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Why did the Breed Reactor Fail?

- Swedish and international nuclear development in a cold war context

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Why Did the Breeder Reactor Fail?

Swedish and international nuclear development in a Cold War Context

by Maja Fjæstad

ABSTRACT

This article discusses the visions about nuclear breeder reactors, plans set out in the aftermath of World War II. This seemed like the ideal solution for future energy, and even small countries, as Sweden, launched breeder reactor programs. The breeder reactor never reached industrial development, interestingly; however, different countries cancelled their breeder project at different times. In this article, in addition to discussing why breeder reactors failed generally, I also suggest possible explanations for the differences in when the reactors failed, particularly between Europe and the United States. Though the breeder reactor never fulfilled its promises, it is an interesting example about the complex mechanisms behind technological development. It tells us a story about a technological failure that is not simple, but must be understood in a social, economical and political context.

The fast breeder is a type of nuclear reactor that aroused much attention in the 1950s and 60s. Its ability to produce more nuclear fuel than it consumes offered promises of cheap and reliable energy, and thereby connected it to utopian ideas about eternal energy. Furthermore, the ideas of breeder reactors were a vital part of the post-war visions about the nuclear future.

But what is a breeder reactor? While there are many types of reactors, including the today common light-water reactor (LWR), the word “breed” described a particular model in which the reactor produces more fuel than it consumes; thereby “breeding” its own fuel. A breeder reactor has a core of plutonium and uranium-238, surrounded by a mantel of uranium-238. The neutrons are not slowed down by a so-called moderator (as in a regular reactor), but left at high speed. Therefore, a breeder reactor is also sometimes referred to as a fast reactor. The emitted neutrons transform the uranium into plutonium, which then can be processed in a reprocessing plant and used as fuel in other reactors. The idea of the breeder reactor was present from the very beginning of nuclear reactors. The first breeder reactor was built already in 1946 in Los Alamos, New Mexico and was called Clementine.[1]

The incentive to build breeder reactors was to a large part the desire to use the uranium in a more efficient way. Breeder reactors can use 80 % of the thermal energy in uranium, compared to about 2 % in the generally used light-water reactors. In the 1940s there was also little knowledge about the magnitude of the world’s uranium resources. In the American nuclear program there was an intention to save the fissile material for military purposes, and in this perspective the use of fuel-saving civilian reactors seemed beneficial.[2]

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[1] Pershagen, Jirlow, Lundell, Vieider, *Snabba bridreaktorer* (Stockholm, 1982), p. 19.
[2] Catherine Westfall, paper presented at SHOT Oct 18 2002 *Heroes and Villains: Movement Narrative and Argonne’s Experimental Breeder Reactor Project.*

The world's second breeder reactor, called EBR-I, started in 1951 at Argonne National Labs in Idaho. It was the first nuclear reactor in the world to actually produce electrical energy, which was used to illuminate the reactor hall. The purpose of EBR-I was to examine the principle of breeding, whereas its successor, the EBR-II was supposed to bring insights about engineering issues. EBR-II was started in 1962 and in the year after, a commercial breeder plant called Enrico Fermi was built in the United States.[3]

An important issue in relation to these reactors was how to cool such a vast power generation. After experiments, liquid sodium was found to be a good coolant. It has good heat conducting properties, and does not slow down the neutrons too much. However, sodium reacts explosively with water and air, and has a tendency to become highly radioactive. Therefore, the technicians were forced to install double circuits of liquid sodium with a heat exchanger in between – a construction that later would lead to several complications.[4]

Sweden, outside of the superpowers, was one of the fairly small countries that gave attention to nuclear power after the Second World War. The first impulse to the Swedish nuclear program came in the fall of 1945 from the Supreme Commander of the Swedish Armed Forces.[5] An "Atoms Commission" was appointed, with a mission to investigate both nuclear weapons and reactors. Later, in 1947, it was decided that the nuclear reactor development would be treated in a separate company, partly state owned and partly private. The Swedish name of this company was "AB Atomenergi", here translated as "The Atomic Energy Co".

In 1949, the Atomic Energy Co made the official decision to build a low-power reactor. The fuel was chosen to be natural uranium moderated by heavy water (water where the hydrogen atom has an extra neutron). To be able to use common water, which can be called light water, to moderate, the fuel has to be enriched uranium. There were two main reasons for the choice of heavy-water reactors. Firstly, national independence and self-sufficiency. There is a considerable amount of natural uranium in the Swedish ores, and heavy water was bought from Norway. Sweden had not been involved in World War II, but, as a neutral country, had well realized the drawbacks of being debarred from import. The second advantage of heavy-water reactors was their production of plutonium. Sweden had at this time, like many other countries, plans of building nuclear weapons. Thus the development of reactors was of interest for energy as well as military purposes. This combination of natural uranium and heavy water was known as "The Swedish Path".[6]

However, extracting uranium required certain time-consuming efforts. In the meantime, an agreement with France was made. Sweden was allowed to borrow three tons of uranium, promising to return the same amount when Swedish production had started.

Many basic facts about neutrons were by this time still unknown in Sweden. International secrecy on nuclear matters was strong, and one of the few written sources was the so-called Smyth-report released by the US in 1945, after the atom bombs. Swedish researchers were forced to experiment and to try to copy what was known about other reactors. Additionally,

[3] *Controlled Nuclear Chain Reaction: The First 50 years* (La Grange Park, 1992), Chapter 2.
[4] Pershagen, Jirlow, Lundell, Vieider, *Snabba bridreaktorer* (Stockholm, 1982), p.41.
[5] The general information about the Swedish nuclear program can be found in for example Karl-Erik Larsson, "Kärnkraftens historia i Sverige", *Kosmos* 64 (1987) or Stefan Lindström, *Hela nationens tacksamhet: Svensk forskningspolitik på atomenergiområdet 1945–1956* (Stockholm, 1991).
[6] Stefan Lindström, *Hela nationens tacksamhet: Svensk forskningspolitik på atomenergiområdet 1945–1956* (Stockholm, 1991).

however, the head the physics department at the Atomic Energy Co made a trip to the United States in the 1940s and managed to receive detailed information about the American reactor CP3.[7]

How was this possible in a time of rigid secrecy? A possible explanation is that good relations to Sweden were important to the United States in the case of war, due to the geographical position of Sweden between East and West. Another possible explanation is the significance of the Swedish supply of uranium. A proof for this is found in a letter from 1946 from C.M. Ravndal at the Legation of the USA in Stockholm. He writes that Scandinavia in ten years could be the politically and economically most important area in Western Europe, and that some sources give at hand that Sweden could produce 120 tons of uranium a year. He ends his letter with “The potentialities in these facts with respect to our policy and attitude toward Sweden are so obvious that I need not comment on them”.[8] Obviously, there was an interest from both sides to cooperate.

It was decided to place the first reactor in a rock shelter close to the Royal Institute of Technology in Stockholm, in what was called “The City of Science”. This was only a couple of miles from the very center of Stockholm, but the risks were not considered to be very great.[9] The reactor came to bear the pragmatic name R1 from “Reactor 1”.

Working in the nuclear field entailed high status, and the social environment of the reactor was one of self-sacrifice, discipline, and masculinity.[10] Working shifts of 27 hours were not unusual.[11] Even though they worked for a (partially government-owned) industrial company, the young men were given the opportunity to write dissertations and acquire Ph.Ds.[12] This persuaded most employees to stay in the company for several years, and the academic publications also facilitated contacts with international organizations and universities. Reactor 1 became a piece of national pride, a symbol for the progress of Sweden and an important triumph for the Social Democratic party. The King visited its grand opening ceremony, and the Nobel Prize winner in physics of each year came to visit.[13] Postcards of the reactor were printed, and it was portrayed in popular magazines.[14] The glorification of the reactor was, of course, an advantage for the company in attracting competent personnel.

In 1955, the conditions suddenly changed. A conference was held in Geneva, called “Atoms for Peace”, by initiative of the American president Dwight D Eisenhower and as a result of years of discussions about how to handle the issues of nuclear proliferation.[15] The hope was to gain better control over nuclear proliferation through peaceful cooperation. At the

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[7] Interview with Karl-Erik Larsson 22/9 2000.
[8] Letter from C.M. Ravndal, the Legation of the United States of America, to Hugh S. Cumming, Division of Northern European Affairs, Department of State, Washington, D.C. RG 59 Subject files 1941-53, box 18. National Archives, Washington.
[9] Karl-Erik Larsson, ”Kärnreaktorn R1 – ett stycke högteknologisk pionjärhistoria, *Daedalus* (1989), p. 109.
[10] See discussion in Maja Fjæstad, *Sveriges Första Kärnreaktor: från Teknisk Prototyp till Vetenskapligt Instrument*. SKI-rapport 01:1 (Stockholm, 2001), p. 32.
[11] Interview with Karl-Erik Larsson 9/5 2000.
[12] Karl-Erik Larsson, *Vetenskap i kärnkraftens skugga* (Stockholm, 2000), p. 45.
[13] Interview with Karl-Erik Larsson 9/5 2000.
[14] ”Den svenska atomreaktorn”, *Teknisk tidskrift* 28 June 1955 (signature SHI), and for example ”Sverige får atomreaktor om några år”, *Svenska Dagbladet* 22 September 1949, ”Teknikens jättar och pygmeer” *Svenska Dagbladet* 24 September 1952, ”Stockholms uranmila färdig i bergvalv” *Dagens Nyheter* 8 August 1953 (signature ”answer”).(From the archive at Tekniska Museet, 2590:a.)
[15] See in depth discussion in John Kriege, “Atoms for Peace, Scientific Internationalism, and Scientific Intelligence" *Osiris* 2006 21:1, p. 161-181.

conference, different countries shared information about nuclear reactor development, workshops were held and papers published. Suddenly, scientific and technological facts about the interesting elements were shared freely between the scientists.

As mentioned, the Swedish reactor program was from 1947 formally separated from the military and handled in a special corporation. There was, however, an agreement about sharing information. The Military ordered a couple of reports from the Atomic Energy Co during the 1950s and 60s.[16] The question of Swedish nuclear weapons was long kept open. The Government undertook the research on this topic with it being needed for both reactors and weapons, and thereby postponed the decision. There was an animated debate in the media about Swedish nuclear weapons and the possible benefits this would render to a small, neutral country. In the beginning of the 1960's, it was more and more clear that Sweden would choose not to build nuclear weapons, although the formal decision was not made until 1968.[17]

Much of the fundamental research was performed at the Atomic Energy Co, with money from the Government. Even though the research was not directly aimed at developing nuclear reactors, it was considered important, since one of the aims with the work was to create know-how in nuclear matters.[18] Also, at this time, there was a strong belief in the linear causal relationship between basic research and industrial development. This conviction gave the individual scientists a sizable freedom in choosing their own research projects, and as long as the experiments were successful they received grants for them.

This could also be associated to an intention of building up scientific expertise and competence in Sweden, also partly for military purposes. It was important to have this kind of knowledge within the country. The education of physicists and the increasing numbers of Ph.D. students in post-war America have earlier been discussed by Dr David Kaiser. He describes how certain rhetoric connected the production of physicists with potential weapon-makers and cold war manpower – even though most physicists did not work with weapon-related issues. Dr Kaiser describes how the number of Ph.D.s granted in physics in the US doubled every seven years in the period 1945-71. In Sweden, the "modern" physical topics as nuclear physics took long time to enter the relatively conservative universities. But instead, there were Ph.D.s produced at the Atomic Energy Co, even though academic work in the industry was unusual by this time. Also, the cooperation between the Atomic Energy Co and the Military can be understood in terms of seeking to develop new expertise. There simply weren't enough people in the country with knowledge about nuclear physics to be able to separate civilian and military development.

The Atomic Energy Co, together with the power industry, planned a Swedish reactor program with a material-testing reactor, and several heat and energy producing heavy water reactors on an industrial scale. To return to our original topic, there was, however, also from the beginning visions of Swedish breeder reactors.

There were several reasons for the Swedes to invest in breeder reactors. The breeders would fit in well in the "Swedish path", since the heavy water reactors produced plutonium that could be used as fuel in the breeder reactors. There were also plans for a waste-fuel cycle with

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[16] *FOA och kärnvapen*, documentation from a seminar November 16 1993 (FOA VET nr 8), p. 151.
[17] Karl-Erik Larsson, "Kärnkraftens historia i Sverige", *Kosmos* 64 (1987), p. 150.
[18] For example expressively stated in "Verkställande Direktörens redogörelse för verksamheten inom AB Atomenergi under 1950" April 26, 1951, enclosure to board proceedings by Harry Brynielsson, p. 7. Studsvik's archive.

a reprocessing plant. The plant would be working on the waste of both the heavy-water reactors and the breeder reactors. It could also be used in extracting plutonium for possible Swedish nuclear weapons. Another reason for Swedish breeder reactors was national independence. The Swedish uranium supplies are of low concentration and could only be mined very slowly. [19] Therefore, it was important to have reactors that were using as little fuel as possible.

The optimism about the fast breeder reactors was notable. In an official report from the government in 1956, breeder reactors were called "the solution for future energy", and Sweden believed it would have a breeder reactor by 1965.[20] The heavy water reactors were seen only as a step towards these new and more sophisticated reactors.[21]

To start the development towards industrial breeder reactors, it was important to build a research reactor. The researchers wanted to apply and adjust mathematical models as well as studying the properties of fast neutrons. Another reason was that the neutrons in an atomic bomb are moving at high speed, and therefore a breeder reactor and its fast neutrons could bring insights in the matter of nuclear weapons.[22] The military was also engaged in building a fast reactor. A study group was formed in the mid 1950s, and a prototype reactor named FR-0 was built in 1964.[23]

In many cases it was the same men that had built R-1, though not quite as young any more, that built FR-0. After R-1, the nuclear business was not quite as "pioneering". The role of the physicists had become less significant. Perhaps the breeder reactor program gave physicists a new field to work on in, and a new and most welcome pioneering task.

For the future of breeder reactors and for the expected industrial introduction, the Atomic Energy Co started a project together with the Swedish power company ASEA – now known as ABB – to study electricity-producing reactors.[24] Much of the focus was on profitability. Since the price of uranium was expected to rise, the breeder reactors were expected to become more profitable than the heavy water reactors, in spite of the fact that breeders were more expensive to build, due to the complicated technology.[25] There were discussions both on developing Swedish commercial breeder reactors, as well as buying them from abroad. The two countries that were considered most interesting to work with on an industrial level were Great Britain and France.[26]

A complicating factor was that Sweden was and is a neutral country, outside the military alliances. This was not appreciated by the NATO countries, which sometimes refused to cooperate with Sweden with the intention that to force Sweden to join NATO. However, it is obvious that Sweden cooperated more with western countries than with the Soviet Union. For example, Malte Jacobsson, chairman of the Swedish Atomic Energy Commission, in 1952 informed the American AEC that "while the Swedish Government had an official policy of

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[19] "PM beträffande förslag till handlingsprogram för arbetet med snabba bridreaktorer" November 25, 1969 p. 3. Studsvik's archive 48:16 ("Diverse tekniska rapporter beträffande R1 R2 R2-0 brid snabb 1965-1970").
[20] SOU 1956:11 *Atomenergien,* p. 17.
[21] Stefan Lindström, *Hela nationens tacksamhet.* (Stockholm, 1991), p. 100.
[22] Interview with Bengt Pershagen 17/1 2002.
[23] Pershagen, Jirlow, Lundell, Vieider, *Snabba bridreaktorer* (Stockholm, 1982), p. 27.
[24] Pershagen, Jirlow, Lundell, Vieider, *Snabba bridreaktorer* (Stockholm, 1982), p. 27.
[25] Margen&Nilson (1970) "Snabba reaktorer", *Atomenergis verksamhetsberättelse 1970,* p. 18.
[26] "PM beträffande förslag till handlingsprogram för arbetet med snabba bridreaktorer" November 25, 1969 p. 3. Studsvik's archive 48:16 ("Diverse tekniska rapporter beträffande R1 R2 R2-0 brid snabb 1965-1970").

neutrality, that quite naturally scientists favored cooperation with the U.S. and had strict security controls over their present program in light of the proximity of the Soviet Union."[27] This is just one example from a large research field, and it is the matter of discussion among of Swedish historians if Sweden was breaking its neutrality on a number of occasions when it cooperated with NATO.[28]

Knowledge exchange mostly took place with the United States. Several young researchers spent a year or a semester at Los Alamos or Argonne National Labs. The cooperation was made in a very informal and unofficial manner, probably in part because of the implications of Swedish neutrality.[29] In a document from 1952, the Americans describe the relations with Sweden in the field of atomic energy as "cordial informal".[30]

The time for the entry of industrial breeder reactors in Sweden was put off later and later in the future. In the mid-1960s, the starting year mentioned was 1985.[31] FR-0 was closed in 1971, since the Atomic Energy Co considered the experiments finished.[32]

During the 1960's, the development of commercial heavy water reactors had started.
A heat-producing reactor had been constructed in Sweden in 1963. The next project was a nuclear power plant, called Marviken. But there were problems with Marviken as cost overruns and growing criticism both from technical experts and from politicians. Finally, even the management of the Atomic Energy Co had to admit that the plant did not fulfill the necessary safety requirements and the project was brought to an end in May 1970. In order to make use of the electrical equipment, an oil furnace was installed, and Marviken came to be known as the first oil-fired nuclear reactor in the world.[33]

The United States had by this time begun to export enriched uranium at a low price, in order to get better control over international nuclear matters.[34] This, together with technical problems with the heavy-water reactors, made the Swedish government abandon the "Swedish path" for a combination of light water and enriched uranium. In 1971, the first industrial nuclear power plant with light water was started in Sweden.

This did not end the dreams about breeder reactors. Other European countries were also working on their programs. Great Britain, France, Italy, Holland, Belgium and Germany also had breeder reactor programs. A notion of how important this was considered to be comes from the fact that these countries in the middle of the 1960s spent half of their government financed nuclear power budget on their breeder programs respectively.[35]

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[27] "Atomic Energy Commission, Visit of Malte Jacobsson, Chairman of the Swedish Atomic Energy Commission. Note by the secretary". Oct 15, 1952. RG 326 AEC Secreatary's general correspondence 1951-58, box 131, research&development 1, Sweden. National Archives, Washington.
[28] See for example in Mikael Nilsson, *Tools of hegemony: military technology and Swedish-American security relations 1945-1962* (Stockholm, 2007).
[29] Interview with Bertill Lundell 24/7 2002.
[30] "Atomic Energy Commission, Visit of H.A.B. Brynielsson. Memorandum by the chief of Special Projects", 1952, page 3. RG 326 AEC Secreatary's general correspondence 1951-58, box 131, research&development 1, Sweden. National Archives, Washington.
[31] Margen&Nilson (1970) "Snabba reaktorer", *Atomenergis verksamhetsberättelse 1970*, p. 22.
[32] AB Atomenergis verksamhetsberättelse 1971, p. 5.
[33] Kaijser, Arne, "From the tile stoves to nuclear plants – the history of Swedish energy systems" in: Silveira (ed), *Building Sustainable Energy Systems: Swedish Experiences* (2001), p. 57-93.
[34] Karl-Erik Larsson, "Kärnkraftens historia i Sverige", *Kosmos* 64 (1987), p. 136.
[35] Margen&Nilson (1970) "Snabba reaktorer", *Atomenergis verksamhetsberättelse 1970*, p. 18.

Eventually, the breeder reactor programs ran into problems. The technical difficulties, for example sodium cooling, were not solved as easily as it had been expected. In America, EBR-I suffered a partial fuel meltdown in 1955. The Fermi reactor near Detroit had a partial core meltdown in 1966. This aroused questions of the safety of breeder reactors.[36]

In the United States, President Jimmy Carter initiated a debate about breeder reactors. He was opposed to them on the grounds of plutonium handling and the fear that this would increase the risk of nuclear proliferation.[37] That standpoint of one of the most important actors made the rest of the world cautious. The peace movement, including, for example, Pugwash, was also opposed to breeder reactors and plutonium production in general.[38] The general skepticism of large technological projects in 1970s also viewed the breeder projects, and nuclear power in general, as destructive.

Another reason for the fading popularity of the fast breeders were that the price of uranium did not continue to rise as expected, much due to new deposits of uranium being found, particularly in Africa. Neither the arguments of saving natural resources nor the claim of profit would speak strongly enough for uranium efficient breeder reactors any more. Now, the higher cost of building a breeder power plant would not be compensated by lower costs of uranium.

Europe was for a long time optimistic about the development of breeders. Great Britain was an early developer of the breeder. They constructed the fast reactors ZEPHYR and ZEUS already in 1954 and 1955. The larger Dounreay reactor was put in operation in 1959. Also, the Soviet Union started its first fast reactor in 1956 in Obninsk. A breeder reactor that arose much attention was constructed in 1973 by the Caspian Sea and was used to desalinate sea water. France and West Germany both built fast reactors in 1966, but the future development was more advanced
in France. Some of the reasons for this might be the difficult permissions process in Germany, and that there was more public approval in France.[39] Germany and EURATOM also participated in the SEFOR project in Arkansas, USA. Germany had plans or a large breeder plant called SNR 300, but this project was terminated in 1991.[40] The IAEA also had a group for breeder reactors, the IWGFR, International Working Group for Fast Reactors, established 1967.

France was the country that developed breeder reactors furthest. They had a very ambitious program, and 1986 they built the breeder power plant “Supér-Phenix” on 1 240 MW. There were plans of five such power plants, but because of economical and technical problems these were never realized. Supér-Phenix was shut down in 1989.[41]

The development in France has been treated by Dr Gabrielle Hecht.[42] She describes a scenario in conflict between the proponents of importing American light-water reactors and those in favor of nationally developed gas-graphite reactors. In this context, the breeder

[36] Pershagen, Jirlow, Lundell, Vieider, *Snabba bridreaktorer* (Stockholm, 1982), p. 21-23.
[37] Pershagen, Jirlow, Lundell, Vieider, *Snabba bridreaktorer* (Stockholm, 1982), p. 200.
[38] *Nuclear reactors : to breed or not to breed : a Pugwash debate on fast breeder reactors held at the Royal society, London, on 28 September 1976 under the chairmanship of Sir Alec Merrison* / ed. by J. Rotblat.
[39] Willy Marth, *The story of the European fast reactor cooperation*, KfK 5155 (Karlsruhe, 1993), p. 19.
[40] Bengt Pershagen, m.fl., *Snabba bridreaktorer* (Stockholm, 1982), p. 21.
[41] Pershagen, Jirlow, Lundell, Vieider, *Snabba bridreaktorer* (Stockholm, 1982), p. 198.
[42] Gabrielle Hecht, “Technology, Politics, and National Identity in France. In: (ed) Michael Thad Allen and Gabrielle Hecht, *Technologies of power.*

reactor became a symbol of the future technological development, and even sometimes for a socialist future in contrast to American imperialism.[43] The fact that the American breeder program wasn't very developed would make it easier to view the breeder reactor as a tribute to French technological glory.

An important project was the EFR, the European Fast Reactor. This was a cooperation between France, Germany, Italy, Belgium, the Netherlands and the United Kingdom. It was launched in 1970 with a meeting between France, Germany and Italy. Great Britain joined the cooperation in 1984 with certain conditions. They wanted the cooperation to be more than support to a French reactor as Super-Phénix; they wanted a European reactor. They also did not want to pay an entrance fee.[44] The plan was that the EFR was supposed to combine the lessons from the French Super-Phénix, the German SNR2 and the British CDFR.[45] The important siting decision was supposed to be taken in the so-called pre-construction phase that was planned to 1993-1997. The construction phase was supposed to take place in the years 1997-2005.[46]

When the national breeder projects started to have problems, the governments' enthusiasm to be a part of a large European project started to decrease. The EFR was phased out around 1993, together with the general scepticism about breeders.

When the international enthusiasm for breeder reactors cooled off, Sweden decreased the governmental support for the breeder program. The opposition against breeder reactors and nuclear energy grew stronger.

In 1979, a decision was made to have a national referendum in order to settle Swedish nuclear energy policy, and it was held in 1980. It resulted in a plan to phase out Swedish nuclear power by the year 2010, which thereafter has been under intense debate.

Today, fast reactor systems are a research topic for fuel processing, so-called transmutation, but the idea of breeder reactors is mostly dead in Europe (there are, however, breeder reactors being constructed in Asia, so whether the breeder is approaching a new future might be a question left open).

The story of the fast breeder reactors is a story about a technology embraced by large enthusiasm, which never realized its expectations, at least in the expected time-frame. The reasons for this are many. Partly, it was technical problems, as those with cooling and safety. There were also economical difficulties since the price of uranium did not develop as expected. There were military implications: the problems of handling and transporting plutonium. Also, there were social or ideological complications, since public opposition rose against breeder reactors. The political consequences were that the financial support from the governments disappeared.

Was the breeder reactor a technological failure? The answer is not self-evident. For the researchers that worked in the development, the breeder reactor filled many of its intended functions. It did create more fissile fuel than it used. And, on another level, it helped them to get a lot of funding for basic research in nuclear physics. On the other hand, for the politicians

[43] Ibid, p. 280.
[44] Willy Marth, *The story of the European fast reactor cooperation*, KfK 5155 (Karlsruhe, 1993), p. 34.
[45] Willy Marth, *The story of the European fast reactor cooperation*, KfK 5155 (Karlsruhe, 1993), p. 56
[46] Willy Marth, *The story of the European fast reactor cooperation*, KfK 5155 (Karlsruhe, 1993), p. 60-61.

it was a failure because in spite of the large sums invested in research, there was no industrial development. My conclusion is that the breeder reactor can be said to be a scientific success, and to a fair amount a technical success, but a political failure.

Was it a painful failure for the Swedes? Maybe not, since the plans of breeder reactors never became very advanced in Sweden. But this also has to be discussed in the larger context of the dreams of Swedish atomic energy in general and the shift from heavy-water to light-water reactors. As indicated above, this is connected to the delicate issue of the interplay between science and nationalism. Developing advanced reactors can be interpreted as a way for a small country to manifest their national independence. Maybe the question is not at all why the breeder reactor failed, but why didn't it fail earlier? Why did some countries pursue the trials with the elusive breeder?

Alexi Assmus writes in "The Americanization of molecular physics" about how the American physicists in the 1920s, before the immigration of German scientists and before the connection between the war and nuclear physics, chose to specialize in molecular physics since the European scientists already had become so successful in atomic physics.[47] Maybe there is a possibility to reason around the suggestion that European countries continued to work on the breeder since the Americans didn't. This is somewhat motivated by some of the rhetoric around the EFR, The European Fast Reactor. The main objective of the EFR, as discussed above, was to combine the insights from different breeder projects in a common European reactor. Important analyses gave at hand that the European breeder R&D budgets would exceed the American.[48] One can note that the EFR was phased out around 1993, which can still be considered to be notably late. My analysis is not elaborated in this case, but I do not think that it is possible to understand this development without referring to the different events in America.

[47] Alexi Assmus, "The Americanization of molecular physics," *Historical Studies in the Physical and Biological Sciences* **23** (1992): p. 1-34.
[48] Willy Marth, *The story of the European fast reactor cooperation*, KfK 5155 (Karlsruhe, 1993), p. 54.

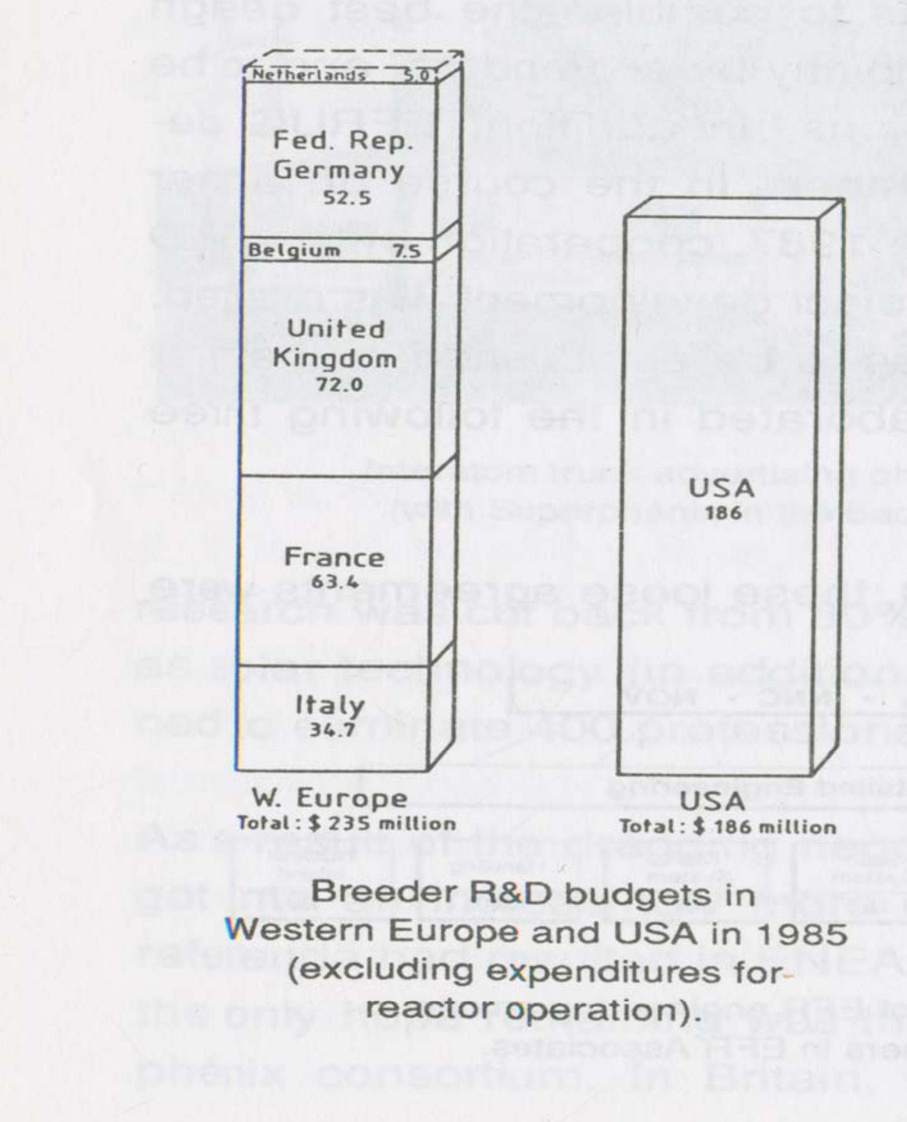

Figure 1. Comparison between European and American Breeder R&D budgets.[49]

An agreement from 1956 for cooperation between the US and Sweden concerning civil uses of Atomic energy starts with the phrase "Whereas the peaceful uses of atomic energy holds great promise for all mankind".[50] This can be considered to summarize the dreams about the breeder reactor. The reactor, sometimes described as something similar to a perpetual motion machine, would bring heat and power to society at a low cost. These visions were a motive for international cooperation – something that was also motivated by the fears of its evil cousin, the atomic bomb.

The breeder reactor never fulfilled its promises. But it is still an interesting example about the complex mechanisms behind technological development. It tells us a story about a technological failure that is not simple, but must be understood in a social, economical and political context.

[49] Willy Marth, *The story of the European fast reactor cooperation*, KfK 5155 (Karlsruhe, 1993), p. 54.
[50] "Agreement for cooperation between the government of the United States and the Government of Sweden concerning civil uses of atomic energy" Jan 18, 1956. RG 326 AEC the secretary's general correspondence 1951-1958, R&D Sweden, box 137. National Archives, Washington.