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The Story of the European Fast Reactor Cooperation

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Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE

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Abstract

The Story of the European Fast Reactor Cooperation

This report is a condensed history of European cooperation in the large breeder power plants with powers in excess of 1000 MWe. The beginning, in 1973, was marked by the so-called Utilities' Convention signed by EdF, RWE, and ENEL on the construction of Superphénix and SNR 2. In 1977, cooperation began among the reactor vendors and R&D organizations in France, Germany and Italy as well as Belgium and the Netherlands. After the British had joined in 1984, planning for the European Fast Reactor, EFR, was started in 1988. The conceptual design phase of the 1500 MWe breeder power plant covered a period of five years and was concluded with an economic assessment and a technical safety analysis of EFR in 1983. A number of ongoing studies are being conducted within a specific EFR program.

Kurzfassung

Geschichte der europäischen Zusammenarbeit
beim Schnellen Brüter

Der Bericht schildert die Geschichte der europäischen Zusammenarbeit bei den großen Schnellbrüteranlagen mit einer Kraftwerksleistung über 1000 MWe. Sie begann 1973 mit der Unterzeichnung der sog. EVU-Konvention zwischen EdF, RWE und ENEL zum Bau von Superphénix und SNR 2. 1977 kam es zu einer Kooperation der Reaktorhersteller und F+E-Organisationen in den Ländern Frankreich, Deutschland und Italien, sowie Belgien und den Niederlanden. Nach dem Beitritt der Briten (1984) wurde 1988 mit der Planung des European Fast Reactors EFR begonnen. Die technische Konzipierung dieses 1500 MWe Brüterkraftwerks erstreckte sich über 5 Jahre und wurde 1983 mit einer wirtschaftlichen Bewertung und sicherheitstechnischen Analyse des EFR abgeschlossen. Einige nachlaufende Studien werden im Rahmen eines gesonderten EFR-Programms fortgeführt.

Outline

1. **An Encouraging Start**

   (1971-1984)

2. **A Thorny Path to the Common Model Breeder**

   (1984-1989)

3. **The EFR Conceptual Design Phase**

   (1988-1990)

4. **The EFR Concept Validation Phase**

   (1990-1993)

5. **The End of the EFR Project**

   (1992-1993)

Content

Preface

The history of European cooperation in large breeder plants with powers in excess of 1000 MWe begins in 1973, when the so-called Utilities' Convention was signed. This triggered the construction of Superphénix and the planning of SNR 2. 1977 saw cooperation beginning among the vendors and the R&D organizations in France, Germany, Italy, and in Belgium and the Netherlands; the United Kingdom joined soon. A particularly important milestone is constituted by the agreements on the European Fast Reactor of 1989. Under the leadership of EFRUG, the utilities' consortium, the vendors' consortium, EFR Associates, was commissioned to plan EFR, a 1500 MWe breeder power plant. The R&D organizations in France, Germany, and the United Kingdom agreed to back the project by contributing research findings.

This report is a chronicle of these phases of European breeder cooperation. It ends with the completion of the second phase of the EFR project.

Many colleagues, whom I would like to thank, have helped me in collecting and presenting these events. Special thanks are due to Mr. Ralf Friese of the Karlsruhe Nuclear Research Center for his translation into English of my report. I am also greatly indebted to my secretary, Ms. Ruth Klausmann-Stern, who not only typed the script, but also compiled the extensive list of references.

Cooperation in the European breeder projects has been an experience which has greatly influenced me and, I am sure, many of my colleagues and friends.

It is for this reason that I
dedicate
this report to all my colleagues who participated in EFR
and the other large breeder projects.

We owe them gratitude, and this report is a tribute to their achievements.

Dr. Willy Marth

Vorwort

Die Geschichte der europäischen Zusammenarbeit bei den Großbrüteranlagen über 1000 MWe Leistung beginnt 1973 mit der Unterzeichnung der sog. EVU-Konvention. Sie war das Signal zur Errichtung des Superphénix und für die Planung des SNR 2. 1977 kam es zur Zusammenarbeit auf Seiten der Hersteller und der F+E-Organisationen in Frankreich, Deutschland, Italien sowie Belgien und den Niederlanden, der bald danach auch die Briten beigetreten sind. Einen besonders wichtigen Meilenstein bildeten die Abkommen zum European Fast Reactor im Jahre 1989. Unter der Führung des EVU-Konsortiums EFRUG wurde der Herstellerverbund EFR Associates mit der Planung des EFR, eines 1500 MWe Brüterkraftwerks beauftragt. Die F+E-Organisationen in Frankreich, Deutschland und Großbritannien verpflichteten sich zur Absicherung des Projekts durch Beistellung von Forschungsergebnissen.

Dieser Bericht zeichnet die genannten Etappen dieser europäischen Brüterzusammenarbeit nach und endet mit dem Abschluß der zweiten Phase des Projekts EFR.

Bei der Zusammenstellung der Ereignisse haben mich viele Kollegen unterstützt, bei denen ich mich nachdrücklich bedanken möchte. Besonderer Dank gebührt Herrn Ralf Friese vom Kernforschungszentrum Karlsruhe, der die Übertragung ins Englische besorgt hat. Recht herzlich bedanke ich mich auch bei meiner Sekretärin Frau Ruth Klausmann-Stern, der nicht nur das Schreiben des Manuskripts sondern auch die umfangreiche Erstellung des Literaturverzeichnisses oblag.

Die Zusammenarbeit bei den europäischen Brüterprojekten war für mich und sicherlich auch für viele meiner Mitarbeiter und Freunde ein prägendes Ereignis.

Ich möchte deshalb diesen Bericht all meinen Kollegen
widmen
die am EFR und den übrigen Großbrüterprojekten mitgewirkt haben.

Ihnen allen gebührt Dank; dieser Bericht soll ihre Verdienste festhalten.

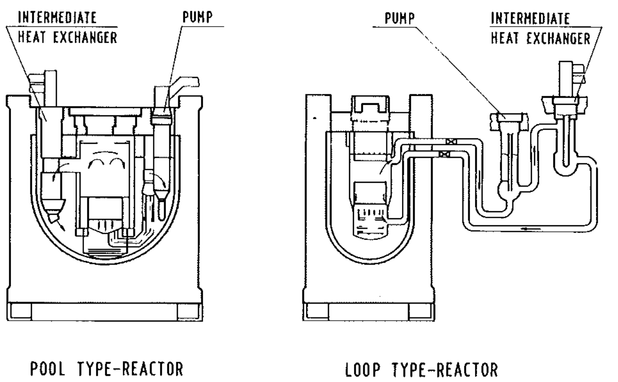
Dr. Willy Marth

1 An Encouraging Start

1.1 The Utilities' Convention

The electricity utilities initiated European fast breeder cooperation.

As early as in 1970, representatives of the French Electricité de France (EdF), the German Rheinisch-Westfälisches Elektrizitätswerk (RWE), and the Italian Ente Nazionale per l'Energia Elettrica (ENEL) met to explore the possibilities of drafting joint purchasing contracts for fast breeders in the power category around 1000 MWe. If one bears in mind that the 250 MWe Phénix reactor in Marcoule in France was just under construction at that time, and the German SNR 300 had barely entered into its planning phase, this approach by the electricity utilities marked a step into a distant future.



Arrangement of components in pool and loop-type reactors.

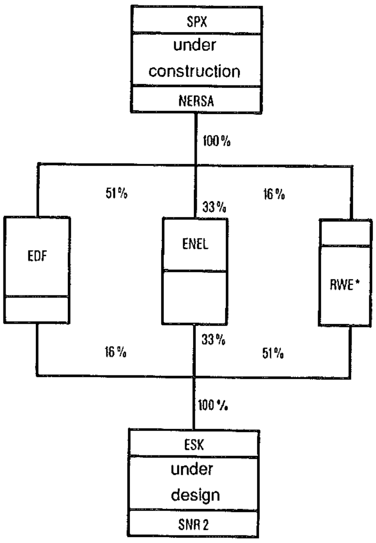
Negotiations proceeded smoothly, and a written letter of intent about the joint purchase and operation of two breeder reactors of 1000 MWe each was signed already in July 1971. The first plant was to be built in France in 1974/75, i.e. approximately one year after the scheduled commissioning date of the Phénix reactor and, like that plant, was to have a primary system designed in the so-called pool configuration. The second breeder, a loop-type plant, was to follow in Germany in 1977/78, where RWE was still hoping at that time to commission SNR 300 in 1976.[1]

A few months later, the Technicatome reactor engineering company was established on the French side, mainly as an offshoot of the Reactor Construction Division of the Commissariat à l'Energie Atomique (CEA). It was owned by CEA (90%) and EdF (10%), managed by Remy Carle, and commissioned to draft a planning study of the French large breeder reactor on behalf of the privately owned Groupement Atomique

Alsacienne Atlantique (GAAA), a company already engaged in the Phénix project as architect-engineer.

Yet, it took until 1973 for the agreement on cooperation among the electricity utilities to be signed. The main reason for the delay was the difficulty the two state-owned power utilities, EdF and ENEL, experienced in establishing international operating companies under private law, which they were barred from doing under their statutes. They first had to seek the agreement of their governments. In Italy, which passed through a number of government crises at that time, that permit took quite a while to come forth.

On December 28, 1973, EdF, ENEL, and RWE at long last signed the so-called Utilities' Convention on the joint purchase and operation of the two Superphénix and SNR 2 breeder power plants of (now) 1200 MWe.[2] In July 1974, Centrale Nucléaire Européenne à Neutrons Rapides S.A. (NERSA) was founded as a company under French law, with its headquarters in Paris, to manage the French Superphénix project. Its opposite number, Europäische Schnellbrüter-Kernkraftwerksgesellschaft mbH (ESK), a company under German law with its headquarters in Essen, was to manage SNR 2. The majority partners holding 51% each were EdF in the case of NERSA, and RWE in the case of ESK. The minority partners in each case held 16%; ENEL held 33% in each project. The RWE holdings in NERSA and ESK later were transferred to SBK, thus allowing Belgian (Electrabel), Dutch (SEP) and British (NE) partners to join. As the delivery contract for SNR 300 had been concluded in the meantime, and as it contained a provision for commissioning the plant in 1979, the start of construction of SNR 2 was not to be expected before 1980.[3,4,5]



* RWE's share was taken over by SBK in 1975 (70% RWE).

European fast breeder cooperation under the utilities' convention of 1973.

The French-German-Italian operators' consortium had no comparable group as its opposite number on the vendors' side. There were, however, consortial agreements between Nucleare Italiana Reattori Avanzati (NIRA) and the French planners and vendors mentioned above, based on licensing agreements and an R&D contract, for a term of fifteen years, between CEA and the Italian Comitato Nazionale per l'Energia Nucleare

(CNEN). The German reactor vendors, Kraftwerk Union (KWU) and its subsidiary, INTERATOM, were not included, although they would have been quite willing to join the consortium of Superphénix vendors.[6,7]

The reason, in addition to a slight hesitancy on the French side, was the express desire of the German partner, RWE, to avoid a monopoly on the vendors' side. Against the backdrop of the quasi-monopoly KWU held in light water reactor power plants in Germany, the decision had been taken to prevent a similar development in the breeder field. "All we want is competition," RWE Executive Board member Heinrich Mandel is quoted to have said in an interview by "Nucleonics Week."[8] However, RWE then saw to it that 16% of the delivery volume of Superphénix was earmarked for German suppliers. For various reasons, though, that percentage was never fully exploited.

1.1.1 Breeder Reactor Experiences in France and Germany

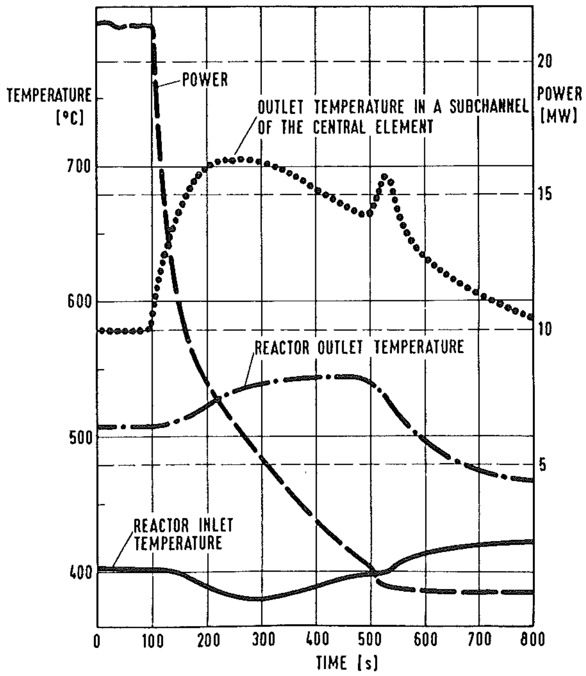
Let us now take a look at the experiences with smaller breeder reactors existing in part in France and Germany. Those experiences had to be taken into account by the utilities unless unacceptable risks were to arise to the planned large breeders. In the interest of presenting a compact outline, the breeder-related research program in the seventies will not be covered, and only the status of the national reactor plants, Rapsodie/Phénix and KNK/SNR 300, respectively, will be described.

France: Rapsodie - Phénix

Unimpeded by any political consequences of the war, France was able to embark on breeder research early on. The first sodium experiments were run in 1953. From that date on, the Cadarache Research Center worked specifically on plans for a small sodium-cooled experimental breeder called **RAPSODIE**. After the partial meltdown of the Mark II metal core load in the American EBR I Experimental Power Plant in November 1955, Rapsodie was equipped with an oxide core and with safety systems able to withstand mechanical energy releases of up to 250 MJ in a Bethe-Tait accident. The reactor, incidentally a loop design, went critical in 1967. Three years later, its power was raised from 24 to 40 MWth to achieve a higher neutron flux for irradiation.[9]

In its nearly fifteen years of operation the Rapsodie reactor attained the high availability of more than 2700 full-load days. Throughout its life it was used to irradiate a large number of materials and fuels, especially for the follow-on model, Phénix, but also, for a fee, for the early Karlsruhe breeder program.

In 1978, the Rapsodie reactor vessel developed a microcrack through which approximately 10 grams of sodium escaped over a period of one year. When the small leak remained undetected and, four years later, a major nitrogen leak in the double tank occurred, the decision was taken in 1983 to decommission and dismantle the plant.

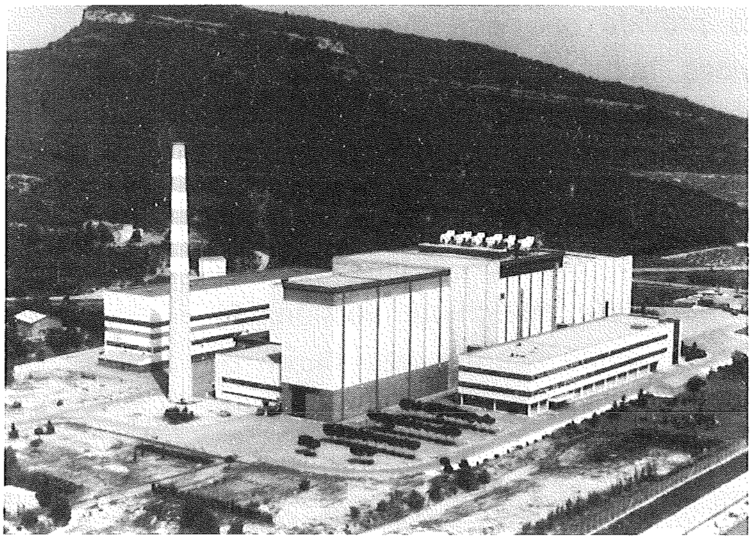


Rapsodie end-of-life test:
unprotected pump coastdown.

Prior to final decommissioning, however, a number of transient experiments to verify the dynamic properties of the reactor were conducted which won worldwide recognition. The positive safety characteristics which, so far, had only been assumed from theoretical calculations, were confirmed in the most convincing way. For instance, in a simulated complete power failure case without the absorber rods dropping, the reactor shut down automatically and the plant consequently changed into the safe operating status.

Construction of the next plant, the **PHENIX** breeder power plant of 250 MWe, was begun in late 1968. Again, CEA was the builder and operator, and Georges Vendryes, head of the French breeder development, was the prime mover. The site was to be Marcoule on the Rhône River, not far from the famous vineyards of Châteauneuf-du-Pape. After almost five years of construction, with a maximum of 700 persons working on the building site, the plant went critical for the first time in August 1973 and was connected to the power grid at its rated power as early as in April 1974. The overall construction cost, the fuel not included, amounted to FF 620 million, which meant that the original estimate had been exceeded by less than 10%.

Over its first ten years, which will be briefly sketched below, the Phénix plant achieved an excellent operating record. Despite some faults to be discussed below, the average load factor between 1974 and 1984 attained the surprisingly high level, for a prototype, of almost 60%.[10]



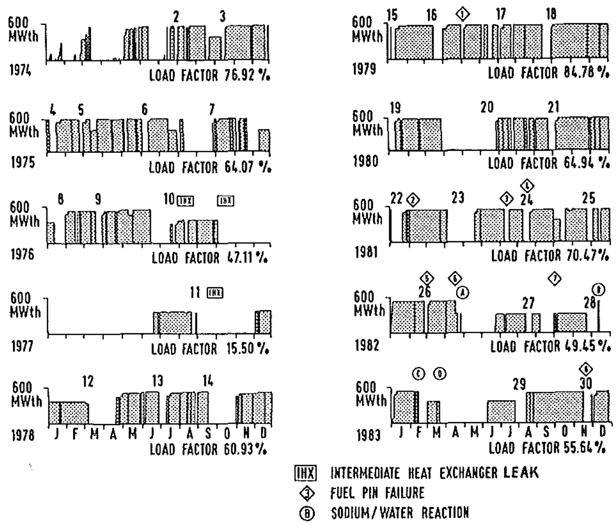
Phénix fast breeder plant in Marcoule.

After nearly two years of smooth operation, cracks were detected in 1976 in several welds of the cover plates in the top part of the intermediate heat exchangers, which caused secondary sodium to leak out. The decision was taken to replace successively the six units, which were identical in design. Repairing the heat exchangers took eighteen months, in which the reactor was operated mostly at part load. After washing and decontamination, the large units had a residual radiation level of less than 10 mrem, which greatly facilitated repair work. It is for this reason that the personnel engaged in that intervention were exposed to the surprisingly low total dose of only 14 man-rem.

The second major defect arose in 1982/83, when four consecutive sodium-water interactions occurred in the reheaters of the steam generators as a result of materials fatigue at a point subjected to particularly high loads. Thanks to the modular design of the steam generators it was possible to repair these defects at relatively short notice, thus preventing them from having a major impact on the availability of the power plant.[11]

In the ten years covered in this review, Phénix suffered only eight fuel element cladding failures, mainly with experimental subassemblies. Thanks to the excellent localization system it was possible to identify the faulty elements within 5 - 10 minutes. Replacing the elements detected in this way by fresh ones merely took some 50 hours of reactor downtime. As a consequence, rod defects in Phénix had but little influence on the availability and operating record of the plant. In the interest of reprocessing the spent fuel elements it was decided in October 1978 to enlarge the existing SAP reprocessing plant by the TOR head end. The new plant had a throughput of 5 tons per year and was able, as a consequence, to provide back-end fuel cycle services both for Phénix and for the Karlsruhe KNK II plant.[12]

The Phénix reactor turned out to be so successful that CEA at times planned a 450 MWe stretch-out version. Although some interest was shown by Japanese, Indian, and American electricity utilities, the plans came to nothing.



Phénix operating histogram 1974-1983.

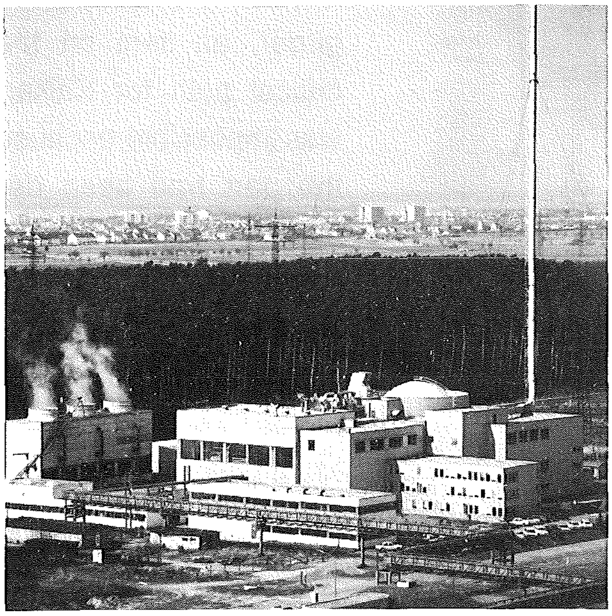
Germany: KNK - SNR 300

The German Breeder Program differed markedly from the French one; its timing was different from the outset, it was managed differently, and it was much more subject to political influences and other factors.

Up until 1955, the Allied powers of the Second World War had barred the Federal Republic of Germany from doing any work in the nuclear field. After Germany had regained its sovereignty and, at the same time, renounced the development of nuclear weapons, the first nuclear research centers, such as Karlsruhe (KfK), were founded in 1956. In 1960, Wirtz and Häfele established the Fast Breeder Project within KfK with the energetic support by the Federal Research Ministry officials Schuster and Schmidt-Küster[13]. As late as 1965, however, the first large sodium test rig was commissioned by Interatom in Bensberg. In 1973, construction of SNR 300 was started at Kalkar, almost at the same time at which the French Phénix breeder, nearly equal in size, was commissioned. In a nutshell, it can be said that, because of the consequences of the war, France was one plant ahead of Germany in breeder development.

Also the administrative setups chosen for the projects were different. Building the KNK and SNR 300 power plants was a responsibility of industry (Interatom and INB/Interatom, respectively); the plants were operated by regional electricity utilities (Badenwerk and SBK/RWE, respectively). The nuclear research centers focused on the accompanying research programs. The licensing procedure under the German Atomic Energy Act for KNK and SNR 300 was identical with that applying to commercial light water reactor plants. Added to this were major legal and political problems and persistent difficulties in gaining public acceptance. Compared with this situation, the French breeder projects for a long time were carried by a spirit of public approval and consent.

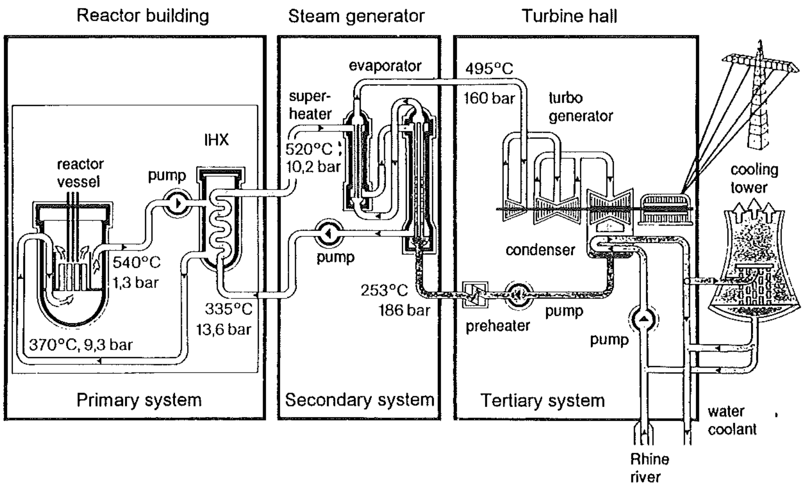
Construction of the **Compact Sodium-cooled Nuclear Reactor (KNK)** was begun by Interatom at the Karlsruhe Nuclear Research Center in 1965 on the base of a fixed-price contract. The KNK I version was designed as a thermal reactor with a uranium oxide core, but had a 20 MWe turbo-generator. After a phase of operation in 1971 - 1974, the plant was converted into a fast reactor (KNK II) with a mixed oxide core in the inner test zone in 1975 - 1977. The reason was the need for irradiation capacity for the SNR 300 follow-on plant.


KNK experimental breeder plant in Karlsruhe.

By 1982, KNK II had attained burnups of approximately 100,000 MWd/t; a couple of fuel elements had been reprocessed in the MILLI pilot reprocessing plant of KfK, and the recovered plutonium had been recycled. In the course of reactor operation, occasional argon bubbles permeated the core; these defects, which were not safety-related, were repaired. In 1983, KNK II was loaded with so-called Mk. II fuel elements, which were larger in diameter and were identical with the specifications of the SNR 300 reload core.[14]

And now on to **SNR 300**, a breeder power plant of 300 MWe power. After preliminary work at KfK, it was planned under the leadership of Interatom together with Belgonucléaire and Neratoom from 1966 onward; in 1972, it was ordered by a German-Belgian-Netherlands operators' consortium under the leadership of RWE. In the final design phase, the German licensing authorities had imposed major changes, such as the installation of an external, actively cooled core catcher; enclosure of the reactor building for protection against high-speed military aircraft; and the design of the entire plant against major seismic events.

After a brisk start, construction slowed down considerably from 1976 on, because the licensing authority of the State of North Rhine-Westphalia had made the hypothetical core meltdown accident according to the Bethe-Tait model practically a design basis accident of the components and systems of the plant. Installing the reactor vessel support girder, an item on the critical path for Kalkar, was impossible because the part had been declared a safety-related component on which a large number of complicated calculations had to be performed first. Moreover, strain measurements had to be conducted on wide-plate specimen of the vessel in order to determine experimentally the accommodation of "Bethe-Tait pressures."[15]



Schematic flow scheme of the SNR 300 fast breeder plant in Kalkar.

Problems arose also in the legal field. The German Federal Constitutional Court in Karlsruhe was made to examine in 1977 whether the SNR 300 fast breeder could be licensed at all under the existing German Atomic Energy Act. In its ruling of August 1978, the Court answered that question in the affirmative, but only after a whole year had been spent in which the project had not progressed.

The next political obstacle arose very soon. In December 1978, the German Federal Parliament decided to establish a Committee of Inquiry into the Future Nuclear Energy Policy, especially the Kalkar SNR 300 project. The Committee met for an incredibly long period of nearly four years, for which the project lay practically dormant. By involving experts pro and con, the Members of Parliament sought to obtain information about all technical, economic, and political aspects of the project. The interplay of various coefficients of reactivity in the core of SNR 300 was among the points treated, others being the risk of containment break and the possibility to replace the uranium blanket by a thorium blanket.

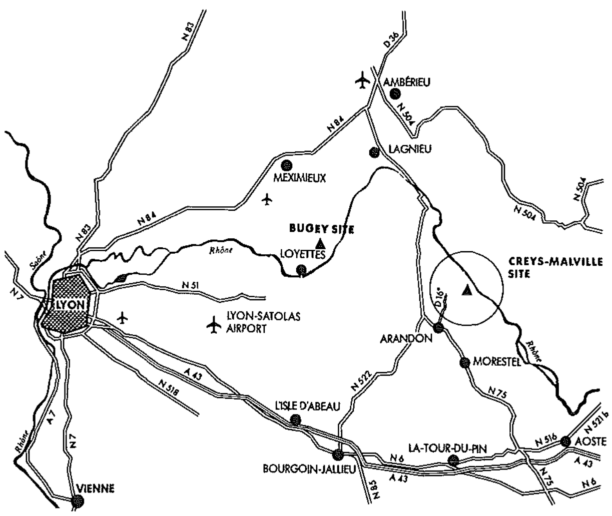
The Kalkar project had fallen into a very deep hole indeed.[16]

1.1.2 The Superphénix and SNR 2 Projects

Let us come back to the Superphénix and SNR 2 projects, which had been decided upon as a result of the Utilities' Convention of 1973 as described above. Under this heading, we will be looking approximately as far as 1982.

Superphénix

Planning the engineered safeguards features of **Superphénix** began quite early: In 1972, the Nuclear Safety Department of CEA drafted recommendations for the safety criteria of the reactor in order to give guidance to the designers; shortly after, the Preliminary Safety Report (1974) and the Manual of Design and Construction Rules (1976) were published.[17,18]



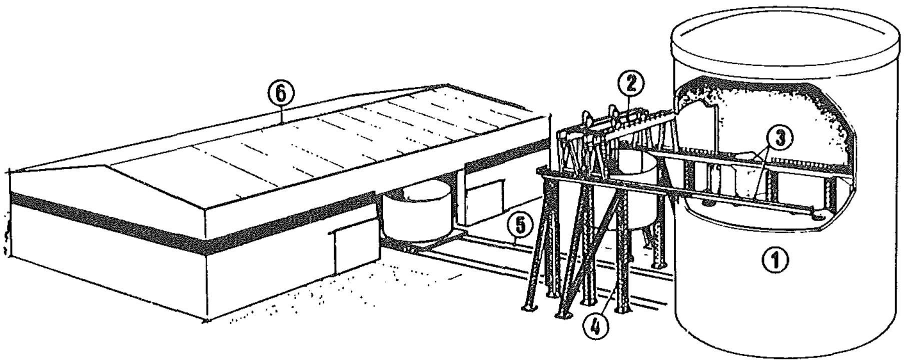
Map showing the site of the Superphénix fast breeder plant.

The Superphénix design provided for a nuclear steam supply system as an integrated pool-type version with a thermal power of 3000 MWth and a plant power of 1200 MWe to be generated by two turbosets. The four primary and secondary circuits in a reactor vessel of 21 m diameter fed one helical-tube steam generator each of the considerable capacity of 750 MWth. The cylindrical reactor building was 64 m in diameter and 80 m high. In many respects, the technical design of Superphénix was a logical extension of the successful Phénix concept. One exception to this rule were the steam generators, which had been modular in the smaller plant.[19]

The power plant was to be sited on the territory of the municipality of Creys approximately one kilometer from the village of Malville, both situated in the Isère Department on the Rhône River, approximately halfway between Lyons and Geneva. Protests against the breeder project in Creys-Malville later were raised again and again from Geneva in Switzerland.

In April 1976, the then French President, Valéry Giscard d'Estaing, approved the project. As a consequence, ground breaking work and the installation of the necessary utility systems were begun on site. In 1977, project work in Creys-Malville started for good, accompanied by one of the biggest anti-nuclear demonstrations France had experienced so far, which resulted in one person being killed and approximately one hundred being injured.

Because of the size of the components, which measured up to 25 m in diameter and weighed up to 850 t, a fully equipped shop had to be set up on the premises. The considerable dimensions of 114 m length, 75 m width, and 38 m height, and a floor area of nearly 10,000 m^2, made it the most impressive building on the construction site. The parts delivered by the vendors were moved into the shop, assembled into large components and then moved on special crane tracks into the installation opening of the reactor building.



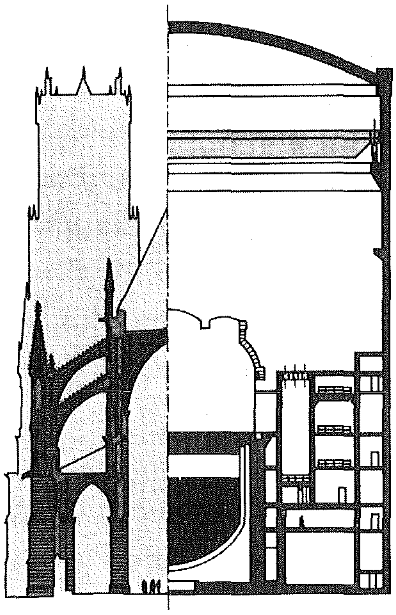
1: reactor building;
2: gantry crane;
3: crane tracks;
4: supports;
5: rails;
6: shop.

On-site assembly for Superphénix.

Construction of Superphénix progressed smoothly. In 1981, the reactor vessel with the two rotating top shields was installed in the finished reactor building. The primary pumps had been delivered on site by that date, as had been 1400 t of sodium. The main contractor for the heat supply system was the French Novatome company established 1977, partly as an offshoot of CEA. The turbo-generators were supplied by the

Italian consortial partner, Ansaldo-NIRA. Various small contracts were shared by the German suppliers, Siemens, Interatom, and BBC.

The world's largest breeder construction site, with huge components to be marveled at, attracted an extraordinarily large number of technically interested or merely curious visitors. In the first six months of 1981, nearly 17,000 people came for a visit, among them, of course, many school classes; but also ministers, even former US President Gerald Ford, were anxious to have a look at this monument in the valley of the Rhône River.[20]



North-south section,
scale 0 ______ 10 m.

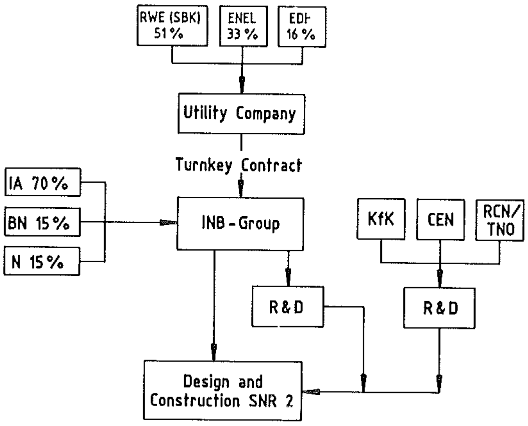
Old and modern cathedrals
(left: Reims, right: Creys-Malville).

Naturally, there were also setbacks. In 1980, the polar crane was to be tested in the reactor building, but the test weight of 420 t oscillated strongly and crashed.

One strange experience occurred in January 1982: Superphénix was bombarded and hit by bazooka missiles. A regular missile launcher later was found on the opposite bank of the River Rhône, some 250 m from the reactor. Five missiles had been fired from there, four had hit the reactor building, one even managing to get inside through the assembly opening, where it hit a girder and fell down. Fortunately, the technical damage caused by this missile attack was relatively slight. As a consequence, the surroundings of the power plant were kept under stricter surveillance.

SNR 2

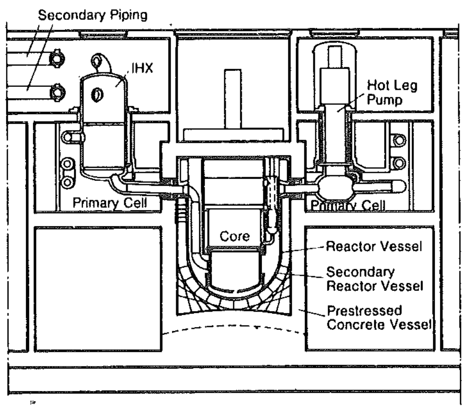
While Superphénix was already under construction, its German counterpart, **SNR 2**, was just about to reach its technical planning stage. In 1976, ESK, the consortium of utilities, commissioned the German-Belgian-Netherlands manufacturer, INB, to preplan a 1300 MWe breeder on the basis of a loop-type concept. Initially, an electric net power of 2000 MWe had been envisaged in order to benefit from economies of scale, but this was soon reduced to the standard size of light water reactors so as not to make the licensing procedure too complicated. Preplanning took approximately up until 1981; however, as will be outlined below, it was interrupted temporarily for closer analysis of the French Superphénix design ("pool analysis").



Organization chart of SNR 2.

Here are the main parameters of the power plant design finally proposed to ESK, the client: The reactor core was to be a homogeneous core with two enrichment zones and 3400 MWth thermal power; the plutonium inventory was to be seven tons. Outside the core barrel there were interim storage positions for spent fuel elements. The reactor vessel was 15 m in diameter and was closed by a triple shield at the top which was to be cooled by nitrogen. Unlike SNR 300, SNR 2 was to have neither a gas bubble separator nor an external core catcher.[21,22]

The four-train primary system was based on a novel pot concept. The circuit vessel as the primary cell constituted the common cavity of a primary system inerted with nitrogen. This design offered a number of advantages: The pipes did not have to be insulated, nor did they require trace heating; both facts made for better accessibility. Moreover, the systems boundary was relatively simple in geometry and offered greater flexibility in pressure and temperature design. Together with the double tank and the reactor top shield cavity, the circuit vessels made up the inner containment. The hot hangers and dampers still to be developed for the pot concept were an important part of the R&D program accompanying the planning phase.[23]



Arrangement of SNR 2 primary and secondary systems.

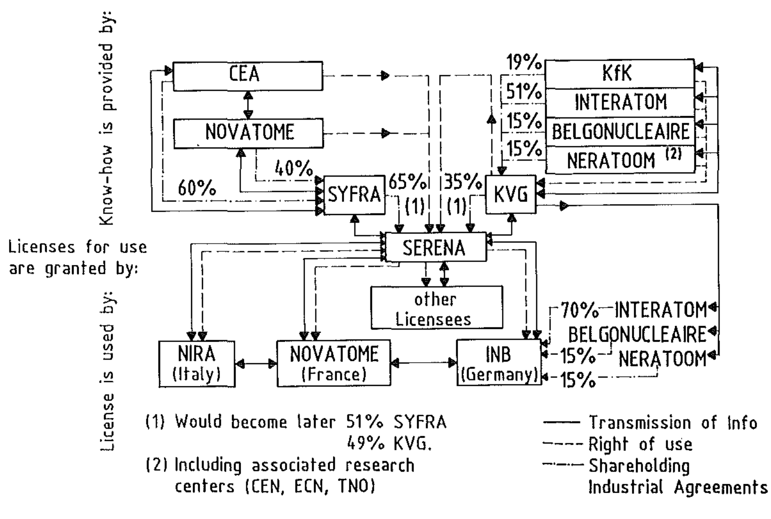
Each of the four secondary systems was equipped with two steam generators of 435 MWth each. For maximum availability, the power plant was to be run at its rated load with merely seven systems of this type. Two different systems were proposed for decay heat removal: The residual heat either was to be passed from immersion coolers in the reactor vessel to air coolers, or through the primary system to special exchange components in the intermediate heat exchangers.

In contrast to the SNR 300 design, the Bethe-Tait accident was to be controlled by preventive measures in SNR 2. Consequently, no specific provisions were made against molten fuel. As far as materials were concerned, the leak-before-break criterion was assumed to apply, and no multiple pipe break of the steam generators without depressurization was considered.[24]

The SNR 2 safety philosophy was to approach customary international standards.

1.2 R&D and Industrial Agreements

Emulating the examples of the electricity utilities, also the research organizations and vendors tried to intensify, and define contractually, the German-French ties. The way was paved by the so-called Declaration of Nice in which the then German Federal Minister for Research, Matthöfer, and his French colleague d'Ornano decided to intensify the cooperation of both countries in the breeder field. In the wake of that agreement, lengthy negotiations took place between German and French organizations, in which also their associated partners in Belgium, the Netherlands, and Italy were involved. On July 5, 1977, at last, a number of agreements on cooperation among research centers and industry were signed, and also the rules about the protection and use of know-how were agreed upon.[25] Here is a brief rundown of the most important agreements:



Interconnections and shares in European breeder cooperation.

(1) The *research centers* agreed on complete exchanges of existing and future breeder know-how and on harmonizing future R&D work with the needs of reactor

facilities to be built. The contracting parties, on the one hand, were the Entwicklungsgemeinschaft Schneller Brüter made up of KfK and Interatom (with Belgonucléaire/CEN, Mol, and Neratoom/ECN, Petten) and, on the other hand, the French CEA (with the Italian CNEN). Alkem was no party to the agreement, as fuel fabrication had been excluded from the exchange.

(2) The *industrial companies*, Interatom, Belgonucléaire, and Neratoom, decided to cooperate closely with Novatome, the main supplier of Superphénix, in order to achieve a maximum of harmonization in the design of future breeders. In particular, precise analyses of the advantages and drawbacks of the pool and loop-type reactor systems were to be performed.

(3) Finally, a joint company was founded, Société Européenne pour la Promotion des Systèmes de Réacteurs Rapides à Sodium (SERENA), which was to reap the benefits of the *know-how* held by the organizations mentioned above, and which was to act as licensor vis-à-vis third parties. The German partners held 35% in SERENA, the French 65%; at a later point in time, holdings were to be balanced out in a 49:51 ratio.

These agreements were concluded for a period of twenty years. A brief outline of the experience accumulated in the first few years of their implementation will be given below.

1.2.1 R&D Cooperation

The purpose of R&D cooperation was to harmonize the R&D programs with the needs of reactor plants. For this purpose, a German-French Steering Committee ("Comité de Liaison") was established, whose members were the top ranking representatives of the contracting parties. Twice a year the Committee reviewed the progress made in the R&D program and decided on new subjects to be incorporated. The Comité de Liaison (CdL) was supported by a Secretariat and by nine Technical Working Groups, staffed equally with two coordinators each, which covered the entire breeder field, from fuel elements to reactor operating experience.[26]

The CdL above all sought to avoid any duplication of effort, which happened quite frequently in the beginning, for both partners began their cooperation with complete programs of their own. The German R&D program had been tailored to the needs of

SNR 300 and to German licensing conditions, while the French topics were primarily aimed at supporting Superphénix. Already at this point the need for harmonization of the reactor plans became apparent, if cooperation was to produce any rationalization benefit.

Some of the founding fathers of
German-French breeder cooperation
(left to right: H.-H. Hennies, KfK; H. Mausbeck, Interatom;
F. Stosskopf, C. Moranville, J. Megy, all CEA).

One important criterion established by the CdL was that new R&D projects to be incorporated should, if possible, be planned as joint German-French projects in order to make optimum use of manpower and equipment resources. This was managed successfully after some teething troubles. One such joint project was the RACINE experiment in which large plutonium criticals for heterogeneous cores were studied in the French Masurca plant, and of which a German scientist (Scholtyssek) was appointed Project Manager. In the CHARLEMAGNE joint irradiation experiment, German and French cladding tube steel varieties were irradiated in the Phénix reactor for comparison purposes. The spacer problem was examined in the Mark II/SAPHIR project. At one time, the debate about lattice and wire spacers, respectively, threatened to turn into a religious war among experts, and management was called upon to end this costly controversy as quickly as possible.[27]

Some experiments, such as the CABRI projects launched already in 1973, were only monitored by the CdL and kept under fleeting surveillance; their execution was in the capable hands of their initiators, Tanguy (CEA) and Keßler (KfK) and their staff (Tattegrain and Kußmaul). There were also projects in which the German side deliberately did not participate, such as the French ESMERALDA sodium fire experiment.

In the first three years of cooperation, roughly 1000 technical reports were exchanged; so far, all of them were confidential, and in the absence of the agreement there would have been no possibility to even get a glimpse of them. In addition, 200 meetings at the level of experts were organized over that period of time, at which 25 joint experiments and projects were planned, among other activities. Also publications became more and more "European," as far as their authors were concerned. This clearly impressed the British, Americans and Japanese, who suddenly found themselves facing a West European "block."

An impression of the magnitude of the R&D program and the associated coordination problems can be obtained from the annual budgets. Thus, the 1978 R&D budget for the fast breeder in Germany, Belgium, the Netherlands, and in France and Italy was the equivalent of US $381 million; the comparable budget of the United States was US $100 million larger.

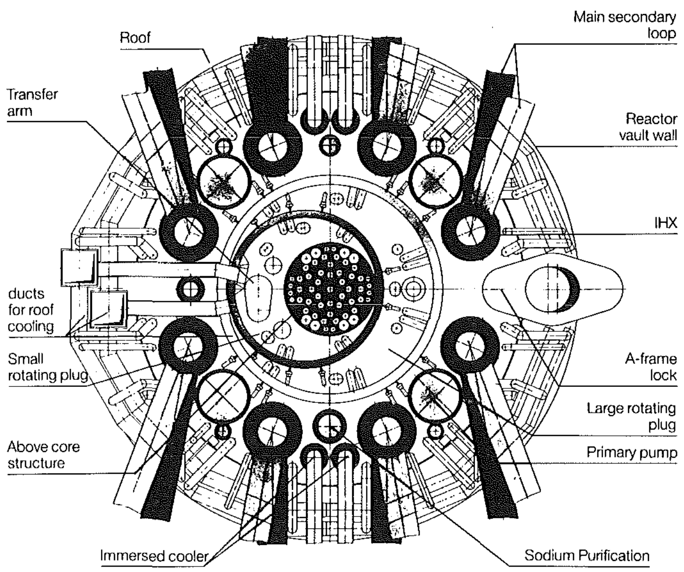
1.2.2 Industrial Cooperation

Also Interatom and Novatome, the industrial partners, swapped staff members who were allowed to study the design basis documents of their respective "competitors" which, so far, had been strictly confidential. About 30 scientists and engineers were delegated for years to foreign sites and learned from the respective partners. Names like Guthmann, Hammers, Heyne and Lefèvre, Gourion, Mesnage stand for many more of their colleagues. What the manufacturers had in mind was a standardized reactor concept acceptable to electricity utilities on both sides of the Rhine River, subject to the same licensing conditions, and whose execution would have differed only as a consequence of site conditions.

But they were still miles away from their goal. First, the details of the loop and pool plans, respectively, of the other partner had to be understood in order for reactor systems to be harmonized in a later phase. As the Superphénix (SPX) prototype pool plant had already reached an advanced stage of development, an expert group was established which was to study the design of this reactor in the light of German licensing criteria. The group proceeded in two steps: First, a German-Belgian-Netherlands (DeBeNe) group analyzed the details of the SPX design on the basis of French documents. Then a mixed group was established together with French experts which carried out an in-depth study, the so-called pool analysis.[28,29]

Finally, both groups found that the pool concept in principle should be capable of being licensed also in Germany. So-called k.o. points, which would have jeopardized the design under German conditions, were not found. All of a sudden, this resulted in the situation that the pool concept could be seriously considered as a design variant for SNR 2.[30]

In some respects, however, the SPX design would have had to be modified and augmented in order to preclude any risks in the German licensing procedure. This applied especially to the cooling of the reactor top: At this point, the German experts would have suggested gas instead of water as the coolant. Also the handling of major sodium fires within the reactor dome, with the afterheat removal lines destroyed, was discussed critically. This was associated with assumptions made about load shedding in the course of crane movements above the reactor. In the vessel region the thermohydraulic conditions, more difficult to fathom than in pool-type reactors, were a point of debate, another one being the complex accident calculations underlying the assumptions about core meltdown. In addition, problems of accessibility and maintenance were addressed which, in the view of DeBeNe experts, were slightly more problematic in pool than in loop-type reactors.



Plan view of SNR 2 reactor top shield.

By 1981, the analysis had been concluded with a basically positive vote on the pool design. In this connection, it emerged that as early as in 1976 the American Bechtel company had made a similar comparison and found that Superphénix would meet also most U.S. standards.

1.3 The Government Breeder Memoranda

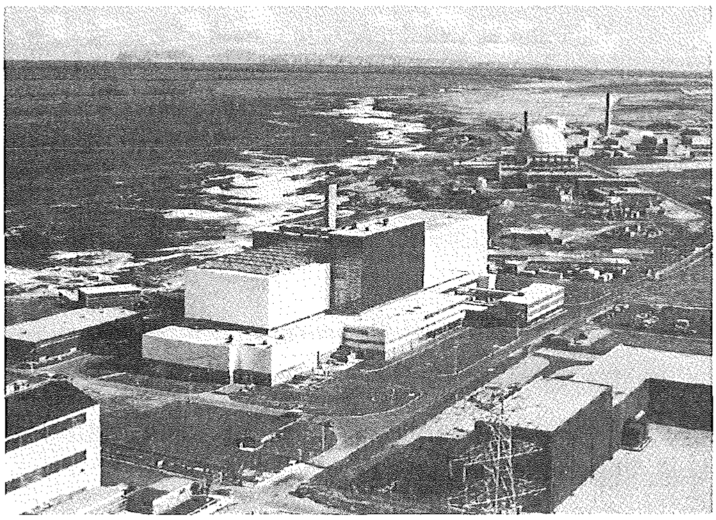
The association of West European breeder organizations had created a block with considerable international repercussions. Agreements were concluded with Japan and the USA about specific exchanges of research findings, and existing ties were strengthened, respectively. Also contacts with the nearest neighbors, the British, became closer, albeit only at conferences and similar formal events, for the time being. It was to take a relatively long time, until 1984, also for Britain to join the European breeder association at government level. Before addressing that event, we should have a look at the technical breeder base of the British.

1.3.1 The British Breeder Base

Like France, also the United Kingdom was in a position to start nuclear development and breeder development immediately after the war. Gas cooled reactors of various designs were the main line of commercial thermal reactors. Fast reactors were the declared goals of development for the reactor generation to follow.

Dounreay Fast Reactor

Construction of the **Dounreay Fast Reactor (DFR)** was started as early as 1955. The plant attained its first criticality in 1959, and its full power of 60 MWth four years later. With its 13.5 MWe turbine it produced 580 million kilowatthours of electricity in nearly fifteen years. Even more important was its use as an irradiation reactor, especially by Japanese and German fast breeder groups. The income derived from this source amounted to nearly £10 million.



PFR Prototype Fast Reactor in Dounreay
(with DFR in the background).

DFR had NaK as the coolant; its primary system was made up of 24 loops. Occasionally, e.g. in 1967/68, leaks occurred in the loops which were difficult to localize. In 1970 there was even a sodium fire which burnt for several hours, but had no impact on the environment. The plant was shut down in 1977 after several end-of-life experiments concerned with studies of boiling phenomena.

Prototype Fast Reactor

The second British fast breeder reactor planned for construction at Dounreay in the north of Scotland was the **Prototype Fast Reactor (PFR)**. It was designed for an electric power of 250 MWe, employed the pool principle, and was planned, commissioned and, later on, also operated by the United Kingdom Atomic Energy Authority (UKAEA). Construction of PFR, which was begun in 1966, suffered considerable delays after lamellar tearing had been observed in the steel used for the reactor top shield, which required this component practically to be remade from scratch. After first criticality in March 1976, a number of sodium-water leaks occurred in the three steam generators, mainly in the evaporator. The affected pipes were closed by explosive plugging; in July 1976 all three circuits were in operation for the first time, and in the following year the plant was operated at an electric power of 200 MWe.

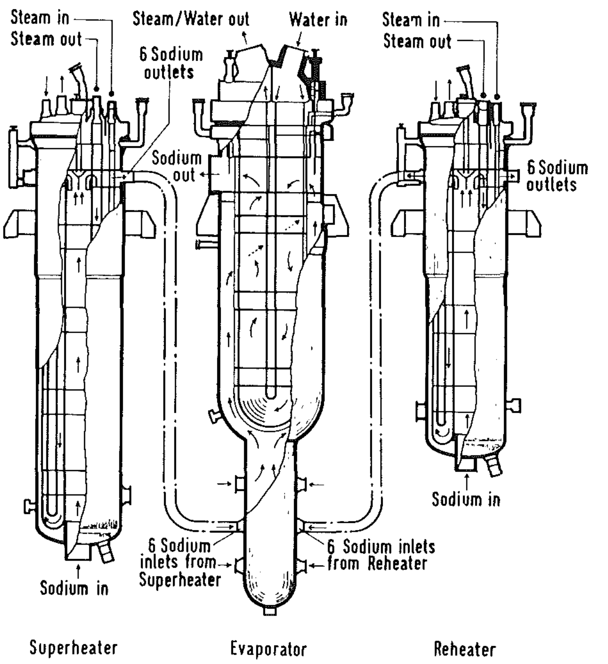


Diagram of the steam generators in PFR.

Until 1979 the evaporator units, all consisting of the 2 1/4 Cr/1 Mo ferritic type of steel, worked without major problems, but then leakages became more and more frequent. Despite *in situ* shot peening of all tube-to-tube plate welds the failures continued to occur. Consequently, a new method was developed to deal with them by fitting a sleeve to bypass the weld and thus keep affected steam tubes in service. Some 3000 sleeves were explosion-welded by 1984. Three-circuit operation was resumed, and early 1985 the output level of 250 MWe was achieved for the first time.

Between 1982 and 1986 considerable problems were encountered with the PFR air heat exchangers on the decay heat rejection loops, although little or no generation was lost. Gas locking and pipe blocking led to uneven tube temperatures and subsequent low cycle fatigue failures at the pulled tees where the tubes joined the headers. The situation was managed by damage accountancy and finally resolved by replacing all three units with an improved design.

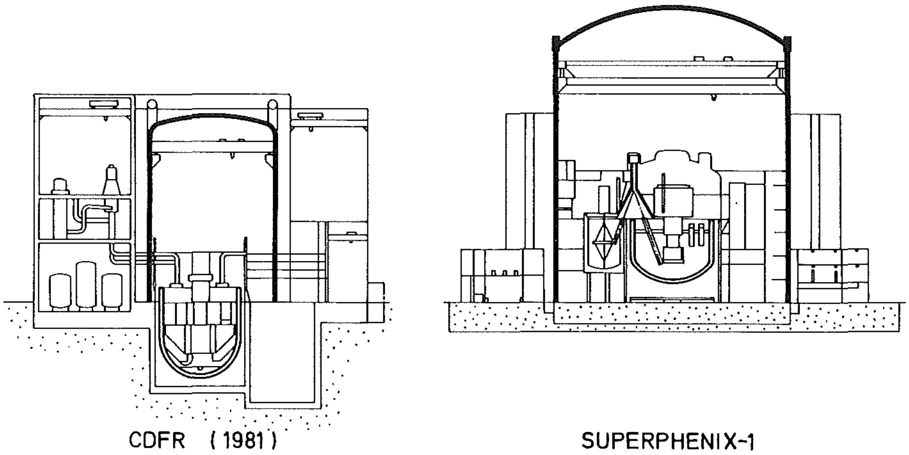
Except for the steam generators and the air heat exchangers, the other components of PFR worked relatively troublefree. This also applies to the sodium loops where, in contrast to the French Phénix, no defects occurred in the intermediate heat exchangers. It is also true of the primary sodium pumps which, by 1985, had already been operated for 200,000 hours without any defect. Also the fuel elements developed an excellent operating record. Although they had been designed only to a burnup of 7.5 %, they allowed irradiation to more than 10%, with only a handful of cladding defects arising.[31,32]

Commercial Demonstration Fast Reactor

Planning for a large breeder beyond the 1000 MWe mark, the **Commercial Fast Reactor 1 (CFR 1)**, was begun in Britain already in the early seventies. The designation, CFR 1, was to indicate that it was to be the first reactor of a series. Roughly around 1975/76, planning activities came to a halt mainly for two reasons: On the one hand, the problems encountered in construction and commissioning of the preceding PFR had aroused public attention. On the other hand, there had been voices within the Government against switching to breeder technology too quickly. These concerns were articulated especially by Energy Secretary Wedgwood Benn who, after all, was able to quote findings by the Royal Commission on Environmental Pollution. The Chairman of that Commission, Sir Brian Flowers, advocated a policy of not enforcing the expansion of large breeders, for reasons of radiation protection, and temporarily shelving CFR 1.

In September 1981, a new large breeder design, the so-called **Commercial Demonstration Fast Reactor (CDFR)**, was presented which had been planned by the National Nuclear Corporation (NNC) together with UKAEA to specifications set by the Central Electricity Generating Board (CEGB). The technical documents were submitted together with a cost calculation showing that the capital cost of the 1300 MWe plant would be some 20% above those of the advanced gas cooled reactor power stations of Heysham B and Torness, whose construction had just been started.[33]

CDFR had been designed as a very compact plant in order to save materials costs. Its vessel, with a diameter of 19 m, was approximately 2 m smaller than that of Superphénix; the sodium inventory was 3000 t (3500 t in SPX). The main components, such as pumps and intermediate heat exchangers, were just as compact. A special effort had been made to keep the pipes of the secondary system short. The steam generator concept was kept open, bearing in mind the unsolved problems in PFR. The systems shortlisted included once-through boilers with straight tubes and J-tube bundles. A set of eight steam generator modules for the four-train plant was assumed. In engineered safeguards, the integrity of the vessel had been given top priority, in line with traditional British reactor design. The core support system included the diagrid, which transmitted the core weight into the primary vessel and, hence, into the reactor top. Provision was also made for easy access in case detailed examinations were necessary.[34,35]



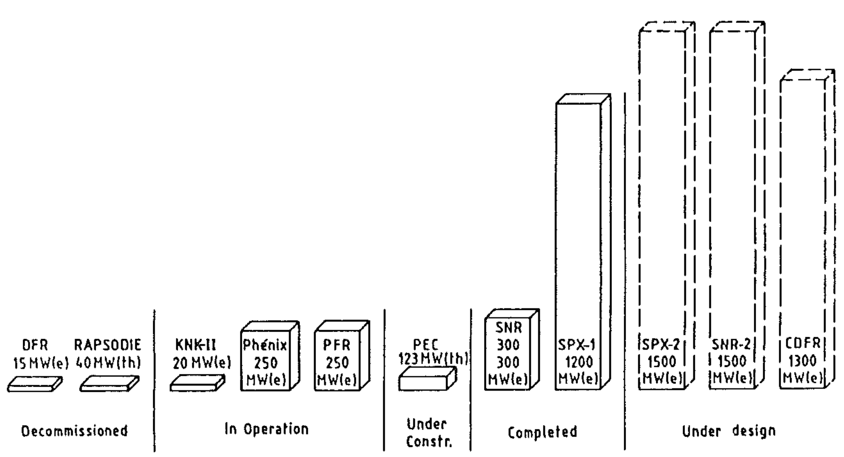
Comparison of the sizes of the CDFR and Superphénix 1 breeder power plants.

1.3.2 The UK on Its Way to Europe

When CDFR was presented publicly by the then UKAEA Chairman, Walter Marshall, in 1981, the press called it a "portfolio for fast reactor collaboration."[36] Indeed, the eight volumes making up the design basis report impressively testify to the status of British breeder technology. In addition, there was a comprehensive R&D program focusing on aspects of materials development, instrumentation, and safety. Even for the ailing PFR a remedy seemed to have been found.

It therefore came as no surprise that many contacts on both sides of the Channel were sought and established between 1980 and 1983. The R&D organizations paved the way. Hans-Henning Hennies, Executive Board member of KfK, in agreement with his colleagues at the Comité de Liaison, invited his opposite number, UKAEA Director Jack Moore, and explained to him the basic principles of the German-French Breeder Research Program in the relaxed atmosphere of a walk in the Black Forest. On the side of industry, exchanges of experience were initiated among NNC, Novatome, and Interatom; at this point the Germans remembered that, ten years before, they had been about to establish a link between KWU and The Nuclear Power Group (TNPG).

These talks, which could not yet be called negotiations, of course proved to be most difficult among the industrial partners, the electricity utilities, and SERENA. They revolved around the question of a common breeder design; the British sought a merger of their design with that of the West Europeans; simply accepting Superphénix 1, or Superphénix 2 already in planning, was not in their interest. On the part of SERENA, the question of an "admission fee" to be charged to the British played a role; the press published rumors of amounts on the order of £50 million.



The European fast breeder program in the early eighties.

As the talks became more specific, special task forces were set up to look into the problems and possibilities resulting from broader international cooperation. **ARGO** was one such task force combining high-level representatives of the manufacturing industries and research organizations in France, Italy, Germany, Belgium, and the Netherlands to investigate practical methods for the deployment of fast breeders in Europe under its Chairman, Georges Vendryes. Incidentally, ARGO was not an acronym, but a reference to Greek mythology, to Jason and the Argonauts looking for the Golden Fleece, in this case the European breeder project. On the side of the electricity utilities, the European Fast Reactor Utilities Group (**EFRUG**) was constituted at approximately the same time with utilities from the countries mentioned above and already including

Britain. Almost unnoticed, EFRUG later was to become the central partner in European breeder cooperation.

On September 5, 1983, the day had come: Peter Walker, British Secretary of State for Energy, announced that his country wanted to cooperate with the West Europeans in breeder development and would immediately begin negotiations to this effect. Obviously, also closer ties with Japan and the USA had been considered, but at that time Japan had not yet embarked on building its MONJU breeder of comparable size, and the American breeder program was difficult to fathom after the recent discontinuation of the Clinch River Project. As far as timing was concerned, the European programs seemed to tally best. Also the fact that the French, like the British, had adopted the pool concept, may have played a role in the British decision in favor of joining the Continent.

The UK was on its way to Europe.

1.3.3 The Government Memoranda Are Signed

Now the lawyers had a hard time drafting the relatively complex system of agreements. Of course, the interests of the governments had to be taken into account, but so had those of industry and of the research organizations. The whole package included the following agreements:

(1) In a *Memorandum of Understanding* the governments intended to declare their wish for long-term cooperation in the breeder field.

(2) The *R&D and industrial partners* in the respective countries were to be invited to draw up another memorandum of understanding with the objective of concentrating all efforts on the introduction of commercial breeder reactors.

(3) In a final, but important, step, specific agreements were to be signed in the R&D field, on industrial cooperation, on *the protection of know-how and on licensing* and, in this way, cooperation proper was to be started.

In addition, agreements were planned in the sector of the nuclear fuel cycle, and the electricity utilities were called upon to exchange holdings in future breeder power plants.[37]

Shortly before the planned signing date of the Government Memoranda mentioned under (1) above the partners on the Continent became worried when the UK announced that it would reduce by 30 percent its R&D breeder budget of currently £150 million.[38] Inquiries soon revealed that half of this reduction was to be compensated by higher sales of electricity from the PFR, while the other half was already considered a rationalization effect derived from future cooperation. Interestingly enough, the British Government ordered a similar budget cut again before the agreements listed under item (2) above were signed by Secretary Parkinson in 1988; a third, very drastic, slashing of funds by the British in the autumn of 1992 (prior to the conclusion of EFR Phase 3) finally brought the end of British participation in the EFR Project.

On January 10, 1984, the German Federal Minister for Research and Technology, Heinz Riesenhuber, invited his colleagues to Bonn for the signing ceremony of the Government Memoranda. The top-level group included the French Minister for Industry and Research, Laurent Fabius; the Belgian Minister for Industry, Etienne Knoops; the Italian Ambassador, Walter Guardini; and the British Secretary of State for Energy, Peter Walker. The Netherlands were granted an option to join this umbrella agreement at a later point in time (which option they renounced formally in 1987).

The ticklish matter of the entrance fee had been settled in advance. It was agreed that the British contributed on an equitable basis primarily in kind rather than in cash. This was to be achieved in part by providing reprocessing capacity for fuel elements with high burnups, for which an excellent facility was available at Dounreay.

Several partners, especially Fabius, emphasized that Europe did not want to turn into a closed shop by signing this agreement, but that also other countries, especially Japan and the USA, were free to join. In addition, the detailed agreements were expected to be signed by the R&D and industrial organizations towards the end of the current year, 1984.

This assumption soon was to prove overly optimistic.

In actual fact, it took until 1989 for this step to be taken.

2 A Thorny Path to the Common Model Breeder

In 1973 - 1984, provisional agreement had been reached on a German-French breeder construction program (Superphénix 1/SNR 2), but how the British were to be integrated was not yet clear. One of the open points was the way in which the UK was to become actively engaged in these two projects. Other interests, not yet specified, arose later, as will be shown in this chapter.

2.1 A Stop Sign to European Cooperation

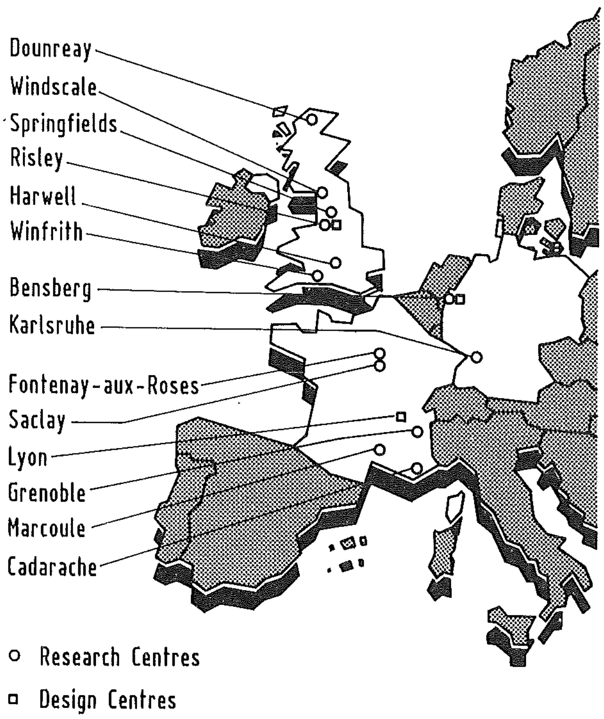
2.1.1 An Auspicious Beginning

Nearly two months after the Government Memoranda had been signed, the envisaged Memorandum of the industrial and the research organizations was signed in London on March 2, 1984. Negotiations about the 22-page document proceeded smoothly, and the Memorandum bore the signatures of the thirteen leading personalities in the five countries concerned. The purpose was to pool the existing resources for the construction of commercial breeder reactors. A staggered program of construction was to be set up under which the countries, one by one, were to build a reactor (and a group of reactors, respectively) or contribute some other important part of the program. As more and more improvements were being made, one commercial type would emerge which would be licensable in all countries as the European Breeder.[39]

The Memorandum contains several references to the definition of the construction program being a responsibility of the electricity utilities. Thus, Article 16 of the Memorandum suggests that the next breeder of more than 1000 MWe (meaning Superphénix 2) probably was going to be built in France, while an agreement about financing the following breeder, to be constructed in Germany (meaning SNR 2), existed within the framework of the Utilities' Convention. Two other Memoranda about fuel fabrication reprocessing were signed only between the French-British organizations, Cogéma, British Nuclear Fuels Ltd. (BNFL), CEA, and UKAEA.

Sir Peter Hirsch, Chairman of UKAEA which hosted the event, also pointed out that a licensing company comparable to Serena was being established in Britain. In fact, Fast Reactor Technology Ltd., or **Fastec** for short, was founded towards the end of the year as a joint venture of NNC (60% of the interest) and UKAEA (40%). Fastec and the slightly older Serena were charged with collecting and exploiting for commercial use all breeder know-how.

The organization in the R&D sector had become relatively complex after the British had joined. Breeder-related research was conducted by thirteen organizations on twenty different locations in five (later six) countries. The manpower totaled 2600 scientists and engineers, and the annual budget amounted to the equivalent of US $235 million.



Research and Design Centers for the European Fast Reactor, EFR.

Even before the detailed contracts were signed, the British were invited to join all management groups in the R&D sector.[40,41] As of 1984, the former Comité de Liaison (CdL) had become a Steering Committee (SC) into which the UK was allowed to delegate three members and one observer. Also the Working Groups, now called AGT, were open to the British experts; in fact, two groups were enlarged to make better use of the special experience accumulated by the new members in instrumentation (AGT 2B) and structural integrity (AGT 9B). The Group of Liaison Agents was to keep the Steering Committee abreast of the needs of industrial reactor designers.[42,43]

An emerging new subgroup of the Steering Committee was the so-called Management Subcommittee (MSC). It met approximately every month or every other month, examined the progress made by the Working Groups, and reported to the Steering Committee which met twice a year. Dave Evans, UKAEA, was the committed Chairman of this body.

2.1.2 The Franco-German Breeder Spat

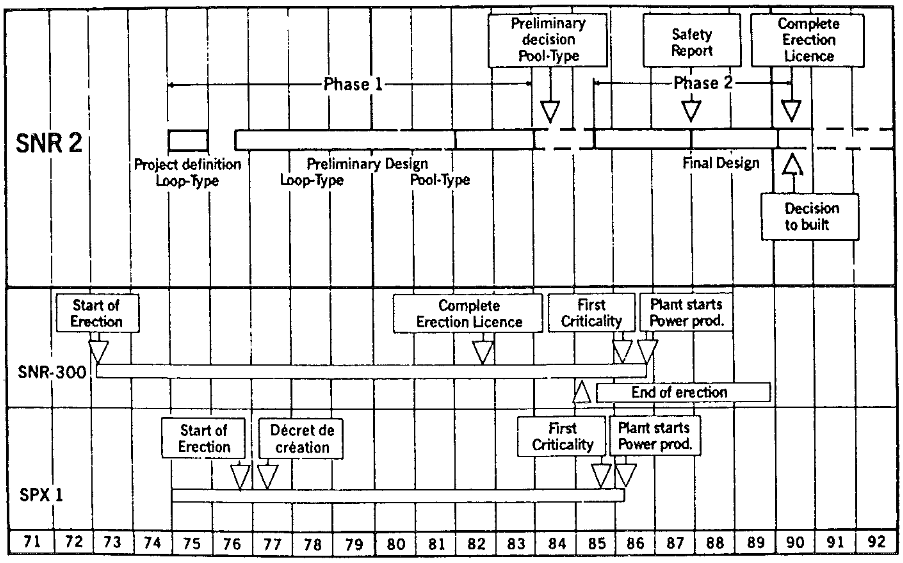
1984 was a busy year, with many meetings of the R&D organizations to flesh out the detailed agreement to be signed. The fields of work had to be defined, duplications as well as gaps had to be avoided. Finding the correct wording in the agreements was entrusted to Jeff Welch (UKAEA) as a native English speaker, English being the "project language" the other West Europeans used as best they could. In November 1984, the detailed R&D Agreement was initialed by all partners. After conclusion of the industrial and licensing agreements, all documents could have been signed. The signing ceremony had been planned at Aachen, the imperial palace of Charlemagne, a symbolic venue for Germans and French alike, on July 3, 1985. Invitations had been sent out, when the German Undersecretary in the Ministry for Research and Technology, Hans-Hilger Haunschild, called the event off at very short notice.[44]

What had happened?

Undersecretary Haunschild had not failed to notice that the research organizations had agreed about the division of their labor, whereas the electricity utilities still seemed to wrestle with a number of problems. In particular, the utilities had not yet agreed on the reactor construction program and the shares to be granted each other. EFRUG had spent more than a year debating these questions, but in vain. Essentially, it boiled down to a dissent between the German RWE and the French EdF which prevented the industrial and licensing agreements from being signed. The main arguments proposed by the French and German sides, respectively, at that time will be briefly listed below (without comments).

EdF argued that the Utilities' Convention of 1973 was no longer in keeping with the times, and should be renegotiated for various reasons. On the one hand, there was the entry of the British, which had added a further dimension to European cooperation. On the other hand, the considerable delay suffered by SNR 300 had shifted the entire program, because the design of Superphénix 2, the French project after Superphénix 1, meanwhile had advanced much further than that of SNR 2. Moreover, the French had grave doubts whether ESK would succeed, in view of the nuclear opposition in Germany, in finding a German site for SNR 2.

RWE insisted on the conventions signed 1973 to be kept to the letter, for, the reasoning went, they were not affected in any way by the accession of the British. In accordance with the Convention, commissioning of Superphénix 1 had to be followed by the construction of SNR 2. For the current planning phase of this power plant, the 16% partner, EdF, was requested to pay the amount of DM 24 million.



Timetables of the SNR 2, SNR 300, and Superphénix 1 fast breeder plants (state as of 1985).

EdF refused to pay and, in turn, proposed to establish a European vendors' consortium, "European Breeder Industry," with British participation and in analogy with the Airbus Consortium. This suggestion was refused by RWE.

After the utilities had run out of arguments, the politicians were called in. An exchange of correspondence took place between President Mitterand and Federal Chancellor Kohl, and at one of their regular meetings in late 1985 the matter was brought on the agenda. The Heads of Government commissioned Renon, then Head of CEA, and Haunschild, BMFT, to solve the problem together with EdF (Guilhamon) and RWE (Spalthoff).

However, both sides stuck to their points of view. RWE demanded that the Utilities' Convention be followed, and EdF in turn expected ironclad assurances that SNR 2 would be built on a German site without any politically motivated delays. Obviously, a competition was on between SNR 2 and Superphénix 2. Despite all efforts, no agreement was reached between RWE and EdF by summer 1986. Then the election campaign for the German Federal Parliament began in Germany, and the subject was felt to be out of bounds for that period of time.[45]

In the following years, 1987/88, the SNR 2/SPX 2 controversy receded into the background as the political and technical problems associated with SNR 300 and Superphénix 1 emerged. However, first the progress achieved in the design of Superphénix 2 and SNR 2 should be outlined.

2.2 Progress in Breeder Design

For a period of approximately ten years, between 1977 and 1987, France was engaged in the design of Superphénix 2 (SPX 2), Germany in that of SNR 2. In Britain, however, design work on CDFR to all intents and purposes was terminated after the report had been submitted in 1981. The Government and CEGB, for the time being, wished the project not to be implemented in their country, but emphasized their participation in SNR 2 or SPX 2 or both. The European breeder agreements had paved the way for this solution.

At the same time, the UK indicated a clear interest in building a medium-sized reprocessing plant in Dounreay. It was to be based on the technology of a small plant existing on the same location, which had proved to be particularly valuable in reprocessing high-burnup MOX fuel rods for PFR. BNFL and UKAEA estimated the cost of such a facility at approximately US $300 million, assuming that the plant could be available for the first of the three planned demonstration breeders by the mid-nineties. It was designed for an annual throughput of 60 - 80 t of heavy metal and was to be called European Demonstration Reprocessing Plant (EDRP). A laboratory for specific problems of reprocessing fast breeder fuel was dedicated in Dounreay in 1985 (Marshall Laboratory).

The plans for EDRP, as for the French Mar 600 and PURR plants, respectively, were given up later, when the deadlines for the demonstration breeder began to slip. Any bottlenecks arising in reprocessing were to be met by blending MOX fuel with LWR fuel in existing reprocessing plants for thermal fuel.

2.2.1 The Superphénix 2 Design

Roughly from the start of construction of Superphénix 1 (1977), France increasingly began to work on the design of the follow-on project, Superphénix 2. The prime contractor and author of the conventional plant studies (BOP) was EdF, while the design of the nuclear steam supply system was in the hands of Novatome; CEA contributed major parts of the R&D program. The primary goal clearly was to cut the costs of SPX 2 on the basis of the design for SPX 1. To this end, even plans of twin or multiple plants were considered temporarily. Thus, Novatome was commissioned by EdF in 1979 to submit a provisional bid for two and six fast breeders, respectively, of 1500 MWe each, for which the name "Saône Reactors" had already been found. In the end, however, plans were drafted for only one reactor. Its name, Superphénix 2, was changed into Réacteur à Neutrons Rapides (RNR 1500) roughly in 1986, referring to the plant's 1500 MWe power.[46,47]

Technical differences in the
Superphénix 1 (Creys-Malville) and Superphénix 2 (RNR 1500)
fast breeder power plants.

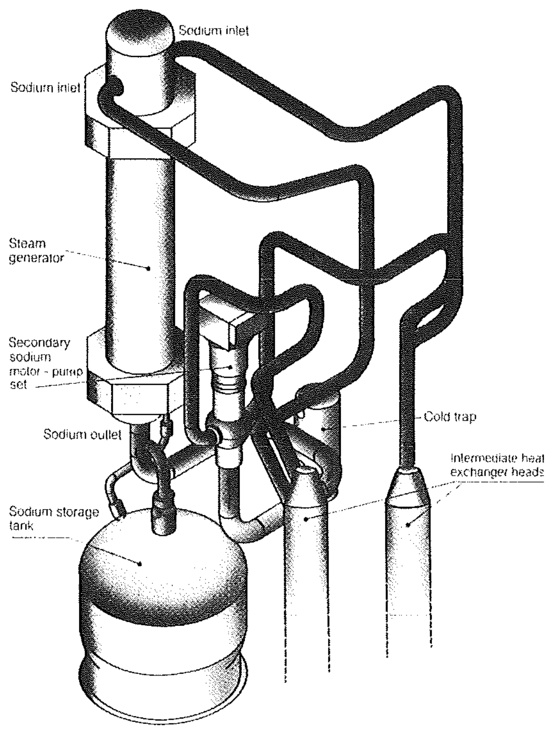
	CREYS-MALVILLE	RNR 1500
OVERALL PLANT		
Gross electrical output	1 240 MWe	1 540 MWe
Storage position for spent fuel	outside reactor block	inside reactor block
CORE		
Pu-inventory of new core (Pu_{239}-equivalent)	4.8 t	6.7 t
Maximum burn-up	70 000 MWd/t	150 000 MWd/t
Residence time of fuel sub-assemblies	640 EFPD	1 320 EFPD
REACTOR BLOCK		
Dome	yes	no
Safety vessel	hung	anchored
Type of roof slab	cold	warm
Roof slab temperature	50 °C	120 °C
Inner diameter of main vessel	21 m	20 m
Inner vessel. Number of redans	2	1
INTERMEDIATE SODIUM SYSTEM		
Loop concept	classical	REGAIN
DIRECT REACTOR COOLING SYSTEM		
Thermal power per loop	3.5 MWth	26 MWth
REACTOR BUILDING		
Ground area	9 900 m^2	6 500 m^2
Building volume	465 000 m^3	330 000 m^3
Concrete volume	132 000 m^3	94 000 m^3

Also the one-off SPX 2/RNR 1500 plant was designed mainly with cost reductions in mind. One step in this direction was the power raise from 1200 to 1500 MWe at practically the same reactor size as in SPX 1. In addition, standards of the N4 pressurized water reactor line were to be incorporated in the turbine sector. Other factors later contributing to cost minimization were the deletion of the external fuel element store, the simplification of secondary fuel handling, and the reduction of the breeding ratio.

The technical design of RNR 1500 provided for a prismatic reactor building. The reactor block housed a two-zone core; it was characterized by a single-walled inner vessel with a self-supporting "redan" and a warm air cooled roof slab. The safety vessel was anchored in the vessel pit concrete. The above-core structure basically consisted of a thick top plate and a cylindrical supporting shell. The main vessel and the roof slab were inspectable in service.

The primary sodium circuit was, of course, of the pool type, which allows containment of all the active sodium in one single vessel. The intermediate sodium circuit consisted of four independent loops each featuring a mechanical pump, two intermediate heat exchangers, and a REGAIN-type steam generator. The single-module helical-tube steam generators with a unit thermal power of 900 MWth were installed outside the containment.

Decay heat removal was achieved by a set of four independent loops filled with non-radioactive sodium. These loops extracted heat through a set of four diversified sodium/sodium heat exchangers plunging into the reactor hot pool and discharging this heat to the atmosphere via sodium/air exchangers.



Outline diagram of a REGAIN loop.

There were a number of major differences in the technical designs of SPX 1 and SPX 2. One of the most striking examples certainly was the abolition of the dome above the reactor in the RNR 1500.

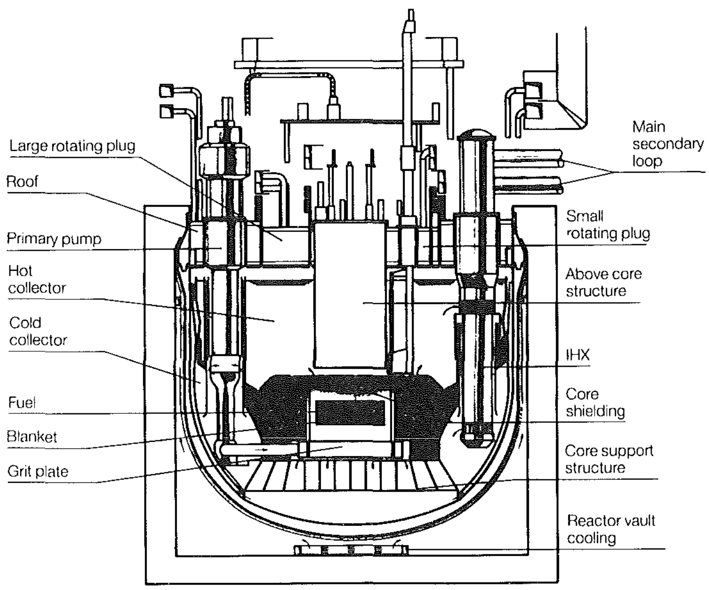
In November 1983 the Conceptual Design Report was documented; in parallel, the FBR-specific Design and Construction Rules (RCC) were prepared. Later on, the RNR 1500 project received a positive recommendation from the "Groupe Permanent de Sûreté des Réacteurs."

In addition to the SPX 2 studies a comprehensive review of the main FBR options was undertaken in France during 1982 - 1983. A team of about 20 experts, led by CEA (Sauvage) and named ECRA (Equipe de Conception des Réacteurs Avancés), was set up in Cadarache with representatives from EdF and Framatome/Novatome. ECRA was to propose more economical alternative solutions for future reactors; the conclusions of these studies[48,49] were later used in the EFR project.

2.2.2 The SNR 2 Design

It will be recalled that ESK had commissioned the INB vendors' consortium to plan the large SNR 2 pool-type breeder in 1976. In 1978 - 1981, the so-called pool analysis was conducted together with Novatome-NIRA. On the basis of that analysis, the INB/KWU consortium was awarded another contract in 1982 for preplanning a 1500 MWe pool-type reactor. The French experience in planning SPX 2 was to be fully utilized in that draft.

The design of the pool-type SNR 2 was nearly completed in 1985. The primary system consisted of a main vessel and a separate guard vessel suspended from the top, a double-walled "redan," eight intermediate heat exchangers (IHX), and four primary pumps. For the secondary system, the SPX 2 "REGAIN" concept with straight-tube steam generators was adopted. In order to improve the availability of the plant, eight secondary systems were provided so that each IHX was directly connected to a secondary pump and a steam generator. The decay heat removal system consisted of four immersed coolers which transferred the heat to four air coolers arranged in separate natural-draft chimneys.



Cross section, SNR 2 primary system.

Compared to SPX 2, SNR 2 had no internal or external core catcher, had smaller steam generator modules (450 MWth), an external fuel element store, and a cylindrical reactor building. The nuclear steam supply system was designed so that full-load operation was possible with seven out of eight steam generators.

Compared with SNR 300, a major reduction in specific plant costs was sought in a number of important ways. Thus, hypothetical core disruptive accidents were to be excluded by preventive measures. Decay heat was to be removed exclusively by passive systems making use of the advantageous thermal properties of sodium. The design approach was based on realistic assumptions about pipe leakages and acceptance of the leak-before-break criterion. Finally, the probability of occurrence of less frequent external impact events, such as airplane crash or gas cloud explosion, was to be taken into account in the load criteria to be established. The German Federal Ministry of the Interior (BMI) established an advisory group to settle these important basic questions. Together with members of the German Advisory Committee on Reactor Safeguards (RSK) it approved the SNR 2 safety concept. This provided an important backing to further planning activities.[50]

After completion of the planning stage, ESK and INB jointly found that there were no grave technical, safeguards or cost differences between the loop and pool designs. RWE clearly favored the pool version of the SNR 2 for the following reasons:[51]

(1) There was already a large breeder plant, SPX 1, which, in addition, had been built in international cooperation.

(2) Considerable additional funds would have to be spent to raise the loop type to the level of technical maturity already attained by the pool type.

(3) The further development and harmonization of only one type in Europe implied cost benefits to all partners.

(4) The anticipated operating performance of SPX 1 was more valuable for a following pool-type than for a loop-type plant.

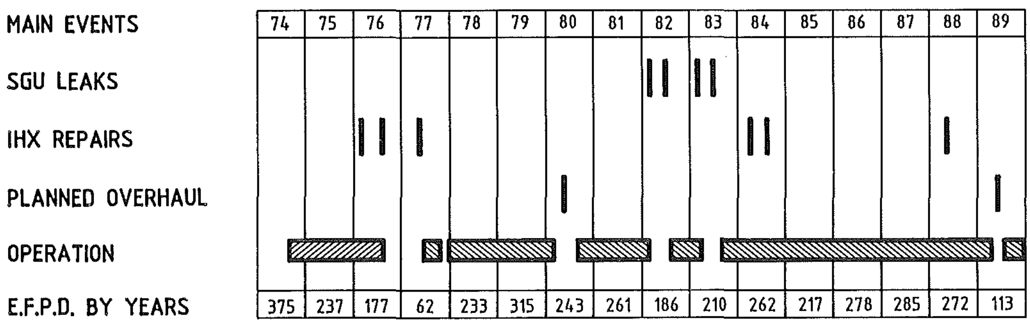
It then became apparent that the two projects, SNR 2 and SPX 2, were in a competitive situation. Both EdF and Novatome tried to find international partners to finance SPX 2 and, in this way, protect the continuity of French fast breeder development. At one point in time, the British CEGB was mentioned. RWE, on the other hand, tried to build the pool version of SNR 2 in accordance with the Utilities' Convention of 1973 as the next breeder to be constructed by ESK.[52]

However, these schemes were counteracted by the severe problems soon experienced in construction and operation of the SNR 300 and SPX 1 plants.

2.3 Problems in Breeder Operation

In the mid-eighties, the leading German and French projects, SNR 300 and Superphénix 1, experienced considerable political and technical troubles described in greater detail in this chapter. However, let us first have a look at the smaller plants, Phénix, PFR, and KNK II, whose reactor operation at the same period of time was free from major problems and resulted in satisfactory availabilities.[53,54]

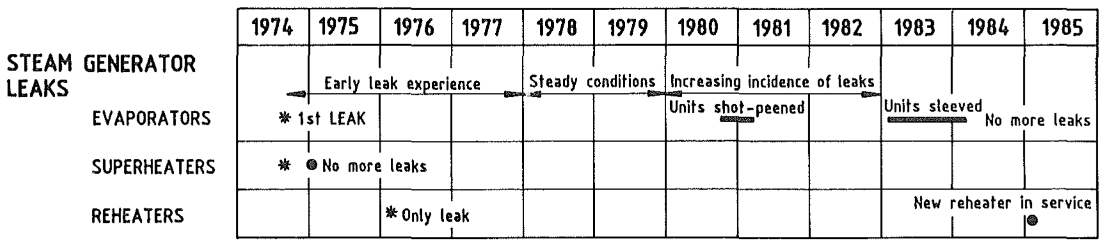
Phénix had a load factor of 50 to 77% in 1980 - 1988. With one exception (1982), the plant was connected to the power grid for more than 200 full-load days annually. In



Phénix operating history 1974 - 1989.

1982/83, leaks in the reheater modules led to a period of operation on two circuits. The failures were located at the welds of the upper bend of these components. In 1986, a small leak developed in one of the IHX, which was replaced by a spare component. Finally, in 1986, a leak occurred in one of the main pipes of the secondary circuit, allowing some 50 kg of sodium to freeze in the insulation.

PFR in Dounreay for the first time attained its rated power of 250 MWe in March 1985,



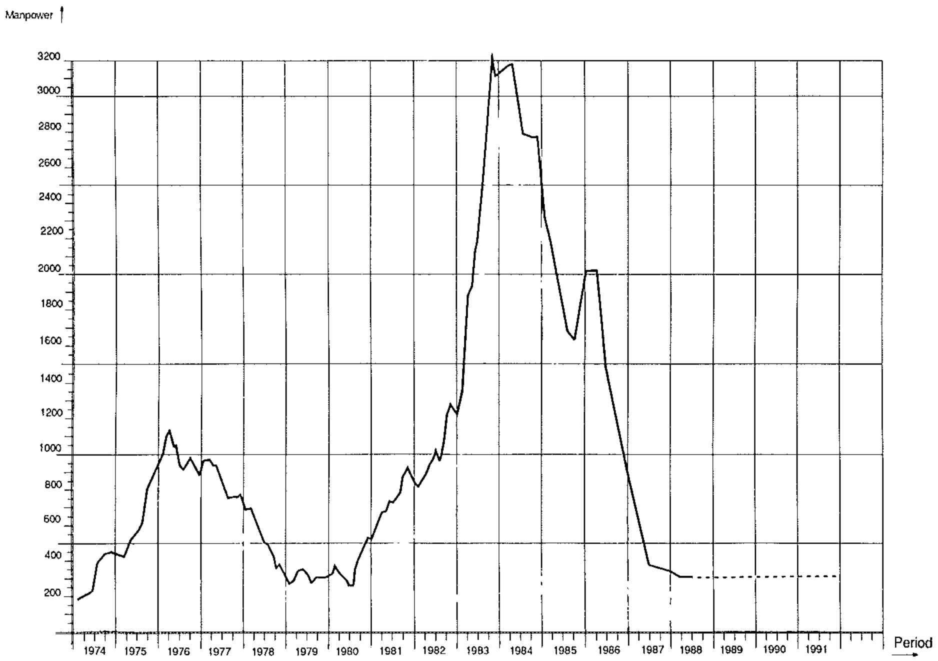
PFR operating history 1974 - 1985.

after sleeving of the evaporator tubes to bypass the troublesome tube/tube plate welding had been completed in summer 1984. The load factors in 1986 - 1989 averaged 40%; 1989 even 51.8% was reached. Some problems still arose in superheater unit 2 which, from 1987 on, was replaced by new equipment together with the remaining original reheaters.

In **KNK II**, the 20 MWe test facility at the Karlsruhe Nuclear Research Center, the rated load had been reached in March 1979 for the first time after the modification. In summer 1982, the MOX fuel elements attained a burnup of 100,000 MWd/t, which was 40% above the design specifications. As a consequence of argon gas passing through the core, a number of unplanned outages had been experienced during this period of operation; the defect was corrected by modifications to the plant. In 1983, the second core of KNK II, with thicker fuel rods, was commissioned. Also this core attained in-pile times far beyond the original design limits.

2.3.1 SNR 300: Technical Progress and Political Trouble

When the Christian Democratic-Liberal coalition government came into office in October 1982, the German SNR 300 breeder project experienced a remarkable revival. Par-



Personnel development on the Kalkar construction site,
1974 - 1988.

liament approved the continuation of the Kalkar project and its later commissioning; as a consequence, building activities were resumed.

Construction now proceeded at a breathtaking pace. The reactor vessel, which had been kept in cold storage on the power plant site since 1976, was moved into its final position in the reactor cavity still in late 1982. Between 1983 and 1985, the 33 large components, especially the sodium pumps, intermediate heat exchangers, and steam generators, most of which had been manufactured in the Netherlands, were transported to the plant and assembled. Also fuel element fabrication at Alkem and Belgonucléaire had been completed in 1985. At peak periods, up to 3300 persons were engaged in assembly work at Kalkar; 900 firms, most of them small and medium-sized enterprises from the Federal Republic and from Belgium and the Netherlands, participated in the development effort. Cooperation among planning engineers, assembly crews, and supervisory and licensing authorities was so successful that the timetable of the project was underrun by no less than seven months on a few occasions - an unprecedented event in the history of the Kalkar Nuclear Power Station.

In May 1985, after sodium had been filled into the primary systems, construction of the breeder plant as specified in the delivery contract was completed. The subsequent prenuclear commissioning phase produced no major problems. Some problems, however, were encountered with leaking storage tanks, a broken vibration lance, and moisture in the top shield. An operating permit for fuel loading and for the critical experiment had been applied for a long time ago. However, it did not materialize. In fact, it never materialized.

What had happened?

The State of North Rhine-Westphalia, the coal country in which Kalkar was situated, had meanwhile embarked on a so-called "coal first policy," which had been coupled with a halt of construction of all nuclear power plants. When the Social Democratic Party won the 1985 elections to the State Parliament with an absolute majority, leading representatives of the State SPD expressed themselves even against commissioning SNR 300. A change of mind in the whole party was brought about by the Chernobyl accident in April 1986. That disaster traumatized large parts of the German public for months and, in particular, reunited the nuclear opposition. Consequently, the Social Democratic Party of Germany at its party congress in Nuremberg in August 1986 decided to opt out of nuclear power altogether within the next ten years. Many delegates expressed themselves especially against the breeder in Kalkar, believing it to have a pilot function in introducing the dreaded plutonium technology. Attempts were even made to establish certain technical parallels between the reactors of Chernobyl and Kalkar:

Both reactors contained burnable components (graphite and sodium, respectively), and had positive coefficients of reactivity under certain operating conditions.

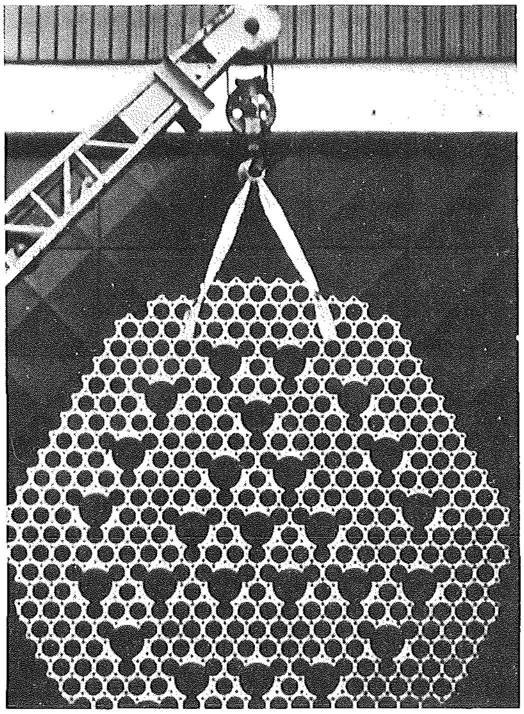
After Chernobyl, no progress was made in the licensing procedure for SNR 300. The plant was ready, but could not be commissioned. Nonetheless, great efforts were made to refute those arguments of the State authorities which were of a technical, not political and ideological, nature. Especially the alleged similarities in the technical concepts of Kalkar and Chernobyl were convincingly explained away by Interatom. The German Advisory Committee on Reactor Safeguards confirmed these findings by the manufacturers in a detailed comment in April 1987. Following an instruction by the Federal Minister for the Environment, Klaus Töpfer, an illustrious group of independent international safety experts from France, the UK, Japan, and USA dealt with the same question six months later, and arrived at the same positive finding about Kalkar. All experts agreed that the mechanical energy release in a Bethe-Tait accident would not destroy the primary system of SNR 300.

Nevertheless, the competent State Minister in Düsseldorf (Jochimsen) continued to refuse the operating permit for the SNR 300.

2.3.2 Technical Problems in Superphénix 1

Ordered by NERSA, the construction of Superphénix started in 1976 and initially progressed quite speedily. However, the first trouble was encountered in the early eighties. The problems caused by the crane system have already been referred to. In addition, there were difficulties in manufacturing the reactor roof slab, which weighed 3000 tons, and whose twelve modules were made partly in France and partly in Italy. Also production of the steam generators caused a delay in the timetable. The complex systems of helically wound tubes were difficult to weld, and quality control of the welds and of the thermohydraulic features was relatively expensive, compared to the conditions in U-shaped steam generators for pressurized reactors.

From October 1984 onward, sodium was filled into the plant. In the prenuclear tests, the engineers registered clearly audible flow-induced vibration noises which exeeded the calculated values and seemed to come from structures within the vessel.[55] The MIR robot developed for inspection of the main vessel welds was used to ascertain the source of the noise. It fell into the gap between the reactor vessel and the safety vessel when manipulated and had to be recovered with difficulty. Finally, the phenomenon was traced back to cold sodium flowing from a special spillway into the inner vessel of the reactor. Changes in the shape of some twenty reflector elements improved the thermohydraulic conditions and solved the vibration problem.



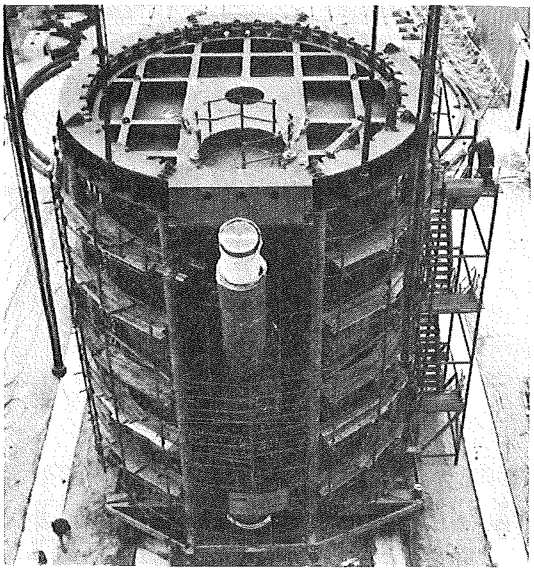
Core cover plug lattice of Superphénix during construction.

Core loading was begun on June 20, 1985, and Superphénix went critical for the first time in the early afternoon of Saturday, September 7, 1985. Accidentally - quelle surprise! - this occurred on the 65th birthday of Georges Vendryes who, of course, happened to be present. After many years of activity as director and mentor of the French breeder program he then retired. The reactor went critical with 325 fuel elements; previous calculations had indicated 326 - a veritable success of the French reactor physicists.

Afterwards, NERSA (Saitcevsky) and EdF (Carle) presented a few cost data at a press conference. Their report showed that technical problems in construction and the associated delays - the plant originally was to have been commissioned in 1982 - had caused considerable extra cost. The total cost of the project ran up to some FF 25 billion, which made Superphénix, on the basis of cost per unit power installed, approximately a factor of 2.3 more expensive than the 1300 MWe LWR plants, Paluel-1 and -2, built at the same time.[56]

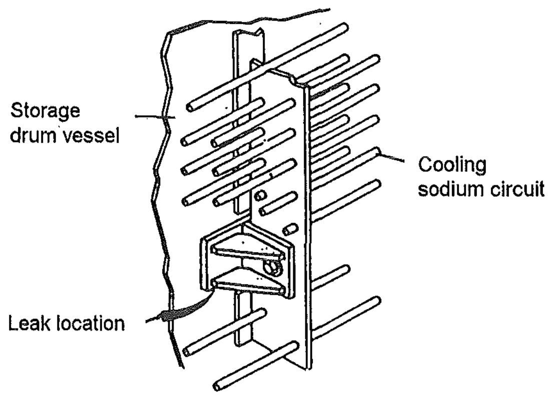
In the following months, the power of Superphénix was raised in steps. In January 1986, the plant was connected to the power grid for the first time, and attained its full power in December of that year. Because of the high thermal inertia of the nuclear steam supply system, the plant was quite stable and easy to control.

A certain amount of difficulties arose from the large number of reactor scrams (74) during the power raise. As a rule, they were due to defects in instrumentation and in the many valves of the plant, but also to human error. In February 1987, one accident was caused by a so-called water hammer. When turbine B was commissioned, steam got into an unpurged pipe full of water and caused a rather severe shock to the adjacent components.[57]



Storage drum of Superphénix before the installation.

By that time the plant had been in operation for some 4000 hours and produced a total of 2 terawatthours of electricity, when a serious defect occurred on March 8, 1987. Leak detectors between the spent fuel storage vessel made of ferritic steel and the safety vessel enclosing it raised an alarm. Immediate measurements seemed to indicate a leakage of sodium into the gap between the two vessels at a rate of approximately 20 l per hour. This suspicion was confirmed, and roughly one month later already 25 m^3 of sodium had spilled into the gap between the two vessels. As it was found impossible to repair the storage vessel at short notice, a decision was taken to reload into the core the few fuel elements held in the storage vessel, and put the approximately 400 dummy elements into special containers. Subsequent materials studies indicated that cracking very probably had been due to embrittlement by hydrogen; the cracks obviously developed disruptive zones under the influence of the residual welding stress.[58]



Superphénix fuel storage drum leak location.

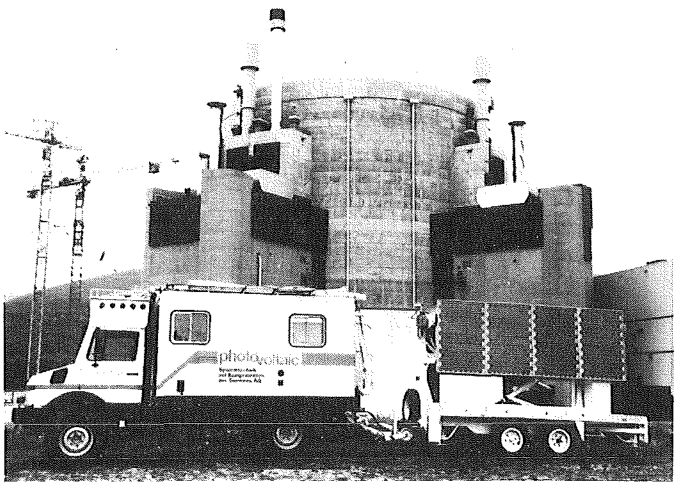
The accident happened at a most adverse point in time. The temporary operating license was about to expire, and the regulatory authority, Service Central de Sûreté des Installations Nucléaires (SCSIN), intimated difficulties in extending it. In addition, it so happened that Novatome was to be taken over as a division of Framatome, also in the summer of 1987. In view of unsettled warranty claims against Novatome - after all, Superphénix had not yet been delivered to NERSA -, negotiations about the merger understandably became more complicated.

The sodium leak in Superphénix threw the French media into high gear. On June 28, the then Prime Minister, Jacques Chirac, joined the public debate and commissioned the competent Minister for Industry, Alain Madelin, to conduct a detailed study of the situation. The Minister soon ordered an inspection to be made of the reactor vessel and the safety vessel, and other quality control measures to be taken.

In the light of this situation it was deemed unlikely that the plant would be restarted at short notice.

2.4 The Utilities Clear the Way

The persistent hesitation of the European electricity utilities to agree on a common breeder program began to have a clearly negative impact on various partners after 1987. The decision taken by the Netherlands not to join the breeder agreement has already been mentioned. Also the Belgians decided at that time to reduce the nuclear share of their CEN/SCK Mol Research Center and lay off several hundred staff members. At the Karlsruhe Nuclear Research Center, diversification began into such new areas as nuclear fusion, climatological research, and microstructure engineering, and the share of breeder research was cut back from 30% to 15%. Even Interatom ventured into new areas, such as solar technology (in addition to catalytic converters, artificial intelligence) and planned to eliminate 400 professional fast breeder jobs by 1990.



Interatom truck advertising photovoltaics
(with Superphénix in the background).

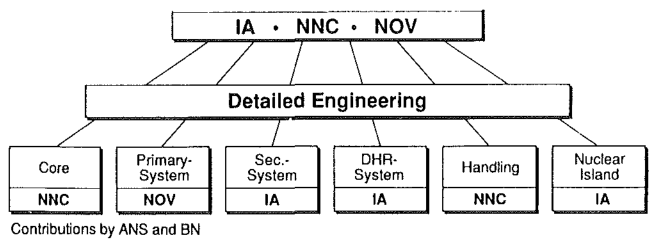
As a result of the dragging negotiations with EdF about Superphénix 2, also Novatome got into an increasingly more difficult situation. In Italy, the outcome of the nuclear referenda had resulted in ENEA ceasing to be available as a partner in the R&D sector; the only hope remaining was that ENEL would continue to be a member of the Superphénix consortium. In Britain, the Government planned to privatize CEGB, thereby creating a difficult situation in the breeder field. And changes became imminent even in France: In 1988, EdF for the first time planned no new nuclear power plant.

2.4.1 EFRUG Decides on the Common Model Breeder

In mid-1987, after the German national elections, EFRUG resumed its exploratory talks. The problems encountered in the SNR 300 and Superphénix reactors, and the gradual erosion among the R&D partners, required quick decisions unless European breeder cooperation was to come apart. In particular, conditions had to be created to make the breeder agreements, which had been shelved since 1984, ready for signature at long last. This primarily required agreement among the utilities on a European breeder construction program.

At a meeting of EFRUG with RWE in Essen in June 1987 finally the ice was broken.[59] In a very frank discussion the partners confessed that, under the present conditions, there was no way to build either Superphénix 2 or SNR 2. Consequently, they decided to get out of this stalemate by concentrating all forces on one common reactor. This Common Model Breeder, initially called EURO 1, was to combine the best design principles of SPX 2, SNR 2, and CDFR, to be designed jointly by all vendors, and to be based on the R&D findings of all research organizations. In addition, EFRUG demanded that EURO 1 be licensable in all partner countries. In the course of further discussions held by EFRUG in Lyons and London in late 1987, cooperation of the R&D partners was obtained, and a preliminary structure of project development was drafted. In a planning phase of five years, the basic concept was to be established in the first two years, and the detailed design draft was to be elaborated in the following three years.[60]

At a meeting at Interatom in Bensberg in February 1988, these loose agreements were formalized. EFRUG and representatives of the vendors and the research organizations agreed on a common approach to the project and resolved to adapt accordingly the wording of the agreements still to be signed. The breeder power plant was to be designed



Distribution of EFR engineering among the partners in EFR Associates.

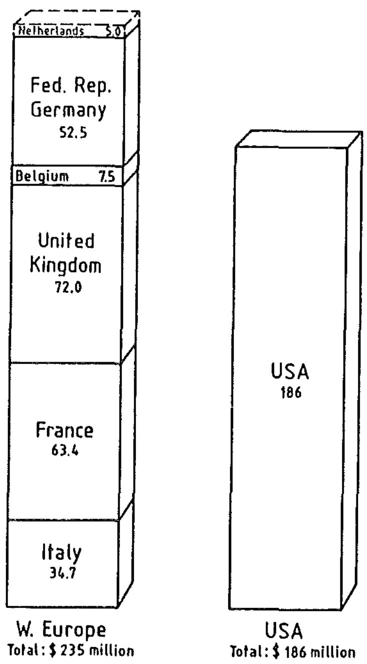
by NNC, Novatome, and Interatom; certain contributions were expected from Belgonucléaire, Neratoom, and Ansaldo. Interatom could hope to be entrusted with the leadership in the field of passive decay heat removal, which was so important to technical safety, and for which Ulrich Wolff of RWE, among others, had argued so committedly. Precisely at the time of the meeting, Matthias Koehler, Vice President of the company, was able to announce that funds for the ILONA experimental facility had been made available. ILONA was to demonstrate the passive decay heat removal of a large breeder reactor.

Yet another decision was taken: The common breeder project was given its new, final name.

EURO 1 became **EFR**: **E**uropean **F**ast **R**eactor.

2.4.2 The European Agreements Are Signed

Now that the electricity utilities had agreed on the technology of a future building program it was possible, at long last, to think about signing the detailed breeder agreements initialed back in 1984 and since waiting to be adopted. The signing ceremony was to be held in Germany by invitation of Minister for Research Heinz Riesenhuber. This time, the venue was not to be symbolic Aachen, but the more mundane Bonn.



Breeder R&D budgets in Western Europe and USA in 1985 (excluding expenditures for reactor operation).

The legal step was delayed again, until 1989, as a result of considerable irritation caused by the British camp. The British Energy Secretary, Cecil Parkinson, had told his Parliament on July 21, 1988 that the Government was planning major cutbacks in the breeder field. For instance, it intended to decommission the Dounreay PFR in five years and shut down the associated reprocessing plant three years later. Decisive cutbacks were planned also in the R&D program. The present annual budget of £54 million was to be reduced to 20 next year and even to £10 million in the following years. This was coupled with major job losses in various British research centers.[61]

This decision by the UK Secretary for Energy jeopardized the European breeder program most seriously before it had even taken off. While France, Germany, and the British originally had each contributed one third to the overall budget, the UK, as a consequence of this political decision, suddenly found itself in the role of a junior partner. It took a letter by Parkinson to Riesenhuber to clarify that the British intended to remain full members of the European Breeder Association.[62]

On February 16, 1989 the agreements finally were signed in Bonn. The R&D Agreement was signed by CEA (Capron), UKAEA (Collier), Interatom (Berke/Brandstetter), KfK (Böhm/Hennies); the Industrial Agreement was signed by Novatome (Villeneuve), NNC (Taylor), Interatom (Berke), and INB (Bürkle). The Agreement on the Utilization of Know-how was concluded between Serena (Rapin/Berke) and Fastec (Taylor). The representatives of Ansaldo had signed a few days before and were not present at the ceremony; the Belgians had been refused accession to the Agreement by their Government a few days before.

Now work on the EFR project could truly begin.

3 The EFR Conceptual Design Phase

3.1 Building the Administrative Structures

After the decision to pursue one single European breeder project instead of a number of national projects, the necessary administrative structures were built up. This was no mean task, given the large number of participating countries, firms, organizations, and persons. It was even more difficult to get the whole machinery working and ensure its efficiency. That this was achieved in a surprisingly short period of time was stated repeatedly later on, also expressed publicly, especially by the utilities.

In anticipation of the problems to be solved, all participants suppressed their national egotisms.

3.1.1 EFRUG Sets the Goals

The electricity utilities associated in the European Fast Reactor Utilities Group (EFRUG) expected the reactor designers to include in the EFR conceptual design the best features of SNR 2, Superphénix 1 and Superphénix 2, and CDFR. In a nutshell, EFR was to be technically better and cheaper than any of the above national projects. On top of that, EFRUG formulated these basic principles:[63,64]

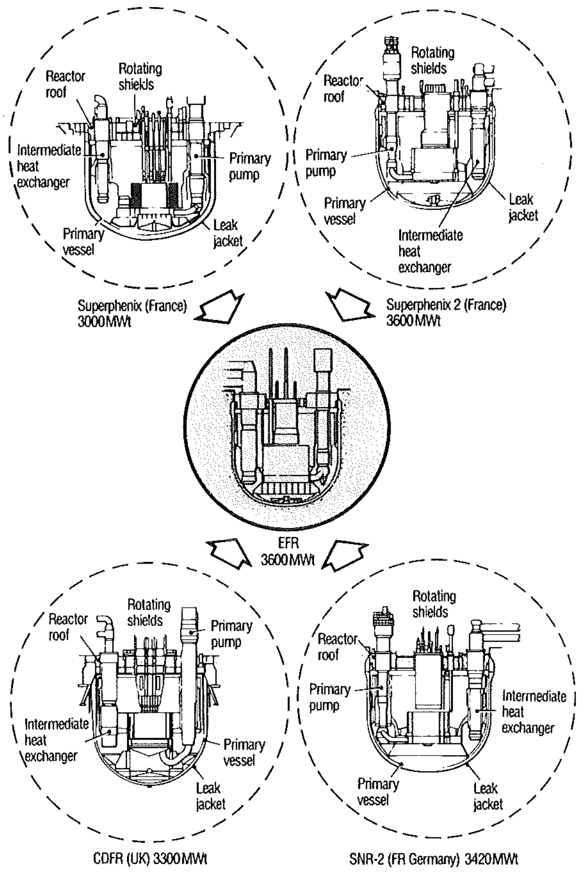
(1) EFR was to make the best use of the (passive) safety features of breeder technology and was to be licensable in all partner countries.

(2) It was to be a robust design, especially with regard to the steam generators, and was to offer good accessibility for inspection and maintenance.

(3) It was to be flexible with respect to fuel production, i.e., allow variable plutonium breeding ratios to be adopted.

(4) It was to be optimized in terms of capital cost and availability, thus representing a model of commercial breeders to be built in competition with thermal reactors approximately from the year 2010 on.

(5) Design activities were to be backed by a broad research and development program carried out by the government R&D organizations.



Comparison of EFR with earlier national designs.

There was also agreement between the utilities and industry that EFR was to be a large monolithic breeder power plant of approximately 1500 MWe power. At that time, EFRUG had no interest in small modular plants, although that development in the USA was observed, and the design companies on both sides of the Atlantic again and again were encouraged to exchange technical and economic data.[65]

The supervisory body in EFRUG was the so-called EFRUG Board composed of high-level representatives of EdF, RWE, ENEL, and Nuclear Electric (NE), formerly CEGB. PreußenElektra and Bayernwerk joined later; UNESA (Spain), became associate members. The executive function of EFRUG was provided by a Secretariat of four very committed middle managers who handled day-to-day business, especially providing the interface with the design companies and the R&D organizations. In technical matters, the Secretariat was assisted by the Project Management Team of the vendors, described below. There was no project leader, an omission which the PMT and the MGRD occasionally had reason to regret.

3.1.2 The Design Companies Get Organized

When design activities for EFR began (the official date was later fixed as March 1988), also the participating reactor vendors organized themselves. Interatom, Novatome, and NNC as signatories to the Industrial Agreement together set up the EFR Associates (EFR Ass. and EFR.A, respectively) consortium; Ansaldo and Belgonucléaire acted as subcontractors in specialized areas. The engineering capacity of these companies comprised approximately 250 persons; for the first, the Conceptual Design Phase, an expense of approximately 500 man-years had been estimated. The budget for EFR.A amounted to some DM 50 million per annum.[66,67]

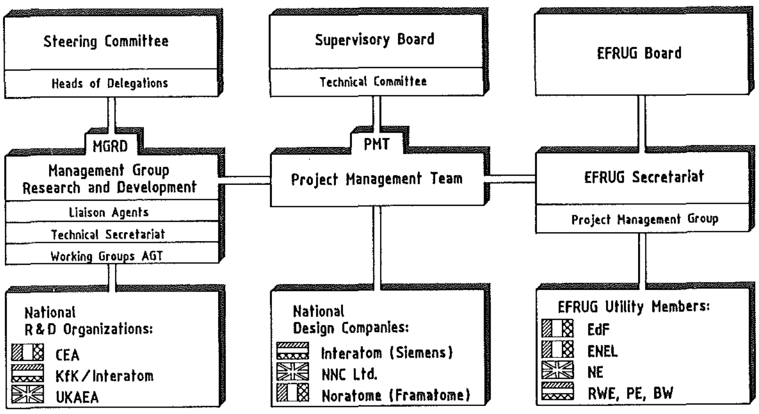
The main systems of EFR were to be planned at the company locations of Bergisch Gladbach, Lyons, and Risley where the proven organizational structures existing in those places could be used. Engineering Areas in line with the expertise of companies were defined as responsibilities. In this way, Novatome became responsible for the primary system, NNC for the core and for handling, and Interatom for the secondary system, the decay heat removal system, and the nuclear island. This rather coarse subdivision, of course, permitted also other design companies to engage in a work package, if their knowledge allowed them to do so.[68]

The Project Management Team (PMT) set up by EFR Associates was responsible for overall coordination and control of the engineering activities, but also for more general problems of safety, quality assurance, codes, and economic evaluations. The Director of the PMT was Kurt Ebbinghaus of Interatom; he was supported by two deputies (C. Mitchell, NNC, and M. Debru, Novatome), and nine project engineers, each with a specific responsibility within the EFR Project. The PMT office was opened in Lyons in June 1990.[69]

The Supervisory Board supervised the activities of the PMT. It was staffed with two high-level representatives each from the company managements of Novatome and Interatom and NNC, and handled important policy matters for the entire project.

3.1.3 Managing the R&D Activities

The management duty of the R&D organizations was to direct the R&D activities at the thirteen research centers in the three partner countries, France, Britain, and Germany, in the light of the needs of EFR. It has been mentioned above that, up until 1988, those organizations had exclusively supported the national projects, KNK II, SNR 300, SNR 2, Phénix, Superphénix 1 and Superphénix 2, PFR, and CDFR. That objective had to be abandoned in favor of the new common project, EFR, although the reactors already in operation (KNK II, Phénix, Superphénix 1, PFR), of course, had to be supported also in the future. Consequently, one of the main activities of R&D management was to identify current research needs and avoid duplication (or even triplication) of effort in existing research programs.



Organizational structures of EFR, the European Fast Reactor Cooperation.

A project management staff was set up also for these purposes by the R&D entities to deal with the organizational aspects of this task. The existing Mangement Subcommittee (MSC) was enlarged and developed into the Management Group for Research and Development (MGRD) effective November 1989. Five to six representatives at the level of Project Managers of CEA (2), KfK (1), Interatom (1), and UKAEA (1 - 2) regularly met to coordinate the R&D efforts associated with EFR. The author of this report was appointed Permanent Chairman of the group and (full-time) Executive Director. For this reason he gave up his position as Head of the Fast Breeder Project (PSB) at the Karlsruhe Nuclear Research Center effective December 31, 1989, not realizing that the EFR Project - as initially envisaged - would be over only four years later. The MGRD met roughly six times a year to discuss the main items of the whole program and accept the most important results. Another important duty of the MGRD was the setting of annual goals for the Working Groups (AGT).

The Executive Director and the MGRD were supported by a Technical Secretariat, the Liaison Agents and the AGT Working Groups. The Technical Secretariat (TS) was located partly at the Karlsruhe Nuclear Research Center and mainly at CEA Cadarache, and comprised 4 - 5 technical specialists delegated there by their countries of origin for periods of 2 - 3 years (plus typists). The TS provided technical support service, administered the work control system, and played an important part in reporting the R&D results.

AGT - Working Groups:

AGT 1	*Fuel Elements and Core Materials*
AGT 2 A	*Sodium Chemistry*
AGT 2 B	*Instrumentation*
AGT 3	*Core Physics*
AGT 4	*Safety Research*
AGT 5	*Thermal Hydraulics and Core Mechanics*
AGT 6	*Reactor Vessel, Handling, and Auxiliaries*
AGT 7	*Thermal Transfer Systems and Components*
AGT 8	*Reactor Operation*
AGT 9 A	*Plant Structural Materials*
AGT 9 B	*Structural Integrity*

In contrast to the Technical Secretariat, the three Liaison Agents (LA) resided in their respective countries. They were the first persons to be consulted whenever a designer needed R&D support. It was their duty to feed these R&D requirements into the relatively complex structure of the R&D partners and monitor the resultant activities. In addition, the LA played an important role in drafting the Annual R&D Reports.

Mention has already been made of the Working Groups (AGT) with one national coordinator each. They met roughly twice a year to harmonize the R&D activities in their areas of responsibility and, in addition, arranged specialist meetings when required. The regular reports by the AGT constituted the substance of the deliberations of the MGRD. In a way, the AGT constituted the backbone of the R&D management structure.

The body supervising the MGRD was the Steering Committee; it set the overall R&D policy. It was composed of four high-level members each of the partner countries (one of whom came from the design organizations), and the Executive Director. Chairmanship rotated annually among the highest ranking representatives of CEA, KfK, and

AEA. The SC met twice a year in different places for discussions of topics, such as the national nuclear power situation, important technical questions of detail, matters of international cooperation and agreements, etc. At those meetings, the Executive Director regularly reported about the R&D Program and about the budget available.

Mr. H. Mausbeck	Interatom	7/1984 - 9/1985
Mr. R. Lallement	CEA	9/1985 - 5/1987
Mr. W. Marth	KfK	5/1987 - 11/1988
Mr. R. Lallement	CEA	11/1988 - 10/1989
Mr. A. M. Broomfield	AEA	10/1989 - 11/1990
Mr. H.-H. Hennies	KfK	11/1990 - 11/1991
Mr. J. Bouchard	CEA	11/1991 - pres.

List of Chairmen of the Steering Committee.

The ways in which these bodies worked will be described in greater detail in the next chapter.

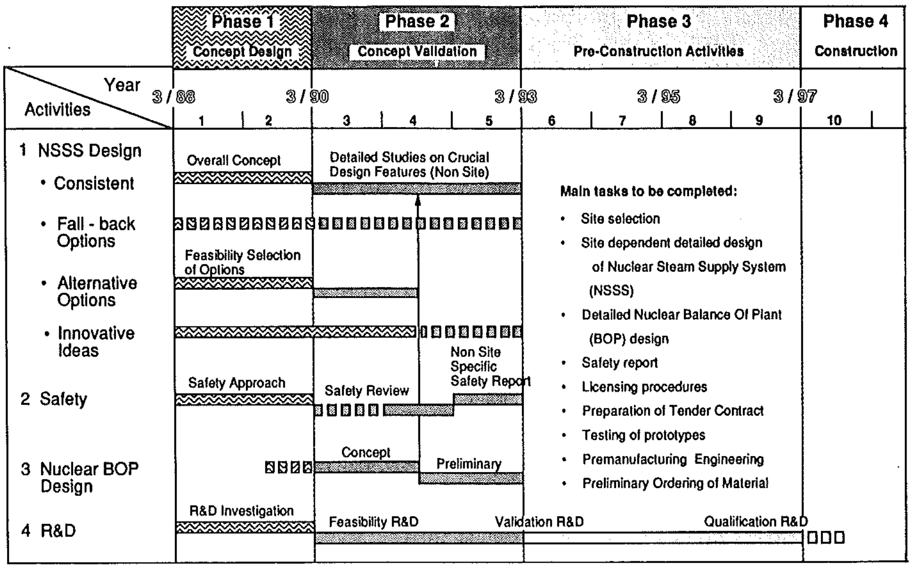
3.2 Planning EFR

3.2.1 The Timescale of the Project

The EFR time schedule provided for several, clearly separated, project sections.[70,71]

The **Conceptual Design Phase** extended over a period of two years, from the official start of the project in March 1988 to March 1990. During that period, the conceptual design of EFR was to be completed. One intermediate step was the First Consistent Design to be presented to EFRUG already in September 1988. It still contained a large number of design options, which were eliminated step by step in the course of 1989 or were clearly marked alternative or fall-back solutions, respectively.

In the course of the ensuing **Concept Validation Phase** (3/1990 - 3/1993) the systems engineering of EFR was to be completed. In-depth studies were to be conducted both of the crucial design features and of innovative alternatives. Moreover, the safety philosophy of EFR was to be checked by an independent body of European experts. Finally, the costs and the economic potential of the plant were to be evaluated relative to those of light water reactors.[72]



EFR timetable.

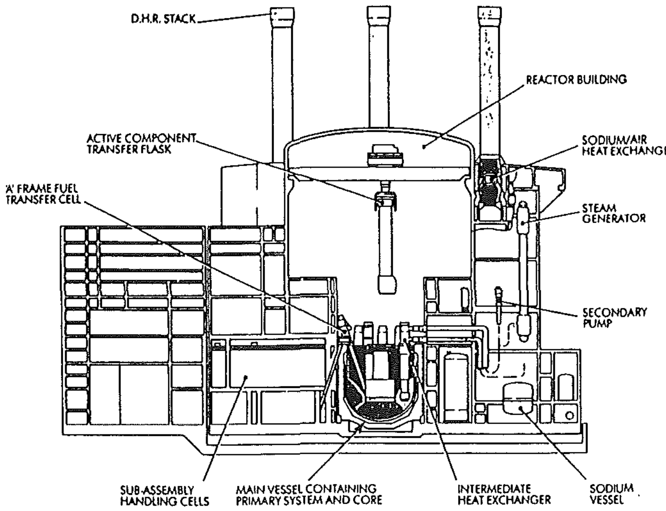
The next two project phases, understandably, were not yet planned to the end. In the **Pre-construction Phase** (1993 - 1997), the important siting decision was to be taken, detailed planning, including the balance of plant (BOP), to be finished, and licensing in the host country to be achieved on the basis of the Safety Analysis Report. The subsequent **Construction Phase** (1997 - 2005) was to be devoted to the construction and commissioning of EFR, for which a span of seven years was deemed sufficient.

Unfortunately, it proved to be impossible to complete this schedule, and the EFR Project in its initial structure was halted at the end of the Concept Validation Phase.

3.2.2 The Technical Design of EFR

This chapter describes the status of technical planning of EFR as presented to the utilities in early 1990, after completion of the Conceptual Design Phase.[73,74,75]

The **nuclear island** rested entirely on a single foundation, and most of the buildings were seismically separated by rubber isolators tuned to a frequency of approx. 1 Hz. The centerpoint of the plant was the circular reactor building, surrounded by three satellite steam generator buildings. Maintenance facilities for active components and fuel handling cells for fresh and irradiated fuels were located outside the reactor building.[76,77]

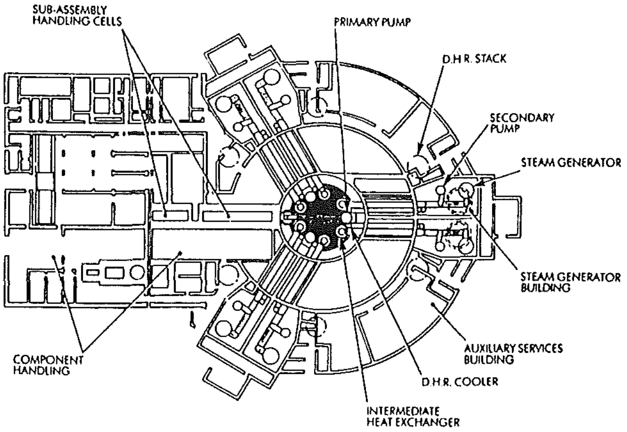


Nuclear island building layout (vertical section).

The **core** was designed to have two enrichment zones and both axial and radial breeding blankets. The fuel management scheme was based on a six-year in-pile time of the fuel. Two core versions (homogeneous and axially heterogeneous) and two core layouts with different breeding gains were selected for further study. A typical option for the homogeneous core included 346 fuel elements, 72 breeder elements, and an internal store with 262 positions. The target burnup for the fuel elements was 20 at.% (190 dpa NRT), which certainly was rather ambitious. The core height had been fixed at 140 cm, for the time being. Two independent shutdown systems were provided, each consisting of a trip system and an absorber rod system.[78]

The **primary system** included six intermediate heat exchangers and three primary pumps. This led to a primary vessel of 17 m diameter, which was rather small compared to the previous SPX 1 design. The intermediate heat exchangers were fitted with mechanical seals and valves; the pumps were designed for single impellers and subcritical shafts. The internal store mentioned above was cooled by forced circulation. The double rotating shield was used with both direct and offset arm refueling machines. The above-core structure accommodated, *inter alia*, the instrumentation for delayed neutron detection and fuel assembly temperature control.[79]

The **secondary system** transports the heat from the primary system to the steam circuits. The choice of six intermediate heat exchangers and six steam generators allowed a six-loop configuration, with each loop being similar in layout and offering improved availability and functional benefits. The steam generators were once-through, straight-tube units made of 9Cr1MoVNb ferritic steel. The "REGAIN" design concept employed a location of the secondary pumps at a low level. The benefits of this concept were the short pipe routes which were expected to save costs.[80]



Nuclear island building layout (horizontal section).

The **decay heat removal** concept was intended to minimize safety-graded emergency power supplies. Six dip coolers in the primary vessel were connected to six sodium-air coolers arranged in natural-draught air stacks. The main pipes connecting the components were designed to have low flow resistances in order to enhance natural circulation. The general approach was to strengthen the passive capabilities by means of natural sodium circulation.[81]

This brief description of EFR should be taken with a grain of salt, because the design was still very much under development in 1990, and was modified considerably in some respects in the ensuing phase. The reduction of the core height was just one case in point.[82]

3.3 Backing by R&D

At many points the design groups working on EFR approached the limits of their knowledge. In most cases, this concerned problems of material, often also thermohydraulic problems, even questions of physics. In those cases they expected the R&D organizations to answer immediately, if possible, or launch the appropriate research programs. The structure of the R&D Program and the most important topics treated will be described below.[83]

3.3.1 The Structures of the R&D Programs

At the beginning of the EFR Project, the thirteen research centers in the three partner countries handled roughly 1200 individual R&D tasks, employing approximately 1000 staff members for these activities. Keeping track of all those activities and tailoring them optimally to the needs of the industrial design companies occasionally resembled the effort involved in keeping a bag of fleas. The program had to be given a certain structure, and this was achieved in various ways.[84,85]

A so-called "Blue Book" listed all R&D activities, i.e., all the single tasks described above. It also indicated who was responsible for performing those activities. In another step, these tasks were condensed into some 140 Work Packages. These packages were ruled by detailed timetables within which the interim steps had to be completed and the expected interim results produced. So-called Work Package Officers were nominated to check compliance with these outlines.

Topic	Percentage of Overall EFR R & D Budget	Contributions of the Partners (percentage) FRG	UK	France
Core	30	33	17	50
Primary circuit thermalhydraulics	5	9	30	61
Decay heat removal	10	88	1	11
Safety	25	51	11	38
Steam generator units	7	11	27	62
Structural materials and design rules	12	34	33	33
In-service inspection and repair	6	65	12	23
Core instrumentation	1	29	34	37
Components, auxiliary systems and handling	4	48	2	50
	100 %			

Allocation of 1991 R&D budget to topics and partners.

The next step in coordination was represented by the AGT mentioned above, an acronym derived from Arbeitsgruppen/Groupes de Travail. The eleven AGT covered the entire Fast Breeder Research Program, both the EFR-related program and the fundamental program extending beyond that framework. Later on, an ad hoc group for in-service inspection and repair (ISIR) was added. The AGT differed clearly in scope (and claims on the budget). The highest expenditures were incurred in the area of the core (AGT 1, AGT 3, and AGT 5). This was followed by safety (AGT 4), while sodium technology (AGT 2A) and instrumentation (AGT 2B) required only comparatively small budget amounts.[86]

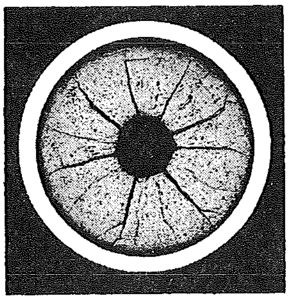
Also the degrees of involvement of the three partner countries differed (deliberately). Core studies were conducted mainly in France, also because the required reactors were available there. In the areas of decay heat removal and safety, the German R&D organizations, KfK and Interatom, bore the main brunt. When it came to problems of steam generators and materials, the British were exceptionally strong, also because of their sorry PFR experiences.[87]

3.3.2 Main Activities of the AGT

The main areas of research covered by the AGT will be described below. In some instances, the subject catalog of a working group comprised more than 100 specific tasks. Consequently, this description can provide only a very rough outline of the research areas covered by an AGT.[88]

AGT 1: *Fuel Elements and Core Materials*

The scope of AGT 1 was to study fuel elements and core materials in the light of their out-of-pile and in-pile behavior. For this reason, the performance of MOX fuel and several steel categories for claddings and wrappers during reactor irradiation was analyzed.[89] In addition, modeling codes were provided, and failed fuel as well as absorbers were studied.[90,91]



Cross section of PE16 pin with 21.7 at.% burnup.

AGT 2A: *Sodium Chemistry*

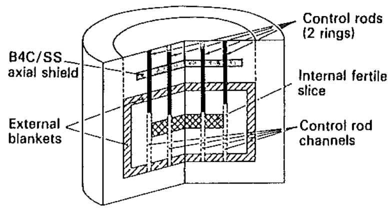
The mandate of AGT 2A was to control sodium quality and sodium purification, the behavior of trapping devices, and the methods of decontamination and waste treatment. Sodium impurity sensors were installed to check their suitability for practical plant use.[92]

AGT 2B: *Instrumentation*

AGT 2B was charged with conducting R&D on core instrumentation and the continuous monitoring instrumentation of steam generators; it also dealt with methods of viewing and in-service inspection and repair under sodium. Various failed-fuel detection systems were studied and intercalibrated for various European fast breeder reactors.[93]

AGT 3: *Core Physics*

AGT 3 was concerned with neutron physics and with providing the data and tools for core and shielding design calculations. Large experimental facilities used were the Masurca reactor at Cadarache and the Nestor reactor at Winfrith. A major task was the development of the ERANOS common neutronics code system.[94]

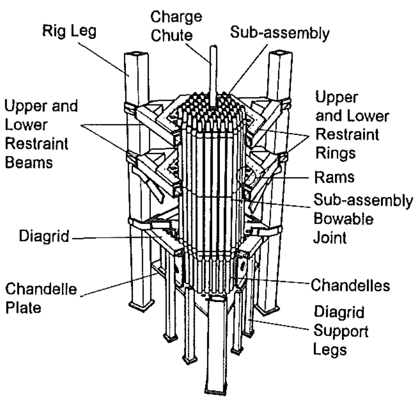


Typical structure of a critical in the MASURCA plant.

AGT 4: *Safety Research*

AGT 4 conducted studies of breeder safety, especially in connection with phenomena in the core. Assessments of subassembly faults, sodium fires, containment loading, and, in particular, the core disruptive accident were of great importance to design companies. Molten fuel physics in connection with movements of fuel ejected from pins were studied in various test facilities.[95,96,97]

AGT 5: *Thermal Hydraulics and Core Mechanisms*



Chardis III rig arrangement.

AGT 5 studied the thermal hydraulics and mechanics of the core as well as core components.[98] Subassemblies distorted as a consequence of irradiation effects were investigated in the CHARDIS III rig a Risley, while the dynamic behavior of core arrays during earthquakes was examined in the RAPSODIE facility at Saclay. Flow patterns at the core exit plane and between wrappers were simulated at the HIPPO test rig (Risley).[99,100]

AGT 6: *Reactor Vessel, Handling, and Auxiliaries*

AGT 6 was involved in thermohydraulic studies in the primary and decay heat removal systems by means of facilities such as THOR (Risley) and ILONA (Bensberg); in addition, R&D was conducted on the thermal environment of the top shield and the fuel handling systems. Elastomer seals were tested extensively with respect to friction, tempereature, and irradiation.[101,102]

AGT 7: *Thermal Transfer Systems and Components*

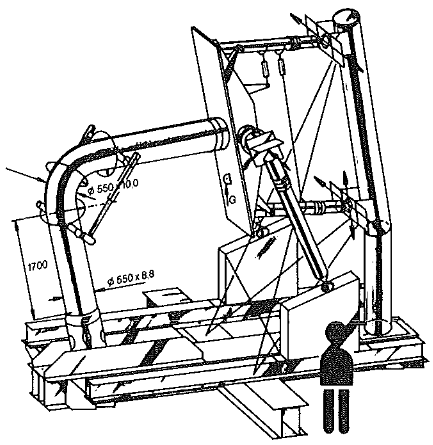
The mandate of AGT 7 primarily was to study the main components of the heat transfer system, such as steam generatores, intermediate heat exchangers, and mechanical pumps. The assessment of sodium-water interactions, thermal hydraulics codes, and the cavitation problem constituted the main areas of work of this group. Supercritical pump shafts were treated at Saclay.[103,104]

AGT 8: *Reactor Operation*

This AGT was concerned with exchanging experiences arising from the operation of the European fast breeder reactors, namely Phénix, Superphénix, PFR, and KNK II. Compiling and comparing the radiation doses received by the personnel, and radioactivity discharges constituted permanent topics. Experiences with fuel assembly handling and the maintenance of large components were particularly valuable.[105,106,107]

AGT 9A: *Plant Structural Materials*

This AGT was to provide verified materials data to EFR designers. Materials of chief interest were 316 L(SPH), mod 9Cr1Mo, and carbon steel. In addition, methods of non-destructive testing were studied. Volumetric inspection techniques for austenitic steel varieties were improved and made compatible with in-service inspection requirements.[108]



Test rig for creep-induced fatigue experiments.

AGT 9B: *Structural Integrity*

This AGT was commissioned to study and produce common design rules in the field of structural integrity so that the required standards of safety and reliability could be met. In addition, methods were to be created which would allow the leak-before-break criterion to be accepted. Benchmark comparisons were provided to validate the constitutive equations and complex ineleastic computer models.[109,110]

4 The EFR Concept Validation Phase

4.1 Achievements of the EFR Assocciates

The EFR Consistent Design as presented to EFRUG by EFR Associates in Paris on November 10, 1989 - the day after the Berlin wall had come down - was appreciated by the utilities. It looked like a successful synthesis of SNR 2, Superphénix 2, and CDFR, and also the support lent by the activities of the R&D organizations in studies of the remaining technical problems inspired confidence. The representative of the German VEBA utility (Krämer), seemed to be so impressed that his company, together with the Bayernwerk utility, joined the EFRUG consortium the year after.

In the ensuing Concept Validation Phase of three years (3/90 - 3/93) the EFR design did not have to be modified greatly. Minor variations were proposed by EFRA.A, such as the solid roof with its simpler cooling mode, or the three-zone core promising a smoother flux pattern. For the rest, the efforts by the design companies were concentrated on analyzing the safety characteristics of the plant, deriving points by which its licensing capability could be judged, and elaborating reliable information about its economic features.[111,112,113]

4.1.1 Safe Design and Risk Minimization

EFRUG had requested that EFR meet a safety level no less stringent than that of a modern thermal reactor.[114] The safety approach taken was that of defense in depth based on the detection and prevention of faults, and mitigation of accidents exceeding the design basis.[115] A considerable enhancement of these conventional systems was foreseen by the introduction of a third shutdown level to exploit and reinforce the natural safety characteristics of the system and exclude core damage even in the event of a failure of the shutdown systems.[116,117,118]

Here are some of the major characteristics of this shutdown level:

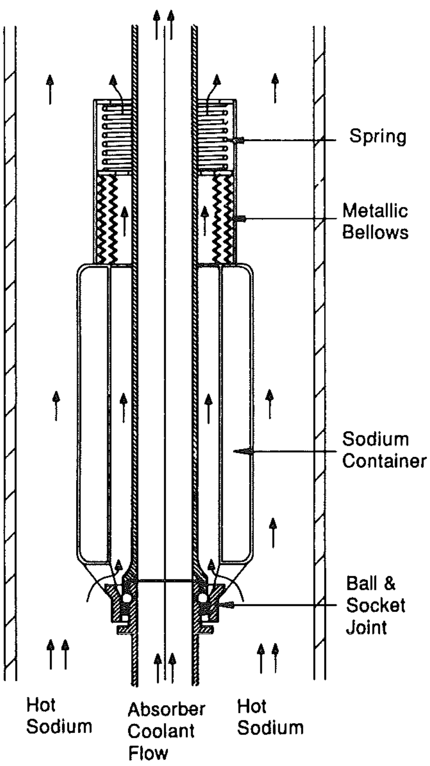
(1) A favorable core geometry and optimized reactivity coefficients were sought. This required a reduction of the EFR core height from the original 1.4 m to 1.0 m and,

hence, a reduced sodium volume fraction, which proved to be beneficial, though entailing a number of economic penalties (annual instead of biannual refueling).

(2) Optimization of the core restraint system and the negative coefficient of reactivity from radial expansion. This meant stiffening the subassembly wrappers at the upper restraint plane to enhance effects of radial core expansion.[119]

(3) Enhancement of absorber rod expansion, which comprised the inclusion of components in the control rod drive lines which significantly enhanced, by factors of 3 or more, the natural thermal expansion of the control rods relative to the core.[120]

Other safety components included stroke limiting devices, absorber rod magnets, and absorber bulk insertion. The efficiency of the third shutdown level was analyzed in depth by the Risk Minimization Group (RMG) under the competent chairmanship of H. Vossebrecker, Interatom; the final report comprising some 350 pages was submitted in July 1992. It claimed that no scenario of core disruption would be in the realm of credibility. However, even then it was not possible to exclude absolutely the potential for core disruption. Some reasonable capability to contain the consequences of such failures was still judged to be necessary.[121,122]



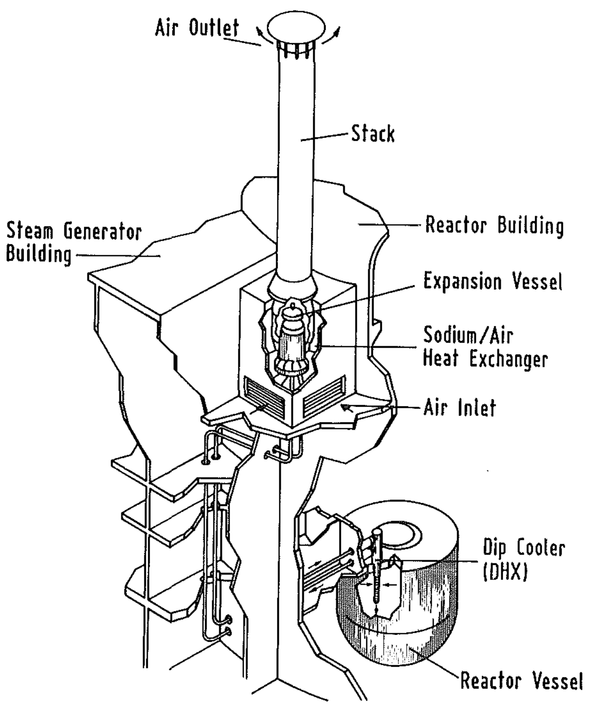
Enhanced thermal expansion hydraulic ring concept.

The results of the EFR safety case were presented to a special group in 1992/1993. This so-called Ad Hoc Safety Club (AHSC) included well-known senior safety experts from France (Quéniart, Natta), Germany (Birkhofer, Löffler), and the UK (Wright, Hirst). In the course of eight sessions they analyzed the major safety systems and components of EFR and expressed (personal) statements on the subjects. In conclusion, their response was quite favorable. The principal design and the proposed safety goals were probably acceptable in the respective countries. Some concern was expressed about the (diminished) protection against an airplane crash of the steam generators. For the containment the Club suggested to take into account the new criteria for the new generation of pressurized water reactors; filters should be provided for radiation protection in case of severe accidents.[123]

A drop of bitterness in this cup of joy, however, was the request by AHSC at its final meeting in March 1992 for calculations of core meltdown accidents, even for the phase of recriticality, despite existing provisions for risk minimization.

4.1.2 On the Economics of EFR

Defining the cost structure and the economic characteristics of EFR were the primary purposes of EFR.A, in addition to safety considerations, in the second half of the Concept Validation Phase. Especially the utilities had an interest in these questions, and so a special working group was constituted of experts from the PMT and EFRUG. It was to ensure, above all, that identical methods and datasets were used in the economic assessment calculations. Two yardsticks were available for cost comparison purposes: primarily, of course, the electricity generating costs of competing light water reactor power plants similar in size, but also the costs of Superphénix 1, which were known by then. The former probably would never be matched entirely, while the latter clearly had to be underrun.[124,125]



EFR direct decay heat removal system.

Of course, a distinction had to be made between the higher cost of a first-of-a-kind plant (FOAK) and the lower cost of a successive series of identical breeder plants. In addition, special costs played a role which could arise from one partner country, in contrast to the others, imposing excessive licensing requirements in one part of an area ("national tuning").

Cost reductions were attempted in various ways:

(1) By simplifying and streamlining plant design.

In this effort, especially the number of components and their weights as well as the building volumes were reduced.

(2) By limiting the number of safety-graded systems.

In this case, e.g., the expensive containment of the emergency Diesel power plants was avoided and replaced by passive decay heat removal methods.

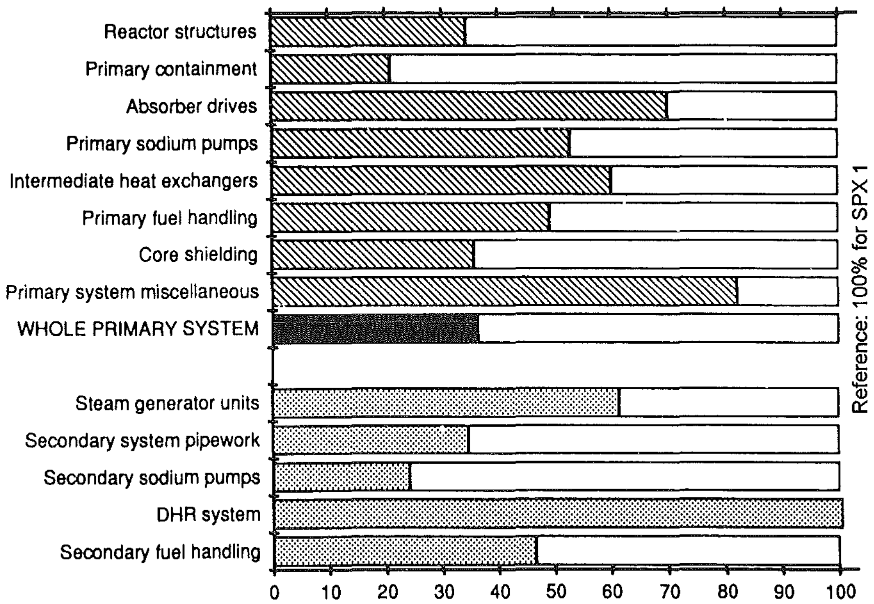
(3) By checking on the methods of manufacturing, especially in an attempt to shorten the construction time of the power plant.

The construction period of EFR (not including commissioning) had been estimated to run up to 60 months, counted from the first permanent structural concrete to fuel loading.

(4) By increasing fuel burnup in order to save fuel cycle costs.

As is well known, 20 at.% had been estimated, which was quite a challenge, especially to the R&D sector.

As a result of these measures, the amount of steel used in the principal parts of the nuclear steam supply system (NSSS) was reduced by some 50%. For the NSSS of EFR this meant a cost reduction by 45% (relative to Superphénix 1), and still of 10% relative to Superphénix 2.[126,127]



EFR/SPX 1 specific weight comparison (steel only).

In 1992, PMT/EFRUG spent approximately 150 man-months to determine the estimated cost of the nuclear island. Nineteen qualified vendors in four countries were invited to tender for 25 key components. The 59 bids received constituted the basis on which the price of the nuclear island was calculated. In February 1993, the EFRUG customer was told that ECU 1.8 billion had been estimated for a one-off plant, ECU 1.3 million for a one-of-a-series plant.[128,129] The utilities, in turn, presented a comparison of electricity generating costs, thereby indicating that the EFR series would be compatible with advanced PWRs.

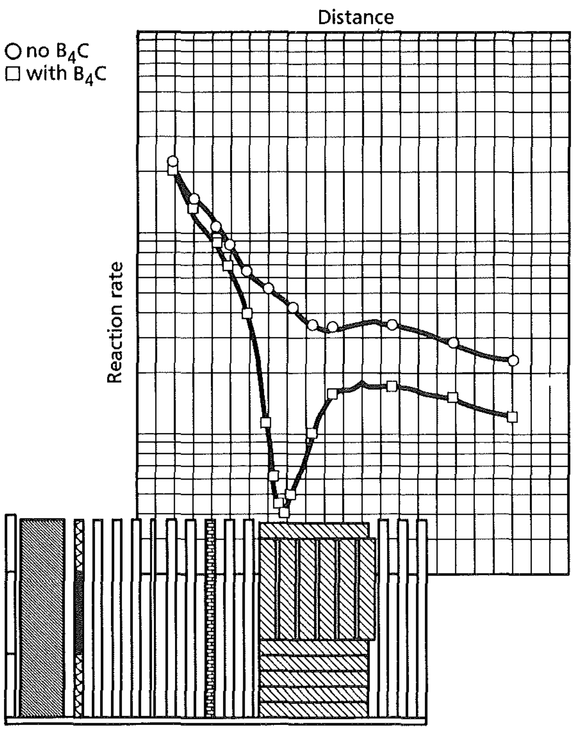
4.2 Results and Facilities of the R&D Organizations

During the two project phases of EFR a number of important R&D findings were made, some of which will be briefly enumerated below. They frequently required new test facilities to be built. Some of the particularly expensive test rigs will also be described.[130]

4.2.1 Major R&D Achievements

In the **reactor core**, the in-pile characteristics of the MOX fuel rods had to be assured. Especially the French and British breeder plants were available for this purpose. In Phénix, a maximum burnup of 16.4%, corresponding to 143 dpa, was achieved for the austenitic 15/15 Ti cladding tube materials: In PFR, the comparable levels for the high-nickel PE16 cladding tube materials already amounted to 21.7 and 135 dpa, respectively. A total of approximately 250,000 rods were irradiated. The sodium-bonded absorbers attained in-pile times of approximately 600 full-load days in the reactors listed above.[131,132,133]

In **core physics**, it was possible to complete experimentally and evaluate the CONRAD criticals for axially heterogeneous cores. The harmonized ERANOS 0.2 code system was tested successfully and delivered to the partners. Also the shielding experiments for the JANUS program were completed.[134,135]

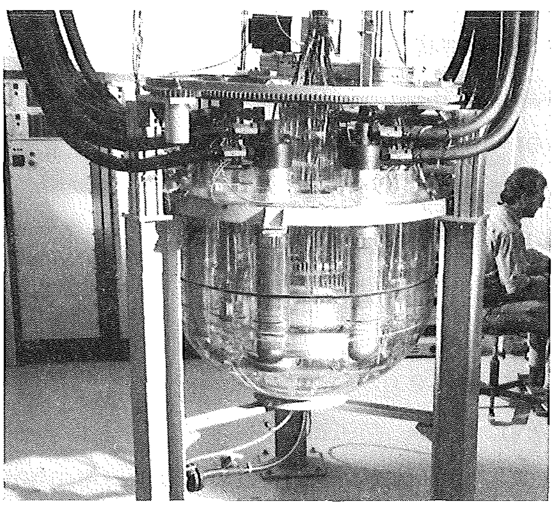


Shielding experiment in NESTOR.

In **core mechanics**, the CHARDIS experiments indicated that even minor misorientations of subassemblies can cause surprisingly high pad loads. In the seismic experiments conducted in the RAPSODIE rig it was seen how important the stiffness of the reactor diagrid is to safety.[136]

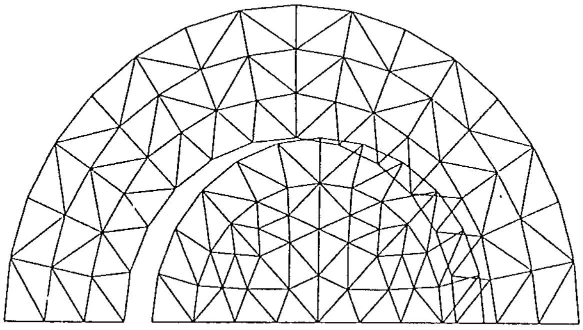
Studies of the **thermal hydraulics of the primary system** were concentrated mainly on the hot pool. A number of special rigs were available for this purpose, especially those at Cadarache and Risley. The experiments confirmed the, fortunately, stable flow behavior under all operating conditions. To achieve a smooth surface without any gas entering, R&D experts suggested the use of porous baffles. Numerous experiments showed that baffles, both in a high and in a low position, guaranteed the desired free surface behavior.[137,138]

In the **steam generator**, one of the most important breeder components, reliable methods of acoustic detection were developed for leakage incidents. Other topics under investigation were sodium-water interactions, and a proposal was made to the design companies to install anti-wastage sheets in the area of the lower tube plate in order to avoid such events from propagating. The thermohydraulic test of an entire steam generator module in Phénix or PFR was considered again and again, but always rejected because of the high cost associated (approx. FF100 million).[139,140]



RAMONA water test model.

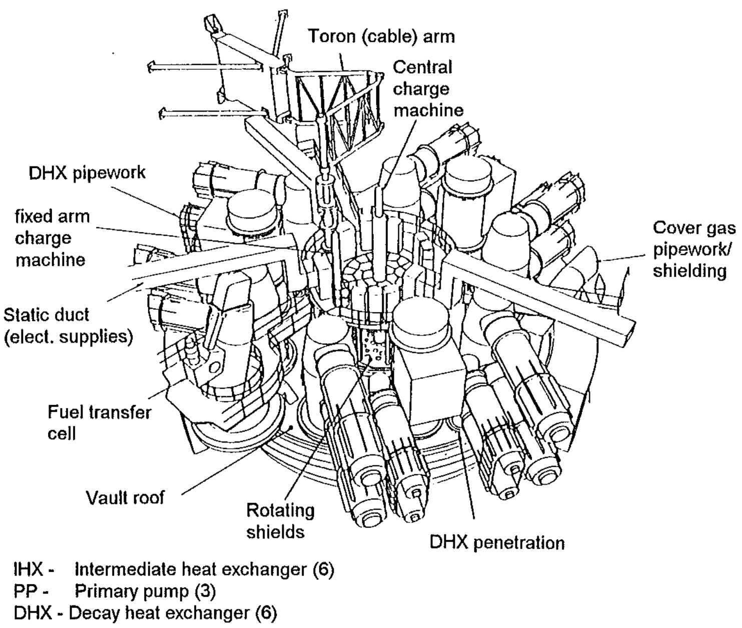
Studies of **decay heat removal** by natural convection were carried out in a number of test rigs at Karlsruhe and Bensberg. The RAMONA (1:20 scale) water test rig was one of the workhorses for a whole array of steady-state and transient tests. ILONA, the 5 MW Na facility, allowed the design of the important helical tube air-heat exchanger to be validated.[141,142]



RAPSODIE mock-up (homogeneous model).

Activities in the area of **safety** covered a broad range of topics.[143] In addition to code improvements for the design basis conditions, the unlikely case, so important to licensing, of a total instantaneous blockage of a fuel element was examined. The mechanical responses were calculated for roughly two dozen cases of unprotected loss-of-flow conditions in EFR; fortunately, they turned out to be tolerable in most cases. The datasets of the CABRI programme just completed were very helpful in this case. In the wake of the licensing conditions imposed on Superphénix, also sodium fire experiments were resumed, and various computer codes were compared.[144,145]

With respect to **materials**, the responsibility of Working Groups AGT 9A/9B, very fruitful cooperation was established with the Design and Construction Rules Committee (DCRC), a group of experts on the side of the design companies. A large number of milestone and synthesis reports confirmed steady progress in the materials field. Thus, e.g., for the 316 L(N) base metal, the stress-rupture data were verified experimentally up to 73,500 hours; for mod9Cr steel, the creep-rupture data were determined for the 500 - 650°C temperature range. Of con-



View of EFR above roof area.

siderable importance were the defect assessment procedures for the leak-before-break and high temperature areas.[146,147,148]

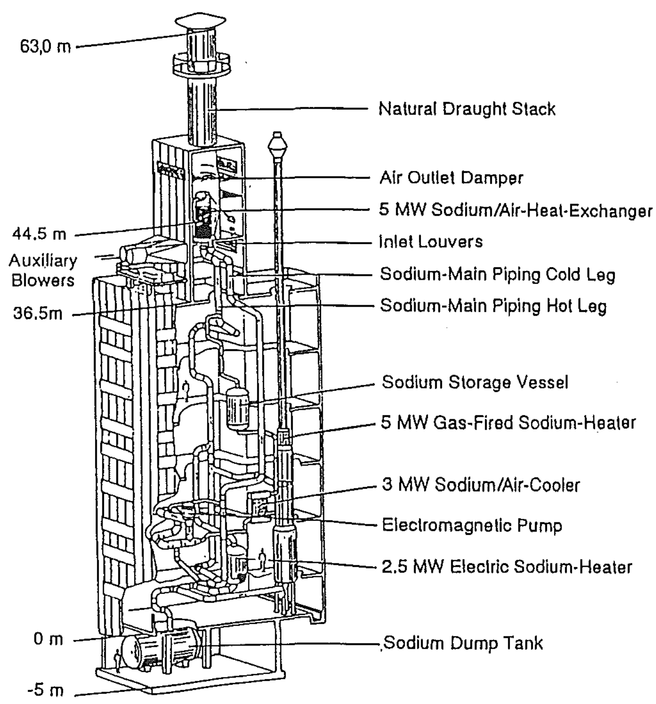
Major progress was achieved also in **in-service inspection and repair** and in **core instrumentation** as well as **large components**. It is not possible, though, to discuss these items in detail within the framework of this report.[149]

4.2.2 Major R&D Investments

Expecting the EFR project to run for a longer period of time than it actually did, the partners built up a number of major experimental facilities in which R&D programs were to be run. In most cases, they succeeded only in part, as the project was terminated after the completion of Phase 2, and the time available for experimenting had been too short. Nevertheless, some of these test facilities will be described briefly below.

In the **United Kingdom**, especially the HIPPO, THOR, CHARDIS III, and SUPERNOAH test rigs should be mentioned. HIPPO (in Risley), a water test rig on a 1:5 scale, allowed the flow patterns at the core exit plane and between the wrappers to be simulated. Flow velocities in the interstitial gaps could be measured by means of sophisticated instrumentation, such as laser Doppler anemometry. THOR, also located in Risley, was commissioned in October 1990. It represented an 0.3 scale water model used primarily to observe the hot pool flow and quantify free surface conditions and potential gas entrainment. The CHARDIS III rig, also in Risley, was commissioned as late as in December 1991. It consisted of 61 subassemblies for studies of distortions and loads occurring during charging and discharging operations. The dummy fuel elements were provided by the French CEA, modified by Interatom in Bensberg, and finally used in CHARDIS III - an example of a successful European cooperation. The last major British test rig to be mentioned here, SUPERNOAH in Dounreay, was used to study medium-sized sodium-water leaks in steam generators. It did not become operational until 1993.[150,151]

In **Germany**, especially a number of test facilities for decay heat removal studies were completed in the second project phase. One of them was the NEPTUN test rig, a 1:5 scale water model in Karlsruhe. It had an electrically heated core of 337 elements with a power of 1.6 MW. The facility was commissioned in December 1991 and allowed only a limited experimental program to be handled for EFR. On an even larger scale, this was true of KIWA, a 1:10 scale water model, also at KfK, designed to simulate the whole flow path of natural convection; it was commissioned in September 1992. The 5 MW ILONA plant for simulation of the sodium heat removal system was commissioned in Bensberg in November 1990. It was completed early enough to allow some important experiments to be performed, including those involving the station blackout accident. Unfortunately, ILONA later was damaged severely by a sodium fire and will be dismantled by Siemens when the Bensberg location will be abandoned.[152,153,154]



ILONA test facility for decay heat removal.

In **France**, under the auspices of CEA, the JESSICA test rig for studies of the core outlet thermocouples, and the MIRSA facility for studies of the argon gas phase, were completed at Cadarache in 1992 and 1993, respectively. As the French breeder programs will be carried on in connection with Phénix/Superphénix, and several EFR-related topics, it is safe to assume that these rigs will continue to be used.

4.3 Convening and Reporting

4.3.1 Meetings galore

Despite such tools as electronic mail or fax equipment, personal **meetings** of members at all levels were indispensable in the execution of the EFR project. Discussions about technical points among five or ten experts, often together with the experimentalists at the site of a test rig, produced results only in personal debates, not by a way of correspondence. In the second project stage, the Concept Validation Phase, some 500 meetings were held in various places in the three partner countries within a period of three years, roughly ten percent of them at project management level (MGRD, PMT, PMG). Although the financial expenditures associated with this "nuclear tourism" were a source of constant complaints, they only played a minor role in the overall budget. The international conferences, which kept participants from their project activities for a week or even longer, certainly had greater financial implications.[155]

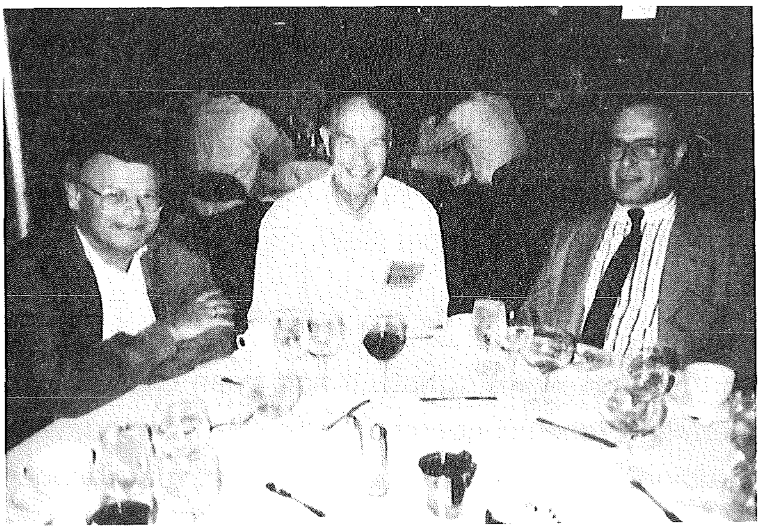
Most of the meetings were held at the level of **AGT** and their subgroups, sometimes 5 - 10 of them. Each country was represented by at least one delegate; often also observers from EFR.A and EFRUG as well as members of the Technical Secretariat attended and expressed their opinions. The most important agenda items normally were discussions and evaluations of the research findings generated, and the inclusion of new subjects of future activity. Occasionally, agreement was established on the delegation of a staff member to the installation of a partner country. As a rule, this was very beneficial to all concerned; however, the willingness to be delegated into a neighboring country declined with advancing age of the candidates (for family reasons).

Twice a year the **PMT** invited the reactor design experts to so-called workshops at which the current design status of EFR was discussed and further activities were agreed upon. These results also had to be sold to the utilities, which was done through the monthly Project Reviews. The representatives of the utilities in the Project Management Group, **PMG**, had a decisive say in these matters and put down their opinions also in written comments after each meeting. Many items were the subjects of heated debates, such as the degree of passiveness of EFR, but never did they detract from the good personal relations among the delegates from R&D, EFR Associates, and EFRUG.

The project language used at these meetings was **English**. It had been chosen as a *lingua franca* already in the era of German-French cooperation, and was retained, without debate, when the British joined. Although the Continental representatives managed to express themselves in English, this was an area where the British representatives scored a clear advantage. Whenever difficult topics arose in the discussion, they were able to speak their native language, use the right shades of meaning and thus, as a rule, get their points across in an optimum way. That this also entailed a "drawback" will be discussed in the next section.

Also the **styles** in which the discussions were conducted differed considerably at the beginning of the talks. The British, because of their traditional training, were accustomed to leading different opinions to a consensus in the course of a debate. The debates were handled as in a club. The French seemed to send their representatives to those meetings with certain instructions. At least this was the impression they gave at the beginning of this phase of cooperation. At times, Paris (and Saclay, respectively,) were never very far. In contrast, the German representatives, especially those of KfK, often excelled in demonstrating their (fierce) individualism, some of them even seeming to obey nothing but their engineer's conscience.

A factor much more important than the language or the style of discussions was the **relationship of trust** among the participants from so many different countries. We should recall that the SNR 2, Superphénix 2, and CDFR Projects initially were competitors and, consequently, their national representatives were in opposition to each other. Although EFR meant concentration on one project, there were still subtle national preferences. It was generally known, for instance, that the German representatives favored an all-passive decay heat removal more than the French experts did. Among the cladding material steel varieties, there was a British variant (PE16) and a German-French preference (15/15 Ti). However, as time went on, the participants in the project came to know the arguments of their partners better and better, which helped them to understand each other's position and, finally, establish a true basis of trust. This became apparent in particular on occasions in the course of the project when it was easily possible to ask the representative of country A to argue, neutrally and without bias, the position of country C in country B.



Let's have a break

(right to left: J. Bouchard, CEA - A. M. Broomfield, AEA; the author).

Even the most important meetings must adjourn for **lunch**. The hospitality offered by the three partner countries was excellent, especially so in France. For the British and the Germans, this occasionally had grave consequences, for difficult agenda items not dealt with before lunch had no chance of being taken up after a (French) lunch.

Consequently, another meeting had to be held, perhaps again in Cadarache.

4.3.2 Documentation and Publications

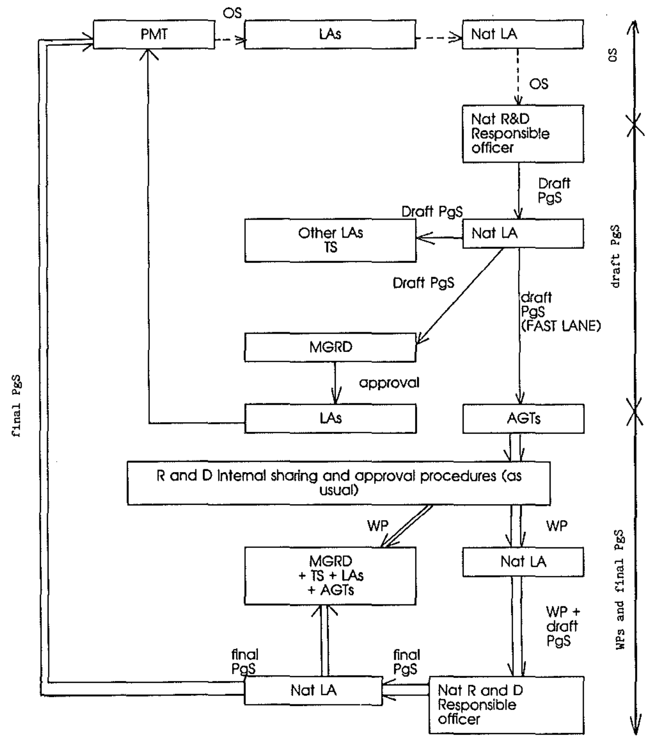
No deliberation without documentation.

All meetings, of course, had to be covered in **minutes** which often had to be written by those who had been able to argue their points in the most sophisticated way during the meeting, namely the British. But there are two sides to each coin. The UK representatives were able to use those documents for reporting to their Department of Trade and Industry (DTI), while the other partners had to write separate reports in German and French. Participants in these project meetings maintained that the minutes of a meeting occasionally were better than the meeting.

The R&D organizations were expected to submit **annual reports**, which summarized their research findings (in bulky tomes). These reports were compiled by the Working Groups and by the Liaison Agents upon instructions by the MGRD.[156] Another report comparing the requirements raised by the design companies with the most important results was compiled in cooperation with the PMT.[157] Both reports constituted the basis of two meetings a year of R&D, EFR.A, and EFRUG, at which the AGT Chairmen presented the results in their respective areas and had them discussed. The reports obviously were read very carefully by the representatives of the EFRUG Secretariat and the Project Management Group (PMG), for the so-called EFRUG comments, critical but competent comments on the chapters of the report, regularly came in two or three months later. In the next annual report, those comments were taken up and answered by R&D.

In addition to this official project documentation, the R&D staff in Phase 2 compiled a total of 1750 internal technical reports and memoranda.[158] 250 **publications** and conference papers were written internationally over the same period of time, mostly by several authors from various partner countries. These publications had to be distributed before they were published or read in order to allow them to be commented upon and corrected in accordance with a formalized scheme. This procedure, which was also laid down in the Cooperation Agreements, initially appeared to be a bit cumbersome, but later worked very smoothly, much to the surprise of all concerned. EFR Associates, the design company, completed some 5000 technical documents, the most important of which was the Consistent Design Specification. Together with the utilities a comprehensive report on the economics of EFR was compiled which, for the first time, took into account national cost structures.

The floods of (written) requirements by the design companies reaching the R&D organizations were registered and answered with particular care. There were two categories of such queries: **Question Sheets (QS)** and **Objective Sheets (OS)**. A question sheet normally was answered by an **Answer Sheet (AS)** based on existing R&D know-how, while a **Program Sheet (PgS)** had to be drafted in reply to an Objective Sheet, because it meant that a new research program had to be initiated.[159,160]



Flow chart for Objective Sheets.

"What experimental evidence is available to confirm the cleaning of subassemblies up to 10 kW?" was a QS, while the request, *"Provide in-service detection techniques to monitor the integrity of the main and the safety vessel for EFR!"* was an OS demanding a PgS. Managing the roughly 200 QS and 120 OS took a tightly run organization, because each of these requirements implied considerable financial expenditures. The Liaison Agents (LA) were responsible for ensuring that all national partners and agencies were queried and the focused, authorized answer was returned to the design companies. The bureaucratic effort involved was immense, but was bravely coped with by the LA.[161]

A very special type of publication was the **EFR Newsletter**. In a way, it was the popular newspaper of the project distributed to all members, irrespective of rank and title. It regularly published the most important R&D findings, covered the workshops of EFR.A and the other meetings, and presented rundowns of management news and world breed-

er news. Readers obviously read the list of publications at the end with great attention for, whenever a publication had been omitted, the (angry) author remonstrated with the two Karlsruhe editors.[162]

Last, but not least, there was a "textile" documentation, the **EFR tie**. The creative idea was developed by the author together with Tony Broomfield on a train ride between Düsseldorf and Karlsruhe in the autumn of 1990. They envisaged a kind of English club tie as a token of connection among project members. In order to gather as many ideas as possible, a tie competition was run in EFR Newsletter No. 3. It was won by Ray Tant, design draughtsman with NNC Ltd., the British partner of EFR Associates.

The German side introduced the distinct green diagonal stripe to reflect the "zeitgeist" in that country.

5 The End of the EFR Project

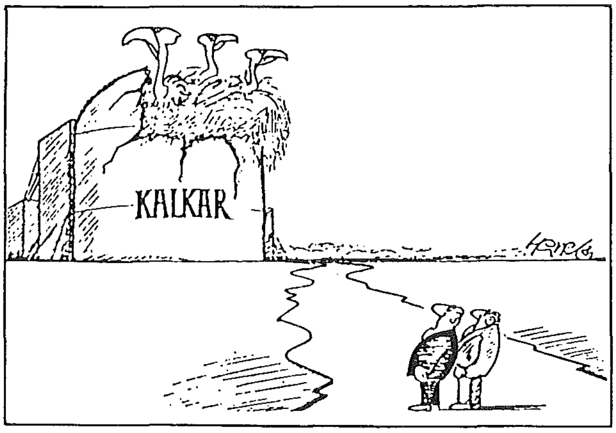
5.1 Problems with the Breeder Plants

In the late eighties and early nineties, the problems in operating the existing breeder plants became more and more evident. SNR 300, though completed in 1985, was beset by political problems after Germany's second largest political party had pledged to opt out of nuclear energy and blocked the licensing procedure. PFR in Dounreay from the outset had been allotted only a brief life span, which was reduced even further by various technical troubles, among which the ingress of oil into sodium turned out to be most aggravating. The French breeders, Phénix and Superphénix, finally suffered from technical problems likely to create political consequences.[163,164]

The difficulties experienced by these reactor plants will be described in slightly more detail below because, ultimately, they contributed a fair share to the demise of the EFR Project.

5.1.1 Political Termination of SNR 300

In April 1988, the **SNR 300** German prototype breeder was still waiting in vain for its operating permit. Almost three years had passed since its completion, and all national and international expert bodies had confirmed its safe design.[165,166] At that point, Klaus Töpfer, the German Federal Minister for the Environment, decided to take a drastic measure. In a formal instruction, he requested the Düsseldorf State Government to restart the licensing procedure for Kalkar and, in particular, refrain from commissioning any further expert opinions seeking to establish comparisons of Chernobyl and Kalkar.[167] In that instruction, the Federal Minister for the Environment had listed criteria to be adopted by the State authorities in the future management of the licensing procedure. Under the German constitution, such instructions by the Federal Government to a Federal State are allowed, although they happen very rarely.[168,169]



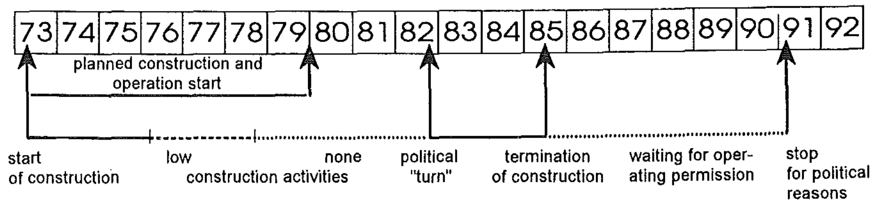
"Nothing but gaps wherever you look"
(Kölner Stadt Anzeiger, 1982).

Nevertheless, the licensing procedure dragged on for another six months until, surprisingly, one day before the deadline, the State of North Rhine-Westphalia sued the Federal Government before the Federal Constitutional Court in Karlsruhe. In its motion, the State argued that the Federal Government, in giving it instructions, had violated the independence of the State.

"Courts of law and God's mills grind exceedingly slowly," the saying goes, and it took until May 1990 for the ruling to come from Karlsruhe. It proved to be a major disappointment to the State of North Rhine-Westphalia, for their action was dismissed on all points. The judges found that the Federal Government had not been *ultra vires* in instructing the State Government. In addition, in the written explanations of the decision, greater expert competence in the licensing procedure under the Atomic Energy Act was attributed to the Federal Government. Minister Töpfer had every reason to be satisfied with this outcome of the legal dispute.[170]

But the State put up more opposition. Only one week after the ruling by the Constitutional Court, the licensing authority in Düsseldorf announced its intention to commission a detailed report on the status of emergency planning and evacuation of the Kalkar Nuclear Power Station. That subject was the sole responsibility of the State and, being outside the Atomic Energy Act, could not be influenced by any instructions from Bonn. This augured lengthy discussions, and more topics in this vein surely would be found in the future.

In the autumn of 1990, a decision had to be taken about financing the extra costs for the 500 remaining staff members of the project. Conditions could not have been worse. SNR 300 in Kalkar had been completed five years ago, but not the slightest progress had been made since in securing an operating permit. On the contrary, the political escalation had in fact aggravated the situation. It was now quite obvious that a license under the Atomic Energy Act could not be obtained against the declared political intention of a State Government, not even by Bonn.



Construction schedule, SNR 300.

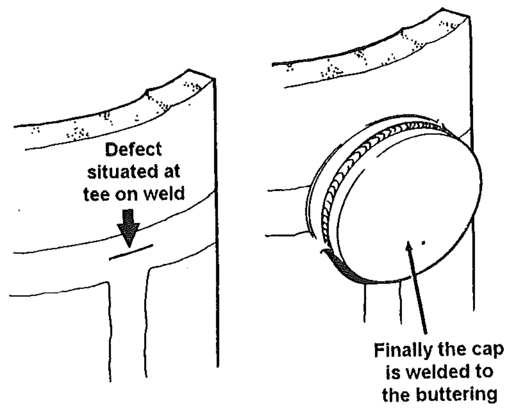
For this reason, the vendor and the operator, in a discussion with Federal Minister of Research Riesenhuber on March 20, 1991, decided to terminate officially the Kalkar project. The political responsibility for the discontinuation of Kalkar was laid at the doorstep of the State of North Rhine-Westphalia. The breeder option was to be kept open within the framework of the EFR Project.[171]

When SNR 300 was given up, also the smaller **KNK II** at the Karlsruhe Nuclear Research Center was doomed to die, as almost the only purpose of that plant had been to pave the way, technologically, for the Kalkar project. This had been done, e.g., by irradiating fuel variants to be used later in SNR 300. It had even been expressed in the wording of the licenses under the Atomic Energy Act for KNK II. When the SNR 300/KNK II link had ceased to exist, these permits would have been open to court action, especially in respect of their immediate execution. For this reason and a number of others, KfK decided to shut down KNK permanently on August 23, 1991.[172]

Now Germany no longer had any fast breeder plant.

5.1.2. Oil Ingress at PFR

PFR had run most satisfactorily in 1986-1989, accumulating 80% of its total electricity production over that period of time. In April 1990, however, a leak occurred in the reheater 1 vessel, and the reactor was shut down. Inspection revealed a total of four defects, all in the main circumferential welds of the vessel. Three of the four welds were located in areas where repairs had been done already in 1987. It was believed that the cracks were initiated by so-called delayed reheat cracking. In that case, defect growth results from the residual tensile stress in the weld. In order to avoid further defects, a new repair technique (patch welding) was developed and carried out over the rest of the year.[173]



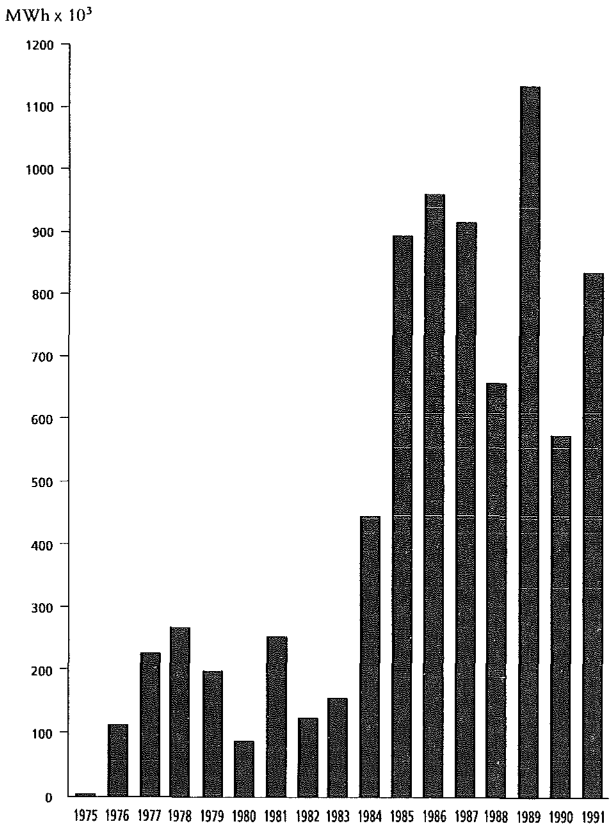
Patch-welding in PFR.

In 1990 PFR, like other AEA plants, became subject to licensing by the UK Nuclear Installations Inspectorate (NII). In this respect, not only the safety case, but even procedures, training, maintenance, documentation, etc. were continuously monitored. As far as the safety case was concerned, the NII identified one significant problem: the integrity and mode of failure of the core support structure. This required PFR staff to develop methods for the detection of a small tilt of the core as a precursor to a rapidly developing failure. For this reason, one year later an instrument was installed which measured the horizontal and vertical movements of a neutron shield rod.

After repair of the steam generator units, PFR was back in operation until June 1991, when a major incident occurred. At the end of run 24, the impurity level in the primary sodium increased due to an ingress of oil from a main pump, later estimated at 35 liters. A team of AEA and NNC staff was put together to study the nature of this effect and its possible consequences. In addition, two experiments were done at IPPE, Obninsk, Russia, which reproduced the conditions in PFR as closely as possible. A new cold trap loop was installed at PFR to return the primary circuit impurity level back to its original design value. The operation was successful, thereby reducing the sodium plugging point from 225°C to an acceptable 150°C.

NII, the licensing authority, however, also requested to check the primary circuit components for possible residual debris which might block the fuel element channels. For this reason, the primary pump filters were removed and examined. Some of the mesh filters, indeed, were found to be partly blocked by sodium-oil-products. Replacing the filter panels was a very time consuming job because of obstructions in the penetrations. Later on, the obstruction which prevented the first two filter units from being replaced, was identified as broken thermocouple tubes. Special equipment had to be provided to remove those broken components. During this repair work, a series of flow tests were carried out on all fuel subassemblies of the reactor. The results confirmed that there were no further blockages.

While the repair of PFR was still in full swing, unexpectedly positive news reached the power plant. Nuclear Electric (NE), together with British Nuclear Fuels Ltd. (BNFL) and Scottish Nuclear Ltd., expressed their readiness to grant PFR financial support. The electricity utilities mentioned above and the reprocessing company intended to cover the operating deficit of the power plant for three years, provided that the British Government was prepared to move the original deadline for decommissioning from 1994 to 1997. The annual operating cost of PFR at that time amounted to approximately £30 million, of which some £11.6 million was covered by sales of electricity in the 1990/91 fiscal year, when the plant had an availability of 33.7%. The sponsors mentioned above expected a future power plant availability in excess of 40%. The proposal of financial assistance was officially submitted for decision to the British Secretary for Energy, John Wakeham, in December 1991.



Gross electricity generation of PFR 1975 - 1991.

When the filter panels were replaced, a routine check in the secondary circuit of PFR showed a rattling noise in two evaporator units. The noise was caused by the rattling of a component caught in a leakage flow through part of the vessel. Over a period of time the gaps had increased, allowing the steam tubes or tie rods to rattle. The noise was successfully controlled by inserting chevron seals into the gaps.

In December 1992, nineteen months after shutdown due to the oil spillage, the reactor was restarted. In January 1993, during severe storms, PFR was reconnected to the grid, operating most of the time on two circuits because of problems in the conventional part of the plant.

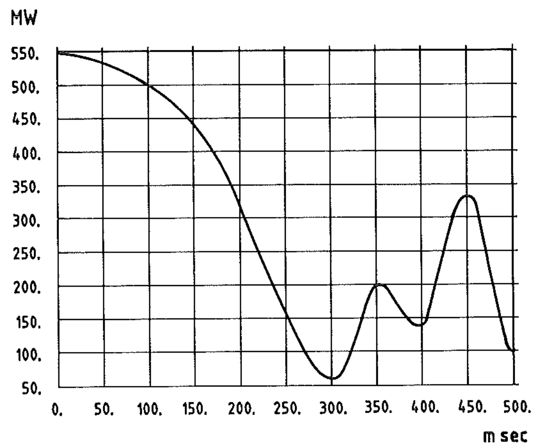
As will be shown in the next section, PFR was well into its last year of operation.

5.1.3 Licensing Problems with Phénix and Superphénix

In the early nineties, a number of incidents occurred also in the French Phénix prototype breeder, which had been run most satisfactorily so far. As a consequence, licensing problems arose which gave rise to long outages. Also in the large Superphénix plant, incidents occurred which had grave impacts on the licensing situation.

In August 1989, **Phénix** was shut down twice because of the "negative reactivity" signal. Initially, electric defects in the area of the neutron chamber were assumed to be the cause, but when there was another shutdown on September 14, the French safety authority, Service Central de Sûreté des Installations Nucléaires (SCSIN), ordered a painstaking examination of the cause and the reactor was shut down by the operator in October.[174,175]

The scrams were assumed to have been due to argon gas bubbles collected in the area of the diagrid. Their abrupt passage through the core could have caused the reactor to be shut down because of the negative void coefficient. As a consequence, the existing diagrid purging holes, which appeared to be blocked, were enlarged so that the gas would be able to pass through the core continuously and safely. Hydraulic tests

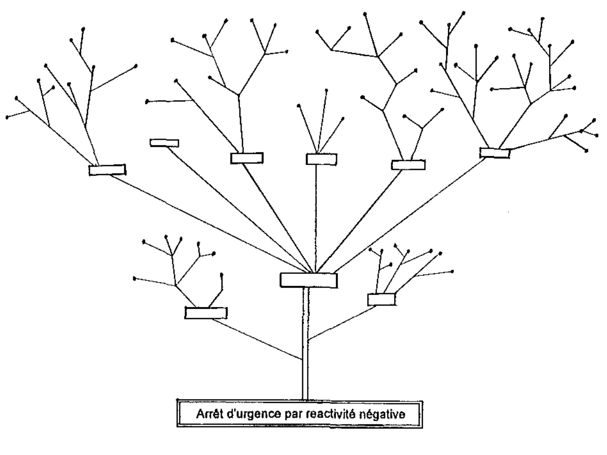


Neutron chamber signal in Phénix
(recorded on Sep. 9, 1990).

carried out in a water rig at Saclay seemed to confirm the effectiveness of the measure, and recommissioning of the power plant was licensed in December.

However, one year later, in September 1990, another surprising shutdown for reactivity reasons occurred. The transient showed two minima with a peak (at 107% of initial power) in between, and then a decay reflecting the insertion of the control rods. Unfortunately, the scram occurred precisely at the moment when the tape of the in-core instrumentation specially installed was being exchanged. As a consequence, it was not possible to analyze the fine structure of the curve. Obviously, the gas bubble theory was untenable and, consequently, was dropped. Instead, a special expert group (under Michel Sauvage) was to trace the causes with German and British assistance. For the time being, the reactor was down by instruction of the authority.

This Comité d'experts spent the next two years examining nearly one hundred possible causes of transients of this type. Most of them were only theoretical in nature, and it was neither credible nor demonstrable that they would ever occur in reality. By and large, they could be summarized under three headings: void effects, as exemplified by the gas bubbles; moderator and absorber effects, respectively, which could have occurred when oil leaked into the sodium; and geometry effects. The latter effects were volume changes of the core and relative motions of core internals, respectively, which could have caused reactivity changes. Finally, the Expert Group confirmed that a radial variation of the volume of the core was the most plausible explanation without, however, being able to clearly identify the initiator. Because of a rather low energy impulse, a "flowering" movement of the core may have occurred, followed by a spring-back effect which put the core (nearly) back to its initial geometry. In October 1992, the licensing authority approved a few test startups of Phénix at a power below 1 MWth which, however, did not produce any further information. Even ten days of power operation at 350 MWth in February 1993 generated no further insights.



Tree showing potential causes of Phénix transient (schematic diagram, "logigramme").

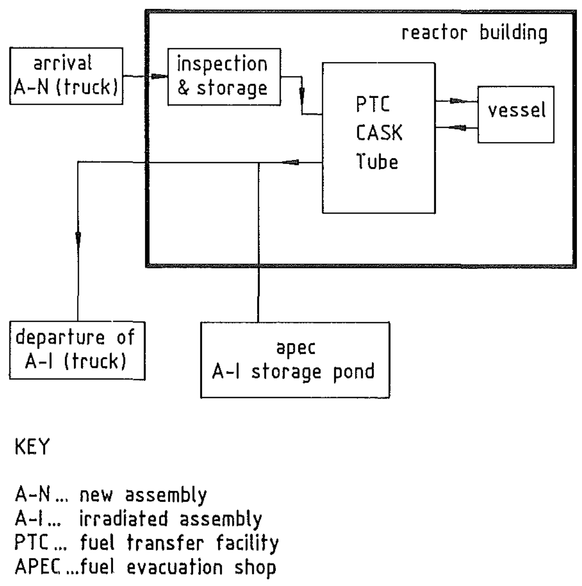
The French licensing authority, now called Direction de la Sûreté des Installations Nucléaires (DSIN), used the enforced outage of Phénix to look into other safety aspects of the reactor. For instance, it demanded an increase in the capacity of the emergency decay heat removal system in line with the burnup of the fuel elements, which had been raised from 80,000 to 130,000 MWd/t. There were various ways of achieving this goal: either by introducing helium into the tank gap, or by removing insulation from the outer vessel of the double-envelope vessel. The authority also imposed conditions with respect to protection against seismic events.

But there was a different problem which proved to be even more time consuming and more costly: Large parts of the secondary sodium circuits showed age-related cracking. In the course of an intensive inspection and repair program, parts of the three circuits made of 321 stainless steel, such as buffer tanks, were replaced and many affected welds were inspected and had to be redone. One crack, over 35 cm long and extending partly through the wall, was even found in a weld made of 304 steel. The failure could be attributed to thermal fatigue induced by alternate flows of hot and cold sodium in a mixing zone. Through-wall defects, although small, were also observed in expansion tanks of the secondary system where they were likely to cause rather costly and time-consuming repair work.

By the summer of 1993, Phénix had been down for two years and a half, except for the ten days of test operation in February mentioned above, mainly as a result of the reactivity drop phenomenon and cracking in the secondary circuit. The restart of the plant is foreseen in 1994.

Let us now turn to Superphénix.

Two years after the incident with the leaking storage vessel in March 1987, **Superphénix** was granted the permit to resume operation. In the meantime, a decision had been taken to make the new storage tank out of austenitic steel and expose it only to argon; the Fuel Transfer Station (FTS) was to be ready by 1991. Recommissioning the power

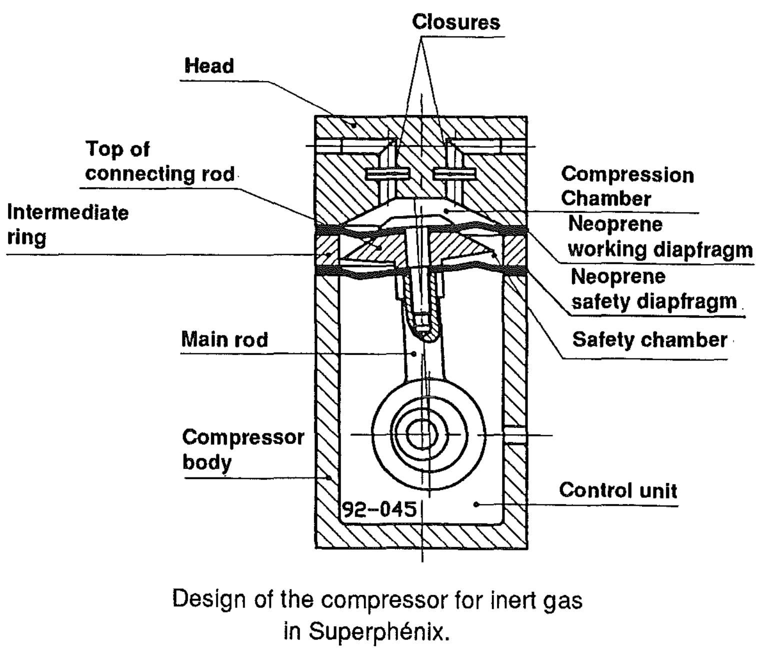


Present scheme of fuel handling in Superphénix.

plant took all of four months. Moreover, the core had suffered a reactivity loss of some 56 full-load days as a result of the conversion of plutonium to americium. The plant regained full load for the first time on June 16, 1989; however, the rated power was maintained only for one month, for turbo-generator A failed in August. In the autumn, Superphénix was shut down for revision for an estimated period of six months.[176]

Before the recommissioning date in spring 1990 there was an extensive discussion of the possibility of Superphénix suffering similar reactivity incidents as Phénix. Because of the rather high positive void coefficient in the central part of the core, the passage of argon bubbles would not have been devoid of some risk. However, the operator was able to demonstrate, together with CEA, that ample provision had been made against gas sparging, and that the purging assemblies in the diagrid certainly were not plugged up. After a sodium leak in the purification cycle had been repaired, Superphénix was able to resume operation in April 1990.

That phase of operation did not last very long. Already during startup, elevated plugging temperatures were found in the primary sodium system and continued to rise excessively. In August, the plant had to be shut down after only three weeks of power operation because the filter cartridges of the integrated primary purification system were clogged. Investigations of the reasons indicated that the membrane of one compressor had been defective for a long time already, and the argon cover gas therefore had been exposed to atmospheric air. There was no measuring instrument to monitor the purity of the cover gas. The amount of sodium oxide produced was estimated to amount to 300 - 350 kg. Subsequent cleaning of the contaminated sodium took several months and was managed by the in-plant cold traps.



Design of the compressor for inert gas in Superphénix.

1990 ended with another regrettable event: On December 13, half of the roof of the turbine building collapsed after the heaviest snowfall in the Creys-Malville region for the past 130 years. Half a meter of wet and heavy snow had loaded the flat roof to a level it was not able to sustain. Fortunately, the turbo-generator underneath was not damaged seriously. Cleaning and repair work, however, took several months. In addition, the incident had damaged the refueling flask stored in the turbine building, which was required for fuel element transports without a "barillet."

A difficult situation ensued with respect to the licensing procedure. Initially, Superphénix had only had an operating permit for the limited duration of 160 full-load days. In August 1990, that permit had been extended to 405 full-load days by Ministers Fauroux and Lalonde, which period covered the operating life of the first core. However, a French-Swiss group of nuclear opponents raised objections to that decision, and the French Supreme Administrative Court, the Conseil d'Etat, surprisingly ruled in favor of the opponents on May 27, 1991. The Court declared the permit granted by the two Ministers null and void on formal grounds, mainly because the conditions for operation with the modified fuel element transfer had not been specified in the permit decision. A difficult situation arose, also because there had been a change in government in the meantime: The Minister for Industry, Fauroux, had been replaced by Strauß-Kahn, and Prime Minister Rocard had been followed by Madame Cresson. Strauß-Kahn, not noticeably a friend of breeder technology, ordered a painstaking review of the technical safety of Superphénix by the DSIN safety authority.

DSIN and the Groupe Permanent des Réacteurs organization of expert consultants (under François Cogne as Chairman) consequently addressed not only the fuel transfer station, which was up for licensing, but also more far reaching safety issues, such as potential sodium fires in the secondary sector. The final report by DSIN of June 16, 1992, which had already been leaked to the "Libération" newspaper and published there, was a surprise, nevertheless. In very clear words, reference was made to alleged weak spots in Superphénix (core reactivity, sodium fire in the secondary system, inspectability of the reactor vessel), and it was proposed to limit the operating permit of the plant to 30% power and grant it for only a few months.[177,178,179]

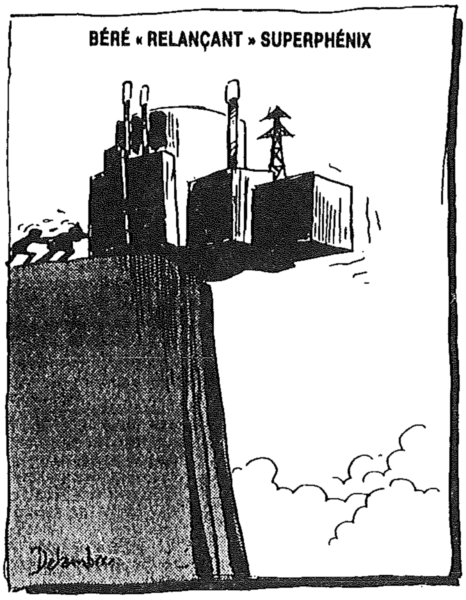
In the meantime, the time for renewing the operating permit had become very short. Superphénix had been down since July 3, 1990 and, in accordance with French law, would have lost its operating permit after two years of outage, which would have been on July 3, 1992.[180] A few days before that date, on June 29, French Prime Minister Pierre Bérégovoy took the decision himself. He issued the following decrees:[181,182]

(1) The safety report by DSIN shall be published.

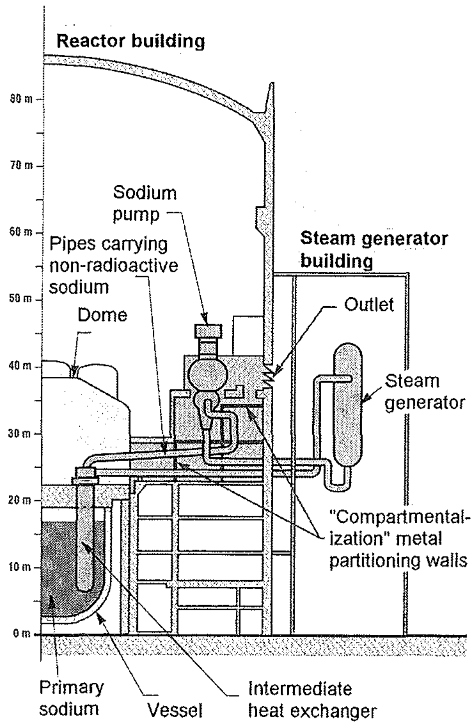
(2) A number of engineered safeguards features shall be added to the plant, especially to protect against sodium fires in the secondary system.

(3) A public inquiry shall be organized at which opponents and proponents of the project can have their say before the new operating permit will be granted.

(4) Minister for Research Hubert Curien was commissioned to write a report indicating to what extent Superphénix could be used for transmutation of radioactive substances.



"Bérégovoy relaunching Superphénix" (Le Canard enchaîné, July 1, 1992).



Backfitting measures in Superphénix.

The report by Minister Curien was presented still in December 1992 and confirmed the usability of Superphénix (and Phénix) for burning plutonium and minor actinides. The public inquiry as a precondition for the new operating permit being granted began in March 1993 and was prolonged twice until June 15. At the time of writing, December 1993, the Chairman of the Committee of Inquiry (Pronost) had submitted a broadly positive report just before the September 30 deadline. The five Commission members favor renewing the plant's license, provided the nuclear safety regulators from DSIN agree. They also recommend the use of Superphénix to test burning plutonium and minor actinides. In a parallel step, NERSA has begun extensive modifications in the secondary system, taking special care of the sodium fire risks.[183,184]

1994 will become a very important year to Superphénix.

5.2 The End

The end of the EFR Project as defined in the agreements of 1984/1989 came almost unnoticed. First, the governments, especially in the United Kingdom and in Germany, withdrew from financing the Research and Development Program. Then the EFRUG partners stopped financing the design companies. There was no need to give noisy notice and, in this way, arouse special attention. As was customary in the government sector, the R&D budgets anyway had to be revised and reallocated annually. EFRUG had not entered into any obligations beyond the Concept Validation Phase, which expired at the end of 1993 after a stretch-out beyond the original date of March 31, 1993.

This allowed the project to be "phased out," and this is precisely what happened.

5.2.1 The Governments Bow out

When it came to reducing the government grants-in-aid towards the R&D programs in various research centers, the **United Kingdom** again took the lead, as it had done in other phases of the project. This time, events were triggered off by the report of the Select Committee on Energy, an all-party group on energy problems established by the British House of Commons.[185] In mid-1990, the Select Committee submitted to the Government in London "The Fast Breeder Reactor," a report commenting critically on the EFR Project. Doubt was expressed in particular of its economics, and the Government was recommended not to approve a start of construction in 1997. Moreover, the project was to be reviewed closely already in 1993.[186,187] The Department of Energy, to which the report had been addressed, published a memorandum in December 1990 in which the report by the Select Committee was more or less approved. Project reviews were announced for 1993 and 1997.[188,189]

However, things moved even faster.[190] Already on November 19, 1992, the U.K. Department of Trade and Industry (DTI), which was now responsible for matters of energy, announced that it would stop financing R&D for the EFR Project effective March 31, 1993. At the same time, there were indications that the original decommissioning date of March 1994 of PFR would not be moved, irrespective of the offer of financial assistance made by the utilities one year ago.[191] The decision by the British Government had been leaked to the press already, and its essence had been covered in the "Independent" newspaper on November 2. Official confirmation followed on the date mentioned above, which happened to be the very day on which the European representatives of the EFR Steering Committee met with high-level representatives from Japan and USA at the ANS Conference in Chicago. This pulled the carpet from under any cooperation talks that may have been planned. The DTI initially agreed to finance the phase-out period to the tune of £5 million annually, but soon the amount was slashed to a total of £2.5 million over a period of three years. As a consequence, massive personnel cuts in the breeder sector were made at the British research centers, especially at Risley. On March 31, 1993, most of the R&D teams were sent into early retirement or deployed in other projects, frequently at other locations.[192]

In **Germany**, the beginning of the withdrawal from the EFR Project can be dated March 31, 1992. On that day, a discussion took place with Federal Minister for Research Riesenhuber, who had invited representatives of Siemens and KfK and the German EFRUG partners (RWE, PreußenElektra, and Bayernwerk). The Minister expressed his willingness to continue to pay the R&D expense of the breeder program at the Karlsruhe Nuclear Research Center, but asked industry to finance not only the planning activities but, in the future, also the development work at Siemens (formerly Interatom). The amount in question ran up to an annual DM 20 - 25 million, mainly for such large facilities as ILONA. No consensus was achieved in the discussion. The representatives of industry considered financing the EFR-related R&D program an obligation of the state to make provisions for long-term projects, while the Minister insisted that these activities, because of their advanced state of development, had grown out of the realm of government funding. As no agreement was reached, the Minister then announced his intention to stop financing the R&D program at Bensberg.[193,194]

And this is what he did, with major consequences. Immediately, R&D work at Interatom was cut back drastically.[195] On March 30, 1993, a memorandum by Siemens indicated that the Bensberg location even would be given up entirely by late 1994. Most of the breeder experts are currently being sent into (early) retirement, others are moved to other locations or simply fired. The sodium test facilities built at great expense, such as ILONA or the 5 MW facility, are demolished; what technical documents are still existing are microfilmed and put into a safe. For whom?

The refusal of the industrial partners to finance the R&D program of Interatom also had grave impacts on the Karlsruhe Nuclear Research Center (KfK). At the Supervisory Board meeting of November 24, 1992, the German Federal Ministry for Research and Technology, the majority partner in KfK, requested the Karlsruhe Nuclear Research Center to stop all activities for EFR by the end of 1993 and henceforth concentrate mainly on research into light water reactor safety.[196,197] The organizational reshuffle this requires is currently under way, with similarly regrettable, though less drastic, impacts on breeder personnel as in the cases of UKAEA and Interatom.

In **France**, there were also annual budget cuts by 10 - 15%, but there was no abrupt backing out by the state. This may have a variety of reasons. On the one hand, the R&D program of the French CEA for years had been financed roughly one third by the state power utility, EdF. On the other hand, France is still operating Phénix and Superphénix, two large breeder facilities, which continue to need a certain backing of R&D. Many research topics are important both to EFR and to the two power plants mentioned above, and thus are necessary *per se*. One example are studies of the hot pool in EFR, or the establishment of provisions against the ingress of argon gas. The results of this R&D activity were directly transferable to Phénix and Superphénix when the problem of reactivity shutdowns of those plants had to be discussed with the licensing authority.

5.2.2 The Withdrawal of EFRUG

The first movements indicating retrenchment by EFRUG became evident at the **top-level meeting** in **London** on December 11, 1991. On that occasion, the top personnel of EFRUG, EFR.A, and R&D had met to evaluate the activities of the current year and establish the main points of activity for the coming project period.[198]

The meeting in '91 was ill-fated also because, at that time, the three large breeder plants were down as a result of defects, namely PFR, Phénix and Superphénix. SNR 300 had been stopped altogether for political reasons.

The Chairman (Goddard, NE) in his introduction drew attention to this most regrettable situation, expressing hope that this would not happen again in future. The practical demonstration of plant availability was of overwhelming importance to the utilities, indeed was one of the most important parameters by which to assess new power plant concepts.

The utilities seemed quite pleased with the progress made in the technical design of EFR and the supporting R&D program. However, the economic data were accepted with a certain amount of scepticism. EFRUG still thought the capital cost of EFR too high. Compared with the most recent French pressurized water reactor line, the N4 reactor, EFR was likely to cost 50 - 70% more. The design companies therefore were requested to look for further savings on the order of 20 - 30%.

Another important topic discussed at the top-level meeting was the timetable of the project. The start of the pre-construction phase, which was Phase 3 of EFR, originally scheduled for 1993, was considered to be premature by the utilities. They instead suggested 1995 or an even later date; correspondingly, the beginning of the subsequent construction phase was to be moved roughly to the year 2000. At the same time, however, EFRUG insisted on the current Phase 2 to be finanalized as scheduled, which would be in March 1993.

This meant a gap of at least two years between Phase 2 and Phase 3, whose financial coverage and program remained open, for the time being.

The next **top-level meeting** was held in **Paris** with a two months' delay on February 11, 1993. The reactor situation had not improved greatly: PFR had been reconnected to the grid a few days before, after nineteen months of outage, but Phénix and Superphénix continued to be down for an unforeseeable length of time. In addition, the Government had decreed the final decommissioning of PFR next year. Quite clearly, the future scope of breeder operating experience in Europe would be much narrower, which was bound to have a negative impact on the EFR Project.

The results elaborated in the Concept Validation Phase by EFR Associates and by the R&D organizations were praised by EFRUG. Also cooperation among the groups and among the participating countries had improved continuously. EFR had developed into a truly European project whose structures served as models to be continued as far as possible.[199]

The only point not solved was funding.

The Chairman (Bacher, EdF) asked the attending representatives of the utilities one by one: RWE (Germany), ENEL (Italy), NE (UK), EOS (Switzerland), UNESA (Spain), EdF (France). None of them were able to promise further funds for EFR. Reference was made, among other items, to the difficult political circumstances and to Superphénix, whose recommissioning was a matter of utmost priority.[200]

The *Project* of the European Fast Reactor EFR, had come to an end.

There were some proposals, though, for an EFR forward *Programme.* It included items, such as scoping studies for a reduced-size prototype, continuation of basic work and broadening of international cooperation. The discussion on participation and financing among the potential partners is still going on.

Future will tell.

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TIMETABLE

1967

January:	First criticality of Rapsodie (Cadarache).
February:	Containment completed of KNK (Karlsruhe).
October:	Germany, Belgium, Netherlands sign MoU on SNR 300 cooperation.

1968

April:	German AEG proposes to suspend gas breeder activities.
December:	Consortium established for SNR 300 construction.

1969

January:	Start of Phénix construction
December:	First criticality of Soviet BOR 60 reactor.
December:	INB manufacturers' consortium presents safety report of SNR 300.

1970

August:	Sodium leak (fire) in DFR.
October:	Sodium filling of KNK I.
October:	New site for SNR 300 proposed: Kalkar (instead of Weisweiler).

1971

May:	KfK-PNC breeder cooperation agreement signed.

July 15: EdF, ENEL, and RWE declare intent to build two large breeder power plants.

August: First criticality of KNK I.

August: SEFOR transient tests performed.

September: Technicatome founded by CEA (90%) and EdF (10%).

1972

January: Utility consortium for SNR 300 formed (SBK).

April: U.S. SEFOR test reactor shut down.

August: KNK I coupled to grid.

November: SBK awards contract for SNR 300 to INB.

December: Sodium filling of Phénix.

1973

April: Start of construction of SNR 300 in Kalkar.

April: Nuclear divisions of AEG and Siemens establish KWU.

August: First criticality of Phénix.

December: Phénix coupled to the grid.

December 28: EdF, ENEL, and RWE sign European Utilities' Convention on behalf of Superphénix and SNR 2.

1974

February: First criticality of PFR.

March: Phénix reaches full power.

July: NERSA founded in Paris.

September: KNK I operation completed.

1975

July:	Start of conversion of KNK I into KNK II.
December:	Presentation of "Flowers Report" in the U.K. (delay in breeder program).

1976

January:	U.K. becomes majority shareholder in NNC (purchase from GEC).
February 13:	Declaration of Nice by Franco-German Research Ministers d'Ornano and Matthöfer.
March:	Soviet BN 350 breeder reaches full power.
April:	Novatome breeder manufacturing company founded.
April:	Superphénix NSSS ordered.
May:	K. Traube resigns Interatom Executive Board.
July:	Leak in Phénix intermediate heat exchanger.

1977

March:	DFR closed down.
April:	U.S. President Carter announces new nuclear program (no reprocessing, reduced breeder program).
July 5:	French-German Breeder R&D and Industry Cooperation Agreement signed in Paris.
August:	Large demonstration near Creys-Malville Superphénix site.
October:	First criticality of KNK II.

1978

March:	Creation of SYFRA.
April:	KNK II coupled to the grid.

July: SERENA founded.

July: Japanese JOYO attains full power.

September: German Minister Riemer proposes to use SNR 300 for plutonium incineration (instead of breeding).

October: Construction of French TOR reprocessing plant in Marcoule decided.

December: Committee of Inquiry into SNR 300 set up by German Bundestag.

1979

March: KNK II reaches full power.

March: German Committee of Inquiry starts work (Chairman: R. Ueberhorst).

1980

February: First criticality of U.S. FFTF reactor.

April: Soviet BN 600 breeder reaches full power.

November: Contractual delivery of KNK II from Interatom to KfK/KBG.

December: Joint INB-Novatome report on SNR 2 pool analysis submitted.

1981

January: Problems with intercrystalline corrosion of SNR 300 vessel.

April: Continuation of German Committee of Inquiry (Chairman: H. B. Schaefer).

July: Gas bubble problems in KNK II.

1982

January: Superphénix attacked with missiles.

April:	Sodium-water leak in Phénix reheater.
May:	Test of Superphénix neutron chambers in KNK II.
September:	Vote of German Committee of Inquiry in favor of SNR 300 continuation.
October:	CEA decides to shut down Rapsodie reactor.
October:	Change in German Federal Government (H. Kohl succeeds H. Schmidt).

1983

June:	ARGO breeder study group formed in Paris.
June:	First criticality of second KNK II core.
September:	Britain states wish to participate in European breeder cooperation.
September:	UKAEA fast breeder budget slashed 30%.
September:	French safety authorities submit instructions on Superphénix 2.
December:	Final report on SNR 2 pool version (Phase 1c) submitted.

1984

January 10:	European Fast Breeder Agreement signed by five governments in Bonn.
January:	CEA sets up CEA Industry (Chairman: G. Renon).
February:	Agreement of EdF and CEGB to pool design and development activities.
March:	European Reactor MoU signed by R&D and industrial organizations.
March 2:	MoU about European R&D and industry FBR cooperation signed.

March:	Two MoU for fuel fabrication and reprocessing signed by Cogéma, BNFL, CEA, and UKAEA.
October:	French cabinet limits EdF to one reactor contract in 1985 and 1986.
October:	Sodium filling of Superphénix.
November:	R&D agreement initialed by partners.

1985

January:	FASTEC founded as joint venture of NNC (60%) and AEA (40%).
February:	Vibrations in Superphénix internal structures detected.
March:	PFR reaches first full power.
May:	Marshall Laboratory for fast fuel reprocessing studies completed at Dounreay.
May:	Construction of SNR 300 completed.
July:	Postponement of signing ceremony of European breeder R&D Agreements by H.-H. Haunschild, BMFT, Bonn.
July:	First fuel element loaded into Superphénix.
September 7:	First criticality of Superphénix.
October:	SNEAK reactor closed down at KfK; converted into Tritium Laboratory.

1986

January:	Superphénix coupled to grid for the first time.
January:	Superphénix costs quoted as approx. FF25 billion (B. Saitcevsky).
April 26:	Chernobyl accident.
August:	German SPD decides to opt out of nuclear energy.
December:	Dutch decide not to join European breeder cooperation.

December:	Superphénix reaches full power for the first time.

1987

March:	Interatom decides to reduce breeder staff.
March:	KfK plans to reduce nuclear activities.
March:	Sodium leak in Superphénix storage drum.
May 11:	First meeting of joint European Fast Reactor Design Group in Bensberg.
June 28:	French Prime Minister Chirac orders investigation into Superphénix barillet leak problem.
June:	EFRUG agrees on common model breeder.
September:	TRANSNUCLEAR affair on illegal shipment of wastes.
October:	UKAEA and NNC discuss plans for European Demonstration Reprocessing Plant (EDRP) at Dounreay.
November:	Anti-nuclear referendum in Italy.
December:	EdF decides to order no nuclear plant in 1988.

1988

February:	EFRUG and EFR.A decide to start design of EFR (Bensberg meeting).
April 1:	Start of EFR Conceptual Design Phase (Phase 1).
April:	Directives issued by German Federal Government to North-Rhine Westphalian State Government.
May:	EFR project presented at Jahrestagung Kerntechnik in Travemünde, Germany.
July:	U.K. Government (C. Parkinson) decides to stop PFR in five years and slash R&D breeder budgets.

October:	North-Rhine Westphalia sues German Federal Government before Karlsruhe Federal Constitutional Court.
December:	French safety authorities express general agreement with RNR 1500 preliminary safety report.

1989

January:	French Government asks "three sages" (Ph. Rouvillois, H. Guillaume, R. Pellat) to reflect on future nuclear program.
January:	Approval of Superphénix to resume operation till 9/89.
February 16:	EFR Agreements signed in Bonn.
April:	Framatome and KWU sign NPI-PWR Agreement.
April 21:	Superphénix resumes operation.
April:	"Cold fusion" euphoria.
May:	Germany gives up Wackersdorf reprocessing plant.
June:	Nuclear sages recommend R&D reorganization in France.
June 16:	Superphénix reaches full power after two years' outage.
August:	Scrams of Phénix due to "negative reactivity."
September:	Approval of Superphénix continuing operation up to 405 efpd.
November:	Creation of Management Group for Research and Development, MGRD (Chairman and Executive Director: W. Marth).

1990

January:	CEA reorganizes institutes into divisions.
March 12:	J. Bouchard nominated as Director of the Nuclear Reactor Division and J.-Y. Barre as Director of the Fuel Cycle Division of CEA.
April 1:	Start of EFR Concept Validation Phase (Phase 2).

April:	Creation of Project Management Team, PMT, at Lyons (Director: K. Ebbinghaus; deputies: M. Debru and C. Mitchell).
May:	Favorable Constitutional Court ruling on SNR 300.
July:	J. Rastoin appointed Director of IPSN.
July:	Sodium cold traps clogged at Superphénix.
July:	U.K. House of Commons Select Committee releases unfavorable report on fast breeder future.
September:	Swiss voters accept ten-year moratorium.
October 3:	Reunification of West and East Germany.
December:	Collapse of turbine generator roof due to heavy snowfall at Superphénix.

1991

March 20:	SNR 300 abandoned.
May 27:	French Conseil d'Etat revokes operating license for Superphénix.
July:	X. Elier appointed Head of Phénix, Marcoule.
August 23:	KfK shuts down KNK II after twenty years of operation.
Sept. 20:	Phénix authorized for ten-days' restart.
October 1:	Interatom absorbed into Siemens/KWU parent company.
October 28:	Europe-Japan MoU on FBR signed in Kyoto.
December:	U.K. utilities pledge continued operation of PFR.
December 11:	EFRUG considers delay of EFR by three years.

1992

March:	Neptun test facility started at KfK.
May 18:	French parliamentary hearing on Superphénix.

May: Russian Ministry of Atomic Energy (Minatom) formally asks to join EFR Project.

June: DSIN (Lavérie) recommends to limit Superphénix power operation to 30% and reduce period of operation.

June 29: French Prime Minister Pierre Bérégovoy makes statement on Superphénix; consequence: operating license expires.

August: U.K. Government confirms 1988 decision to shut down PFR by March 1994.

November 19: U.K. Government decides to stop financing EFR by March 31, 1993.

November: Through-wall crack found in Phénix 2 secondary sodium system.

December: French Research Minister Hubert Curion submits report on use of Phénix/Superphénix as actinide burners.

1993

January: H. Krämer, Chief Executive Officer of PreußenElectra utility, resigns.

February 11: EFRUG decides at top level meeting (Paris) not to enter EFR Phase 3.

March 30: Siemens announces plans to abandon Bensberg site (formerly Interatom).

April 30: Public inquiry on Superphénix opened (prolonged twice).

July: CEA announces new strategic orientation plan; less emphasis put on fast breeder reactors.

September: J. Pronost, Chairman of Superphénix Inquiry Committee, submits report.

September: UKAEA announces split into government and commercial divisions.

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Germany: E. Guthmann, IA/Sie - W. Marth, KfK - D. Grosser, IA/Sie - G. Heusener, KfK.

United Kingdom: A. D. Evans, A. M. Broomfield, A. M. Judd.

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*) during various phases of the Project.

Liaison Agents (LA)

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Italy: P. Casalini

United Kingdom: G. E. I. Smith, N. Sheriff.

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Italy: L. Pierazzi.

United Kingdom: D. M. Donaldson, D. Ockenden, D. J. Wilkes, A. Darke.

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AGT 1

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United Kingdom: K. G. Bagley, K. M. Swanson, C. Brown

AGT 2A

France: N. Lions, A. L. Champeix, D. Antonakas, J. Leclère.

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Italy: B. De Luca.

United Kingdom: A. D. Evans, A. Hamer.

AGT 2B

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United Kingdom: E. J. Burton, P. Thomas.

AGT 3

France: J. C. Mougniot, Ph. Hammer, J. Recolin, A. Khairallah, M. Salvatores, P. Bergeonneau.

Germany/DebeNe: R. Schroeder, KfK - S. Pilate, BN - R. De Wouters, BN - F. Helm, KfK.

Italy: A. DeCarli, R. Tavoni.

United Kingdom: D. E. J. Thornton, R. F. Burstall.

AGT 4

France: F. Penet, C. Le Rigoleur.

Germany/DeBeNe: G. Heusener, KfK - G. Vanmassenhove, SCK/CEN - F. Hofmann, KfK.

Italy: M. Pezzilli

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AGT 5

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AGT 6

France: X. Elie, N. Lions, J. C. Bouchter.

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AGT 7

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Italy: C. Salgo, P. Casalini.

United Kingdom: K. Eickhoff, A. M. Judd, M. Pilbeam, A. E. Collinson.

AGT 8

France: A. Giudicelli, J.-M. Chaumont, X. Elie.

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United Kingdom: A. M. Broomfield, C. V. Gregory, E. R. Adam.

AGT 9A

France: M. Weisz, P. Petrequin, M. Aubert.

Germany/DeBeNe: D. Grosser, IA/Sie - W. Dietz, IA/Sie.

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AGT 9B

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Delegates to France and Germany

for SPX 1/SPX 2 and SNR 300/SNR 2 experience exchanges:

H. Ballhausen, IA/Sie - R. Bryk, IA/Sie - H. Buchholz, IA/Sie - M. Buchwalder, Nov - A. DeBremaecker-LeRigoleur, SCK.CEN/KfK - L. De Cecco, ENEA - R. De Wouters, BN - C. Essig, IA/Sie - K.-F. Freudenstein, IA/Sie - H. Giese, KfK - O. Götzmann, KfK - A. Gouriou, CEA - J. Griner, Nov - R. D. Groot, Ner - E. Guthmann, IA/Sie (German team leader) - W. Gyr, IA/Sie - H. W. Hammers, IA/Sie - Ch. Heyne, IA/Sie - H. Höll, IA/Sie - J. Hüsken, IA/Sie - B. Klemme, IA/Sie - R. Kußmaul, KfK - J. Lallement, Nov - J.-C. Lefèvre, Nov (French team leader) - N. van Leuven, Ner - C. Lorin, CEA - V. Luster, IA/Sie - B. Mesnage, CEA - J. C. Moisset, CEA - H. Nagel, IA/Sie - R. Navez, BN - B. Percie de Cert, Nov - I. Ristow, IA/Sie - F. Rohdenburg, IA/Sie - P. Sardain, CEA - W. Scholtyssek, KfK - K. W. Schwitters, IA/Sie - A. Stanculescu, IA/Sie - L. Stevens, BN - H.-J. Walter, IA/Sie - H. Wilhelm, IA/Sie.

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Engineering Tasks - Coordinators:

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EFRUG Board: P. Bacher, EdF - B. Broecker, PE - D. Brosche, BAG - R. Carle, EdF - Y. Cousin, EdF - A.-W. Eitz, RWE - H. U. Fabian, PE - R. S. Fidler, NE - S. C. Goddard, NE - B. d'Ongia, ENEL - W. Ringeis, RWE - F. Velona, ENEL - D. Vignon, EdF - E. Wild, BAG.

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Members of the Comité de Liaison / Steering Committee and locations of meetings

Year	KfK	Interatom/ DeBeNe	CEA	UK	Location CdL / SC
1977	**Hennies**	Mausbeck Guthmann	Moranville Rapin Megy Stosskopf		Saclay (F)
1978	**Marth**	Höchel	Lallement Villeneuve Petit		Bensberg (D) Marcoule (F) Karlsruhe (D) Gif-sur-Yvette (F)
1979					Kalkar (D) La Hague (F)
1980					Karlsruhe (D) Creys-Malville (F)
1981					Bensberg (D) Pierrelatte (F)
1982		Weisbrodt	**Bouchard** Chalot		Bensberg (D) Paris (F)
1983			Rastoin		Weinheim (D) Rouffach (F)
1984			Benoist	Evans Welch Smith Hardingham	London (UK) Rome (I)
1985				Swanson	Avignon (F) Chieming (D)
1986		Brandstetter	**Lefèvre**	**Broomfield** Holmes	Antwerpen (NL) London (UK) Bologna (I)
1987				Judd	Gif-sur-Yvette (F) Cologne (D)
1988				Broadley	Chester (UK) Amsterdam (NL)
1989		**Köhler** Grosser			Bouziges (F) Georgshausen (D)
1990	**Heusener**		**Sauvage**		Edinburgh (UK) Toulouse (F)
1991				Gregory	Berlin (D) Windsor (UK)
1992			**Livolant**		Grenoble (F) Hamburg (D)
1993					Wilmslow (UK) Creys-Malville (F)

Bold type: **Member**
Normal type: Membership expired