuclear weapons (except that the required plutonium was not to be of weapons-grade quality). The basic technique of producing plutonium is the same for both military and civilian use. The plutonium to be used in a nuclear weapons device has to be of special quality, in practical terms, almost only plutonium 239.[76] In order to

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70 "Diskussionsunderlag vid överläggning med Överdirektör Björkeson och Professor Ljunggren den 26 februari 1949", by Sigurd Nauckhoff, 26 February 1949, H 37:1. FOA.

71 "Överenskommelse", H 129, 30 October 1950, FOA.

72 Olof Forssberg's study (basis), p 18.

73 Interview with Bengt Pershagen, 5 October 2001.

74 Olof Forssberg's study (basis), p 18.

75 Interview with Professor Emeritus Jan Rydberg, 8 November 2001. Olof Forssbergs study (Basis), pp. 15-17.

76 About the practical implications for different so-called "Direct-usable Fissile Materials", see Maerli, Morten Bremer, "Managing Excess Nuclear materials in Russia", pp. 49-51, in *Nuclear Weapons into*

produce plutonium of weapons-grade quality, special arrangements such as on-load refueling to allow low burn up should be in place.

Furthermore, it is important to emphasise that both FOA and AE conducted plutonium research. The reason why FOA conducted this research was that the plutonium had to be in metallic form in order to be used in a nuclear weapons device. Therefore, FOA carried out research with the purpose of producing metallic plutonium. Simultaneously, AE developed methods to separate plutonium from uranium (reprocessing) in order to be used as fuels in the reactors (plutonium recycling). This procedure would imply a better use of the natural uranium.

Who should then manufacture the nuclear weapon itself, if Sweden had chosen to realise these plans? The project did not go that far, but for example, FOA recommended in the main study of 1957 that a more flexible organisation should be created than is common in the state sectors,[77] (see further chapter 4.1).

3.2. The Plans to Manufacture Nuclear Weapons are investigated

The first FOA-study of a Swedish manufacture of nuclear weapons was finished as early as 1948. The study assumed that plutonium was preferable to U-235 in the actual nuclear explosive devices.

If plutonium production as envisaged was to succeed at all, a large reactor would have to be built, the report further maintains. A prerequisite for such a complex scheme was that an experimental reactor would first be operated to find out how best to design the main reactor (it might even be necessary to build an intermediate experimental reactor in order for a project of this magnitude to succeed, according to the authors of the report).[78]

The study concludes that it would take about eight years, probably longer, to produce a nuclear weapon.[79]

It would take additional eight years before the next main FOA-study would be ready. The assignment from FOA had gone to associate professor Sigvard Eklund who had formerly been working in the physics department at FOA but, since 1950 had been head of research at AB Atomenergi.[80]

The 1948 study had assumed that plutonium was preferable to U-235 in the actual nuclear explosive devices. This was still the case. However, the results of recent year's research indicated that heavy water was preferable to graphite as a moderator.

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the 21st Century. Current Trends and Future Prospects. (Ed. Joachim Krause and Andreas Wenger). Studies of Contemporary History and Security Policy, vol 8, 2001.

77 "Utredning beträffande underlag för konstruktion av atomladdningar", 21 August 1957, Swedish National Defence Research Institute, H 4065-2092. About these manufacture plans, see Agrell 2002, pp. 156-159.

78 Swedish National Defence Research Institute, Outgoing documents 1948 B IV, Volume 4, H 35:2.

79 It was estimated that it would take two years to set up the mining and production operation, five to ten years to produce 500 to 1000 tonnes of uranium at a production capacity of 100 tonnes per year, and one year to produce bombs ready for use.

80 Swedish National Defence Research Institute, "Preliminär utredning av betingelserna för framställning av atombomber i Sverige", 1953-03-05 H 4011-2092.

Fuel Cycle with Production of Weapons-grade Plutonium in a Natural Uranium Reactor

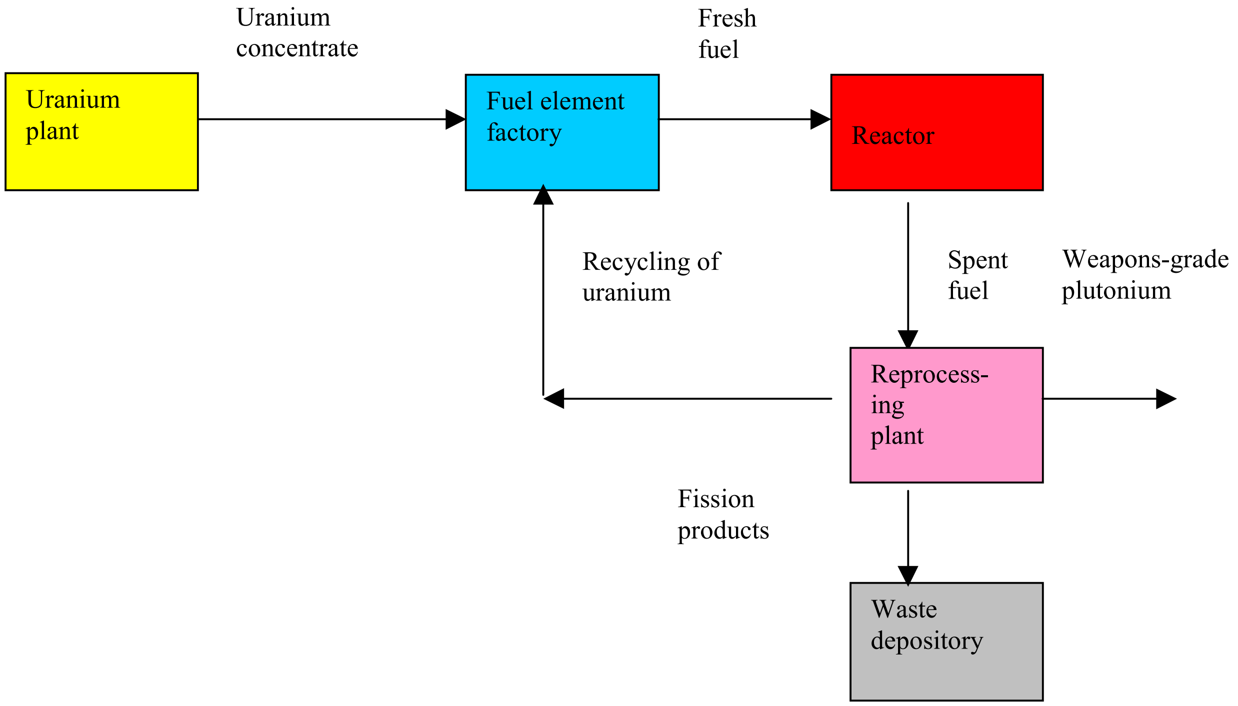

Figure 1: This figure describes in a simplified form how the co-operation between FOA and AE was planned in a possible manufacture of nuclear weapons. AE was responsible for the production of uranium and fuel elements, the procurement of inspection-free heavy water and the design of reactors and a reprocessing plant in order to enable a production of weapons-grade plutonium. AE's responsibility extended to the point where weapons-grade plutonium was produced. Further steps, until the nuclear weapons were manufactured, was FOA's responsibility.

The production of 3-5 nuclear explosive devices per year required a reactor capacity of 150 MW, see Alternative 1 below, which was lower than the figure arrived at in the 1948 study. In this case two reactors would have to be built, since, as far as was known, no reactor moderated with heavy water with a higher rating than 75 MW had been built anywhere in the world. On the other hand, if 1-3 nuclear explosive devices were considered sufficient, a 75 MW reactor should be enough, the study concluded.

Alternative	Uranium (tonnes)	Heavy water (tonnes)	Graphite (tonnes)	Annual consumption **uranium** (tonnes)
1 (one reactor)				
Min	5	10	200	5
Max	20	40	400	5
2 (two reactors)				
Min	10	20	400	10
Max	40	80	800	10

Table 1: The alternatives proposed in the studies and the required amounts of uranium, heavy water and graphite. Source: Swedish National Defence Research Institute (FOA), "Preliminär utredning av betingelserna för framställning av atombomber i Sverige", 1953-03-05, H 4011-2092.

The intention was to extract the uranium in Sweden, since importing uranium from abroad was regarded as impossible. AE had experimental production running and expected soon to start factory production of five tonnes of uranium per year. It would certainly be possible to double the production after a few years, according to the report. Converting, raw uranium concentrate into metallic uranium was a technically demanding process.

Heavy water could beneficially be imported from Norway, the head of research at AE continued. Norwegian production was 7 tonnes per year, but it was estimated that this could be increased to 15 tonnes.

This meant that the amount required for Alternative 1 could be met from Norway in three years and the maximum amount in Alternative 2 in six years.

All this assumed that Sweden would be able to import Norwegian heavy water. However, there was one problem with this arrangement, Eklund continued. There were no guarantees that Norway would meet these Swedish requirements. For this reason Sweden ought to consider whether the best option might not be to bank on domestic production. On the other hand this would probably lead to a certain amount of delay and higher costs, Eklund concluded.[81]

A specially chosen group made up only of certain representatives of AK and AE was appointed to comment on Eklund's report.

The appointees delivered several comments, the most important for the purpose of this report concerns the choice of nuclear material. They were not entirely in agreement with Eklund as regards the choice of nuclear material. If a larger scale production were to take place and the time factor was not crucial, it was not at all obvious that plutonium

[81] It is interesting to note that Israel was considering the same approach. During the 1950's, Norway and Israel were negotiating for the sale of heavy water for the Israeli Dimona reactor. The agreement signed in 1959 meant that at big step had been taken towards producing Israeli nuclear weapons. See Cohen, Avner, *Israel and the Bomb,* pp.1 33-34, 60-62, 83, 87.

would be the best alternative. The report concluded that a study should investigate the matter.[82]

In March of 1953 it was decided, that such an investigation should be made. AE was the purchaser while Svenska Ångpanneföreningen should do the main part of the cost calculations to build a gas diffusion plant for a production of U-235. The purpose of the investigation was to find out whether plutonium was a better alternative than U-235 in a nuclear device.[83]

In the same year, the extraction plant for uranium went into operation.[84] Another significant activity was initiated in the beginning of 1950's, the experiments to separate plutonium from uranium which was important for the civilian fuel cycle. For this purpose, some kilograms of irradiated uranium oxide (UO_2) had been procured from France. A research programme was organised in order to test the successfully used methods from the United States, Great Britain, Canada, and France.[85]

3.3. A Co-operation with impediments

In April 1955, FOA sent AE a proposal for more intimate co-operation between the two parties in the nuclear chemistry field in order to avoid duplication of work. In the view of the country's limited resources in nuclear chemistry research, such a co-operation would be desirable, Jan Rydberg and Carl-Johan Clemedson wrote in the letter. As a background to the proposal, a working programme of separation of plutonium at FOA 1 was attached, as well as a scheme over the planned test station at Ursvik outside Stockholm. The proposal contained twelve points, which dealt with the future plutonium research in Sweden. Furthermore, it was suggested that a contact group should be created with representatives from both parties in order to make a more efficient co-operation possible.[86]

The proposal by Rydberg and Clemedson was not favourably received. The conducted interviews and the analysis of the documents indicate that the suggested intimate climate of co-operation was never created. Certainly, a rewarding co-operation on several issues was undertaken, but it is more correct to say that AE made the work when FOA demanded it, but no more than that.

There were several reasons for this. Firstly, research concerning nuclear weapons was a very secret activity. The only individuals who knew about the work in detail were the high level managers in AE. For secrecy reasons, efforts were made to avoid the knowledge becoming proliferated.

Secondly, there was also competition between FOA and AE. The involved individuals at FOA were first and foremost researchers who dealt with nuclear weapons

[82] Olof Forssberg's study (basis), p 26 et seq. The authors of the joint communication were the chairman of AK, county governor Malte Jacobsson, the managing director of AE, Harry Brynielsson and the secretary of AK, Gösta Funke. Other appointees were: professors Hannes Alfvén, Torsten Gustafson and The Svedberg, director Erik Bengtson and colonel Torsten Schmidt, see Jonter 2001, p. 33.

[83] Olof Forssberg's study (basis), p. 33.

[84] "Aktiebolaget Atomenergi, årsredovisning 1953".

[85] "Pm angående arbeten med plutonium inom sektionen för kärnkemi", av Erik Haeffner 13 februari 1955, H-pärm II, 171-260, Direktionsarkivet, Studsvik AB.

[86] Skrivelse från FOA till AE, 28 April 1955, H-pärm I, 1-70, Direktionsarkivet (DA).

constructions from a principle point of view. The main purpose was, of course, to perform technical studies for a manufacture of nuclear weapons. Most of the employees at AE were engineers whose prime goal was to develop the nuclear energy in terms of electricity and heating. These different perspectives did not seldom conflict.

A significant example is that the two parties did not know how far each organisation had reached in order to produce plutonium up to the mid-1950's. AE succeeded in separating plutonium from uranium in 1955 with a method developed in 1952. It was the manager for the chemistry department, Erik Haeffner and his colleague Thor-Ulf Sjöborg who separated the first visible amount of plutonium (1,5 mg). The source material was a l,5 litre solution of 0,5 kg active uranium.[87]

Erik Haeffner maintained in an interview that plutonium in very small amounts was actually produced as early as 1952. AE had borrowed uranium oxide from France where it had been irradiated in the country's first reactor. However, it was a different story to produce plutonium in laboratory scale for further process studies compared to developing industrial extraction method which was done in 1955.[88]

At a seminar at FOA in November 1993, Jan Rydberg stated that he was involved in FOA's first successful tests to separate plutonium into micro amounts. According to Rydberg they took place in 1954. Rydberg had borrowed irradiated uranium pellets from the Norwegian reactor JEEP in Kjeller, which could be used in the separation tests. It was the engineer Birgitta Olausson who made the separation in a laboratory test, according to the seminar report.[89]

Irrespective of FOA or AE produced Sweden's first amounts of plutonium; this episode shows how far from intimate co-operation the two parties were even until the mid-1950's. However, the co-operation became closer in the following years.

3.4 The nuclear weapons research takes a step forward

At the end of November 1955, FOA's third main study was complete. The study, which was made by Torsten Magnusson, arrived at the conclusion that plutonium was a better alternative than U-235 in the nuclear device. First, reactors could be built which could be used for both nuclear weapons manufacture and energy production. Such a solution was considered to be financially more beneficial. Second, Sweden's scarce personnel resources in the nuclear energy field could be used more efficiently. Third, it was also possible to make progress with civilian energy development, even if Sweden decided *not* to manufacture nuclear weapons.[90]

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[87] "Rapport angående Pu-arbeten inom sektionen F. Läget den 1.6.1955", by Haeffner, 2 June 1955. H-pärm I, 1-70, Direktionsarkivet (DA).

[88] Interview with Erik Haeffner, 29 September and 22 November 2001.

[89] Fröman, Anders, *FOA och kärnvapen – dokumentation från seminarium 16 november 1993,* FOA VET om försvarsforskning 1995, p. 36. Jan Rydberg reiterated this in the interview in Gothenburg, 8 November 2001.

[90] "Utredning av betingelserna för framställning av atomvapen i Sverige", by Torsten Magnusson, 25 November 1955, Swedish National Defence Research Institute, 87-H 163:1-21A.

AE's investigations of the technical and economical conditions of a manufacture of U-235 by the gas diffusion method had shown that this solution would imply higher production costs.[91]

The 1955 study establishes that it was technically possible from then on to produce a Swedish nuclear weapon, given access to plutonium. Technically the plutonium question had been solved – although it would be modified with time. It was equally clear to FOA what steps would have to be taken in a production process and approximately what the project as a whole would cost in the form of capital and scientific and technical expertise.[92]

3.5. Summary: 1947-1955

A co-operation emerged between AE and FOA during 1948, which was formalised in an agreement in December 1949. In general terms, the agreement meant that the parties should share their research results and to assist each other with investigation activities within the framework of nuclear weapons research. FOA should be responsible for this nuclear weapons research, which included the entire design work as well as research in order to produce metallic plutonium. AE undertook to be in charge of the design of reactors and a reprocessing plant, and the manufacture of uranium and plutonium. These tasks were on AE's agenda even if Sweden decided not to acquire nuclear weapons (except that the plutonium did not have to be of weapons-grade quality).

AE co-operated with Svenska Skifferolje AB in the area of uranium. A uranium production plant was built in Kvarntorp in 1953. In the same year, AE initiated plutonium research. Several methods were tested for manufacture of plutonium, and the so-called redox method became the principal line in these activities. In 1954, AE investigated the cost of constructing a gas diffusion plant for a production of U-235. The results should form the basis for the FOA study of 1955.

In July 1954, Sweden's first reactor, R 1, was started for research activities.

The FOA study of 1955 concluded that plutonium was preferable to U-235 in the nuclear devices. Additionally, the study maintained that the plutonium production would take part within the framework of the civilian nuclear energy development.

It is not correct to characterise the co-operation between FOA and AE as close and intimate up to 1955. The initiatives to create a more efficient climate of co-operation between the two parties failed. Certainly AE made several studies for FOA, but these were not made in a spirit of close co-operation. On the whole, it is more correct to say that AE dealt with the civilian nuclear energy development, and the experiences gained in these activities could be used in order to give basic information for a manufacture of nuclear weapons.

A fuel element factory had been built in Stockholm whose first task was to produce metallic uranium fuel element. The nuclear chemistry research bore fruit and, in 1955 AE could produce its first amounts of plutonium in milligram quantities on a pilot plant scale.

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91 About FOA study of 1955, see Jonter 2001, pp. 37-38.

92 Jonter 2001, p. 47. See also Olof Forssbergs study (basis), pp. 50-51. Studies of a manufacture of U-235, see "Gasdiffusionsanläggning", 11 February 1955, by Vilhelm Nordström, H-pärm II, 171-260, Direktionsarkivet (DA).

After seven years of research activities, an extensive competence had been created: a pilot plant for uranium extraction, a research reactor and a fuel element factory. In addition, a cadre of researchers and technicians had been formed.

The prerequisites for a Swedish nuclear energy programme had been established, and consequently the first steps toward a possible nuclear weapons production were taken.

4. The period 1956-1959

In 1956, the Swedish parliament took the decision to initiate "the Swedish way". At AE the research activities continued on a broad scale in the light of the research information, which became available after the Geneva conference. For instance, a Van de Graaff accelerator was purchased in the United States in 1956 (the accelerator was, however, delivered a couple of years later), which was used in studies of nuclear reactions with fast neutrons. The Van de Graaff accelerator could also be used by FOA in order to produce data on how nuclear reactions develop in a nuclear device. For this reason, an agreement was entered upon between the two parties in which FOA should bear 1/5 of the costs.[93]

A pilot plant for separation of plutonium and fissile products from irradiated uranium was nearly finished completed at Studsvik in 1956. The plant was partly taken into operation for experimental work. A co-operation with the Norwegian-Dutch organisation JENER had been initiated in order to co-ordinate the experimental work with the extraction of plutonium and other fissile materials.

Moreover, a new method of separating plutonium from uranium (without using reduction compounds) had been developed and tested on a laboratory scale.[94]

In 1956, a co-operation was initiated with the Swedish ironworks Kohlswa Jernverk with the purpose of manufacturing sintered uranium dioxide fuel of suitable. Two years later ASEA was also involved in this activity.[95] AE was, however, responsible for the terminating centerless grinding operation of uranium dioxide pellets to produce the requested precise dimensions.[96]

4.1. AE's first investigation on choice of reactor for a production of weapons-grade plutonium

In May 1957, the Supreme Commander gave FOA the task of conducting a new study of the possibilities of producing nuclear weapons. The study should be made in two stages. The aim of the first stage was to arrive at a more general and approximate estimates of possible nuclear weapons manufacture. The plan was that this would be completed before the end of the year.

The second stage would contain more detailed results and design proposals in principle. AE should study the reactor needs and investigate the production of weapons-grade plutonium.[97]

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93 "Aktiebolaget Atomenergi. Årsredovisning för 1956". About the agreement between FOA and AE, see "Anteckningar från överläggningar med FOA och AB Atomenergi den 4 oktober 1960"; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

94 "Aktiebolaget Atomenergi. Årsredovisning för 1956".

95 PM by Hydén 24 February 1965, "Bränsleutredningen 1965", VD-arkivet, CA, Studsvik AB.

96 Interview with Hilding Mogard, 16 October 2001.

97 Jonter 2001, pp. 40-41.

In 1957, the research to develop suitable fuel elements for the Ågesta reactor was intensified. AE's fuel element factory at Liljeholmsvägen in Stockholm was the first in Europe to use the corrosion hesitant Zircaloy for canning uranium oxide. Zircaloy is capable of enduring temperatures up to 300-350° C.[98]

In the same year, the experimental work at the pilot plant for separation of plutonium continued. Among other activities, studies of a remote controlled apparatus, which should be used for reprocessing of the reactor fuel, were undertaken.

Furthermore, at the department of chemistry several studies were performed during 1957. For instance, basic investigations were conducted with regard to developing methods to produce heavy water and U-235.[99]

At the turn of 1957, a co-operation was discussed in order to carry out a study aimed at planning and conducting criticality experiments, which were important in achieving effective nuclear explosive device.[100]

In a written communication, dated 16 May 1958, FOA asked for permission to conduct these criticality experiments. AE would be in charge of the experiments, which would also include equipment and service arrangements.

The investigation should be carried out by a work group consisting of three representatives from AE respectively FOA.[101]

There was never any need to do these experiments, since the 1958 Geneva conference provided the required information.[102] In addition, when the IBM 7090 computer, which was considered to be the most powerful in northern Europe at the time, went into service at FOA, the work of calculation became much easier.[103]

In December 1958, the group came to the conclusion that only complementary measurements with plutonium and tests in a fast reactor at low output, a so called zero energy output reactor, was needed in the light of the new knowledge.[104]

In January 1958, AE completed a partial report on the choice of reactors for a Swedish nuclear weapons programme. In the report, AE favoured a separate reactor for the production of plutonium for weapons use only. Such a solution would be technically and economically preferable compared to a reactor for both civilian and military use. There were many reasons for this, according to AE. One of the main ones was that a dual-purpose reactor would have to undergo frequent fuel changes, which was a complication. In addition, such a reactor would give rise to a number of technical and scientific problems in the form of lower pressure and temperature levels.

A pure production reactor with an annual output of 40 kg of plutonium required 60-70 tonnes of uranium per year.

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98 Interview with Hilding Mogard, 16 October 2001.

99 "Aktiebolaget Atomenergi. Årsredovisning för 1957".

100 "P.M. rörande AE:s deltagande i visst utredningsarbete", 19 december 1957; "PM rörande visst utredningsarbete", 11 mars 1958.

101 Magnusson to Brynielsson, "Utredning betr. Kritikalitetsförsök", 17 May 1958, "Hemliga handlingar" DA, Studsvik AB, H 4034-2092 FOA.

102 Fröman 1993, pp. 58, 105; Forssberg's study (basis), pp. 91, 116.

103 Fröman 1993, p. 76.

104 "Rapport från FOA/AE-gruppen beträffande kritikalitetsförsök", 17 December 1958, H 4000-2091, FOA-arkivet.

Moreover, 40 tonnes of heavy water would be needed, AE stated in the report. It was estimated that actual plutonium production could start in 1965.[105]

4.2. AE's plans to build a reprocessing plant

To generate plutonium in reactors is one matter. A quite different matter is to produce plutonium for recycling in the planned civilian nuclear power stations, or for use in nuclear weapons. To enable this, the plutonium has to be extracted from fission products and the depleted uranium. This requires a reprocessing plant, which would be costly and time-consuming to build.

In the mid-1950's, AE made plans for the construction of a pilot reprocessing plant at Studsvik. For fiscal year 1958/59, financial funds were allowed for such a construction plan.[106] These plans were, however, abandoned since the Studsvik area was not considered as an appropriate area for an reprocessing plant.[107]

Instead a co-operation was initiated with the Norwegian nuclear energy research station at Kjeller in order to produce basic information of how to build a reprocessing plant.[108]

In March 1958, an agreement was entered upon with the Norwegian "Institutt for Atomenergi" to fulfil this purpose.[109]

In the same month, a working party was formed with representatives of both FOA and AE in order to deal with the plutonium issue.[110]

A plutonium laboratory would be built at FOA's area at Ursvik and finished in January of the following year. A number of closed protection boxes had been built to be used when working with the toxic plutonium substances.

In addition, a special vacuum furnace had been tested to allow laboratory-scale casting of plutonium metal. AE would be able to use the laboratory until the metallurgical laboratory at Studsvik was completed.[111]

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105 Olof Forssberg's study (basis), p. 87 et seq.

106 Svenke, Erik, "Den svenska atombränsleförsörjningen", p. 63. Article in *Det svenska atomarbetet. Nuläget och framtidsperspektiv*. Stockholm 1958.

107 "Anteckningar från sammanträde med representanter för FOA den 9 februari 1960"; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

108 Interview with Erik Haeffner, 2 October and November 2001.

109 "Styrelse PM om plutoniumarbetet", 19 January 1962; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB. See also Njølstad, Olav, Strålande forskning. Institutt for energiteknikk 1948-1988. Tano Aschehoug 1999.

110 Olof Forssberg's study (basis), p. 88

111 "Berättelse över verksamheten vid Försvarets forskningsanstalt under budgetåret 1958/59, Swedish National Defence Research Institute, H 3457/51.

4.3. AE's second investigation concerning the choice of a reactor for weapons-grade plutonium

On 1 July 1958, AE issued its second report 2 concerning the choice of reactors for a production of plutonium of weapons-grade quality. The report deals with the manufacturing costs for weapons-grade plutonium when fuel elements canned in aluminium are used. Additionally, cost estimates were made for the building of a reactor and a reprocessing plant, as well as a manufacture of metallic plutonium and to dispose of the waste.[112]

In the same month, FOA presented two important programmes regarding the future of the Swedish nuclear weapons research. The programmes had been prepared in the light of the research now having reached a stage where a decision on the issues could be taken whether Sweden should acquire nuclear weapons or not.

AE's study concerning the choice of reactors for a production of weapons-grade plutonium was the basis for parts of the programmes.

One of these, known as the device programme, was concerned with the production of nuclear weapons if parliament said yes to such a manufacture; the other, the protection programme, was intended to be used if parliament said no. The protection programme was focused on the work of developing an efficient protection against nuclear weapons attacks. In this research, experiments with plutonium were included, but the used material did not need to be of weapons-grade quality.[113]

The government took the line of the defence bill drafting committee and maintained that Sweden was not ready to make a decision on the nuclear weapons issue. In the bill, which was approved in July 1958, it was proposed that FOA should be given more funds to conduct protection research. In other words, the protection programme was approved and the device programme was rejected. The conducted research was not allowed to carry out studies aimed directly at the manufacture of nuclear weapons.

In the debate that followed, it was primarily the international developments of nuclear weapons that was put forward as an argument for postponement. The underlying idea was that Sweden should study the security policy situation in the years ahead and conduct protection research at the same time. This would mean that Sweden would not lose much time if the international situation developed in a more threatening direction and the future security policy analysis favoured Swedish nuclear weapons.[114]

From the point of view of the research institutes, the interpretation of the decision taken by parliament was far too narrow. If FOA were really to be able to make the necessary preparations within the consideration period allowed, the concept would have to be broadened.[115]

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112 "Rapport över Etapp 2:1 av utredningsuppdrag beträffande reaktorer för produktion av vapenkvalitet", 1 July 1958. The report is still under secrecy classification. About the report in general, see Olof Forssberg study (basis) p. 91.

113 Jonter 2001, pp. 42-44.

114 For a detailed discussion and analysis of the various lines of argument in the debate that followed, see Ahlmark, Per, *Den svenska atomvapendebatten*, Stockholm 1965.

115 For example, parliament rejected the Swedish National Defence Research Institute's request for fiscal year 1960/61 to be allowed to produce basic information for a more secure technical and economic basis for nuclear weapons designs. However, the Minister of Defence stated in the finance bill that it

In the previous study, the protection research is analysed and the conclusion is that FOA went further in its efforts to make technical and economical estimates than the defined protection programme allowed.[116]

4.4. New investigations are planned

A problem, which occupied AE during 1959, was how the Ågesta reactor could be inspection-free which was a basic condition if the facility were to be used for a production of weapons-grade plutonium. Certainly AE had some amounts of uranium and heavy water at its disposal which could guarantee an operation of the reactor for some time. However, the amounts were not sufficient. The views on how long these amounts should last were divided within the company.

In a report from February 1959, the conclusion was made that the scarce amounts of uranium and heavy water would only last a couple of years for the Ågesta facility. To supply the Swedish need of inspection-free heavy water an additional 70.5 tonnes had to be procured in 1963. For the time being, the report concluded, there were 36 tonnes of heavy water in the country (10 tonnes from Norway[117] and 26 tonnes inspection-free that had been purchased in the United States[118]).

Although it was possible to import from Norway, domestic production needed to be investigated. ASEA was contracted to undertake an investigation for such a production.[119] This investigation should be concluded in October 1960, which meant that a pilot plant should be ready by then as well.[120]

In September 1959 FOA asked AE to investigate the technical and economic preconditions for the production weapons-grade plutonium.

Under this assignment, the plutonium produced would be based on Swedish uranium and inspection-free heavy water.[121]

In a memorandum by AE, the preconditions for the assignment were discussed. The purpose of the new investigation, according to the memorandum, was to make a comparison between the planned reactor facilities within the civilian nuclear energy programme (which should be used as dual purpose reactors to enable production of

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was his intention to submit to the government a proposal for extended research into protection, Forssberg 1987, p. 38 et seq.

116 Jonter 2001, pp. 42-43.

117 "Beträffande D 2 0-anläggning", 19 August 1959; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

118 Jonter 1999, p. 25.

119 "Beträffande D 2 0-anläggning", 19 August 1959; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

120 "Förslag till arbetsprogram och budget för det fortsatta D 2 0-arbetet"; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

121 In November, AE replied to the Swedish National Defence Research Institute and described how and in what order the investigation work should be done, 20 November 1959, H 4067-2092. Swedish National Defence Research Institute accepted AE's proposed approach, 26 November 1959, H 4071-2092.

plutonium for both civilian and military use) and a reactor solution for only weapons-grade plutonium. In the first task, the technical as well as the economic consequences for a dual purpose production should be investigated:

"A first task is therefore to bring up to date the previous investigation of 1 July 1958 (which implied producing plutonium with a maximal content of 2 % Pu-240, my remark, TJ) and to complement it with an alternative of a maximal content of 3.5 % Pu-240."[122]

The reactor output would be 125 MW, which would enable an annual production of plutonium of 40 kg.[123]

In November 1959, a work plan was made where the preconditions of the different alternatives were described, and when the partial studies were estimated to be completed.[124] FOA accepted the proposal and indicated that work had to be undertaken as soon as possible.[125]

4.5. Summary: 1956-1959

As a consequence of Parliament's decision in 1956 to initiate the Swedish nuclear energy programme, research became intensified at AE. The planning of the next reactor R 2, which was to be operable in 1959, started. New devices were procured and new laboratories were put into operation. For instance, a Van de Graaff accelerator was purchased in the United States in 1956 which was used in studies of nuclear reactions with fast neutrons. The Van de Graaff accelerator could also be used by FOA in order to produce data on how nuclear reactions proliferate in a nuclear device. For this reason, FOA should bear 1/5 of the costs.

Mainly speaking, the co-operation with FOA increased during this period. The most important assignment AE made for FOA was to develop basic information of design and operation of reactors used for a weapons-grade production. The basic information should form the basis of the FOA study of 1957, which dealt with a possible manufacture of nuclear weapons.

In the conducted studies at AE, it was shown that a pure production reactor (a reactor only used for a production of weapons-grade plutonium) would be the best alternative. Both economical and technical reasons favoured this alternative. The problem with this solution was that the dual-purpose alternative would then be abandoned.

In 1958, a working group was created with representatives from both FOA and AE in order to investigate the forms of plutonium production. Another important assignment for AE was to plan for the criticality experiments together with FOA, which had been initiated in 1957. There was never any need to do these experiments at such as a proportion as was planned, since the 1958 Geneva conference provided the required information.

AE co-operated with other organisations and companies during this period. For example, a project was initiated with the Norwegian research station JENER to produce

122 "BETR. Utredningsuppdrag från FOA", 19 September 1959, "Hemliga handlingar", DA.

123 Ibid.

124 "Koncept till brev till FOA", 11 November 1959, "Hemliga handlingar", DA.

125 Olof Forssberg's study (basis), p. 103.

basic information for building a reprocessing plant. In addition, a method (The Silex Process) to separate plutonium was to be tested.[126]

ASEA investigated the possibilities for a domestic production of heavy water at the request of AE. ASEA together with Kohlswa Jernverk was also involved in the sintering of uranium pellets for the Ågesta reactor.

[126] Letter from Åke Hultgren, 13 December 2001.

5. The period 1960-1968

At the beginning of 1960, the heavy water issue was discussed internally at AE. In the previous year, ASEA had started an experimental work for domestic production. Even though the results were preliminary, some conclusions could be drawn.

Firstly, some heavy water had to be imported, even if a domestic production was started. For the Ågesta and Marviken facilities about 250 tonnes had to be procured during the 1960's.

Secondly, a heavy water plant had to be built in Kvarntorp unless inspection-free heavy water could be imported from Norway at reasonable costs.

Thirdly, it was conceivable that the costs for a domestic production would rise if the water quality at the Kvarntorp plant was not acceptable. If this was the case, the plant had to be located in a place where the water quality was better which meant higher production costs.[127]

5.1. AE's third and fourth investigation concerning the choice of a reactor for weapons-grade plutonium

During 1960, AE made three reports for FOA regarding the production of weapons-grade plutonium. The reports were made in view of the request from September 1959, which was discussed in the former chapter. The investigations give detailed technical information including cost estimates and personnel requirements.[128]

In the report, which deals with the preconditions for a production of weapons-grade plutonium, two alternatives are compared. The costs would be lower if a reactor for weapons-grade production was used instead of a dual-purpose reactor, the report concluded.

Moreover, if a plutonium production were to be arranged with frequent fuel changes in a heat-producing reactor, the heating costs would even be higher than if a conventional system with oil was used.[129]

In an appendix to the last AE report 3, a new cost calculation was made with changed conditions for a heat-producing reactor. However, not even such an arrangement would lead to competitive costs.

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[127] "Beträffande D2O-försörjning genom import eller inhemsk produktion", 9 January 1960; "Anteckningar från sammanträde med representanter för FOA den 9 februari 1960"; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

[128] "Rapport över Etapp III av utredningsuppdrag beträffande reaktorer för produktion av plutonium av vapenkvalitet", 28 April 1960; "Tillägg till rapport över Etapp III av utredningsuppdrag beträffande reaktorer för produktion av plutonium av vapenkvalitet", 17 November 1960; "En rapport över etapp IV beträffande val av reaktor för plutoniumtillverkning av vapenkvalitet". The reports are still under secrecy classification. The following report is an open source: "Svensk plutoniumfabrik under 1960-talet", 20 June 1960, H 4162-434. About the reports in general, see Olof Forssbergs study (basis), p. 116.

[129] Olof Forssberg's study (basis), p. 116.

In fourth report a new cost calculation was made for the production of only weapons-grade plutonium. The method used was the same as in partial study 3. The conclusion was that the costs would be 25-30 % higher than the partial study 2 of July 1958 had shown. It was regarded that the main reason for this was the increased reactor costs.[130]

In October 1960, representatives from AE and FOA discussed the continued co-operation at meeting. The different alternatives for a possible nuclear weapons manufacture were under consideration. Regarding the plans for heavy water production, the managing director for AE, Harry Brynielsson, mentioned that the experimental work at Kvarntorp would soon be completed. The cost estimate was rather precise in the light of the results from the pilot plant and from information received from the United States.[131]

For what reason should a heavy water plant be used? Frankly speaking, it was possible to import heavy water from the United States if it was to be used only for civilian and peaceful purposes. In addition, this alternative would imply much lower costs compared to the production of heavy water in Sweden or import from Norway.

If a plant was to be built it was only for the use of manufacture nuclear weapons. Or, as the manager of AE expressed it: "A civilian need for such plant does not exist for the time being".[132]

Different reactor alternatives were discussed. In this context, the possibility of building a reactor for component testing which also could be used for the production of plutonium of weapons-grade quality was discussed. This project proposal was named RX.[133]

RX implied a reactor, which allowed the testing of "a cut out part" of a power reactor core. Additionally, the RX reactor should have a similar cooling system and data regarding temperature and pressure as a power reactor.[134]

Sigvard Eklund reported on the project at a meeting with FOA. The manager for the physics department at FOA, Torsten Magnusson, maintained that the Swedish national defence might bear some of the costs for such reactor for component development. From this point of view, it would be desirable if the reactor could start operation at the beginning of 1966.

At the same meeting, Erik Svenke reported on the cost calculations made for the construction of a reprocessing plant, which was to be used for both civilian and military purposes.

Brynielsson questioned the viewpoint that AE should bear the whole cost of 60 million crowns to build the plant. Torsten Magnusson objected that the Swedish national defence would hardly pay 60 million crowns even if the facility could be of use for the

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[130] Ibid.

[131] "Anteckningar från överläggningar mellan FOA och AB Atomenergi den 4 oktober 1960"; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

[132] Ibid.

[133] Ibid.

[134] About the RX reactor, see Brynielsson, p. 215.

protection research. However, he asserted, FOA could allocate funds for a pilot project.[135]

5.2. AE's fifth and sixth investigation concerning the choice of a reactor for weapons-grade plutonium

During 1961 AE had completed two investigations for FOA. The first report dealt with the preconditions for a production of plutonium of weapons-grade quality at Ågesta. The report concluded that such a production could be realised with fuels canned in either Zircaloy or aluminium. Furthermore, a comparison showed that the first alternative was the best in view of the reactor. On the other hand, this choice would lead to higher fuel and reprocessing costs. In the case of aluminium the circumstances were the opposite. In both cases the output would be 19 kg plutonium 239 per year.

In a letter of 13 April 1961, FOA extended the assignment for AE to include studying the preconditions for production of plutonium of weapons-grade quality at Marviken.

In September the same year, the report was completed with the title "Report on stage VI of investigation report concerning reactors for production of plutonium of weapons-grade quality". A rough estimate was made of the costs for production of plutonium and reprocessing.[136]

5.3. The plans for a reprocessing plant mature

Around 1960, AE had reached a level of knowledge for preparing a design proposal for a reprocessing plant. In June 1960, the head of the chemistry department, Erik Haeffner, presented a brief report entitled "Swedish plutonium factory in the 1960's".[137]

The report was a summary of the gained knowledge, partly in co-operation with the Norwegians in Kjeller, and partly from the building of Eurochemic's pilot plant in Mol, Belgium, for which research and development work had started in 1958. Eurochemic was a company created within the framework of the European nuclear energy co-operation in OEEC (later known as OECD).

The reprocessing plant at Mol was in operation during the period 1966 to 1974. AE was represented as a shareholder and looked after Swedish interests on the Eurochemic board and technical committee.[138]

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135 "Anteckningar från överläggningar mellan FOA och AB Atomenergi den 4 oktober 1960"; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

136 "Rapport över Etapp V av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet"; "Rapport över Etapp VI av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet". The reports are still under secrecy classification. About the reports in general, see Forssberg's study (basis) p. 122.

137 "Svensk plutoniumfabrik under 1960-talet. Kortfattad utredning", by Erik Haeffner, 20 June 1960, FOA H4162-434, FOA:s arkiv.

138 Hultgren, Åke, *Upparbetning av Ågestabränslet 1969*, p. 1. About the history of the plant, see Wolff, Jean-Marc, *Eurochemic (1956-1990): Thirty-five years of international co-operation in the field of nuclear engineering: the chemical processing of irradiated fuels and the management of radioactive wastes*. Paris: Nuclear Energy Agency, Organisation for Economic Co-operation and Development.

Erik Haeffner was manager at the Eurochemic company from 1958 to 1960. When he returned to AE, from where he was on loan to Eurochemic, the planning of a Swedish reprocessing plant was of highest priority.[139]

The planned Swedish plant should manage chemical reactor fuel from Ågesta, Marviken and the planned reactor experiment RX. Its purpose was to produce the end-product uranium oxide and plutonium in the form of oxide or metal. Through reprocessing, i.e removing fission products and the plutonium from the spent fuel, the plutonium can be recycled in the reactor.

A planning of a pilot project was estimated to take nine months and a personnel of 30 chemists and technicians. It was estimated to take about 2,5 years to build the factory including a personnel requirement of 90 persons. Where the reprocessing plant should be located had not yet been decided.[140]

The reprocessing plant in Mol was both a blessing and a scourge depending on how a Swedish manufacture of nuclear weapons was considered. The responsible individuals for the Swedish civilian nuclear energy development viewed the European co-operation in a positive way. In fact, the future facilities could be used for reprocessing of Swedish nuclear materials. In this context, the alternative to build a costly Swedish plant was not too attractive.[141]

In spite of the continued co-operation within the OEEC, AE took a step further in order to build a Swedish reprocessing plant. A more detailed preliminary study was made of a plant with the capacity to reprocess 250 kg uranium per day at an annual production of 500 tonnes of uranium fuel element. The preliminary study was estimated to be finished in April 1962.[142]

The previous plans to build a pilot plant at Studsvik were abandoned because it was considered impossible to extend the capacity within the existing limits. Investigations to find suitable areas for such a plant had already been initiated. The active chemical laboratory at Studsvik was designed to match the demands of a larger reprocessing facility.[143]

5.4. AE's seventh investigation concerning the choice of a reactor for weapons-grade plutonium

In the autumn of 1961, ASEA started to explore the possibilities of a production of weapons-grade plutonium at the Marviken reactor. At the end of January 1962, ASEA summarised the preliminary results in the view of the fact that the final design of the

139 Haeffner prepared the pilot project study for the reprocessing plant in Mol in 1957 as a basis for decision for the OECD. Interview with Erik Haeffner, 2 October and 22 November 2001.

140 "Svensk plutoniumfabrik under 1960-talet. Kortfattad utredning", av Erik Haeffner, 20 June 1960, FOA H4162-434, FOA:s arkiv.

141 Jonter 2001, p. 51-52.

142 "Styrelse PM om plutoniumarbetet", 19 January 1962; "AE Utredningar om Tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

143 "Anteckningar från sammanträde med representanter för FOA den 9 februari 1960"; "AE Utredningar om tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

reactor would soon be decided. Although the results were preliminary they were considered as reliable:

1. According to the design proposal prepared by the industrial group ASEA-NOHAB, it was possible to produce 125 kg plutonium of weapons-grade quality per year at Marviken.
2. If the reactor should "guarantee" a production of 70 kg plutonium per year, oxide fuels canned in aluminium had to be used. As a consequence, a dual-purpose solution was excluded (i. e. a simultaneous production of electricity was not feasible).
3. According to the ASEA investigations, AE's proposal to reduce the volume of the reactor core by 10-15 %, without initial preparations for operation at lower temperatures was not preferable. According to ASEA, it was not possible to produce the needed amounts of weapons-grade plutonium and simultaneously produce power for civilian use at a considerable level.

Against the background of the conducted investigations, ASEA made the following recommendation:

> *With regard to a possible future use of the Marviken facility for weapons manufacture, it is obviously of importance that the present reactor volume is maintained, and that the plant is planned to enable arrangements for later operation at lower temperatures. The latter is particularly important if the AE proposal of a reduction of the reactor volume should be accepted.*[144]

Because of the conducted investigations regarding the design of the Marviken plant, FOA requested AE in August 1962 to make a new study of a plutonium production of weapons-grade quality. In December, the study was ready ("Report on stage VII of investigation report concerning reactors for production of plutonium of weapons-grade quality"). By and large, the report concluded that the production costs for a boiling reactor would be 10-20 million crowns higher than if a pressurised version was chosen. The results of the studies formed the basis for the Supreme Commander's investigation of 1962 (ÖB-investigation).[145]

In February 1962, an important report was completed. The "nuclear device group" presented its results.[146] The group had been appointed on 27 June 1961 with the task of producing better basic information for elaborating the Supreme Commander's future approach in connection with the Supreme Commander study to be presented in 1962.

It was still unclear when the programme would be able to start. If a pure weapons programme were to be launched, the completion time would be considerably shortened. However, since the intention was that a possible nuclear weapons programme would be accommodated in the framework of the civilian power production, it would take much longer. For this reason, the authors of the study proposed a gradual process of acquiring a nuclear weapons capability:

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[144] "Försvarstekniska aspekter på Marviken-reaktorn", 25 January 1962, "Hemliga handlingar, V, 2/62-12/62, 1/63-21/71", DA, Studsvik AB.

[145] Olof Forssberg's study (basis), p. 148.

[146] "Kärnladdningsgruppens betänkande", HH 006. Declassified according to government decision Fo 95/2454/RS.

Such an approach would mean postponing a definitive decision until devices could be added to the organisation relatively quickly, but it assumes that all necessary measures are taken to prepare for rapid acquisition – including research into the construction of the necessary plant. These measures must not pre-empt the definitive decision, only facilitate the elaboration of a flexible security policy. However, this may mean exploiting the civilian atomic energy programme to a greater extent than would be economical from the point of view of pure acquisition.[147]

If the programme with 100 tactical nuclear weapons were carried out during the period 1965-75, the total cost was calculated to be 5 % of the entire budget of the Swedish defence force. If a programme were begun in 1964/65 with planned completion in 1979/80, this would correspond to 2,7 % of the entire military budget during this period.

Marviken was considered to be the best alternative. The precondition was that heavy water without any inspection restrictions would be available, and that a reprocessing facility could be built.[148]

5.5. The pilot study of a Swedish reprocessing plant is concluded

In April 1962, AE's pilot study of a Swedish reprocessing plant was completed. Olof Hörmander and Alf Larsson were the authors of the report. The plant was planned to be built in Sannäs in the county of Bohuslän, 23 km south of Strömstad on the west coast.

The production capacity was estimated at 270 kg plutonium per year at a price of 78 Swedish crowns per gram. The preconditions for the plant were a production capacity of 250 kg reprocessed uranium per day and that the enrichment of U-235 in the spent fuel should not be higher than 1.5 %.

The annual costs to run the plant were estimated at 21 million Swedish crowns. The initial costs were calculated to arrive at 116 million Swedish crowns and distributed as follows:

Initial capital expenditure cost	105
Technical investigations	3
Housing	1
Spare parts store	1
Operation group cost up to start of the plant	3,6
Running in of the plan	2,4
Total cost	116,0[149]

[147] Ibid.

[148] Ibid.

[149] "Kärnkemisk anläggning. Förprojekt. Sammanställning. Aktiebolaget Atomenergi", 2 April 1962, CA, Studsvik AB.

5.6. Reactor FR 0

At the end of the 1950's, AE had plans to develop a fast reactor. With a fast reactor the natural uranium was expected to be utilised to a higher degree, even up to 50-60 % according to the person responsible for the project, Eric Hellstrand.[150]

The technique is called breeding, which means that more plutonium can be produced than is consumed.[151]

As a first step AE decided to build a zero power reactor to study criticality conditions for such systems and the neutron flux interaction with different reactor materials. FOA supported the plans to construct such a zero power reactor as the neutron flux energy distribution in such a system to a degree resembles that of a nuclear device for weapons use. FOA could thus use the reactor to test calculation methods to be used in a nuclear weapons programme. In part, this work could replace the criticality experiments, which had been planned since the mid-1950's.[152]

Several researchers from FOA were affiliated to the project.

In 1964, the zero power reactor named FR 0 went into operation. AE borrowed 600 kg metallic uranium, containing 20 % U-235, from USAEC.

Furthermore, 8 kg plutonium was borrowed from Great Britain in 1969 to be used for reactor experiments for a short period of time.[153]

FOA prepared metallic plutonium foils to be used in cross section measurements in the FR 0 reactor. For this purpose, FOA disposed of 130 g of plutonium.[154]

In 1971, the project was brought to an end since the interest waned when the United States lowered the price of enriched uranium. Thus there were no incentives to invest in a costly technique with the aim of utilising the uranium more efficiently.[155]

5.7. AE's eighth investigation concerning the choice of a reactor for weapons-grade plutonium

In April 1963, FOA requested AE to carry out a new study of reactor options in the light of the rapid technical development, which was thought to have made earlier studies obsolete. The technical reports on the production of plutonium resulted in the conclusion that the Ågesta reactor was not suitable for this purpose. Two alternatives were discussed in the request. The following preconditions were given:

1. The percentage of plutonium 240 must not exceed 2% or alternatively 3.5%.
2. The production capacity alternatives should be 80 or 160 kg plutonium per year. If the latter capacity would not be reached, the highest figure should be given.
3. Domestic uranium and domestic heavy water should be used.

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[150] Interview with Eric Hellstrand, 1 November 2001.

[151] Letter from Nils Göran Sjöstrand to Thomas Jonter, 15 June 2001.

[152] Olof Forssberg's study (basis), pp. 156-157.

[153] Interview with Eric Hellstrand, 1 November 2001.

[154] Hultgren, Åke, *Upparbetning av Ågestabränslet 1969*, p. 4.

[155] Interview with Eric Hellstrand, 1 November 2001.

4. The Marviken reactor should be investigated, partly in the form of dual-purpose production of energy and weapons-grade plutonium, partly as a pure producer of plutonium. The Marviken reactor should be compared with a pure plutonium-producing reactor loaded with metallic uranium fuel canned in light metallic cladding. If other options were considered favourable by AE, these should be brought up for discussion with FOA for a possible investigation.

In July 1963, AE accepted the assignment.[156]

At the end of 1963, a joint analysis group was formed with representatives from both AE and FOA in order to develop co-operation regarding plutonium research. The group held meetings every quarter of the year where information was exchanged. FOA should be responsible for activities on the qualities of metallic plutonium and the chemistry of plutonium while AE should be in charge of the production of suitable fuel elements. The analysis and purification work was located at FOA. The co-operation continued until July of 1972.[157]

In March 1964, AE's study of reactor options was completed ("Report on stage VIII of investigation report concerning reactors for production of plutonium of weapons-grade quality"). The study concluded that the best alternative was a pure production reactor. AE had also included cost estimates for the construction of the necessary fuel factory and reprocessing plant. The plan was to locate all these plants at Sannäs in Bohuslän, in the southwest of Sweden.[158]

In a supplementary to the nuclear device group's report from 15 September 1964, it was stated that the preconditions of the report still prevailed. The best economical option was to use separate reactors for production of plutonium of weapons-grade quality.[159]

This option was also regarded as the best because of the indication that the Marviken plant should be loaded with enriched uranium instead of natural uranium. In this case, the enriched uranium would have to be imported from the United States, which gave the American government the right of inspection. Consequently Marviken could not be used for nuclear weapons production.

The choice of enriched uranium was not the only problem. Obtaining heavy water would also come up against complications. Was it at all realistic to expect to obtain all the required heavy water from Norway, the authors of the memorandum asked themselves? [160]

When the time came for the presentation of the Supreme Commander's defence study 1965 (ÖB-65), the army administration decided not to make any requests for the inclusion of nuclear devices. The freedom of action approach would however remain in force.[161]

The basic information for a chiefs of staff meeting on 15-16 March 1965 also stated that the freedom of action approach should also apply for the time being. At the same time, the freedom of action approach conducted up to then was considered far too vague, making rational planning more difficult. The concept of freedom of action would have

[156] Olof Forssberg's study (basis), p. 159.

[157] Hultgren, Åke, *Upparbetning av Ågestabränslet 1969*, p. 4.

[158] Olof Forssberg's study (basis), p. 171.

[159] "Svensk kärnvapenforskning, 1945-1972". Stockholm 1987, p. 50.

[160] Olof Forssberg's study (basis), p 145 et seq.

[161] Ibid., p. 190.

to be defined more precisely to make possible the preparation of the necessary technical documents in order to shorten the production time after a positive decision on the issue. Such a procedure required preparations in the form of project planning and design work. In concrete terms, this would mean, for example, that heavy water would be stored to speed up production – if a decision to acquire nuclear weapons were taken.[162]

These thoughts resurfaced at a meeting of the regional chiefs in the defence force in May of the same year, but heavy water and uranium oxide were not mentioned specifically. On the other hand, it was stated that the freedom of action concept must be extended to include storage possibilities for the necessary raw materials. The combined costs of carrying out the necessary construction work and storage were calculated at 50 million SEK.

In addition, it was now evident that the civilian nuclear energy development was elaborated without taking possible future requirements for nuclear devices into consideration. In view of this it would be extremely important for these preparations to be done, those attending the chiefs of staff meeting argued. [163]

During the late autumn of 1965, the chief of defence staff requested FOA to investigate alternative research plans in order to be able to comply with the government's and parliament's decision on ÖB-65.[164]

FOA worked out a plan in the budget proposals for 1966, which would enable it to meet the Supreme Commander's requirements. However, the government maintained that it was not possible to meet FOA's request.

Parliament approved the government's proposals. [165]

In practice, this decision meant that the Swedish plans to acquire nuclear weapons had been abandoned. With the reduced scope for action that the decision of parliament entailed for continued research, it was more or less impossible to make the necessary preparations that were required in order to be able to realise a programme at a reasonable cost and in a reasonable time.

One consequence of the decision of parliament was that some planned research projects had to be radically changed and in some cases cancelled. For example, AE's uranium works at Ranstad, where test operation started in 1965, did not become the significant producer of uranium as had been planned. In addition, AE did not continue with the plans for setting up a reprocessing plant for the production of plutonium, for which land had been purchased in Bohuslän.[166]

In practical terms, the construction research had been removed from the agenda, even though it would take some time before the current projects could be phased out. The continued co-operation between AE and FOA was characterised by reductions and less importance.

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[162] Ibid., p. 193 et seq.

[163] Olof Forssberg's study (basis), p. 195 et seq.

[164] Swedish National Defence Research Institute, Department 4, Office, Incoming and outgoing secret documents 1965 F, Volume 62, H 4222-5.

[165] Bill 1966:1, Appx 6, p. 188 et seq.

[166] On these plans, see Olof Forssberg's study (basis), p. 195.

5.8. Summary: 1960-1968

During 1960, AE was occupied with the issue of acquiring inspection-free heavy water. ASEA had initiated experimental work for AE. The preliminary investigations showed that it was possible to produce domestic heavy water at reasonable costs, at least in comparison to an import from Norway. On the contrary, if the heavy water were to be bought in the United States the cost would be considerably lower. The problem with the last option was that the heavy water could not be used in a production of nuclear weapons.

Another problem for the plans to manufacture nuclear weapons was the conducted investigations of the choice of reactors for a production of weapons-grade plutonium. These studies showed that the best alternative was a pure production reactor for weapons-grade plutonium. The Swedish heavy water reactor programme was on its way into a dead-end.

When the United States also lowered the price of enriched uranium, there were repercussions for the Swedish plans to connect the manufacture of nuclear weapons to the civilian nuclear energy development. The private industry saw no advantages in investing in a dual-purpose reactor, which was much more expensive than if enriched uranium, were used.

In 1965, it was decided that the civilian nuclear energy would choose to import enriched uranium, and as a consequence the dual-purpose reactor technique was abandoned. Now only one alternative remained, the defence command argued: to use production reactors for weapons-grade quality. For this reason, the defence command felt that is was compelled to carry out the gradual acquisition procedure if a freedom of action approach worthy of the name were to be applied. However, in the 1966 budget proposals the government said no, and with this the Swedish nuclear weapons plans were in practice abandoned.

As a result of the decision to purchase enriched uranium from the United States, AE's uranium factory at Ranstad, which started trial operation in 1965, was abandoned. Neither were AE's plans for a reprocessing plant, for which land had been purchased in Bohuslän, fulfilled.

It was now clear that the light water reactor technology was to dominate the Swedish nuclear power development.

6. Period: 1968-1972

In August 1968, the Swedish government signed the Non-Proliferation Treaty (NPT).[167]

Although the plans to acquire nuclear weapons were abandoned, the co-operation between AE and FOA in the plutonium field continued up to 1972. This co-operation was mainly focused on pure protection research.

In 1970, the preparations for a total phasing out of the co-operative plutonium research were begun. The main theme in this work was to transfer as much personnel as possible from FOA to AE. FOA should not conduct extended plutonium research, and for this reason their gathered resources ought to be transferred to AE. FOA should instead request consultant assignments from AE concerning some plutonium issues.[168]

In May of 1972, a two-day conference was held at FOA. The experimental plutonium research was discussed in the form of lectures and seminars. The purpose was to give the researchers who had been involved in these activities an opportunity to share their experiences with others.[169]

The co-operation between AE and FOA in order to produce basic information of a nuclear weapons manufacture could come to an end.

It is worth mentioning that an inter-departmental work group was created in the aftermath of the Sannäs project with the aim of analysing the future need for reprocessing for the Swedish nuclear power. In the context of the planned enlargement of the nuclear power, it was considered that a reprocessing plant was needed around 1990.[170]

A parliamentary report (Aka-utredningen) suggested in 1976, that project studies for a reprocessing plant would be initiated immediately in order to enable an annual operation of 800 tonnes of uranium in the beginning of the 1990's.[171]

However, even this time the plans to build a reprocessing plant in Sweden came to nothing.

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[167] Prawitz, Jan, *From Nuclear Option to Non-Nuclear Promotion: The Sweden Case*. Research Report from the Swedish Institute of International Affairs, Stockholm 1995, s. 19 f.; see also Dassen van, Lars*, Sweden and the Making of Nuclear Non-Proliferation: From Indecision to Assertiveness*. SKI Report 98:16.

[168] "Samordning av plutoniumverksamheten vid AE och FOA. Tel.samtal med doc. Uhler den 1.4.1970"; "PU-kommittér FOA-kommittén Pu-experiment i Ågesta Pu-kommitté RK-Rm", DA, Studsvik AB.

[169] *Föredrag vid FOA plutoniumdagar 3 och 4 maj 1972*, part I-II, FOA 4 Rapport, C 4524-A2. January 1973.

[170] *Upparbetning av kärnbränsle. Studie av arbetsgrupp inom industri-, jordbruks- och civildepartementet.* Stencil I 1971:1.

[171] SOU 1976:30, *Använt kärnbränsle och radioaktivt avfall. Betänkande av Aka-utredningen*. Stockholm 1976.

7. Conclusions

The co-operation between AE and FOA, which was initiated at the end of the 1940's, was necessary in order to produce basic information for a possible manufacture of nuclear weapons. The personnel and technical resources were limited and for this reason co-operation between the parties was needed.

In the light of this need, the formal agreement, which was signed in 1949, was a logical development. A division of responsibility was to be made in order to avoid a duplication of work, and to create the best conditions for both civilian and military nuclear energy research.

In general terms, AE was responsible of the production of uranium, the manufacture of fuel elements, the building of reactors and a reprocessing plant which could be used if Sweden came to the conclusion to realise a nuclear weapons programme. AE was also in charge of planning for the procurement of inspection-free heavy water.

The plutonium research should be carried out in close co-operation. This co-operation would imply that AE delivered basic information for a possible production of weapons-grade plutonium while FOA was focused on the manufacture of metallic plutonium.

Between 1949 and up to 1968, when the Swedish government signed the Non-Proliferation Treaty (NPT), four main investigations regarding the technical conditions for a manufacture of nuclear weapons were made (1953, 1955, 1957 and 1965). AE prepared several reports within the framework of this FOA research. These were mainly assignments that dealt with reactor techniques, production of plutonium and procurement of heavy water.

A pilot plant for uranium production was put into operation in Kvarntorp in 1953, and two years later a fuel element factory was built at Lövholmsvägen in Stockholm. A co-operation was also initiated with the Swedish ironworks Kohlswa Jernverk and ASEA with the purpose of manufacturing fuel in a suitable shape for the planned nuclear power facilities. The contracted companies were mainly dealing with the sintering of uranium oxide pellets.

One of AE's most important tasks was to produce plutonium. The experiments to produce plutonium started in 1952. Already three years later, on 20 May of 1955 to be precise, the researchers at AE succeeded in the efforts to produce plutonium in small amounts.

The access to plutonium was a vital component not only for civilian energy production purposes, but also as an ingredient in the process of manufacturing nuclear weapons. For this reason, a reprocessing plant had to be built in order to separate plutonium from the spent fuel. In the civilian programme plutonium oxide would be mixed with uranium oxide and recycled in the form of fresh reactor fuel. Alternatively weapons-grade plutonium metal would be used in the military programme.

AE was occupied with this issue from the mid-1950's up to the mid-1960's. Different proposals were sketched. One of these proposals was to build a reprocessing plant in Studsvik. However, in the end AE came to the conclusion that the best location for such a plant was Sannäs on the west coast.

Step by step, the Swedish heavy water programme seemed to be realised, although some of the more optimistic goals had to be reconsidered. However, a dark cloud became more and more threatening; namely the light water reactor technology in the United States. The Swedish private industry saw an opportunity to develop this technology, which meant that the reactors had to be loaded with enriched uranium. The interest in the light water technology grew even stronger when the prices of enriched uranium in United States were drastically lowered.

Additionally, as conducted studies led to the conclusion that the Swedish heavy water programme would be very costly, the actors of the private industry became even more sceptical. In addition, a reprocessing plant was planned at Mol, within the European nuclear energy co-operation. As a participant in the co-operation, Sweden would be allowed to use this plant and other planned reprocessing facilities.

The problems grew for the plans to connect a possible nuclear weapons manufacture to the civilian nuclear energy programme. The studies from the end of the 1950's, pointed in one direction; the best, and definitely the most economical alternative for a Swedish nuclear weapons programme was to build a separate reactor for the production of plutonium of weapons-grade quality.

In 1965, a decision was taken which meant that the nuclear weapons issue was now dead. It was decided that the Marviken reactor – which was planned to be used for the possible production of weapons-grade plutonium – should be loaded with enriched uranium. This decision implied that the imported enriched uranium would be under foreign control and as a consequence the reactor was not allowed to be used for producing nuclear weapons.

From then on, the civilian nuclear energy programme developed without consideration of the military plans for possible manufacture of nuclear weapons. For this reason, FOA outlined a proposal to the government to implement a gradual acquisition within the framework of production of purely weapons-grade plutonium. However, in the 1966 budget proposals the government said no, and with this the Swedish nuclear weapons plans were in practice abandoned.

How important was the role AE might play in the nuclear weapons plans?

In the light of the fact that the civilian nuclear energy programme should form the basis in a possible manufacture of nuclear weapons, it is correct to say that AE created the main preconditions for such a production.

The plans to launch a dual-purpose programme turned out to be an economically and technically worse solution than if two separate projects had been chosen. The advantage of investing in the domestic uranium deposits, and to be independent as a nuclear materials producer, was shown in a ten-year period be the opposite: to invest in the light water technology was now considered to be a much more attractive option.

That the heavy water reactor technology was abandoned together with the preconditions for a manufacture of nuclear weapons was not obvious. There were alternatives of action. These alternatives of action had a price – economically, technically and politically.

However, the politicians were not willing to pay that price.

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Appendix 1: AB Atomenergi's holdings of heavy water, plutonium and U-235, 1947-1972

Sweden's possession of nuclear materials has been a subject of registration (accountability) according to law since 1956. Before this date, the figures are uncertain. In the registers, it is possible to study the traffic of import and export since 1956 in terms of natural uranium, uranium dioxide, enriched uranium and plutonium. This bookkeeping also includes the holding of heavy water.[172]

In the mid-1950's, a domestic production of natural uranium was begun. I have not found it important to account for this specific holding. It is worth mentioning that 213 tonnes of uranium were produced in the period from 1965 to 1968 at the Ranstad plant.[173]

Neither have I considered it important to account for the fuel elements, which have been purchased or borrowed from other states as to be used in the operation of Swedish reactor plants. The reason for this is that Sweden has never owned an enrichment facility or a reprocessing plant, and it has therefore never been possible to produce U-235 or plutonium of a weapons-grade quality.

In this report, only the holdings of plutonium, U-235 and heavy water are accounted for during 1945-1972.

The IAEA safeguards system went into practice for Sweden in 1975, even though the Swedish government ratified the NPT in 1970. In 1972, a tripartite agreement was signed by Sweden and the United States in order to regulate international control of the Swedish nuclear energy facilities. [174]

During the period from 1972 to 1975 the United States Atomic Energy Commission (USAEC) conducted inspections of Swedish facilities in order to check that nuclear materials imported from the United States were not being used in a nuclear weapons production.[175] From 1972 onwards, it has been taken for granted that IAEA knows what is occurring in the nuclear energy field in Sweden.[176]

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[172] How this nuclear materials control emerged, see Jonter 1999, pp. 26-27.

[173] "Ranstadsverket" in the National encyclopaedia, by Nils Göran Sjöstrand .

[174] See Jonter 1999, p. 29.

[175] Ibid., pp. 28-29.

[176] For a detailed study of the Swedish traffic of nuclear materials, see "Sammanställning av uppgifter om transporter av kärnämne till och från Sverige under åren 1956-1979" and "Sammanställning av uppgifter om transporter av kärnämne till och från Sverige under åren 1980-1987", (unpublished version at the Office of Nuclear Non-Proliferation, SKI).

AB Atomenergi's holdings of heavy water: 1956-1972

1959	36 tonnes (26 tonnes from the United States and 10 tonnes from Norway). This amount was inspection-free, i.e. it could be used without control from the seller)[177]
1962	50 tonnes[178]
1967	115 tonnes
1968	202 tonnes (of which 164 472 kg was under inspection by the United States)

The heavy water came mainly from three countries: the United States, the Netherlands and Norway. For example, the division of the holdings of 31 December of 1967 was as follows:

The United States	25 155 kg 164 472 kg (to be used in the Marviken plant)
Norway	5 576 kg
Netherlands	1 899 kg
Unknown origin	5 229 kg

What happened to the heavy water when the heavy reactor water technology was abandoned in Sweden?

The main part was sent to facilities in Canada and the United States. The Canadian AECL received 164 472 kg on 15 October 1970. This heavy water was intended to be used in the Marviken reactor. On 28 August 1974, 23 000 kg was sent to Canada, the United States (USAEC) received 25 155 kg.

Source: Work documentation of deputy head of the Office of Nuclear Non-Proliferation, Göran Dahlin, SKI, during the years 1987 to 1988.

177 "Möjligheterna att hålla R3/Adam inspektionsfri", 5 February 1959; "AE Utredningar om Tungt vatten 1957-1967, 1970-1974 (SKI tillstånd). Uran 1956-1962, Allmänt 1957-1959 Prognoser 1960", VD-arkivet, CA, Studsvik AB.

178 Olof Forssberg's study (basis), p. 145.

Holdings of plutonium: 1956-1972

Import and export

Date	Record number	Applier	Sender/ receiver	Subj
630117	AETR 18 AETR 442	AE	USA	Import of 500 g Pu
631025	Rfk TW6/Bik AETR/AE	AE	USA	Export of 500 g Pu
640824	Rfk AETR 48	AE	United Kingdom UKAEA	Import of 200 g Pu[179]
650805	Rfk AETR 85	AE	USA USAEC	Import of 399 g Pu
661012	Rfk AE/442 AETR 147	AE	United Kingdom UKAEA	Import of 404 g Pu[180]
690210	Rfk 5/69 AE/444 AETR /69	AE	United Kingdom UKAEA	Import of 8000 g Pu
690616	Rfk Div/442	BRD	AE	3500 g Pu (1)

(1) The last-mentioned figure in the year 1969 is related to the permission to transport 3 500 g plutonium. In the end, only 2,7 kg plutonium were imported.[181]

The plutonium used by FOA for research was transferred to AE, the last delivery took place in 20 December 1972.[182]

In total, AE had 12 208 g of plutonium at its disposal (including the plutonium borrowed from abroad) in the period from 1963 to 1969.

[179] The plutonium should be used for research purposes by FOA. The amounts of plutonium which FOA had at its disposal, see Jonter 2001, p. 77.

[180] Ibid.

[181] Hultgren, Åke, "The Plutonium Fuel laboratory at Studsvik and its activities". IAEA Symposium "Plutonium as a Reactor Fuel". Brussels, 1967; *Upparbetning av Ågestabränslet 1969*, September 1995, appendix 23.

[182] Ibid., p. 4.

Appendix 2: Reactors, laboratories and facilities in AE ownership where nuclear materials activities (especially with plutonium, U-235 and heavy water) took place

R 1 (located at the Royal Institute of Technical in Stockholm). Heavy water reactor. The reactor contained about 3 tonnes of metallic uranium in aluminium claddings tubes and about 5 tonnes of heavy water. Situated in a rock cavern 15 metres under the ground, R 1 went into operation in 1954 and was a research reactor. In 1970, the reactor was shut down.

Output: 1 MW.

Nuclear Chemistry Laboratory (located in the rock cavern in affiliation to R 1).

Extraction laboratory (Situated on the ground, close to R 1). In the laboratory, extractions of small quantities of plutonium were carried out.

Zebra (Zero Energy Bare Reactor Assembly) was a sub-critical reactor, which was built close to R 1. The reactor was used for studies on cores of different fuel and moderator arrangements. In 1959, the plant was moved to Studsvik.[183]

TZ (Tryckzebra). In 1963, ZEBRA was rebuilt to a pressurised sub-critical reactor, which was able to make measurements up to 250° C.[184]

KRITZ (located in Studsvik) was a rebuilt version of TZ, which went into operation in 1969. This zero energy reactor was used for reactor physical measures on the light water reactor systems.[185]

R 2 (located in Studsvik) is a light water reactor which started in 1960. The reactor was loaded with enriched uranium from the United States, and has been used for research activities, especially materials testing. The reactor is still operating.

Output: thermal output of 50 MW.

R 2-0. Research reactor located in the same water pool as R 2.

R 3/Adam (Ågesta) was a heavy water reactor which went into operation in 1963. The reactor plant was designed for combined heat and electricity production. Ågesta was a prototype plant with a combined output of 65 MW, 55 MW was used for district heating of the suburb Farsta south of Stockholm and 10 MW for electricity production. In 1965,

183 Interview with Eric Hellstrand, 1 November 2001.

184 Ibid. See also Brynielsson 1989/90, p. 202.

185 Interview with Eric Hellstrand, 1 November 2001.

the operation was taken over by Vattenfall utility. Finally, it was shut down in 1974 when it was considered uneconomical.

Data:

Capacity	65 MW	later 80 MW
of which electrical	10 MW	later 12 MW
Core inventory	18,5 ton uranium dioxide	
Maximal fuel temperature	1325° C	
Heavy water	69 tonnes	
Heavy water in the reactor	51 tonnes	

FR 0 was a zero power reactor (located at Studsvik) which was used for research activities. The rector core contained of 20 % U-235 and 80 % U- 238. The reactor was started in 1964 and was taken out of operation in 1971.

R 4 (Marviken) was a heavy water reactor, which was ready to be taken into operation in 1968, but the project, was abandoned. The reactor should have been loaded with 40 tonnes of 1-2 % enriched uranium U-235 from Great Britain. The heavy water was imported from the United States.

Data:

	Superheating	Boiling reactor
Capacity, thermal	463 MW	593 MW
Capacity, electrical	132 MW	193 MW
Core inventory	26,3 ton UO_2	+7,3 ton UO_2
Enrichment	1,35 % U-235	1,75 % U-235
Heavy water	180 tonnes	
Operating pressure	49,5 bar	
Temperature	259° C	472° C
Temperature, feed water	120° C	126° C

Fuel element factory located at Liljeholmen south of Stockholm. In the factory different methods for manufacture of oxide fuel were worked out. Additionally, fuel elements were produced (uranium pellets and uranium rods) to be used in the reactors.

Hot cell laboratory located at Studsvik. In the laboratory fuels and material which have been radiated were investigated.

Aktiva Centrallaboratoriet (ACL) was even called the plutonium laboratory and was situated in Studsvik. In the laboratory work with plutonium was carried out.

Laboratoriet för aktiv metallurgi (RMA), Studsvik. In the laboratory work with plutonium was conducted.

Appendix 3: AE’s main reports made for FOA within the nuclear weapons research 1945-1972.

1958

“Rapport över Etapp 1 av utredningsuppdrag beträffande reaktorer för produktion av plutonium av vapenkvalitet”. 9 January1958.

“Rapport över Etapp 2:1 av utredningsuppdrag beträffande reaktorer för produktion av plutonium av vapenkvalitet”. 1 July 1958.

1960

“Rapport över Etapp III av utredningsuppdrag beträffande reaktorer för produktion av plutonium av vapenkvalitet”. 28 April 1960

“Tillägg till rapport över Etapp III av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet”. 17 November 1960.

“Rapport över Etapp IV av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet”.

1961

“Rapport över Etapp V av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet”.

“Rapport över Etapp VI av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet”. 14 September 1961.

“Rapport över Etapp VII av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet”. 12 December 1962.

1964

“Rapport över Etapp VIII av utredningsrapport beträffande reaktorer för produktion av plutonium av vapenkvalitet”. 16 March 1964.

Appendix 4: To Make a National Based Historical Survey of Non-Proliferation of Nuclear Weapons. Experiences from the Example of Sweden

Abstract

This paper presents a project which was initiated by the Swedish Nuclear Power Inspectorate (SKI) and accepted by the Agency as a support programme task to increase transparency and support the implementation of the Additional Protocol in Sweden. A general model of how such a historical review of a state's non-proliferation policy of nuclear weapons has been created in order to serve as a guide for other countries strengthening of their safeguards systems in the framework of the Additional Protocol. The model contains four parts, comprising of components such as a state's profile of nuclear activities and role in the non-proliferation policy, nuclear weapons research, and how to evaluate a state's capability to produce nuclear weapons.

1. Introduction

How is it possible to make a review of a state's nuclear energy activities in the past? Furthermore, how is it possible to evaluate a state's capability to produce nuclear weapons? The Additional Protocol stipulates that the states in question not only have an obligation to render accounts for current activities, but are also responsible for delivering information about planned future operations. However, the Swedish Nuclear Power Inspectorate (SKI) has chosen to go a step further and also include what took place in the past. Although the Additional Protocol does not compel member states to carry out such historical reviews, SKI has decided to report openly on Swedish nuclear weapons research since 1945.

As a consequence SKI initiated a project in 1998 to carry out this historical survey.[186] The project was accepted by the agency two years later as a support programme task to increase transparency and to support the implementation of the Additional Protocol in Sweden. Besides making a survey of Swedish nuclear energy activities since the mid-forties, the aim is to create a general model of how to conduct historical reviews in order to serve as a guide for other countries strengthening of their safeguards systems within the framework of the Additional Protocol.

In this paper, I will describe how this project was carried out which in turn hopefully can say something generally about how such an investigation can be designed.

2. Research Concerning Swedish Nuclear Weapons: A General Background

To understand the nature of the Swedish nuclear related activities, and especially the Swedish plans to produce nuclear weapons, a short summary is needed. The Swedish plans to produce nuclear weapons, which were abandoned in 1968 when the Swedish government signed the NPT, was based on a dual-purpose technology. The production

[186] Jonter, Thomas, *Sverige, USA och kärnenergin. Framväxten av en svensk kärnämneskontroll 1945-1995* (Sweden, USA and nuclear energy. The emergence of Swedish nuclear materials control 1945-1995). SKI Report 99:21; *Försvarets forskningsanstalt och planerna på svenska kärnvapen*, SKI Report 01:5 *Sweden and the Bomb. The Swedish Plans to Acquire Nuclear Weapons, 1945-1972*. SKI Report 01:33. *Nuclear Weapons Research in Sweden. The Co-operation Between Civilian and Military Research, 1947-1972*, SKI Report 02:18.

of nuclear weapons was designed as a part of the civilian nuclear energy development. A company, AB Atomenergi (AE), was created in 1947 to deal with the civil industrial development. The company conducted research and built facilities such as reactors and a fuel element plant which also in part were designed to suit a possible future production of nuclear weapons. The Swedish National Defence Research Institute (FOA), which was responsible for the military use of nuclear energy, began with nuclear weapons research as early as 1945. Admittedly, the main aim of the research initiated at this time was to find out how Sweden could best protect itself against a nuclear weapon attack. However, from the outset FOA was also interested in investigating the possibilities of manufacturing what was then called an atomic bomb. When, in 1954, the Swedish Supreme Commander advocated nuclear weapons, this research became the object of political discussions and conflicts.[187] Resistance to these plans began to emerge among the public, in parliament and even among the government, where Prime Minister Tage Erlander had been in favour of acquiring nuclear weapons well into the 1950's.[188] Not only Sweden as a whole, but also the social democracy movement, was divided on the issue. For this reason, a bill was drafted which laid down a period for consideration. This meant that Sweden could postpone a decision on the issue. According to the bill, the reason for the consideration period, or freedom of action as it has also been called, was that research had not reached the technical level at which a decision could be taken on the issue.[189]

The bill laid down that, for the time being only protection research could be done, excluding research aimed directly at producing nuclear weapons. Parliament passed the bill in July 1958.

Did FOA stay within the limits of protection research as regulated by the government? Over the years, this question has been the subject of debate and a government report. A vital task for this project was to analyse whether or not FOA went beyond the defined limits.

3. The Swedish Nuclear Activities Profile since the Mid-Forties

The first objective was to make a general inventory of Swedish nuclear operations since 1945. How could this be done without too much time-consuming archival work? A general overlook was needed, and that general view was not actually reached in Sweden but in a gigantic archive across the Atlantic Ocean, namely the National Archives in Washington DC. The reason for this was that United States global nuclear energy policy since World War II was designed to prevent proliferation of nuclear weapons. The US administration collected extended information about all nations' nuclear energy activities. The United States Atomic Energy Commission (USAEC) which was responsible for the nuclear trade, particularly since the "Atoms for Peace"-programme was launched in the mid-50's, followed every participating nation's developments in this respect. Detailed reports were sent to Washington regarding the progress of the Swedish nuclear energy operations, especially after the mid-50's when Sweden started to make serious plans for production of nuclear weapons.

On several occasions the US archives have given detailed information on Swedish issues where the Swedish counterparts have been sparse. The most spectacular example is from the end of the 1950's. In the US files I found exhaustive reports on how Swedish military, diplomats and researchers belonging to the military establishment

187 *Alltjämt starkt försvar. ÖB-förslaget 1954* (ÖB 54); Kontakt med krigsmakten 1954:9-10.

188 Erlander, Tage, *1955-1960*, Stockholm 1976, pp. 75-101.

189 Bill 1958:110.

started to explore the possibilities of acquiring nuclear weapons from United States. The Swedish archives contain hardly any information about these talks. There is not enough room here to explain the reason behind this silence, a not too daring guess is that the Swedish non-aligned policy made the officials consciously cautious when documenting sensitive information in foreign policy matters. It is likely that even other states, with which the United States co-operated within the nuclear energy research, have similar sensitive fields that have not been objects for documentation in domestic archives.

The reading of reports and analysis by the State Department, CIA and USAEC gave me the general picture I was looking for. Through this archival research I could study organisation charts of the Swedish nuclear energy projects, identify key people involved in the activities, and track dates when important meetings were held. This reading gave me useful information to follow up in the Swedish archives and above all, provided me with well-informed summaries and evaluations of the aims and capabilities of the Swedish nuclear developments. In this context, it is important to understand that at this time much of the documentation concerning nuclear weapons related research conducted by FOA was classified.

After this general inventory, I could start the work in the Swedish archives to map out how the nuclear energy projects have been organised since 1945. An important task was to locate the government authorities, organizations, private companies, universities and research institutions who were involved in the activities and who had the authoritative power at different times. This part of the survey can be of much help in tracking information and documentation otherwise hard to find.

It was now possible to make a first review of the Swedish nuclear activities based on Swedish archives as well as a comparison with the US general picture. This archival research was combined with a study of government reports and literature on the emergence of the Swedish nuclear energy and nuclear weapons research.

Now it was possible to start analysing how the Swedish nuclear materials control system has been developed over the years. This includes a list of international inspections of nuclear materials and nuclear facilities in Sweden. An important aim was to show how the early inspection routines were worked out, and how they developed later on, especially in regards to the co-operation with the US and the IAEA. Another important task was to check if nuclear materials existed which is not accounted for in the information handed over to the IAEA.

Another important task was to make a list of Swedish archives which contain documentation about both civil and military nuclear energy activities: to show in general terms what each archive contains, especially in regards to nuclear materials, facilities and equipment which could be used in a production of nuclear weapons. It is also important to investigate whether the archives in question are open or not for the public or the research.

3.1 FOA and the Plans to Manufacture Nuclear Weapons

The next step was to analyse FOA's nuclear weapons research, a field that so far had not been analysed by historians, political scientists or other researchers. Admittedly the issue had been touched on in articles and studies, but then in a more general way, describing the main aspects of Swedish official policy. The texts were not based on a thorough review of sources relating to the activities of FOA during the relevant period from 1945 up to 1968, when Sweden signed the NPT.[190]

The first aim of this part of the project was to investigate whether or not FOA went beyond the defined limits of the allowed protection research.

The second aim was to place Sweden's nuclear energy research in the context of the international scientific discussion of nuclear weapons proliferation. In this discussion, Sweden has been regarded as an advanced country scientifically and in terms of nuclear technology, a country that refrained from making nuclear weapons even though it was considered technically capable of doing so. It has been generally accepted in the international discussion that Sweden reached a latent capability to begin concrete preparations for nuclear weapons manufacture at the end of the 1950's. However, that notion is not based on any review of FOA's nuclear energy activities, but on open sources.[191]

The model used is described in part 4.

The third aim was to follow up the way in which the nuclear weapons activities were phased out after Sweden signed the NPT in 1968 (in other words, how Swedish protection research developed after the agreement had been signed).

The fourth aim was to investigate how much plutonium, uranium (natural and depleted) and heavy water FOA had at its disposal within the framework of the research it conducted.

3.2 The Civilian and Military Co-operation

Even though the FOA study dealt with the co-operation between FOA and AE in order to make technical preparations for a nuclear weapons production, the picture was far from clear. I could show what main tasks AE were responsible for within this co-operation and what reactors and other facilities the company had in its possession. However, rather little was known about what AE did in detail and what consequences it had for the project as a whole. Another unsolved issue was how much heavy water, plutonium of weapons quality, U-235 and natural and depleted uranium AE used or had in its possession during the period from 1945 to 1972. Important questions to be answered were: what laboratories, reactors and facilities were used for activities with nuclear material, especially with plutonium, U-235 and heavy water, and where they were located?

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190 See for example Agrell, Willhelm, *Alliansfrihet och atombomber. Kontinuitet och förändring i den svenska försvarsdoktrinen 1945-1982*, Stockholm 1985 and *Svenska förintelsevapen. Utveckling av kemiska och nukleära stridsmedel 1928-70*, Lund 2002; Björnerstedt, Rolf, "Sverige i kärnvapenfrågan", *Försvar i nutid*, 1965:5; Forssberg, Olof, *Svensk kärnvapenforskning 1945-1972*, (government report) Stockholm 1987; Fröman, Anders, "Kärnvapenforskning", in *Försvarets forskningsanstalt 1945-1995,* Stockholm 1995, and *FOA och kärnvapen – dokumentation från seminarium 16 november 1993*, FOA VET om försvarsforskning, 1995; Garris, Jerome Henry, *Sweden and the Spread of Nuclear Weapons*. University of Calfornia, Los Angels, Ph. D; Jervas, Gunnar, *Sverige, Norden och kärnvapnen*, FOA report C 10189-M3. September 1981; Larsson, Christer, "Historien om en den svenska atombomben". *Ny Teknik*, 1985-86; Lindström, Stefan, *Hela nationens tacksamhet: svensk forskningspolitik på atomenergiområdet 1945-1956*, Stockholm 1991; Larsson K-E, "Kärnkraftens historia i Sverige", *Kosmos*, 1987; Larsson, Tor, "The Swedish Nuclear and Non-nuclear Postures", *Storia delle relazioni internazionali* 1998:1.

191 For example, Stephen M Meyer states that this happened in 1957, Meyer, Stephen M, *The Dynamics of Nuclear Proliferation*, Chicago 1987, p. 41. Meyer bases this assertion on a dissertation by Jerome Garris, "Sweden's debate on the proliferation of nuclear weapons", see p. 207, footnote 3.

In addition to the archival studies, I conducted interviews with former employees at AE and FOA who were involved in this research. This part of the presented model can give new knowledge and perspectives that are hard to find in the archives. This is especially important in cases when documentation is lacking or is scanty. This method was of much help in the study of the co-operation between FOA and AE, where in some cases the documentation was not too exhaustive.

4. The Swedish Role and Interaction in the Area of International Non-Proliferation

In this part of the project I started to create a profile of the Swedish organisation charts which, of course, have changed over the years. A number of essential questions could now be answered such as: which departments of government have been responsible for different nuclear related matters and at what times? How did the safeguard systems emerge? Which companies, universities and institutions have been involved and to which specific areas of the nuclear related research and development have they contributed?

Then I continued and made a list of national laws that have regulated the use of nuclear materials and heavy water since 1945. Essential questions are; how have the import and export regulations been designed since 1945? Who has had the permission to use sensitive nuclear materials and on what conditions?

In this context, I also made a list of all the international agreements and conventions in the nuclear energy field which have been signed and ratified by Sweden since 1945.

Additionally, a list of bilateral agreements in the nuclear energy field between Sweden and other states was compiled. It is also important to notice that not all co-operation necessarily went through bilateral (government controlled) agreements procedures. If a state used other procedures it is, of course, important to find documentation of this co-operation, in order to make a reliable survey.

This part of the project also includes a list of archives that contain documents on the Swedish atomic energy development, both for civil and military use.

5. How is it Possible to Evaluate a State's capability to Produce Nuclear Weapons

The appendix does not demand such an evaluation, but I have used a model, which enables me to evaluate the Swedish capability. From my point of view, it is not possible to make an analysis of the nuclear weapons activities at FOA without such a model. I have used a model from the American political scientist Stephen M Meyers study *The Dynamics of Nuclear Proliferation*. With his model I can define essential terms such as "nuclear weapons programme" and "latent capability".

Why do certain states choose to take the step from latent capability to operational capability? Meyer distinguishes four steps in the process from decision to finished nuclear explosive devices:

1. A state decides to acquire latent capability to manufacture nuclear weapons;
2. A state has reached latent capability;
3. A state decides to manufacture nuclear weapons;
4. A state possesses nuclear weapons.

A state is regarded as having a nuclear weapons programme when the intended programme has been started with an aim to producing at least one nuclear explosive device per year on average for several years. It is immaterial whether the state in question has any plans for a weapon carrier or whether nuclear weapons tests are planned.

In addition, a state is regarded as having achieved latent capability when it has achieved the capability to carry out the above nuclear weapons programme.

But how can the latent capability of a state be measured in a more concrete sense?

A great deal of resources are needed in order to carry out a complete nuclear weapons programme. Firstly, purely material resources such as steel, concrete and obviously nuclear materials are needed. Secondly, scientific expertise is needed. This means more than simply having sufficiently developed nuclear physics and nuclear chemistry available; the scientific knowledge must extend to other areas such as classical mechanical engineering, thermodynamics, kinetic theory and the metallic properties of uranium and plutonium. Thirdly, a state needs technical know-how and extensive organisational ability to be able to design and run the programme. It will also need a developed ability to be able to maintain and replace parts in an efficiently functioning nuclear weapons programme.[192]

Meyer divides the possible latent capability of states into three categories.

1. For a state entirely lacking in nuclear infrastructure, and which decides to produce finished nuclear explosive devices, it would take up to six years from the initial experiments to produce the first nuclear weapon.
2. For a state with a modest nuclear infrastructure, the goal of producing the first device could be achieved in two to three years.
3. A state with an advanced nuclear infrastructure would be able to produce a finished nuclear explosive device within at most two years. Such a state possesses practically everything that is needed apart from the actual weapons factory. There are two forms of advanced capability: either the state has both a plutonium-producing reactor and a reprocessing plant (or a "hot cell") or it has a uranium enrichment plant. In either case, the country in question has practically all the resources needed to start a nuclear weapons programme.[193]

6. Conclusions

The results of my research can be summarised in mainly six conclusions. The first deals with the US nuclear weapons policy towards Sweden. The US policy can be analysed in two periods. In the first period, 1945-1953, the US policy towards Sweden followed the same pattern as towards the rest of Western Europe. The most important aim was to prevent Sweden from acquiring nuclear materials, technical know-how, and advanced equipment that could be used in the production of atomic weapons. During this period the Swedish plans to produce her own nuclear weapons were rather undeveloped. It was, for instance, not a debated issue among political organisations or in the media.

The first priority of the US administration was to discourage the Swedes from exploiting their uranium deposits, especially for military purposes. In the eyes of the Swedish actors, the US policy was considered too restrictive. As a result of this restrictive policy, Swedish researchers developed co-operation with other nations, especially with Great Britain and France. The first Swedish research reactor was actually constructed with assistance and help from Commissariat á l'Energie Atomique (CEA).

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[192] Meyer, Stephen M, *The Dynamics of Nuclear Proliferation*, Chicago 1987.
[193] Ibid., p. 37.

In the next period, 1953-1960, the US policy was characterised by extended aid to the development of the Swedish energy programme. Through the "Atoms for Peace"-programme, the Swedish actors now received previously classified technical information and nuclear materials. Swedish companies and research centres could now purchase enriched uranium and advanced equipment from the United States. This nuclear trade was, however, controlled by the USAEC. The American help was designed to prevent the Swedes from developing nuclear capability. The second Swedish reactor, located in Studsvik and finished in 1959, was in fact constructed with American financial help and technology.

From the mid-1950's Swedish politicians and defence experts realised that a national production of atomic bombs would cost much more than was supposed 4-5 years earlier. As a consequence, Swedish officials started to explore the possibilities of acquiring nuclear weapons from United States. The Swedish defence establishment assumed that even though Sweden was not a member of NATO, it would be in the US interest that the Swedish defence was as strong as possible to deter a Soviet attack.

The US administration reacted negatively to these Swedish plans. The US jurisdiction made it impossible to sell to Sweden or otherwise let the Swedes have American atomic bombs. The official policy was based on the Atomic Energy Act which only permitted the US government to contribute to other nations' nuclear weapons capability if the country in question had a mutual defence agreement with United States. This was not the case with neutral Sweden, American officials claimed.

The Swedish inquiries regarding the acquisition of American nuclear weapons took place from 1954 to 1960. Although the American administration adopted a negative attitude towards these Swedish ideas from the beginning it, nevertheless, became a dilemma for the US government. It was considered as a better alternative to equip the Swedish defence with US atomic bombs if the other option was that Sweden otherwise would produce its own nuclear weapons. In the first alternative, the US administration had at least control over the use of the atomic bombs. It would be harder if the Swedes produced their own bombs, concluded experts within the State Department.

Albeit running this risk, the National Security Council (NSC) arrived at the decision in April 1960 that United States should not provide Sweden with nuclear warheads. It was of course in theory possible that the Swedes could develop a nuclear weapons programme by themselves, but it was not held to be likely by the NSC. A Swedish atomic weapons programme would cost too much for a small country like Sweden, the NSC concluded. Furthermore, such a Swedish weapons programme would be dependent on American goodwill and assistance, i.e. certain materials and advanced equipment had to be imported from the United States.

The second finding of this research project considers the extent of international inspections of nuclear materials and reactors in Sweden 1945-1975. From 1960 to 1972, it was only the United States, through the Atomic Energy Commission, who carried out inspections of nuclear materials of US origin.[194]

The third conclusion deals with the nuclear weapons research carried out by FOA and AE. FOA performed an extended research until 1968, when the Swedish Government signed the NPT, which meant the end of these production plans. Up to this date, five

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[194] See Appendix 2, p. 52 in Jonter, Thomas, *Sverige, USA och kärnenergin. Framväxten av en svensk kärnämneskontroll 1945-1995* (Sweden, USA and nuclear energy. The emergence of Swedish nuclear materials control 1945-1995). SKI Report 99:21.

main investigations of the technical conditions were made, 1948, 1953, 1955, 1957 and 1965, which all together expanded the Swedish know-how to produce a bomb.

Was then protection research the only research that was performed? The conclusion of this report is that FOA went further in its efforts to make technical and economical estimates than the defined programme allowed, at least in a couple of instances. The findings in this analysis support the assumption that it was a political game that made the Swedish Government introduce the term protection research to escape criticism, while in practical terms construction research was performed in order to obtain technical and economical estimates for a possible production.

The fourth finding of this research project is that Sweden reached latent capability to produce nuclear weapons in 1955. This is at least two years earlier than what is normally claimed in the international literature on nuclear proliferation. For example, in Stephen M Meyer's classic study "The Dynamics of Nuclear Proliferation", Sweden is said to have reached latent capability in 1957. Meyer's study refers to another study in this respect. An analysis of the declassified documents from FOA concludes that this is at least two years too late.

The fifth result of this project is the review of the de-commissioning of the nuclear weapons research in Sweden after the NPT was signed in 1968.[195]

The sixth result is the account for how much plutonium, natural and depleted uranium and heavy water FOA and AE had at their disposal within the research programme. The result of this investigation concerning FOA is presented in the report *Sweden and the Bomb. Swedish Plans to acquire Nuclear Weapons, 1945-1972*.[196] At the end of this year, the figures of the nuclear materials AE had at its disposal will be published in a SKI report.[197]

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195 *Sweden and the Bomb. Swedish Plans to acquire Nuclear Weapons, 1945-1972.* SKI Report 01:33.

196 Ibid.

197 *Nuclear Weapons Research in Sweden. The Co-operation Between Civilian and Military Research, 1947-1972,* SKI Report 02:18.