KfK 5455
Dezember 1994

The SNR 300 Fast Breeder in the Ups and Downs of its History

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Translated by Ralf Friese.
Printed as a manuscript.

A German version of this report, without the illustrations,
was published in March 1992 and is available as KfK 4666
under the title
“Der Schnelle Brüter SNR 300 im Auf und Ab seiner Geschichte.“

Kernforschungszentrum Karlsruhe GmbH,
Postfach 3640, D-76021 Karlsruhe, Germany.

ISSN 0303-4003.

ABSTRACT

"The SNR 300 Fast Breeder
in the Ups and Downs of its History"

The Fast Breeder Project was founded in Karlsruhe in 1960. After an initial period of fundamental research, industry assumed responsibility for designing the SNR 300. Construction of the Kalkar Nuclear Power Station was hampered by a variety of political influences, but finally completed in 1985. As a consequence of the North Rhine-Westphalian party-in-government's opting out of nuclear power, no startup permit was issued for the SNR 300. Consequently, the Kalkar Nuclear Power Station project was discontinued for political reasons in March 1991.

ZUSAMMENFASSUNG

"Der Schnelle Brüter SNR 300
im Auf und Ab seiner Geschichte"

Das Projekt Schneller Brüter wurde 1960 in Karlsruhe gegründet. Nach anfänglichen Grundlagenforschungen übernahm die Industrie die Auslegung des SNR 300. Der Bau des Kernkraftwerks Kalkar wurde durch vielfältige politische Einflußnahmen gestört, 1985 aber letztlich doch fertiggestellt. Wegen des Kernenergieausstiegs der regierenden Landespartei in Nordrhein-Westfalen konnte die Inbetriebnahmegenehmigung für den SNR 300 nicht erlangt werden. Im März 1991 wurde deshalb das Projekt Kernkraftwerk Kalkar aus politischen Gründen beendet.

OUTLINE

1 THE BEGINNINGS OF THE FAST BREEDER PROJECT
(1957 - 63)

2 THE PROJECT BECOMES INTERNATIONAL
(1962 - 64)

3 INDUSTRY COMES IN
(1964 - 66)

4 THE STEAM COOLED BREEDER PROJECT DISCONTINUED
(1966 - 69)

5 THE BEGINNINGS OF THE KALKAR NUCLEAR POWER STATION
(1969 - 73)

6 START OF CONSTRUCTION AND FIRST DIFFICULTIES
(1973 - 78)

7 COMMITTEES, COMMISSIONS, EXPERT OPINIONS
(1978 - 82)

8 A TURNING POINT AND AN UPSWING
(1982 - 85)

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PREFACE

The Fast Breeder Project, including the construction in Kalkar of the SNR 300, covered the 34-year period between 1957 and 1991. In the first twelve years, most of the development work was centered at Karlsruhe, then activities moved to Bensberg and, still later, to Kalkar.

An attempt is made in this report to record, in a spirit of accuracy and fairness, the performance of those participating in the Project, and to recall the events marking the development. The development of the fast breeder in Germany, with its manifold technical complications and the weight brought to bear by politicians and the public, is not a project history like many others; it is a technology saga. Describing it in full detail would fill a tome. Bearing in mind everybody's lack of time, and also in the interest of readability, I decided to limit this account to approximately one hundred pages.

The Kalkar Nuclear Power Station has been completed, but it has never been commissioned because of the lack of political consensus among the major political parties. Law enforcement by the State of North Rhine-Westphalia in the interest of opting out of nuclear power made the SNR 300 a failed investment monument. Kalkar is not the first project failing because of the dissent of political parties in energy policy issues. Whether it will be the last one remains to be seen.

Many of my colleagues have spent decades, some even their entire professional careers, contributing to the development of the fast breeder; theirs is a tremendous technical achievement.

To them this report is dedicated.

It has been a fascinating job - despite all that went with it.

Dr. Willy MARTH

Examining the **past**
makes us more certain
in assessing the **present**
and forecasting the **future**.

1. THE BEGINNINGS OF THE FAST BREEDER PROJECT (1957 - 63)

The beginnings of the Fast Breeder Project date back to 1957.

In the 1957/58 winter term, **Professor Karl Wirtz** ran a seminar about fast breeder reactors at the Institute for Neutron Physics and Reactor Engineering (INR). On that occasion, the scientific interest in the physics of fast neutrons, the breeding process, and the technical conceptual design of breeders was aroused at the Nuclear Research Center. The "computer" then available to the INR, a Zuse Z 22, was used for some preliminary calculations showing the interdependence of the core structure, critical mass, and breeding ratio [1, 2, 3].

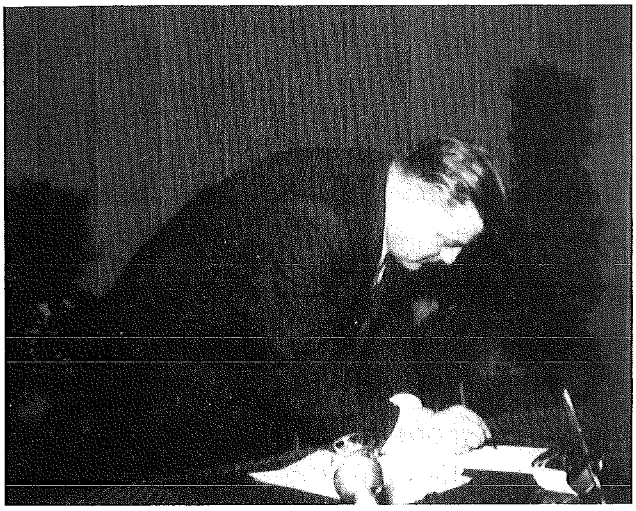
This was a modest beginning, leaving open many questions. Consequently, the Head of the INR Theoretical Group at that time, **Dr. Wolf Häfele**, was delegated to the Oak Ridge National Laboratory (ORNL) in the United States for one year in 1959 to familiarize with work in the area of thermal breeders going on at that center. At that time, Wirtz was rather skeptical of the sodium cooled breeder, especially because of the core meltdown accident in the EBR I, and wanted to learn from the ORNL arguments against the fast breeder developed at the competing Argonne National Laboratory (ANL).

However, Häfele came back from the USA all enthusiastic about fast breeder technology. In a detailed memorandum he outlined the drawbacks of the thermal breeder working on uranium 233, especially its low breeding ratio, and proposed to study the fast breeder at the Nuclear Research Center[4]. On April 1, 1960, the INR and the Technical Reactor Department (TA/R) jointly set up the "Fast Breeder Project Group," appointed Dr. Wolf Häfele its leader, and announced the event to the management of the Nuclear Research Center in a memorandum dated April 21, 1960. At Karlsruhe, most of the physics studies underlying the FR 2 reactor had meanwhile been completed, and scientists welcomed this prospect of a new major activity [5].

This marked the beginning of the Fast Breeder Project in Karlsruhe.

1.1 Authorization and Organization

The establishment of the **Fast Breeder Project**, **PSB** for short, was an absolutely unique event at the Nuclear Research Center. True, some of the work on the FR 2 had already been carried out in a joint effort by several institutes, but they had not been coordinated by a project management staff, but mainly by the Institute for Neutron Physics and Reactor Engineering (INR) and by top management. Consequently, authorization by the official bodies of the company and the expert groups of the German Advisory Committee on Atomic Energy was required to ensure that the Fast Breeder Project was given the proper mandate and last, but not least, the necessary funds.



Franz-Josef Strauß, first German Minister for Atomic Affairs, signing the document establishing the Karlsruhe Nuclear Research Center.

On May 15, 1960, the Supervisory Board of the company approved the Project as requested by management. The decision was based on a memorandum which explained the planned stepped approach by the Project Group - as it was still called at that time. According to the **plan**, three development steps were to be taken [6]:

(1) Preselection of possible reactor lines under physics and engineering aspects.

(2) First conceptual design draft of the type of reactor envisaged, and performance of physical and technical experiments.

(3) Execution of a critical zero power experiment.

This was to be followed by detailed planning of the type of reactor chosen, and then by the construction of the nuclear power plant.

In the reasons given in support of the project application it was stated that future developments might well replace the present line of power reactors by breeder reactors. In the U.K., 1970 was envisaged as a date for this change, while elsewhere a longer period of development was being considered. For Germany, this would open up the possibility to be in the front line of development of an important reactor line.

At the request of the Supervisory Board, also Working Party III/1, "Nuclear Reactors," and Expert Committee II of the German Advisory Committee on Atomic Energy were asked for their opinions on the Project. Under the chairmanship of Prof. Maier-Leibnitz, Working Party III/1 approved the Project on December 7, 1960, expressly including the possibility of reasons arising for which it might have to be discontinued after the three years applied for. Expert Committee II, chaired by Prof. Winnacker, approved the Project on February 9, 1961; in its decision, it warned against prematurely transferring it to an international level [6].

In the **organization** of the Project Group, initially a core staff of 20 was to be set up for the first stage. The Project Leader was to determine the general policy line and, in important decisions and in recruiting more personnel, had to agree with the Heads of the INR and the Technical Reactor Department (TA/R) [5].

From the outset, development work on a fast breeder was considered a major activity. A nuclear research center was deemed to be the appropriate type of organization for such a job. The spectrum of administrative units of the Center, whose cooperation was sought, was correspondingly broad [6]:

(1) Institute for Neutron Physics and Reactor Engineering (INR), for theoretical calculations, experimental work, basic concepts, fundamental design drafts.

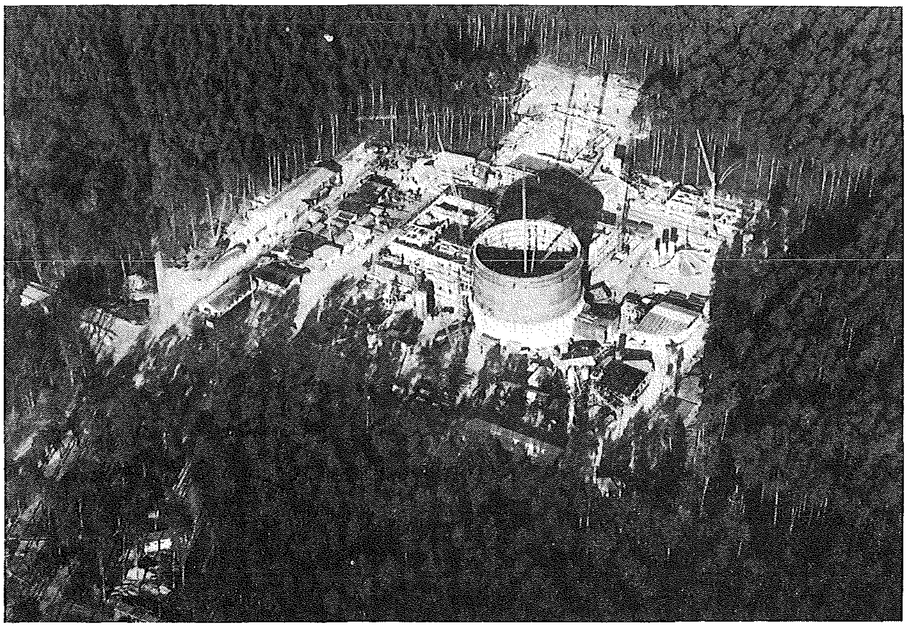
(2) Technical Reactor Department (TA/R), for design drafts and major technical experiments.

(3) Institute for Hot Chemistry (IHCh), for the development of reprocessing techniques.

(4) Institute for Radiochemistry (IRCh), for studies of the diffusion of fission product noble gases.

(5) Institute for Transuranium Elements (TU), for plutonium technology.

(6) FR 2 Reactor Operations Division (RB), for irradiations of fuel specimens.



The FR 2 research reactor under construction.

A period of three years (1961 till 1963) was deemed to be sufficient for preliminary theoretical and experimental work; afterwards, the final design draft and construction of the breeder reactor were to be decided upon. The total Project costs were estimated at DM 200 million; this amount included the planned SNEAK zero power plant, but not the plutonium to be obtained from the USA [6].

Coordination of the Project work among the Institutes and the Project Management early on had been made the responsibility of the so-called Breeder A Committee. Its members were the Heads of the administrative units listed above, the General Managers of the Center and, of course, the Project Leader. The Committee met approximately once a month under the chairmanship of Wirtz (from 1966 on, under the Technical General Manager, Dr. Walther Schnurr). The weekly project discussions (also called Brain Trust - BT - meetings) were led by Häfele. They served for detailed Project control and included the Project staff plus a few Heads of Institutes and important senior staff members.

From the outset, much attention was devoted to the public presentation of the progress made in the Project. This was done at annual **Status Reports**, which initially were internal affairs, but soon were attended by prominent external guests, frequently also the Federal Minister for Research in office. The painstaking organization of the one-day lecture event became an impressive ritual normally preceded by a "full rehearsal" the day before.

1.2 Project Goals and Fundamental Problems

After the administrative and financial preconditions for the Project had been established, Project Management defined the fundamental **goals** to be worked upon over the next few years [7, 8, 9]:

(1) The envisaged type of reactor was to be a genuine breeder, i.e., its breeding ratio was to be clearly above 1.

(2) It was to work with the smallest possible critical mass.

(3) Its safety level was to correspond to that of thermal reactors.

(4) The fuel element was to permit a very high burnup to be attained at low manufacturing costs.

(5) The reactor was to operate in a closed cycle, i.e., the plutonium generated in-pile was to be separated by fuel reprocessing and then recycled in the reactor.

(6) The breeder power plant was to be as economic as possible.

The general wording of these project goals has remained valid to this day; in a few cases (breeding ratio, reprocessing), one would even wish that they had not been suppressed temporarily or later reduced in significance.

In the early phase of the Project, around 1960/61, there were quite a number of fundamental issues which had to be resolved in a major effort. Although these discussions have long since come to an end, some of the points should be reiterated for their historic interest.

For some time, weighing between an external and an internal breeder was a major issue. In the first breeder generation, much emphasis was placed on the breeding ratio.

As the amounts of plutonium available were small, and typical nuclear power plant capacities were below 100 MWe, the resultant reactors had metal fuel and high enrichment levels (> 30%). The cores of these reactors contained only little fertile material; nuclear transmutation took place mostly in the surrounding breeding blanket of U-238. These reactors were called **"external breeders;"** their breeding ratio was 1.5 and more [9, 10].

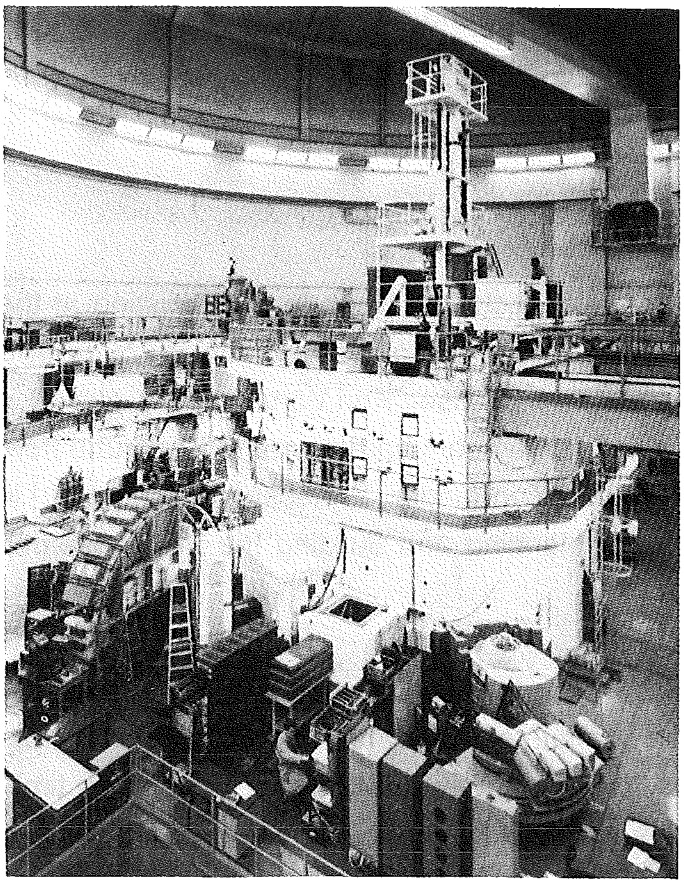
Because of their high concentrations of fissile materials these breeders were cooled only with liquid metal. The burnup of metal fuel elements at that time was limited to 10-15,000 MWd/t because of swelling. For nuclear power plant operation, the external breeder version was unsuitable because of the frequent reloading, associated outages, and the many reprocessing steps.

The transition from a metal fueled to an oxide fueled external breeder was an obvious step to take, but it failed on grounds of safety. While the expansion of the **metal fuel** ensured inherent dynamic stability because of the resultant negative power coefficient, there was no reliable expansion in oxide fuel of low density and high burnup. Moreover, the safety potential inherent in the Doppler effect had to be forgone, as the sign of that effect could not be proven with sufficient reliability at that time.

The solution of these problems was found in the step to the **"internal breeder,"** with fuel enrichments of 10 - 15% in the core, still the customary level. This had become possible as a result of the interest by electricity utilities in larger units, and also the increased arisings of plutonium from thermal power reactors. The large fraction of uranium 238 in the core guaranteed a highly negative Doppler coefficient and an almost constant reactivity throughout the burnup period, with the consequence of short control rod travel. Finally, also the needs of the operators were met, because they thought they needed only one core reloading outage per annum when using oxide fuel.

In **reactor control**, the development of scram units was pursued for some time. The still insufficient knowledge of the dynamics of fast reactors had initiated the work. To this day, it has remained a cause for amazement to uninformed and superficially informed persons that fast and thermal reactors, despite their different average neutron generation times, have approximately the same control characteristics [7].

From the outset, the **fuel element** occupied a central position. As very high burnups were to be achieved with oxide fuels, the "strong can, weak fuel" concept was discussed for some time. A strong, thick-walled cladding was to enclose the oxide fuel which, because of its high thermal plasticity, was not expected to show particularly good stability characteristics. The design envisaged were simple cylindrical tubes of molybdenum and Inconel, respectively, with an outside diameter of 5 mm, which were to contain a mixture of PuO_2 and UO_2 vibrated into place. The tubes had very thick walls, which is expressed in the 1:2 ratio of volumes of the cladding and the fuel. In this concept, which naturally would have been implemented at the expense of the breeding ratio, burnup was considered to be limited only by fission product gas buildup. The upper pressure limit was assumed to be around 500 - 600 bar. Later on, also the neutron physics properties of molybdenum required that this material be given up; as a result of errors in measurement, the absorption cross section initially had been taken to be much too low [7, 8].



Experimental installations around the FR 2.

The early inclusion of the **fuel cycle** in the overall concept has already been mentioned. The fabrication of breeder fuel elements initially was devised as a process almost entirely run by remote control because of the radioactivity of the higher Pu-isotopes. In this way, reprocessing required no high decontamination factors; a factor of 10 per extraction cycle was deemed to be sufficient.

In the early Project Memoranda, the **coolant** surprisingly plays a minor role. It was hardly ever discussed, once some eccentric ideas hatched at ORNL, such as a reactor operated like the molten salt reactor, with liquid plutonium and advantageous plutonium compounds, respectively, had been shelved. Of the two protagonists of the Project, Wirtz and Häfele, Wirtz, for safety reasons, preferred helium, while Häfele, for reasons of heat transfer, was in favor of sodium. Finally, both coolants were studied side by side. After Ludolf Ritz had been appointed Head of the Institute for Reactor Components in 1961, also steam cooling was taken on board [4, 11].

From 1961 on, the three coolants, **sodium**, **helium**, and **steam**, were to be tested as equally important variants; a decision was not to be taken until later.

1.3 The Role of the INR

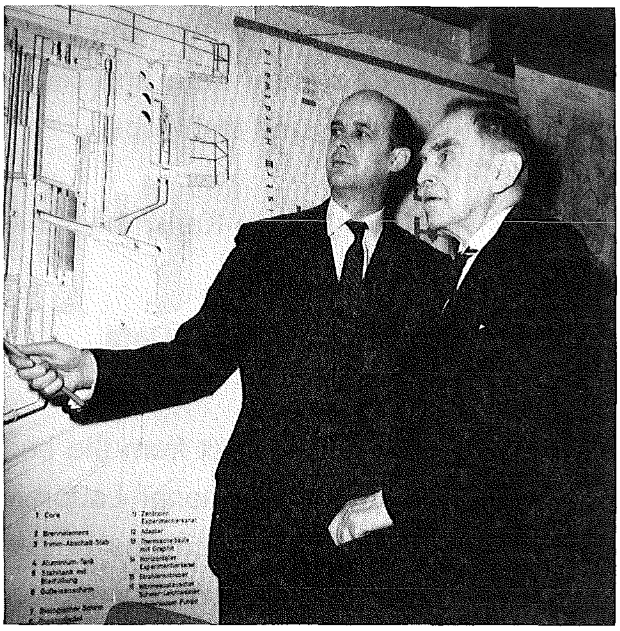
Among the roughly half dozen of Institutes and Technical Departments existing at the Nuclear Research Center in the early sixties, the **Institute for Neutron Physics and Reactor Engineering (INR)** under its Director, Professor Karl Wirtz, clearly played a dominant role. In 1956, Wirtz and 36 of his staff members had moved to Karlsruhe from Göttingen, where he had been Head of Division under Professor Heisenberg; in Karlsruhe he had assumed responsibility for planning and building the FR 2 research reactor [12].

After the Breeder Project had been established, the Institute grew to more than 100 members, attaining its maximum manning strength of 170 in 1964, among them approximately 20 students and guest scientists from Germany and abroad. For a long time, the Institute was organized in four Groups and Departments, respectively: Theory, Experiment, Test Rigs, and Materials. The Theoretical Department also operated the computer facility of the Center; for the rest, it elaborated the basic principles of safety as well as nuclear data and codes. The Experimental Department, among other activities, ran the SUAK, STARK, and SNEAK experimental facilities, while the Technical Test Rigs Department was mainly concerned with reactor studies and the associated experimental setups. The Materials Group, finally, was responsible for fuel element development, including irradiations. Later, in 1963, also the Measurement and Control Department (MRTA) was added.

It was a logical consequence of the increasing size of the Institute, but also of the personalities it contained, that independent units developed out of the INR. In 1963, the Institute for Applied Nuclear Physics (IAK), under Karl-Heinz Beckurts, and the Institute for Applied Reactor Physics (IAR), under Wolf Häfele, in 1964 the Institute for Reactor Components (IRE), under Dieter Smidt, were founded, and the Heads of these Institutes were made professors. The INR, in a way, was the mother of all these institutes.

Also the later Managing Director of the Kalkar Nuclear Power Station, Werner Koop, came from the INR.

Wirtz managed his Institute in a paternalistic style; his staff had to deliver quality. Publications, above all, had to offer in-depth scientific and technical contents. In order to get this point across, he created an **INR** Prize. the awarding ceremony of which was one of the highlights of the annual Christmas parties, and was always associated with a detailed citation by the boss. The Prize was coveted far beyond its real value of DM 500, as all members of the Institute knew that it was not automatically awarded to the higher brass, such as Group Leaders or Heads of Department, but everybody had a chance to win it for some scientific achievement. In his Christmas addresses, Wirtz never failed to emphazise the achievements not only of his scientists, but also of the other staff, for instance the cleaners. He also made the point to Management and the shareholders (1961) to use as a basis for a pay scheme at the Nuclear Research Center not the pay regulations for public service employees (the so-called BAT), but the much more favorable pay scheme of the electricity utilities. Unfortunately, he failed in these efforts [13].



Professor Wirtz explaining the FR 2 design to Nobel Prize winner Otto Hahn.

Wirtz clearly had a predilection for the **helium** coolant because of its safety characteristics, such as non-flammability and low void coefficient. But he loyally supported the decision in favor of sodium taken by the Project Management, even in the turbulent days of the coolant debates in 1968/69. However, he thought the combination of Project Leader and Head of Institute in a single person (as had sometimes been the case under Häfele) administratively wrong, and he expressed that opinion quite frankly [14].

As Chairman of the Scientific Council, Wirtz always strove to find for the Center a clear scientific and technical profile. He urgently warned against abandoning the nuclear field prematurely, given the large number of open technical and scientific problems. He successfully counteracted the intentions at the Center in the late sixties to switch to accelerator research.

The Fast Breeder Project at the INR and in the whole Center developed most impressively in the years to follow. The committed project management by Häfele, the enthusiasm of all participants, and the absence of any external obstacles of the kind people are forced to fight against nowadays, all contributed to this atmosphere. A characteristic feature of that boom period were the thoughts about basic safety questions, the deliberate collection of nuclear data and codes, and the construction of physico-technical experimental facilities and test loops.

Professor Karl Wirtz died in Karlsruhe in February 1994 at the age of 84.

1.3.1 Safety and Nuclear Data

In safety matters, the Project from the beginning sought close contacts with the USA, especially the Argonne National Laboratory (ANL) run by the U.S. Atomic Energy Commission (USAEC). The causes of the **core meltdown accident** in the EBR I had meanwhile been recognized as spontaneous positive power oscillations of the Mark II core, caused by a positive bowing coefficient of reactivity. The Bethe-Tait report, which was to be quoted widely later on, gave an impression of the maximum release of mechanical energy to be expected in a nuclear excursion, and the negative Doppler effect was assumed to be an important inherent possibility of power reduction in oxide reactors [15, 16, 17, 18].

At a seminar held in Washington in late 1962, the importance of the **Doppler coefficient** for the safety of fast breeders was hotly debated between Häfele and Spinrad (ANL). While Häfele attributed to the Doppler coefficient an overriding importance in respect of safety, Spinrad considered it merely one factor besides many others, such as core structure. Nevertheless, at that early date, closer cooperation in safety matters was agreed between the USA and the Federal Republic of Germany, which later developed into a relationship of trust over many years [19]. The work going on in Karlsruhe soon was reflected in pioneering publications furthering the knowledge of prompt supercritical power excursions [20, 21, 22].

Around 1963, the positive, destabilizing sodium void coefficient became a matter of increasing interest at the Nuclear Research Center. The clear assumption that reactors of more than approximately 300 MWe can experience positive reactivity effects and, consequently, suffer core degradation, was rightly considered an important phenomenon and became a matter of concern especially to the Head of INR, Professor Wirtz. As a consequence, extended boiling experiments were planned at the IRE, in the course of which the sodium expulsion process and the two-phase flow of liquid metals was studied in detail [23, 24].

Under the assumption of non-functioning shutdown systems, the first calculations of the Bethe-Tait accident were carried out. The significance of the equation of state for evaporating fuel had already been recognized, and also the secondary-excursion concept came up at that time. In one of the first estimates, a 1000 MWe reactor had been attributed an energy release "clearly below 1000 MWs" [25].

Probably the biggest uncertainty factor in the nuclear calculations of fast reactors was introduced by the **cross sections** of the reactor materials, which were not known very precisely. For this reason, careful checking and revision of the database available was initiated, which found its expression in a three-volume KfK report by INR staff member J.J. Schmidt. That study was the basis of the first Karlsruhe set of group constants, KfK-26-10. The group constants were formed with a weighting spectrum typical of a 1000 MWe sodium cooled breeder. After resonances had been taken into account, this led to the RESI program system, part of the comprehensive MIGROS system [26, 27].

The programs designed for approximate solutions of the neutron transport equation were combined in the "Karlsruhe Nuclear Program System," **NUSYS**. It offered information about nuclear reactor quantities, such as criticality, power distribution, safety coefficients, breeding ratio, etc., and reached the limits of applicability not so much in the programs proper, but rather in the restricted capacity of the IBM 7070/7074 computer installed at that time.

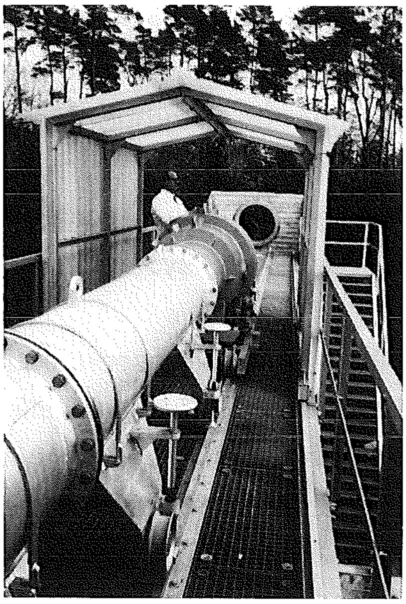
A one-dimensional burnup code was available for **burnup calculations**. It was used also for calculations designed to optimize the breeding blanket. Calculations about fuel management, even at that time, were run to determine the changes in the composition of the Pu isotopes over long periods of reactor operation and multiple Pu-recycling [28].

1.3.2 Van de Graaff Generator, SUAK and STARK

For cross section measurements, a **Van de Graaff generator** was purchased and commissioned in 1964. It operated by directing the proton pulse generated in a high-frequency ion source onto a lithium or tritium target, which released neutrons with a broad energy spectrum between 10 keV and 1.5 MeV. Application of the time-of-flight method allowed the fission cross sections of the most important breeder isotopes, U-235, Pu-239, Pu-240, and Pu-241, to be determined in the energy range indicated above.

A **cyclotron**, bought originally for research in radiochemistry, was used also for cross section measurements within the Fast Breeder Project after 1965. It covered the energy range between 0.5 and more than 10 MeV [29].

In October 1964, the "Karlsruhe Fast Subcritical Assembly" **(SUAK)** was commissioned. It was an unshielded subcritical system with a multiplication constant, k_{eff}, not exceeding 0.9. Neutron pulses were periodically applied from the outside to a uranium cube of 30 to 50 cm length of the edges. In principle, this allowed the neutron time-of-flight to be measured from the setup to a remote detector; if the flight path is known, the energy distribution of fast neutrons can thus be determined between a few keV and several MeV. Extensive measurements were conducted to determine the so-called decay constant. This is an integral reactor quantity dependent on the composition of materials and sensitive to changes in the fast neutron spectrum, especially in the resonance range.



The beam tube of SUAK.

The third experimental facility commissioned in 1964 was the "Karlsruhe Fast-Thermal Argonaut Reactor" **(STARK)**. It was developed from the thermal Argonaut reactor, whose inner graphite reflector zone had been replaced by a fast core zone with variable material compositions. The two zones were separated by a cylindrical buffer blanket of natural uranium to reduce the penetration of slow neutrons from the thermal into the fast regions. The dynamic behavior of the reactor was determined almost exclusively by the thermal driver core, which greatly facilitated operation. After the necessary startup measurements, work with this facility served for the development of methods of detection for neutron spectra and reaction rates, as well as reactivity determination. Especially the research into noise analysis, which was begun in STARK, should be mentioned.

1.3.3 Test Loops

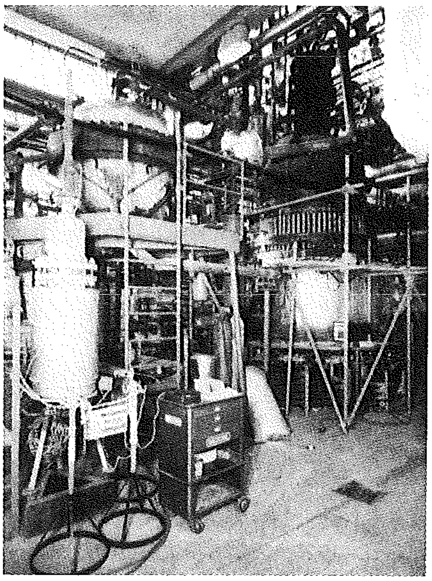
To gather practical experience with the three coolants, technical-scale test loops had to be built and were planned from the outset.

At the Institute for Neutron Physics and Reactor Engineering (INR), a 500 kW **helium loop** was built which allowed pressures of up to 50 bar and heat flows of up to 300 W/cm^2 to be generated. The setup, among other purposes, was used for measuring heat transfer coefficients in fuel rods at high temperatures and at various surface roughness levels [10].

A whole set of test loops were built at the Institute for Reactor Components (IRB). In the **sodium corrosion loop** with three test sections of 12 kW each, the corrosive impact of sodium on cladding materials, initially in particular vanadium alloys, was examined. Another, physically adjacent, sodium loop (280 kW) allowed fundamental hydraulic and thermohydraulic investigations to be performed in fuel rod bundles [30].

This had been preceded by the technically sophisticated development of **finned tubes** for the steam cooled breeder. In this design, space between the fuel rods is kept by helical fins on the cladding tubes. Compared to the helical wire concept already customary at that time, the integrated concept offered major advantages in terms of avoiding plate out, hot spots, and fretting corrosion. In addition, at a given maximum cladding temperature, it allowed the highest enthalpy rise and the lowest pressure drop to be achieved, i.e. it was near-ideal in the thermodynamic and fluid dynamic sense. Technical development was carried out together with industry, but was stopped later at Inconel 625 because of difficulties arising in manufacture, cost problems, and also when the steam cooled breeder was discontinued. Experience with the Inconel 800 cladding tube material in the Mol 7D in-pile experiment for the sodium cooled breeder was excellent; six finned tubes were used, and a burnup of 90,000 MWd/t was achieved.

A system of key significance in the development of the steam cooled breeder was the 3 MW **Löffler circuit** established at the IRB. The circuit was arranged within a pressure vessel, the bottom part holding the electrically heated "core," the upper part, the spherical evaporator, and the dome-shaped superstructure, the steam compressor-steam turbine system. The flowsheet and the mode of operation simulated a reactor circuit, with the turbine being replaced by a steam pressure reducing and desuperheating station. In an extended experimental program, startup and shutdown processes as well as transients occurring in assumed accidents were studied.



The 3 MW Löffler circuit.

The IRB also ran other test rigs for the development of steam blowers and Löffler evaporators, and for studies of thermohydraulics and hot spot corrosion in fuel elements [30].

2. THE PROJECT BECOMES INTERNATIONAL (1962 - 64)

2.1 The Association with EURATOM

Cooperation with Euratom, which was laid down in an agreement in 1963, was an extremely important decision. It stabilized the Project by including an internationally experienced partner willing, in addition, to contribute considerable funds [31, 32].

Already in 1960, when the Karlsruhe Project was founded, **EURATOM** considered embarking on breeder development on a large scale. Those plans were initiated also by the finding that the contribution the Community was able to make in the fields of light water, gas or organically cooled reactors was limited, for a variety of reasons. As a consequence, attention was devoted to breeders, and at one point in time even the construction of a fast zero power assembly was considered, which was bound to lead to contacts with the Karlsruhe plans. Initially, EURATOM thought about building a critical assembly at Cadarache. However, this was in line with neither the German nor the French ideas, and ultimately agreement was reached on the construction of two national plants at Karlsruhe **(SNEAK)** and Cadarache **(MASURCA)**. For these plants, plutonium had to be obtained from the USA which, under the agreements with the Community, was not possible on a national level, but only through EURATOM [33].

In the spring of 1963, after lengthy negotiations, the **Agreement of Association** in the fast breeder field was signed by EURATOM and the Federal Republic. Similar agreements were offered to, and accepted by, France and Italy. The agreement mainly provided for exchanges of information and delegations of personnel. For the Karlsruhe Breeder Project, a budget of DM 185 million was earmarked for the period 1963 - 67, to which EURATOM was prepared to contribute 40%. In addition, the Community pledged to obtain 300 kg of plutonium from the USA; the material arrived in 1965 and was shared equally between Karlsruhe and Cadarache [34, 35].

In 1965/66, the **Netherlands** and **Belgium** entered into similar agreements of association with EURATOM, with the proviso that they were to associate themselves either with France or with Germany. The reason for this condition was fear, on the part of EURATOM, that otherwise there would be too much of a dispersion of breeder activities in Europe. The two countries, as we know, joined Germany. The Karlsruhe Project Management included the Belgian organizations, **CEN/SCK Mol** and **Belgonucléaire**, as well as the Netherlands institutions, **RCN Petten** and **TNO/Neratoom,** in accordance with their levels of experience and the requirements of the Project [36].

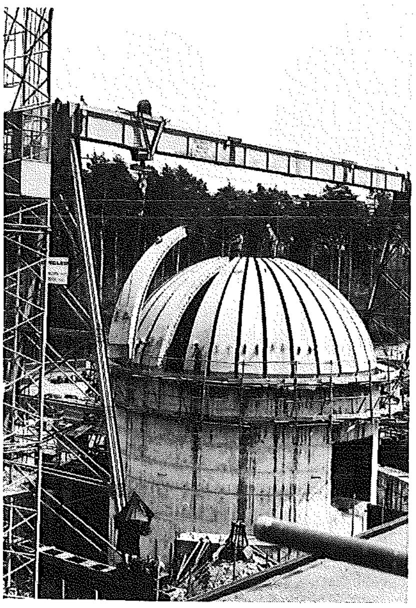
A. H. De Haas van Dorsser and J. van Dievoet,
the Breeder Project representatives respectively of the
Netherlands and Belgium.

CEN/SCK Mol had experience in reprocessing, particularly by the volatilization technique. Belgonucléaire had already worked with the Enrico Fermi Project and with French plutonium and reactor projects and, consequently, was assigned a special role in fuel development. **RCN Petten** and **TNO/Neratoom** were to assume responsibilities for fundamental studies and for work on sodium components.

Cooperation with EURATOM and the resultant internationalization lent to the Project a high degree of stability. The number of scientists and technicians involved in the PSB increased to 400 by 1966; in addition, the same number again were staff members in the infrastructure sector. This paralleled the increase in personnel at the Center, which had run from 120 to 3000 persons between 1956 and 1966.

2.1.1 The Karlsruhe Fast Zero Power Assembly (SNEAK)

By far the most sophisticated research facility planned at the Nuclear Research Center at that time was the Karlsruhe Fast Zero Power Assembly **(SNEAK)**. It was built in 1964 - 66 by Siemens on the basis of ideas developed by the Project under the management of Dr. Peter Engelmann, Häfele's deputy. The reactor core was designed flexible, thus allowing fast cores of variable sizes, geometries, and compositions to be assembled. Accordingly, the core was made up of a large number of element tubes suspended into a grid plate from below. The tubes were filled with platelets 51 x 51 mm^2 in cross section and of variable thickness. The mixtures of these platelets made of uranium, plutonium, steel, graphite, aluminum oxide, sodium, polythene, etc. determined the composition of the core. In this way it was possible to simulate at random the configurations of fast reactors fueled with uranium and plutonium, cooled by sodium or gas, and containing a variety of cladding and structural materials. Provided the necessary amounts of fuel were available, these "reactors" were studied on a full scale, but at a low power level (1 - 1000 Watt) and at room temperature [37].


The SNEAK experimental reactor under construction.

The **experimental program** in SNEAK encompassed the determination of critical masses, power distributions, control rod worths, breeding ratios, neutron spectra and, above all, the important power coefficients (Doppler coefficient, void coefficient, etc.). A large number of experimental facilities were available for running these measurements, including a pile oscillator, a Doppler loop, a pulsed neutron source and others.

The **plutonium** (175 kg) and enriched uranium (550 kg of U-235) initially required to build up the core was purchased under the EURATOM Association Agreement mentioned above and made up most of the cost of the SNEAK facility. In the further development of the Project it was possible to increase the amount of plutonium to 300 kg, that of U-235 to 1000 kg. In addition, more than 60 t of natural uranium and depleted uranium, respectively, was bought.

SNEAK was built parallel to the French zero power facility, **MASURCA**, at Cadarache. That plant contained not platelets, but rodlets filled with metal fuel, but its inner tube dimensions were chosen so that the plutonium inventories could be exchanged.

The construction of SNEAK was delayed, among other events, by a fire in the insulating layer on the roof which had occurred during welding activities. Nevertheless, both plants were commissioned in the night of December 15 to 16, 1966. SNEAK I was a replica of ZPR III assembly No. 41; it took up all the uranium fuel available. Criticality was attained with 179 elements; predictive calculations had indicated 178 elements.

The first plutonium core assembly, SNEAK 3, was measured in 1968 in connection with steam-cooled breeder activities.

2.1.2 The Southwest Experimental Fast Oxide Reactor (SEFOR)

Originally, another large facility was to have been erected on the premises of the Karlsruhe Nuclear Research Center. The Doppler coefficient was to be determined by analyses of power excursion measurements in a fast test reactor to be operated at a few megawatt power, **"Karlsruhe Powder Godiva."** From the beginning, the Project had attributed considerable significance to the verification of a sufficiently high negative Doppler coefficient of the fuel. As a result of the switch from metal to oxide fuel, the expansion coefficient and its stabilizing impact on the power level ceased to be available, and all hopes were now focused on the inherent shutdown effect provided by the Doppler coefficient. The rather strange names, "powder" and "Godiva," referred to the oxide fuel powder and to the absence of any covering blanket or reflector in the planned reactor. In a rather bold comparison, it presented itself like the legendary English Lady Godiva who rode a horse without wearing any clothes. A precursor, the U.S. metal reactor "Godiva," had been built and used for weapon research purposes by the USAEC [2].

The plan to run this experiment, which was not without danger, at the Karlsruhe Nuclear Research Center was dropped when it became known in 1962 that General Electric in the United States was on the verge of building a similar test reactor to be called EFCR (Experimental Fast Ceramic Reactor). Negotiations about cooperation were begun and converged in a number of agreements signed in 1964: KfK and EURATOM acquired an interest in Southwest Atomic Energy Associates (SAEA), an association of 17 utilities in the southwest of the USA. They commissioned General Electric to build the 20 MWth reactor now called **SEFOR** (Southwest Experimental Fast Oxide Reactor). KfK contributed \$3.5 million to the construction cost; the USAEC financed the subsequent experimental program to the tune of \$12.7 million [38].

Signing the SEFOR agreements
(left to right: J. R. Welsh, SAEA; R. Greifeld and W. Schnurr, both KfK).

Cooperation in SEFOR functioned very smoothly despite the large number of partners, which included the French CEA. From the outset, a large group of Karlsruhe scientists worked on site in the United States of America together with delegates from Interatom, Siemens, and the French CEA, all of whom made committed contributions to the reactor design and to test preparations. The first superprompt critical **transient tests** were carried out in 1971/72, slightly later than originally planned, and confirmed the power-reducing effect of the negative Doppler coefficient. When an excess reactivity of \$1.3 was added deliberately, the power briefly rose to approximately 1000 times its previous level; this power excursion was accommodated within split seconds by the negative action of the Doppler coefficient, thus leaving time for the safety system to shut the plant down.

2.1.3 Fuel Development

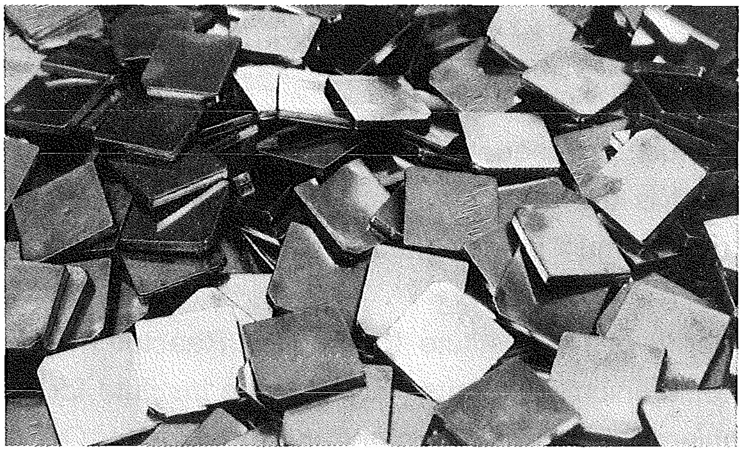
Many documents in those early years contain references to the special importance of the fuel element for the breeder reactor; this is seen most clearly in the Technical Annex to the EURATOM Association Agreement [39]:

> "The design of a prototype with such consequences for the future must be based on the fact that the fuel element is the most important component determining everything else. In a way, the reactor must be designed around the fuel element."

Fuel development was a responsibility of the Institute for Applied Reactor Physics (IAR), the European Institute for Transuranium Elements (TU), and the Institute for Radiochemistry (IRCh). Also the Plutonium Prototype Laboratory and the Reactor Operations Division with the Hot Cells (RB) joined in the effort. The Institute for Materials and Solid-state Research (IMF) was founded under Professor Fritz Thümmler in 1965 and, initially, worked not only on uranium oxide, but also on uranium mononitride and coated nuclear fuel particles as source materials for oxide cermets of high thermal conductivity. The IMF was the first of the up to four subinstitutes to be established in the course of time [40].

One special feature of Project organization at that time was the early inclusion of **NUKEM**, a subsidiary of DEGUSSA. The firm was bound to the Project through development contracts from the outset and for many years, as this was felt to obviate the need for an independent fuel development department at the Center. After 1965, NUKEM had fabricated some 5000 UO_2-pellets and vibration-compacted some 75 kg of fuel into rods under these development contracts. Some of the UO_2 was mixed with cerium oxide, cerium being intended to simulate the plutonium chemically without having its alpha activity. Also the addition of molybdenum was tested, as it was hoped to improve thermal conductivity of the fuel.

In December 1963, **ALKEM** was founded as a joint subsidiary of NUKEM and Dow International (30% interest), a U.S. company experienced in handling plutonium. ALKEM rented premises at the Institute for Hot Chemistry (IHCh) and was awarded the contract for manufacturing the platelets for SNEAK. Fabrication proceeded at such a rapid pace that the Project Leader was able to show the audience at the 1965 Status Report a plutonium-bearing SNEAK platelet. The SNEAK contract for a long time remained the largest production contract in the world for mixed oxide pellets, and had served to demonstrate the skills of ALKEM. ALKEM later also manufactured mixed oxide fuel rods, especially for irradiation within the PSB. In 1971, the company gave up its Karlsruhe facilities and moved to Wolfgang near Hanau in the State of Hesse. This also expressed the need by the NUKEM parent company to concentrate its fuel activities in one place [23, 25].


Sodium-filled steel platelets for SNEAK.

The Institute for Materials and Solid-state Research (IMF) from the beginning recognized the fuel cladding to be a critical component. The desired operating parameters, namely linear rod power (> 300 W/cm), sodium temperature (approx. 550 °C), and burnup (around 100,000 MWd/t), required highly heat-resistant materials. The search was concentrated on iron, nickel, and vanadium alloys. There was also some interest in molybdenum alloys. Early studies were devoted to the creep-rupture strength of 16/13-CrNi and 20/25-CrNi types of steel, and Incoloy 800 and Inconel X in various stages of heat treatment. In the presence of sodium, the time-to-rupture of tubes made of 16/13-CrNi steel was found to be reduced. The strengths of the vanadium alloys developed jointly with the Metallgesellschaft were determined in vacuum test rigs. Also techniques, such as electron beam welding and hot isostatic pressing for the production of cermet fuel rods, were learned at that time [41].

Initially, only the FR 2 thermal reactor of the Center, with a neutron flux of nearly 10^{14} n/cm^{2}s, was available for irradiation of the test fuel rods made by NUKEM, ALKEM, or at the **Prototype Laboratory** under the responsibility of Karl Kummerer. For the spacious central channel of that reactor, the Institute for Reactor Development (IRE) designed the so-called burnup loop, a helium cooled in-pile loop for a maximum specimen power of 30 kW. A short-time in-pile rig supplemented this loop, which was operated successfully for many years.

The so-called **capsule test rigs** were operated on fuel element positions and isotope channel positions in the FR 2. These instrumented capsules contained specimens surrounded by liquid sodium and a lead-bismuth alloy, respectively. Also this design worked well after the operators had learned how to fill the Pb-Bi eutectic into the capsule without leaving any voids.

The lack of a reactor on the premises with a sufficiently high fast flux soon was felt as a disadvantage in materials irradiation. The **Compact Sodium-cooled Nuclear Reactor (KNK)**, in its KNK I version, was not a fast reactor, but a thermal reactor. Thanks to the efforts also of Wirtz and Häfele, it was moved to Karlsruhe from its original planned site at Jülich, but an unmoderated mixed oxide core was not installed until the late seventies. In the meantime, the Fast Breeder Project had to use expensive external irradiation facilities. Also in administrative terms, KNK was not fully integrated into KfK by 1973, but was under the management of the independent GfK Experimental Facilities Division and was operated by KBG, a subsidiary of the Badenwerk AG utility.

To make up for the lack of in-house irradiation capacity, connections were established with the CEN/SCK Mol Research Center, where the **BR 2 reactor** with a maximum fast flux share of $5 \times 10^{14} n/cm^2 s$ had been available since 1968. Contracts were signed, which remained in force until the end of the Project, under which part of the BR 2 irradiation space was reserved to PSB. In the course of the Mol I test series, 16/13, 15/25, and 20/25-CrNi types of steel, various nickel-base alloys (Inconel 600, 625, X 750), and vanadium-base alloys were irradiated. In the subsequent Mol II series, tubes were kept under an internal pressure and exposed to the neutron field at an elevated temperature. One of the most important results elaborated in those years was the confirmation of theoretical concepts of high-temperature embrittlement. According to those findings, this type of radiation-induced damage is due to helium bubbles at the grain boundaries; the helium is produced in (n, α)-reactions.

2.1.4 Reprocessing

The problems of the external nuclear fuel cycle, especially of reprocessing, were addressed vigorously right from the beginning. Initially, the Decontamination Department studied the recovery of uranium from aqueous fission product solutions; subsequently, the responsibility for reprocessing associated with the fast breeder was transferred to the Institute for Hot Chemistry **(IHCh)** [42].

One of the points raised in the reprocessing discussion at that time was the choice between **wet and dry** reprocessing. Some people thought that converting ceramic spent fuel into an aqueous phase was a detour on the road to refabrication. They also were afraid of the high radiation exposure of the organic solvents and the criticality problems associated with the higher plutonium content. In the dry methods, molten salt was subjected to pyrochemical processes. A drawback associated with this procedure was the low decontamination factor, which did not exceed 10^1 - 10^2, while aqueous methods were believed to attain 10^8. The fuel recovered in the dry process could have been used in fast reactors despite its minor fission product contamination; however, refabrication into fuel elements would have had to be handled in hot cells, undoubtedly giving rise to extra cost.

Another dry technique considered at that time was the so-called volatilization process. As the USAEC based its repurchase of spent uranium on the price of uranium hexafluoride, some people thought about reprocessing by fluoride volatilization. Because of the low raw material price of chlorine, also chlorination was discussed, for instance, in Belgium.

The early decision by the Institute for Hot Chemistry (IHCh) in favor of the aqueous **PUREX process** for breeder fuel reprocessing turned out to be wise. Theoretical considerations converged in the decision to build the **MILLI plant**, a laboratory-scale reprocessing plant with a capacity of 1 kg per day. It was planned by a German industrial group, and completed with the committed participation by the Institute for Hot Chemistry and the Technical Department [43].

In 1967-70, also the Karlsruhe Reprocessing Plant **(WAK)** was designed and built by the Uhde-Leybold-Lurgi engineering consortium at a total cost of almost DM 70 million. It was commissioned by the Gesellschaft zur Wiederaufarbeitung von Kernbrennstoffen (GWK). WAK employed the solvent extraction process in combination with the chop-leach method to extract fuel from spent fuel elements. In the early phase of operation, light water reactor fuel elements were to be reprocessed, and subsequently the plant was to be used for the advanced reactors, Kalkar LMFBR and Schmehausen THTR. In actual fact, however, only fuel from light water reactors was reprocessed (approx. 200 tons), until the plant was to be decommissioned in the late eighties [44].

3. INDUSTRY COMES IN (1964 - 66)

The inclusion of EURATOM and of Netherlands and Belgian partners had strengthened the financial base of the Project as well as its further technical course. Although still young, the Karlsruhe Breeder Project increasingly attracted the attention of the international breeder community which, however, was already able to base its work on smaller fast experimental reactors (EBR II in the USA, DFR in the UK, Rapsodie in France, BR-5 and BOR-60 in the USSR). Undoubtedly, relations with the United States of America were most advanced; liaisons with the European partners, France and Britain, were far less developed, though those countries were much closer geographically.

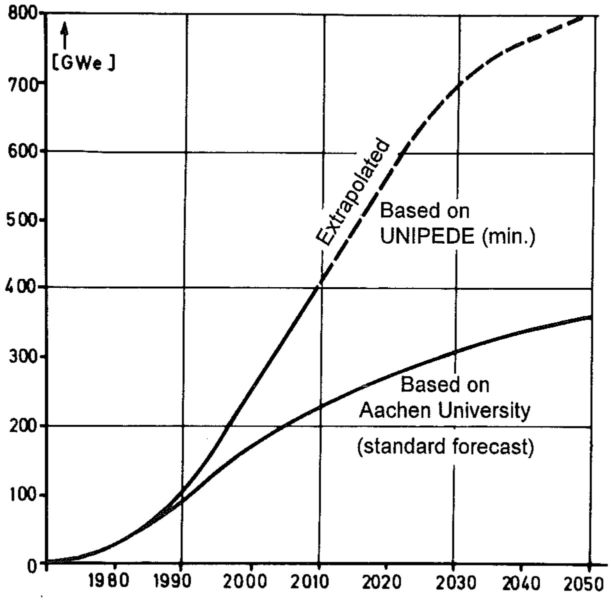
Relations with German industries mainly existed in the form of delivery contracts. This changed in 1964 - 66 as a consequence of some decisive events, which will be outlined below.

3.1 Assessments of the Energy Situation

In the autumn of 1964, a **"Nuclear Power Reserves Study Group"** was established at the Nuclear Research Center, members of which were AEG, BBC-Krupp, GHH, Interatom, NUKEM, RWE, and Siemens as industrial members, the German Federal Ministry for Research, and GKSS Geesthacht, KFA Jülich, and the Aachen Technical University as research institutions. Under the leadership of the Fast Breeder Project, a comprehensive report written about the situation of the power economy and the economic potential of the nuclear power plant lines known at that time, and presented at the 2nd Foratom Congress in Frankfurt in 1965. A EURATOM report published roughly at the same time contained an analysis of the prospects of nuclear power in the European Community and arrived at comparable conclusions [45, 46].

KfK report No. 366, so widely quoted afterwards, also contained **forecasts** of the uranium reserves, the electricity requirement in Germany, the specific electricity generation costs of various types of reactors in the seventies, and the split of the market between light water reactors and breeders by the year 2000.

World uranium reserves in the three price categories of $8, 20, and 30/lb U_3O_8 were estimated at a total of 4.4 million tons of U_3O_8. This was based on the assumption that some 5%, i.e., 0.22 million tons, would be available for Germany [45].



Strategic calculations of the nuclear generating capacity installed in the DeBeNeLux region by 2050.

For the year 2000, the generating capacity installed in the then Federal Republic of Germany was estimated at 230 GWe; the nuclear share was assumed to be around 110 GWe. In a **dual-type strategy** approach, it had been assumed that this requirement would be met exclusively by light water reactors and sodium cooled fast breeders. For the LWR capacity, the maximum of approx. 30 GWe had been calculated for the year 1995; the fast breeder capacity was assumed to rise continuously and reach approx. 80 GWe around the year 2000.

The rapid **penetration of the breeder** into the energy market was attributed to two reasons [36]:

(1) The compact construction of a breeder reactor, due to the absence of the moderator, implies a considerable relative decrease in capital costs for larger plants. Problems arising from the use of fast neutrons do not affect the costs, as they are only "physical" in nature.

(2) As breeder reactors require no enrichment and achieve high burnups, the fuel cycle costs will be lower; they were estimated to be less than Pf 0.4/kWh, including expenditures for the first core.

On the basis of these capital costs and nuclear fuel cycle costs, the specific **electricity generating costs** were calculated as follows for the period 1970 - 85:

Sodium cooled breeder:	Pf 1.62/kWh,
light water reactor:	Pf 1.91/kWh,
gas cooled breeder:	Pf 2.19/kWh.

The KfK 366 study referred to above concludes that the difference in costs between a line consisting only of light water reactors and a combination of LWR/breeder reactors, cumulated up until 1984, already implies cost savings of DM 1 billion. By that time, the total expenditure then estimated for fast breeder development would have been recouped in the economic sense.

The **conclusions** arrived at in the study can be summarized as follows:

> "There are valid reasons to engage in breeder development, if only because of the limited natural fissile material reserves.
>
> Because of the excellent economic potential of the fast breeder, there is every reason to do so quickly." [36].

3.2 The Schedule Becomes Tighter

The favorable assessment of the situation of breeder reactors within the framework of energy policy seemed to agree with the international situation. In 1963, the first successful sale of a light water power plant took place in the United States of America under economic conditions and in competition with fossil fired power plants. This **"Oyster Creek event"** had frequently been regarded as the breakthrough of nuclear power.

But competition seemed to be developing even in the breeder sector. Press releases by **General Electric** in the United States were interpreted in Karlsruhe to indicate an intention of that company to offer fast breeders at economic terms already in the mid-seventies [36, 47, 48].

A memo written for the benefit of the German Federal Ministry for Research reads as follows:

> "... Under these circumstances it is to be expected that Britain, France, and especially the United States will be able to offer large breeder power plants economically around the mid-seventies, and have all the necessary information as a consequence of their prototype experiences. General Electric, as is well known, announced this situation publicly (Nucleonics, November 1964) ... Given the immense speed of development at the present time, it is now imperative to take the step towards prototype construction in Germany quickly ... That there is brisk

> competition already in the development phase is the best proof of this reactor development being promising." [36].

In the light of this presumed **competitive pressure** from the USA, the PSB Project decided in 1965 to start detailed planning and construction of prototypes at an earlier point in time. Originally, i.e. even until 1964, plans had foreseen the decision among sodium, steam, and helium coolants to be taken at the end of extensive development activities, and the start of construction of one prototype approximately around 1973. In addition, it had been felt necessary to work with a fully tested fuel element. According to estimates in 1965, sodium and steam as coolants seemed to enjoy equal development potentials, and as no decision was possible at that time it was decided to design **two prototypes** in a parallel effort, each with 300 MWe power, namely a steam cooled and a sodium cooled fast breeder. For the fuel element, only a minimum of advance testing was to be required, while the actual statistical fuel element tests were to be moved forward into the prototype reactor phase proper.

Now the timetable for the sodium cooled prototype was as follows:

Detailed planning and licensing:	1965-68.
Construction:	1969-71.
Trial operation:	from 1972.

The steam cooled prototype was to be built in the same steps, only one year later. For the 1000 MWe demonstration power plants, 1973 was envisaged as the start of planning activities, 1977 for the start of construction. By the start of operation of the first prototype, the SCHARADE (fast chemical processing and refabrication plant) reprocessing plant was to be built with a capacity matching these requirements in order for breeders to be operated in a closed cycle right away [23, 36].

Designing and building two 300 MWe prototype power plants would have exceeded the possibilities available at the Nuclear Research Center by far. For this reason, it was planned from the beginning to integrate German industry at this project stage. In November 1966, **two industrial consortia** were established: the AEG/GHH/MAN group of industries was commissioned by the then Federal Ministry for Scientific Research to draft the construction documents for the steam cooled breeder line, while the Siemens/Interatom group was to design the sodium cooled breeder. The activities by both industrial groups were to result in the presentation, by 1969/70, of documents allowing the contracts for the two prototypes to be awarded. The companies were chosen on the basis of past experience in the field: AEG was involved in building the Superheated Steam Reactor (HDR) and had already delivered the VAK light water nuclear power plant, while Interatom was commissioned to build the KNK reactor and even at that time had an extensive background of experimental experience in the sodium field, e.g. with the 5 MW facility [37, 49, 50].

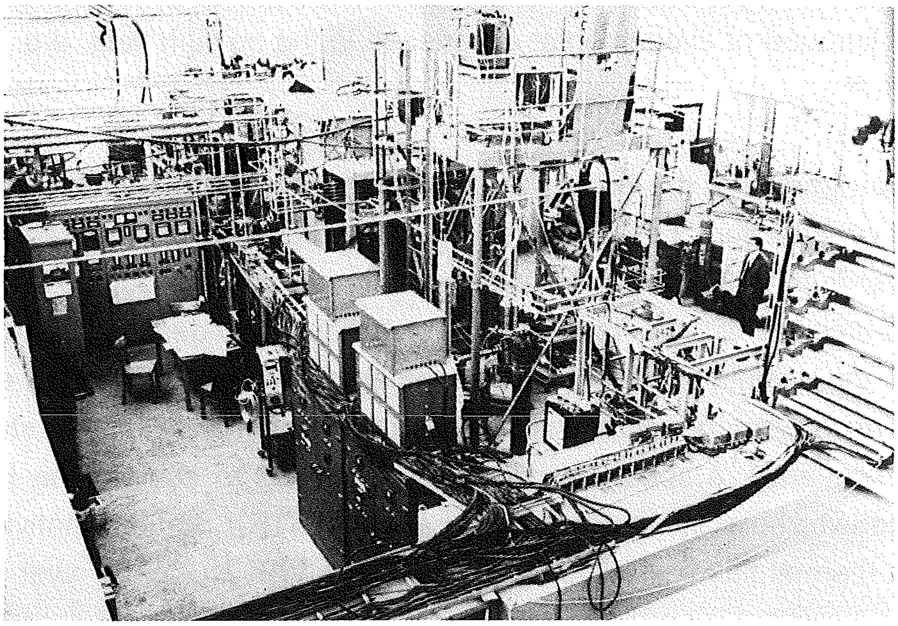
The **appropriation conditions** of the Federal Ministry for Scientific Research had required, *inter alia*, that construction of the sodium breeder be preceded by the irradiation with fast neutrons in sodium of 30 mixed oxide fuel rods to a burnup of 50,000 MWd/t. For the steam cooled breeder, 500 fuel rods were to be irradiated under representative conditions. While, for the sodium cooled breeder, irradiation facilities seemed to exist abroad, e.g. in the Enrico Fermi reactor, there was no such possibility for the steam cooled breeder. Consequently, a special program was planned to convert the HDR thermal reactor in Großwelzheim into a fast-thermal reactor (STR). Some tentative inpile experiments in a thermal flux field were to be run in the VAK Nuclear Power Station.

This deliberate inclusion of industry marked an important turning point in the administrative execution of the Fast Breeder Project. As important responsibilities were being shifted from Karlsruhe to the partners in industry, this entailed a certain amount of friction. Where PSB Karlsruhe could refer to its knowledge of basic breeder principles and its reactor studies, the industrial side was probably more experienced in plant engineering.

3.2.1 Reactor Design Studies

The reactor designs and test loops were the technical counterparts of the physical experimental setups and the fundamental studies mentioned above. Planning studies of breeder power plants cooled with helium, sodium, and steam were completed one by one, and served for studies of the technical plant concepts, safety problems, and capital costs as well as fuel cycle costs.

The first reactor design completed at Karlsruhe was for a 150 MW nuclear power plant **cooled by helium**. Advantages of helium were considered to be the simpler technology of the cooling circuits, the lower void coefficient, the higher breeding gain, and the chemical neutrality and lower susceptibility to activation of the helium coolant. However, when the helium reactor design was investigated in more detail, soon the disadvantages of the coolant appeared as well. The high gas pressure, the large heat exchangers, the high pump capacity, the bulky pressure vessel, the uncertainties of emergency core cooling, and the lack of suitable cladding materials implied severe technical problems which, ultimately, would have led to negative economic consequences as well. In 1963, a report about Karlsruhe activities in the field of helium cooling was presented at the Argonne conference, but afterwards this cooling variant had practically ceased to exist, and a decision was then sought only between sodium and steam. On the other hand, the helium cooling concept experienced a comeback in the late sixties/early seventies, when technical developments had overcome many of the drawbacks mentioned above, and a large American company came on the scene [51].

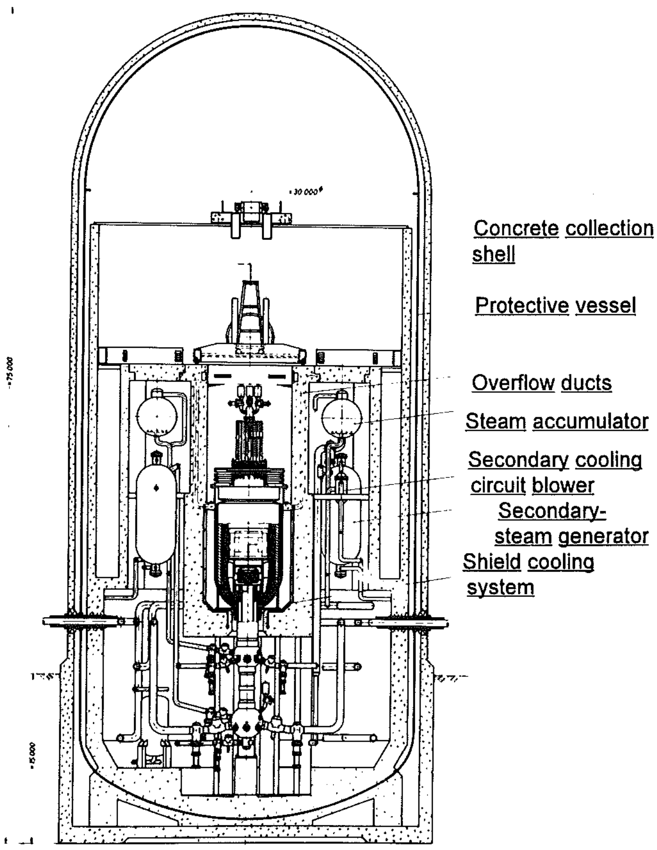


Helium-cooled irradiation loop for fuel elements.

The first consistent German reactor design of a sodium cooled breeder was the so-called **Na-1 Study**. It had been produced under the responsibility of the Technical Department of KfK, later converted into the Institute for Reactor Development (IRE). The reactor had a power of 1000 MWe, a steam temperature at the turbine inlet of 540 °C, and an efficiency of 40%. The reactor core, with a height-diameter ratio of 1:3, was moderately flat and reflected the outcome of a carefully balanced compromise between the highest possible Doppler coefficient, the lowest possible void coefficient, and the highest possible internal breeding ratio. In the design of the primary system, the expected safety of the pool design was to be combined with the economic advantages, also presumed, of the loop design. In this way, the entire primary system was accommodated in a cylindrical containment only 28 m in diameter. The top section of the reactor containment was to be designed as a hot cell allowing the tops of the fuel elements to be grabbed by manipulators under direct viewing conditions for loading and unloading. The costs were estimated together with numerous industries; capital costs were to be DM 440/kW, fuel cycle costs, Pf 0.33/kWh [52].

One major finding in the subsequent engineered safeguards analysis indicated that also in sodium cooled fast breeders a conventional safety system of the kind known from light water reactors was sufficient for control and shutdown.

After the Sodium Study, IRE compiled the so-called **D-1 Study**, the design draft of a 1000 MWe steam cooled breeder. It was based on many findings elaborated at IRE and IRB. At those Institutes, it was felt that the steam breeder could well outperform the boiling water reactor in economic terms, as steam, being a single-phase coolant, allowed the move towards the higher pressures and temperatures of conventional fossil fired power plants [53].



Schematic diagram of the steam cooled fast breeder.

As the coolant in a steam cooled breeder had to evaporate outside the reactor core, various flowsheets were examined for feasibility, reliability, efficiency, etc. Finally, the so-called **Löffler circuit** was chosen, and a prototype was set up at the IRB. The main criterion of this circuit is the physical separation of evaporation from superheating it allows, although both processes are due to the nuclear heat of the reactor core. In the Löffler circuit, the reactor core acts as a superheater of the saturated steam generated in the evaporator and recirculated by a steam compressor. The superheated steam leaving the reactor is split into two partial streams. The smaller partial stream, approximately 40% of the total volume of superheated steam, flows straight to the turbine; the other, larger, partial stream is passed to the evaporator where its heat is used to evaporate the feedwater. The saturated steam generated is passed back to the reactor by the steam compressor. The Löffler circuit was attributed certain advantages in technical safety, also because the evaporator automatically acts as a heat sink and source, respectively, in pressure fluctuations [30].

The D-1 Study completed in early 1966 was based on the Löffler circuit. The pressure in the plant was 160 bar. Inconel 625 was to be used as a cladding material for the fuel subassemblies.

The D-1 Study was received with much attention in the United States of America and compared with two other studies of steam cooled breeders by Babcock and Wilcox within the Alternate Coolant Task Force. The B & W plants also were to be operated in a direct circuit, but were designed for low pressures (88 bar) and supercritical steam pressures, respectively [54].

In a **comparison** of the two studies, Na-1 and D-1, the following situation was described by the PSB Project Management in 1966:

> "Sodium cooled fast breeder reactors have a slightly higher breeding ratio and, hence, a more advantageous fuel cycle. They are more economic in the baseload regime of very large units (>1000 MWe).
>
> Steam cooled fast breeders are characterized by lower capital costs in the medium-power range (approx. 1000 MWe), which offset the slightly higher fuel costs. Especially outside full-load operation, they may be superior to sodium cooled breeders in this unit size category.
>
> Consequently, both systems are complementary in a sense. For this reason, both the sodium and the steam cooled breeder versions will be developed further." [10].

4. THE STEAM COOLED BREEDER PROJECT IS DISCONTINUED (1966 - 69)

4.1 Decisionmaking

This prediction did not come true, however; on the contrary, work on the steam cooled breeder began to slow down and soon had to be abandoned entirely.

The decision to **discontinue the Steam Cooled Breeder Project** had become apparent already in 1966 and was accompanied by a violent, even emotional, debate until 1971. The most important stages in this decisionmaking process will be outlined below:

(1) In late 1967, AEG found that the HDR could not be turned into a fast-thermal reactor (STR) because the Doppler coefficient was not negative enough.

(2) In March 1968, Project Leader Häfele indicated at the Status Report for 1967 that parallel development of the steam and sodium lines might have to be given up.

(3) In April 1968, at the 6th meeting of the Fast Breeder Project Committee, AEG themselves proposed to discontinue design work on the steam cooled breeder.

(4) In December 1968, Working Party III/1, "Nuclear Reactors," unanimously arrived at the same finding.

(5) In January 1969, the same result was proclaimed by the Breeder A Committee at Karlsruhe.

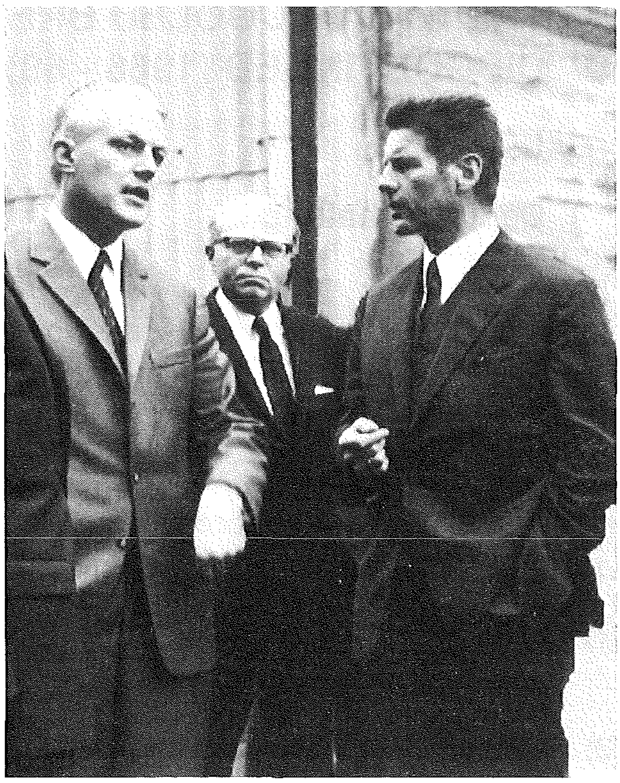
(6) At a hearing of the experts pro and con on January 23 and 24, 1969, which had been organized by Federal Minister for Scientific Research **Dr. G. Stoltenberg** together with members of the Parliamentary Committee for Scientific Research, the decision was prepared on technical grounds.

On February 5, 1969, Dr. Stoltenberg, announced that the Steam Cooled Breeder Project would be phased out. His press release ran as follows:

"(1) The development of the steam cooled fast breeder as an independent subproject within the Fast Breeder Project will be discontinued.

(2) Industrial activities within this subproject must be brought to a meaningful conclusion such that a comprehensive final report can be produced. This should be compiled so that it could serve as a basis on which work could be resumed, if required.

(3) Specific projects within the Basic Program of the Fast Breeder Project at the Karlsruhe Nuclear Research Center will be continued, especially fuel pin development."



Discussing the breeder reactor
(left to right: Federal Minister for Research Stoltenberg, G. Schuster, BMwF; R. Harde, Interatom).

This **decision** was explained in an annex:

"The German Steam Cooled Breeder Program had to be reexamined thoroughly because of technical difficulties encountered with respect both to the basic objectives and to the timetable.

In the light of the new international situation, a development of a steam cooled fast breeder in the Federal Republic of Germany would have to be carried out in isolation and without the backing by findings elaborated in parallel developments abroad.

As things now stand, the concept of the steam cooled fast breeder reactor promises no advantage over that of the sodium cooled fast breeder reactor with oxide fuel elements; on a long-term basis, the steam cooled fast breeder does not seem to offer any potential for further development corresponding to that of the sodium cooled fast breeder in the switch to carbide fuel.

> The date of commercialization of steam cooled breeder power plants will be delayed over previous assumptions, thus adding to the risk associated with the market introduction of this type of nuclear power plant." [55].

A decision had been taken, but it had done nothing to stop the discussion. Following an initiative by Federal Minister for Research Leussink, Dr. Stoltenberg's successor, a **public hearing** on the grounds underlying that decision was held within the framework of the 1970 Status Report at Karlsruhe on February 15, 1971 [56].

R&D work on the steam cooled breeder was not discontinued for good until 1974. This phase-out program, which caused expenses totaling approx. DM 5 million per annum, concentrated on the following items: experiments on steam contamination in the primary system conducted in the FR 2 superheated steam loop; out-of-pile corrosion tests in the HKW loop; DRF trefoil irradiation experiments (discontinued after a defect); preparations for the irradiation in VAK of four fuel rods with a pressure equalization system (not carried out).

The discussion about the Steam Cooled Breeder Project caused considerable **polarization** at the Nuclear Research Center. The arguments of the antagonists, Project Leader Professor Häfele and IRB Institute Director Ritz, for a long time sounded like opposed, even hostile, points of view and greatly damaged the public reputation of the Center. Perhaps we should briefly go through those points of view and also list the most important arguments raised by the industrial partner, AEG, and by K. Rudzinski, a journalist and committed critic of the Sodium Cooled Breeder Project.

4.1.1 The Arguments of the PSB Project Management

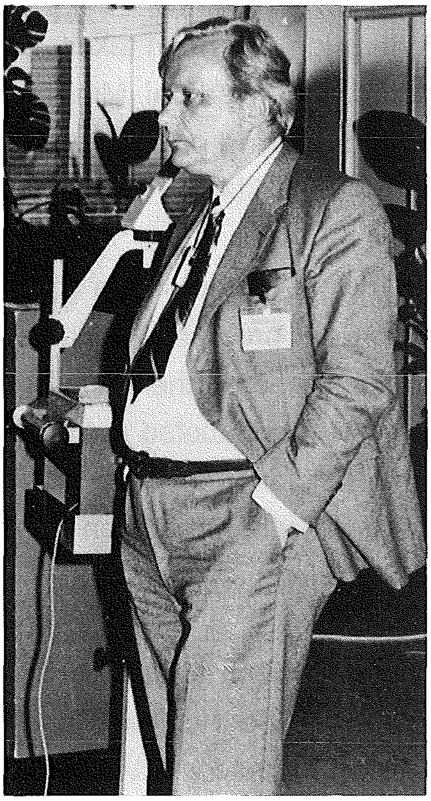
Project Leader **Professor Häfele** was in favor of discontinuing the Steam Cooled Breeder Project, thus articulating the official opinion also supported by a majority at the Nuclear Research Center. These were his main reasons:

(1) The Pu-α event has had a much more negative impact on the predicted breeding capabilities of the steam cooled breeder than on those of the sodium cooled breeder; α is the ratio between the (n, γ)-capture cross section and the fission cross section. At the IAEA Conference about the Physics of Fast Reactors held in Karlsruhe in October 1967 it became known that the KAPL data for Pu were too low for the resonance range of 10 - 20,000 eV. Higher α-val-

ues mean a lower breeding capacity, which affects especially the steam cooled breeder, because of its softer spectrum and as its breeding ratio anyway is lower than that of the sodium cooled breeder.

The reduction in the breeding ratio by 4 points, together with the concept, pursued up to that point, of a strong, freestanding cladding tube made of Inconel 625, would have left almost no breeding capacity for the steam cooled breeder. This would have required a switch to a concept of a weak cladding material, primarily Incoloy 800, partly supported by the fuel ("toothpaste tube concept").

(2) Given the impossibility to convert the HDR, a separate test reactor would have had to be built for fuel element irradiation. The associated expenses would have been DM 200 million over a period of six years. Construction of the steam cooled prototype would have been delayed by the same length of time although, according to earlier concepts, it had been planned for construction at the same time as the sodium cooled breeder.



Project Leader W. Häfele,
advocate of the sodium cooled breeder.

(3) In-pile experiments in the EBR II run by General Electric in the United States of America had indicated that nickel-bearing fuel rods experienced unexpectedly high defect rates in a fast neutron flux. On the other hand, the German-American EVESR Program found that it was precisely the nickel component which made the cladding material stable under superheated-steam corrosion conditions. The question of a cladding material suitable for a steam cooled breeder thus was wide open again.

(4) The fuel rod cladding tubes in a steam cooled breeder are subjected to a high external pressure accompanied by high temperatures in the early stages of irradiation. This load may cause "buckling" produced by the omnipresent initial "ovalities," i.e. deviations from the ideal round shape. Experiments indicated that, under the systems steam pressures of 120 - 170 bar under discussion,

maximum cladding tube temperatures of 700 - 735 °C and cladding tube wall thicknesses of less than 0.4 mm, the required times-to-rupture would not be reached.

(5) As far as safety is concerned, emergency core cooling of the steam cooled breeder reactor is problematic. While a sodium cooled breeder has a practically non-pressurized coolant of high thermal conductivity, steam cooled breeders, in all probability, would require many active measures to be taken, such as water sprayed into a superheated core. In addition, there is the drainage accident, which can occur only in a steam cooled breeder. Consequently, the licensing procedure of the steam cooled breeder reactor is burdened with major problems, some of which have not even been fully recognized.

(6) In the early summer of 1968, General Electric in the United States announced that, because of many technical problems and, above all, lack of support by the U.S. Atomic Energy Commission, they no longer intended to work on the steam cooled breeder line. As a consequence, the German Steam Cooled Breeder Project would have had to bear the entire development risk all alone.

(7) On an international level, the development of the sodium cooled breeder line has reached the most advanced stage. In addition to Germany, the USSR, USA, UK, France, Japan, and Italy pursue this line. Agreements securing exchanges of experience thus can help to back the basis of in-house development.

(8) The sodium cooled breeder reactor operated on oxide fuel can be improved by the use of carbide fuel in a further step. This applies especially to the increase in the breeding ratio, while simultaneously reducing the fuel inventory[47, 57, 58, 59, 60, 61, 62].

4.1.2 The Arguments Used by AEG

AEG, the leading industrial partner in the Steam Cooled Breeder Project, was in favor of terminating activities. **Dr. Kornbichler**, responsible AEG Project Manager, cited these reasons, among others:

(1) A factor of overriding and, finally, decisive importance, in the opinion of AEG, is the fact that General Electric in the United States had given up the ESCR (Experimental Steam Cooled Reactor) Project and, consequently, steam

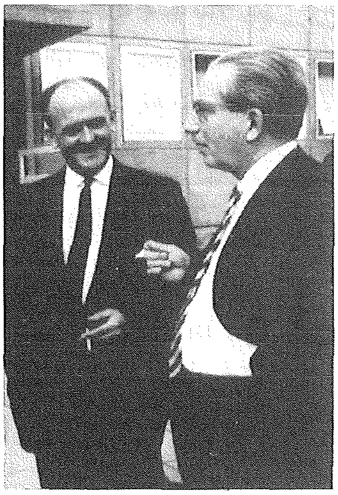
cooled breeder development altogether. As also Sweden, Italy and Japan wanted to discontinue their efforts in this field, Germany would be isolated. Without international exchanges of information, experience would grow more slowly, and the risk of setbacks would increase. On top of that, it would be the first time that Germany would have to carry a reactor line through to success all on its own. When the high temperature, heavy water, and light water reactor lines were developed, considerable external know-how was added, without which the effort sometimes would have been hard to sustain.

(2) Assessing the future market and, in particular, the commercial prospects of steam cooled breeders is a venture replete with considerable risks. Industry, however, must seek not only technical, but also commercial success. When competitors, such as General Electric, abandon a development line, surely after having pondered that decision for a long time, this means that also AEG should proceed very cautiously.

(3) An important, though negative, technical event is the failed attempt to convert the HDR reactor into a fast-thermal reactor (STR). After approximately one year of activities it was seen that the small core planned would not have a sufficiently negative Doppler coefficient; other measures envisaged to achieve quasi-inherent safety were not deemed to be reliable enough. The alternative concept of a large, all fast reactor core failed, especially for cost reasons. Now that STR is not available, no representative irradiation test of steam cooled breeder elements would be possible [56, 63].

4.1.3 The Arguments Voiced by L. Ritz

Ludolf Ritz, an engineer by profession, had been Head of the Institute for Reactor Components (IRB) since 1961 and had been closely associated with the Steam Cooled Breeder Project. Before joining KfK, Ritz had been Chief Engineer with Parsons in Newcastle, where he had contributed to the British Atomic Energy Program, also by studies of steam cooling systems. After he had joined Karlsruhe, incidentally on a recommendation by Otto Hahn, he resumed his earlier activities with the full approval of Project Management.



L. Ritz, advocate of the steam cooled breeder, discussing with W. Schnurr.

However, his work was not confined to those studies, for his Institute also investigated sodium components in liquid metal loops.

Ritz was in favor of continuing the Steam Cooled Breeder Project, and he expressed the opinion of a non-negligibly small minority at the Nuclear Research Center:

(1) As far as plant design is concerned, the steam cooled breeder reactor is most closely related to the light water reactor. As the LWR line has proved to work satisfactorily so far, this would constitute an important argument in favor of continuing this development line. It would also agree with the conservative inclinations of manufacturers and operators of steam power plants, who will be skeptical in accepting revolutionary innovations, such as the introduction of coolant metals. On top of that, they can always refer to costly experiences associated with former technical modifications.

(2) The sodium cooled breeder is a revolutionary innovation, with respect to both its coolant and its components. In addition, it suffers from an inherent cost disadvantage, as its technical design is much more complicated than that of a steam cooled breeder. Achieving industrial maturity and economic competitiveness of the sodium cooled breeder line will take another ten or fifteen years and require very high development expenses.

(3) In the autumn of 1968, the European Nuclear Energy Agency (ENEA), an independent organization, published the draft of a comprehensive Steam Cooled Breeder Report, which contains this positive assessment [64]:

> "From this evidence we have concluded that there should be no major feasibility problems and that, although substantial proving is required in certain areas, in particular the fuel element, the reactor can be constructed essentially on the basis of existing technology."

(4) The creep buckling problem can be counteracted effectively by a pressure equalization system for fuel rods developed at the IRB. In this design, the usual gas plenum is replaced by a compartment filled with water and steam, respectively, kept at temperature by the saturated steam entering the reactor. Water and steam, respectively, is separated from the helium fission product gas mix by a lead seal which is liquid at operating temperature. The pressure

equalization system allows the use of thinner fuel element claddings which, in turn, benefits the breeding ratio [62, 65, 66].

Irrespective of this clear opinion about the steam cooled breeder line, Ritz and his Institute continued to participate in the Breeder Project now that the decision in favor of sodium had been taken. In a reorientation phase, a sodium laboratory was built to work on materials studies and heat transfer problems.

Ludolf Ritz died in Karlsruhe in June 1991 at the age of 82.

4.1.4 The Arguments Brought forth by K. Rudzinski, Journalist

Kurt Rudzinski, journalist, after unfinished studies of chemistry, Science Editor of the "Frankfurter Allgemeine Zeitung" (FAZ), followed the breeder activities at the Nuclear Research Center with critical interest. Around 1965 he came to the conclusion that the development of the sodium cooled breeder line was absolutely wrong, and expressed his conviction in many articles in his paper. His criticism became even more vociferous when the discontinuation of the steam cooled breeder line was rumored and then came true. Rudzinski argued his point vehemently and with a surprising knowledge of detail. His Wednesday columns were famous and feared, also because of the headlines, which contrasted markedly with the rather self-effacing style of his paper. Here is a selection:

K. Rudzinski, critic of the sodium cooled breeder, talking to W. M. Lehmann, KfK.

"Is Karlsruhe Gambling away a Chance in Nuclear Technology?" (May 1, 1965).

"Steam Cooling Gaining Ground." (January 26, 1966).

"The Sodium Cooled Breeder - Billions Spent on Misdirected Investments." (July 20, 1966).

"Billions down the Drain." (October 26, 1968).

"Steam Breeder Fuel Elements - no Risk." (December 18, 1968).
"Reactor Theology and Reactor Reality." (January 27, 1969).
"Wrong Forecasts in the Fast Breeder Project." (April 8, 1970).
"The End of Sodium Breeder Illusions." (May 6, 1970).

Rudzinski was also famous for timing his articles. Many of them appeared shortly before status reports or reactor conferences, influencing the opinions of experts and politicians by first-hand information indicative of a considerable amount of inside knowledge. Moreover, they caused MPs to inquire, during question time of the German Federal Parliament, about specific decisions taken within the Project, or about events at the Nuclear Research Center. Finally, other media picked up his arguments or wrote about the author:

"Secret Slaughter." (Der Spiegel, December 2, 1968).
"Grumbling and Cheating." (Der Spiegel, June 2, 1969).
"FAZ Journalist Fighting the Establishment." (Capital, 2/69).

K. Rudzinski was firmly convinced of the technical and economic advantages of steam technology as compared to sodium technology, and untiringly explained them to his readers again and again on the basis of many examples. In detail, his arguments went along the lines of what was written above. However, one should not forget that this exchange took place as early as in the mid-sixties, when the arguments against nuclear technology or breeder reactors were not as familiar, even hackneyed, as in the following decade.

At the Nuclear Research Center, it was regretted that Rudzinski only rarely verified the information he had received from unofficial sources by talking to those responsible for decisionmaking. It was also felt that the Karlsruhe Fast Breeder Project, compared to other research organizations, was one of his pet objects of criticism. The consistently negative approach to the sodium cooled breeder and to PSB research activities did lend to these FAZ articles a unique flavor, but the frequent repetitions smacked of a loss of proportion. Many staff members at the Nuclear Research Center also regretted that the two main combatants, Häfele and Rudzinski, did not seem to find - or seek - an opportunity to meet for personal discussions and, perhaps, reconcile these differences of opinion which, in their early phase, were still purely theoretical.

It is little known that Rudzinski was interested in a great many things other than technology. Thus, he was an enthusiastic collector of coins, taught himself the difficult art of coin photography, participated in several excavations as an archaeologist, and wrote renowned articles about Greek vase painting.

In any case, the critic signing K. R. has become one of the inseparable parts of the history of the Fast Breeder Project.

Kurt Rudzinski died in Frankfurt in February 1992 at the age of 80.

5. THE BEGINNINGS OF THE KALKAR NUCLEAR POWER STATION (1969 - 73)

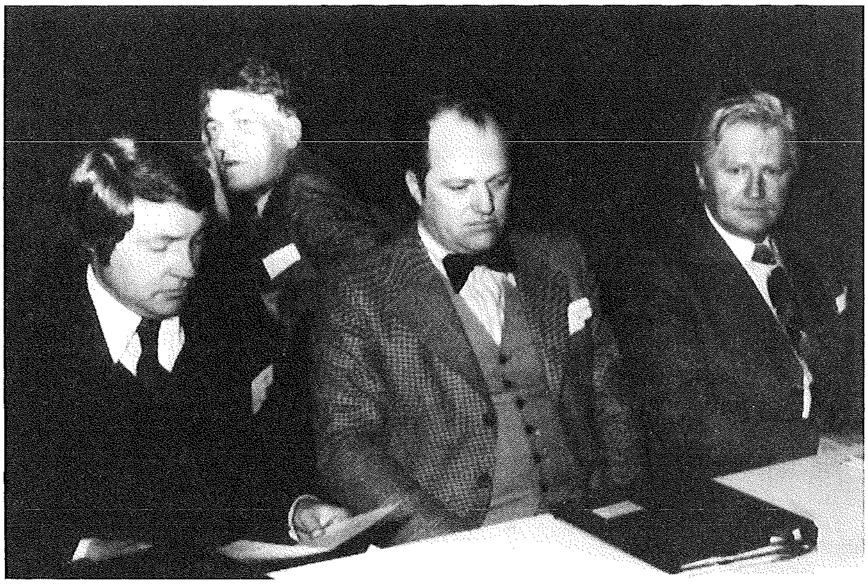
5.1 The Contracting Parties Are Established

After 1966, there was a clear **division** in the administrative setup of the Breeder Project. The industrial partners assumed more and more responsibilities for the detailed design of the SNR 300 Project based on the Na-2 Study. The Centers, especially the Karlsruhe Nuclear Research Center, kept fundamental research and, in some instances, also research and development for the SNR 300 accompanying the construction phase.

The important function of assembling all partners of the SNR 300 Project around one table was taken over after 1966 by the **"Fast Breeder Project Committee."** That body was composed of representatives of the governments, the manufacturing industries, the utilities, and the research centers under the chairmanship of the German Federal Ministry for Scientific Research, and met approximately twice or three times a year to take the decisions necessary for the SNR 300 Project to be continued. After the SNR 300 delivery contracts had been concluded, the Project Committee ceased to meet, but was reinstituted in 1977 and continued to exist until the early eighties.

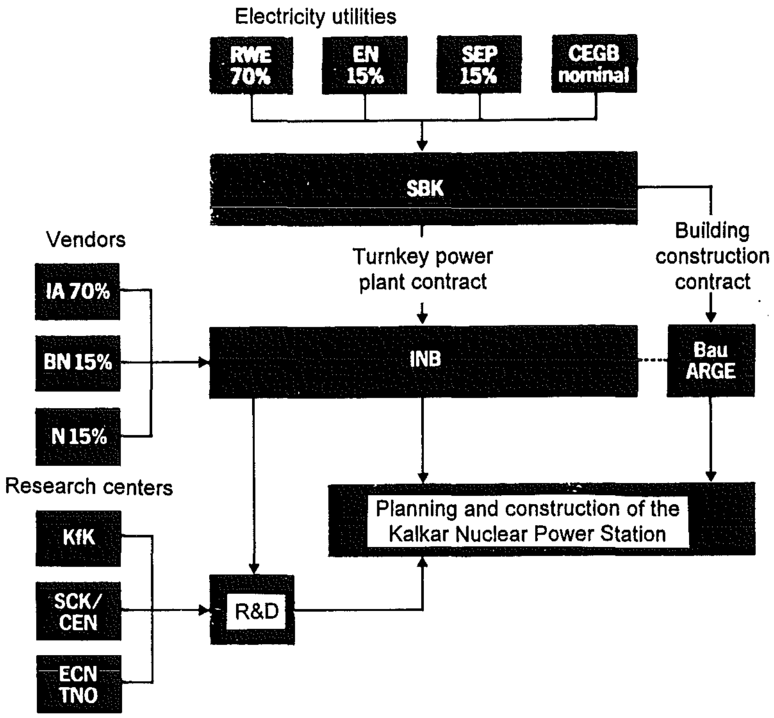
The Vendors' and Operators' Consortia for the SNR 300, i.e. the later contracting parties, were organized step by step over several years; this development will be summarized below [67, 68].

The **Vendors' Consortium** for the SNR 300 was established along the lines of German-Belgian-Netherlands cooperation among the research centers, which had been in existence since 1965. That cooperation had been regarded as most satisfactory by all partners. Consequently, memoranda were exchanged at government level in 1967 on extending cooperation to the construction of the SNR 300. The government agreement already determined the way in which the Project was to be financed, and subsequent shares in deliveries were to be defined, in a ratio of 70:15:15. One year later, Siemens and Interatom (Federal Republic of Germany), Belgonucléaire (Belgium), and Neratoom (Netherlands) signed an Agreement on Cooperation in Development and Construction of the SNR 300 based on these memoranda. In 1972, when the SNR 300 delivery contracts were signed, this so-called SNR Consortium was renamed "Internationale Natrium-Brutreaktor-Baugesellschaft mbH" **(INB)**. Its members were Interatom, Belgonucléaire, and Neratoom. The Luxatom company from Luxemburg for some time held a 1% share in the SNR Consortium, but withdrew in 1972, before the contracts were signed.



Advocates of the sodium cooled breeder project
(left to right: A. W. Eitz, SBK; D. Smidt, KfK; W.-J. Schmidt-Küster and
U. Däunert, Federal Ministry for Research, Bonn).

Between 1969 and 1974, a number of changes occurred in the German partners, **Siemens** and **Interatom**. In 1969, Siemens acquired a 60% interest in Interatom, while North American Aviation opted out, and the interests held by the other members were decreased. At the same time, Siemens terminated its breeder development activities and moved the staff, i.e. those who wanted to be moved, from Erlangen to Bensberg. Later on, also the remaining partners in Interatom, namely Demag (1971) and Deutsche Babcock and Wilcox (1972), withdrew, leaving Siemens the sole owner of Interatom. These shares were transferred to Kraftwerk Union in 1974, when the nuclear divisions of Siemens and AEG had been included.



The organization of the Kalkar Nuclear Power Station.

The **Consortium of Buyers and Operators** of the SNR 300 was set up by German, Belgian, and Netherlands electricity utilities. Karlsruhe initially had suggested to plan and build the SNR 300 together with the manufacturing industries and deliver it to one operator after completion. However, the German Federal Ministry for Research had not accepted that proposal, wanting to include the operator in the responsibility for the Project as early as possible [36, 68].

As a consequence, the "Projektgesellschaft Schneller Brüter" **(PSB)** was founded in 1969 as a company under private law, with the leading members being **RWE** as a German utility and Synatom (Belgium) and SEP (Netherlands) as the two foreign partners. The name of the company, PSB, was frowned upon at Karlsruhe as it was likely to be mixed up with the same abbreviation (in German) for the established Fast Breeder Project of the Nuclear Research Center. PSB (Essen) was to prepare construction of the SNR 300 on the part of the subsequent buyers, i.e. to settle especially matters of financing, contracts, and licensing. In 1972, the company gave way to the "Schnellbrüter-Kernkraftwerksgesellschaft mbH" (SBK), which officially commissioned INB to deliver the SNR 300. This took care of the problems with the abbreviation PSB. In 1973, the

British Central Electricity Generating Board (CEGB) joined the Buyers' Consortium with a share of 1.65%.

5.2 From the Basic Design Studies to the SNR 300

The **SNR 300 design** was based on the so-called Na-2 Study, which had been elaborated under the leadership of the Nuclear Research Center and with the cooperation of Siemens and Interatom between 1965 and 1967. This constituted the first German design concept of a 300 MWe sodium cooled breeder. Compared to the earlier **Na-1 Study** of a 1000 MWe breeder, the coaxial design of the primary system was abandoned in favor of a conventional three-loop system. As later in the SNR 300, the reactor core was designed as a dual-zone core; concepts, such as "pancake cores," "modular cores," and "spectrum softening cores," were already being considered for safety reasons, but finally not felt to be necessary. Should all three main circuits fail, the decay heat was to be transferred to the NaK coolers and air coolers by natural convection. The reference is cited here as a particularly striking example of the "multi-people papers" very much *en vogue* in the late sixties [69].

In the **safety analysis** forming part of the Na-2 Study, core meltdown was considered a very unlikely accident. As a worst-case estimate, even at that time mechanical energy releases were calculated for hypothetical Bethe-Tait accidents. Because of the very different geometries, physical assumptions, and methods of computation, these figures cannot be compared directly with the 370 MWs later not to be exceeded for the SNR 300 [70].

The containment as the most important protective device against releases of radioactive materials in accidents was the subject of particularly detailed consideration. The bone dose was found to be the most important effect of radiation exposure and, consequently, plutonium, not iodine, was seen to be the limiting element. Under these circumstances, a double containment with exhaust air handling of the annulus was considered to be necessary [71].

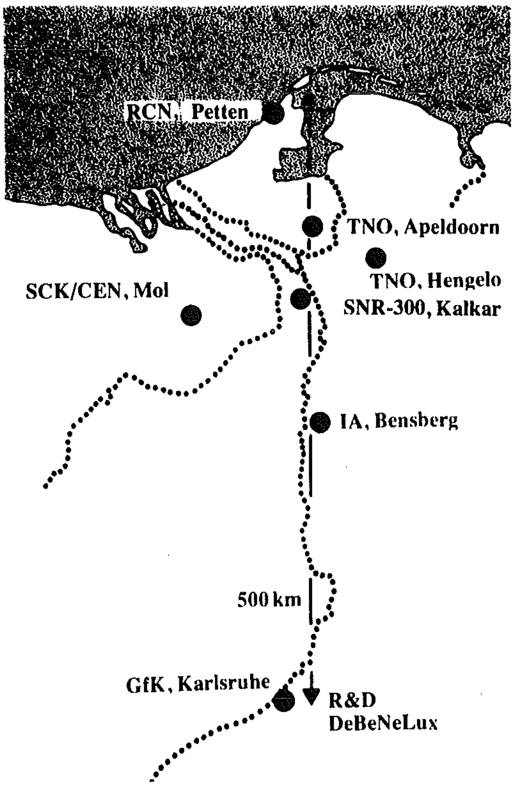
The **SNR 300 Safety Report** was drafted by the SNR Consortium as the responsible body and submitted on December 31, 1969. It consisted of two volumes of text and one volume of diagrams and pictures, and constituted the first consistent draft of the SNR 300. The plant had been designed to a power of 300 MWe, but was to allow an extrapolation to 1000 MWe with little risk to most of the components. For the heat transfer system, the loop concept was selected "because of the greater ease of construction and extrapolation, and also because of the higher development potential with a view to the possible elimination of the sodium intermediate circuit." The components located below the emergency sodium level were arranged in concrete troughs for protection against loss of coolant. No separate emergency cooling circuits were envisaged. In the field of safety, gaps were found to exist still in the phenomenon of fuel-sodium interaction and the propagation of accompanying pressure effects. The direct consequences of a superprompt critical energy release were felt to be concentrated on the reactor cell [72].

The detailed technical plans for the SNR 300 as submitted in the Safety Report in 1969 were changed decisively in subsequent negotiations with the licensing authorities and the operator. As a consequence, much of the planning had to be revised, causing considerable delays in time and extra cost [73, 74, 75, 76, 77, 78].

5.2.1 Requirements by the Licensing Authority

The electricity utilities had planned **Weisweiler** in the three-country region around Aachen as the **site** for the SNR 300, because several (lignite fired) generating units were already operated in that part of Germany by RWE, and the necessary infrastructure existed. However, when compared with the site criteria redefined by the Advisory Committee on Reactor Safeguards **(RSK)** in summer 1970, the population density around Weisweiler was found to be too high. The RSK recommended to find a site with a population of less than 40,000 within a radius of 5 km. The Projektgesellschaft Schneller Brüter relatively soon found a suitable reactor site at **Kalkar** near Kleve on the Lower Rhine River; the new site also had the advantage of being very close to the Netherlands partner ("can be reached by bike"). It is characteristic of the situation at that time that the Ministry for Research (now called BMBW, i.e. Federal Ministry for Education and Science) received a number of letters in which those responsible for local governments and districts asked to be allowed to site the SNR 300 on their territories [79].

The severest technical criterion imposed by the expert consultants was the need to take into account the Bethe-Tait accident. The vessel and the primary system were to be designed so as to withstand mechanical loads of 150 and 370 MWs, respectively. In addition, in case both reactor vessels were to fail, a **bottom cooling system** ("core catcher") was to be provided for, which would be able to accommodate the molten core and cool it permanently. This criterion, which clearly exceeded the international state of the art at that time, later turned out to be the main reason for the considerable extra work required for the Kalkar Nuclear Power Station.



The geographic locations of the key organizations involved in the SNR 300.

The design basis accident for a leak in the primary system was the prompt break of the main coolant pipe. Under this condition, a minimum coolant level was to be ensured in the reactor vessel, which was to be achieved by the so-called trough concept in which as many parts of the primary system as possible were to be arranged in collection troughs and above the equilibrium level.

The other requirements imposed by the authorities and expert consultants implied immersion coolers, gas bubble separators, an in-vessel sodium inlet line, and an aerosol recirculation system, which meant an almost complete redesign of the SNR 300 primary system.

Moreover, as the licensing procedure went on, higher load assumptions had to be made to take into account **external impacts**: The outer containment was to withstand the impact of a high-speed military aircraft and the gas cloud explosion of an LNG tank vessel passing by on the Rhine River.

Finally, also a cooling tower was demanded, especially to keep the thermal pollution of the Rhine River sufficiently low in hot summer months.

5.2.2 Requirements by the Operators

The outer **containment** of the original SNR 300 design had a cylindrical shape, as was customary for light water reactors. In 1970, following a requirement by the operators, it was made rectangular, as this shape was felt to provide more space for maintenance and repair. As one of the main advantages of the sodium cooled fast breeder is its low pressure in the primary system, and the Bethe-Tait accident and the external impacts were not used as basic design criteria by the customer, it seemed logical to give up the more pressure resistant cylindrical containment. The approaches used in comparable prototype facilities in France (Phénix) and the United Kingdom (PFR) made this an understandable measure.

For the **steam generators**, the straight-tube type was envisaged. The operator had doubts about this technical concept and demanded that also a variant, the helical-tube type, be incorporated in at least one system. The original demand for an additional supplier for this type was given up as soon as problems had arisen about delivery agreements for large components.

Other modifications related to the handling system, the fuel element storage capacity, and the hot cell which, unfortunately, was reduced to an observation post, a change much regretted at a later date.

The modification discussed most widely affected the **reactor core** and the breeding ratio. In the course of an economic analysis it had been found in the autumn of 1972 that the SNR 300, because of its surprisingly high fuel element costs, probably would be operated only at a major deficit, compared with light water reactors. Possible savings were looked for, and it was decided to have thicker fuel rods (7.6 mm diameter) for the reload cores in order to reduce greatly the fuel rod fabrication costs because of the smaller number of fuel rods. The core array was modified so that the full reactor power could be achieved already with the first core immediately after commissioning and not, as had been planned originally, after a prolonged burnup period. The inner breeding blanket row was replaced by fuel elements, while the outer row was equipped with (cheaper) reflector elements. Consequently, the new fission zone in the reactor core was made up of 205 elements instead of the 151 planned earlier, while the number of blanket elements had dropped from 144 to 96.

As a consequence of the reduction of the breeding blanket, the **breeding ratio** of the SNR 300 dropped to slightly less than unity. When this became known, a violent debate arose among the experts and in the press. Angry voices were heard also at the Nuclear Research Center, where a breeding ratio above unity had always been regarded as one of the goals [80].

Differences of opinion about this decision persisted for a long time. The proponents of the core modification argued that economic operation of the SNR 300 had priority while the plutonium breeding gain was insignificant during the startup phase of the reactor. Their opponents considered direct proof of the SNR 300's ability to breed at a breeding ratio slightly in excess of 1 to be of such overwhelming importance that even an uneconomic mode of operation could be accepted temporarily.

5.3 The Price of the SNR 300

These technical modifications required a revised safety report for the SNR 300 to be compiled, which was presented in mid-1971. In May 1972, the positive overall expert opinion was expressed by the Technical Inspectorate (TÜV); in June, the Advisory Committee on Reactor Safeguards took a final positive vote, and on December 18, 1972, permit 7/1 was issued, in which Kalkar was accepted as the site, and the first construction measures were authorized.

The **delivery contracts** between INB and SBK were signed in November 1972 and became valid in March 1973, after the governments had agreed to make their financial contributions. Construction work at Kalkar was begun in April 1973. The SNR 300 Project had become the Kalkar Nuclear Power Station Project. As the two terms were used interchangeably in public statements, the same procedure will be adopted in this report.

Compared to earlier concepts, this meant a delay by two years. However, the parties involved realized that this period had been necessary and had helped to make the SNR 300 acceptable to the licensing authority and the subsequent operator.

In contrast to expectations of the electricity utilities, the safety report presented in late 1969 was not accompanied by a commercial bid for the nuclear power plant. Instead, an "estimated price" of DM 670 million was quoted, according to Interatom CEO

Rudolf Harde," in order to enable the three participating governments to enter first into preparatory negotiations" [56].

Planning the modifications of the SNR 300 and examining its risks in greater depth had a major impact on the **price** of the nuclear power plant. The total cost of the SNR 300 at November 1972 prices now ran up to DM 1534 million, which amount breaks down as follows [81]:

SNR 300 costs as per 1972 delivery contract		
Delivery contracts	DM 984.7 million	
Provisions for extra cost	DM 247.0 million	
Builder's costs	DM 103.0 million	
Provision for price escalation	DM 200.0 million	
Total cost	**DM 1534.7 million**	**(not including the Pu for the first core)**

As the price of the nuclear power station had become considerably higher than originally estimated, the Federal Ministry for Research in Bonn established a commission which spent several weeks examining the "justification of the prices" of all components and systems without, however, contributing greatly towards a price reduction.

The equity capital envisaged for the shareholders in SBK was DM 120 million. Moreover, the governments were to participate in the financial risk of operation to the tune of up to DM 150 million [82].

Earlier **cost estimates**, such as those drafted in 1965 (DM 310 million [36]) or in 1971 (DM 670 million [56]), were exceeded greatly by the contract price of DM 1535 million. This clearly revealed the margin of uncertainty inherent in such estimates as long as the scope of delivery is not known sufficiently well, no detailed engineering plans are available, and contractual conditions, such as warranty, penalties, etc., have not yet been negotiated. The situation at that time is characterized by a statement made by a representative of industry (Dr. Kornbichler, AEG) in a public panel discussion at the 1971 Status Report:

> "Let me first of all correct the idea that the costs of a reactor yet to be developed can be estimated to the first or second digits after the decimal point. It has been our experience with light water reactors that they took at least ten years of development before the order of magnitude of the costs became at all evident ..." [56].

The **PSB** Project Management Staff at Karlsruhe later was repeatedly taken to task for its relatively low cost estimates for 300 MWe breeder power plants. Although it is not the primary duty of a research center to publish such economic data, those figures yet were not invented. The French and British breeder reactors of comparable unit sizes, Phénix and PFR, were already under construction in 1968 and 1974, and their costs were known at least tentatively. When the final accounts were settled, Phénix cost FF 595 million, PFR, £45 million. Consequently, their final prices were even below the expenditures for the SNR 300 estimated at that time. The higher contract price of the SNR 300, and the horrendous extra costs incurred later, cannot be attributed to the complexity of breeder technology alone, but clearly carry a national component [83].

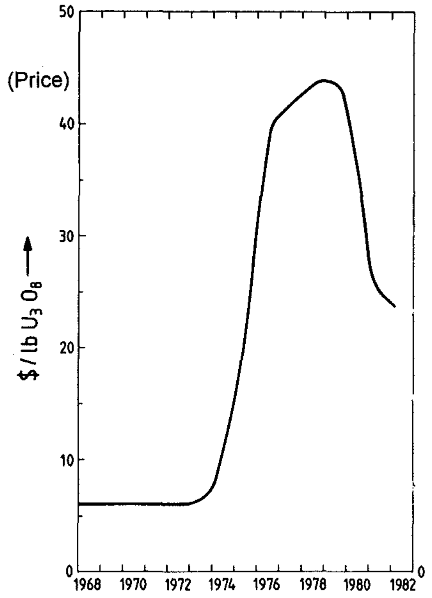
Under the delivery contracts for the Kalkar Nuclear Power Station, the Vendors' Consortium was to participate "adequately" in the **risk** of the Project and even contribute progressively to its extra cost. A cumulated risk of approx. DM 200 million was estimated under this heading. The remaining financial requirement was to be paid out of public funds [82].

G. Scheuten, as CEO of SBK, declared the SNR 300 ready for construction as far as the **terms and conditions** in the delivery contract were concerned. Except for the price, they largely corresponded to the terms and conditions applicable to LWR nuclear power plants. Performance obligations could be modified subsequently only by unforeseeable events and findings caused by sodium technology or by the impact of fast neutrons. Nobody will have realized at that time that a sizable fraction of the extra cost incurred later resulted from that very area [84].

5.3.1 The Changed Economic Assessment of the Breeder

After more clarity had been achieved about the technical design and the cost structure of the SNR 300, this also meant a reassessment of the **economic potential** of the sodium cooled fast breeder. In contrast to pre-1969 estimates, it was now generally assumed that, on a short and medium term, the breeder would be inferior to light water reactor plants in terms of electricity generating costs. Equality in costs of these two types of nuclear power plants was forecast for "the nineties." However, this was assumed under the premise of a major rise in uranium prices. The nuclear fuel cycle was assumed to offer a cost advantage of the breeder reactor, provided that the costs of uranium were sufficiently high; that assumption was also supported by the continuous rise in separative work costs. The fuel rod fabrication costs were estimated at DM 790/kg on the basis of a fabrication plant of 50 t/a loaded to capacity. The reprocessing costs at that time were estimated to run up to DM 500/kg [68, 82, 85].

Generally, the breeder was felt to be at a disadvantage in **capital costs**. This was due especially to the more sophisticated circuit systems which, obviously, could not be simplified very much. The technical design drafts of all prototype and demonstration reactors moved towards a standard scheme and, except for differences between loop and pool designs, did not differ too much in costs. Efforts to eliminate the secondary system or install a CO_2 system had been abandoned in general[73].



Rise and fall of uranium prices between 1973 and 1982.

Certain cost advantages of the breeder were expected to arise from **economies of scale**. Because of the unpressurized primary and secondary systems, plant powers of 2000 MWe and above appeared to be feasible. However, as long as unit sizes were limited by the hypothetical Bethe-Tait accident, no credit could be taken of this possibility.

The need to pursue the breeder technology was explained especially with the need to ensure the supply of low-cost fuel. Building the SNR 300 was felt to be necessary because expertise in advanced fast breeder technology had to be demonstrated also in the interest of nuclear power plant exports. In addition, it was a "pledge" to be used to exchange experience with other industrialized countries developing breeder reactors. The SNR 300 was the German loop concept to be contrasted with the pool concept pursued by the French and the British. Finally, everybody had realized in the meantime that the licensing procedure stood a chance of succeeding only if it concerned a real project promising a feedback of experience[82].

5.4 The Status of the R&D Program

When the technical documents of the SNR 300 were examined in April 1970, an ad hoc Committee on **"Readiness for Construction of the SNR 300"** was set up to express its opinion on the feasibility and the risks of this power plant. In its activity, the Committee identified 26 problem areas which it felt required in-depth investigation. These included structural material swelling; oxide deposits in aerosol compartments, steam and carbon traps; dynamic stability; and matters of repair and maintenance. Most of these items resulted from current problems encountered in the KNK experimental reactor and were closely connected with the ongoing R&D program, respectively.

In addition, when commissioning the industrial consortium, the Federal Ministry for Research in 1966 had formulated a number of technical **grant-giving criteria**, whose compliance status also had to be assessed. They also constituted part of the R&D sector, mainly covering fuel elements, safety, and sodium technology. In the sections below, therefore, the progress and the problems in these research areas in the early and mid-seventies will be explained in slightly more detail. The R&D program will not be covered afterwards, as this report is mainly concerned with the history of the SNR 300 plant [86, 87].

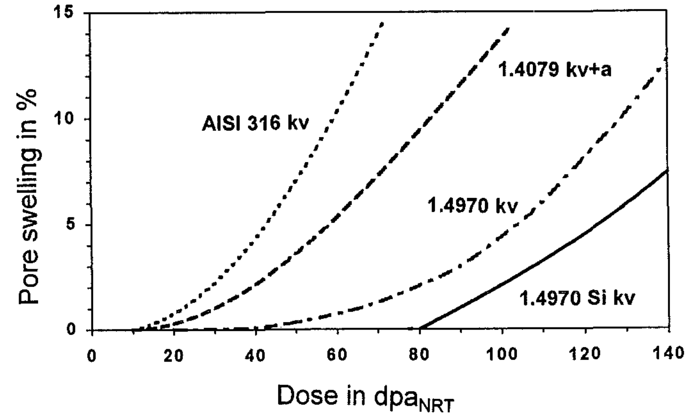
5.4.1 Fuel Elements and Fuel Cycle

The accident at the Enrico Fermi Reactor in October 1966, which had been caused by a blocked fuel element and ultimately caused the reactor to be shut down permanently, had greatly hampered the **irradiation plans** of the Project. The FR 2, with its thermal spectrum, was no proper substitute, especially since 1967 when the phenomena of swelling of the cladding tube material had been recognized and, like high-temperature embrittlement in some ways, had been attributed to the impact of fast neutrons. Materials irradiation required fast test reactors. As a consequence, the epithermal BR 2 at Mol was increasingly used in the early phase; 50% of its capacity was leased initially for a period of five years and spent especially on capsule and loop irradiations.

The situation became much more manageable after an agreement had been signed with the United Kingdom about irradiation in the Dounreay Fast Reactor **(DFR)**. A bundle of 77 fuel rods was irradiated jointly with the French CEA, with "DeBeNeLux" (Germany/Belgium/Netherlands/Luxemburg) securing a share of 39 rods. The DFR 350 experiment, together with the DFR 304 three-rod monitoring experiment, was a complete success. A burnup of 53,000 MWd/t was attained in 1971, thus formally meeting one of the grant-giving criteria of the Federal Ministry for Research. However, the cladding materials were the 1.4988 and 1.4981 steel grades not used again later. In the autumn of 1970, the French **Rapsodie Fortissimo** plant was added as another irradiation reactor, and the irradiation bottleneck more or less ceased to exist[88, 89].

By 1975, more than 100 fuel rods had been irradiated in a fast flux in the DFR and Rapsodie Fortissimo reactors to a burnup of 90,000 MWd/t. 220 rods had achieved burnups in excess of 50,000 MWd/t. Post-irradiation examinations were conducted mostly at the hot cells of the Nuclear Research Center. In this way, oxide fuel was examined for pore formation, resintering effects, and releases of gaseous fission products. Especially the FR 2, BR 2, and Siloe reactors were used to study fuel swelling and in-pile creeping. In the important field of chemical interactions (compatibility), the dangers to the cladding posed by the Cs, Te, and I fission products were recognized. For the first time, the microprobe allowed the radial distributions of Pu and U in spent fuel rods to be made visible[90, 91, 92].

In the early seventies, the potential of oxide fuel was largely felt to have been exhausted, and the Project Management Staff recommended a gradual switch to **carbide**. The problem of internal corrosion appeared to be less severe in that material; thanks to its far better thermal conductivity and higher heavy metal concentration, carbide fuel especially allowed smaller fuel inventories and higher breeding ratios to be achieved. In 1973, 15% of the PSB funds already were spent on carbide development. In the sector of **cladding material**, a preselection had resulted in the Nb- and Ti-stabilized steel grades of 1.4988, 1.4981, and 1.4970, respectively. The criteria applied, above all, included high thermal stability, sufficient post-irradiation ductility, and minimal swelling rate. Detailed analyses of the



Pore swelling of various materials used for fuel rod claddings.

non-uniform in-pile results coupled with comprehensive out-of-pile investigations resulted in the choice of 1.4970 type steel. This was the correct decision to take, as has been evident to this day. For the fuel element shroud and the spacers, 1.4981 type steel was proposed [93, 94].

On the basis of existing R&D findings, the INB Industrial Consortium in 1974 specified the fuel elements for the first core **(Mark Ia)** of the SNR 300. The rod diameter was to be 6 mm, which was halfway between the diameters used in the PFR (5.85 mm) and Phénix (6.25 mm) plants. The pellet density was determined to be 86.5% of the theoretical density and 80%, respectively, of the smear density; later, it was known to be at the lower end of the international scale. Experimental backing of the spacer was minimal; the honeycomb type was chosen, which consisted of spot-welded strips and had a certain similarity to the British design. As no complete overview had as yet been obtained of the swelling of cladding material and the associated gradients, the design deliberately was planned on the conservative side. The burnup contractually guaranteed by INB was 55,000 MWd/t [95, 96].

The second reactor core of the SNR 300 was to be equipped with so-called **Mark II** fuel elements. They were characterized not only by higher fuel density, but also by thicker fuel rods (7.6 mm diameter), especially to reduce fuel element fabrication costs, which made up a major part of the fuel cycle cost. At the same time, the fuel rods were to be made more compact, which meant the use of spark eroded spacers.

Industrial **mixed oxide production** was well under way, with approx. 100 kg of breeder fuel each manufactured by ALKEM and Belgonucléaire, including the lots for KNK II. ALKEM had left the premises of the Nuclear Research Center in 1971 and built its fabrication plant at Wolfgang near Hanau. Fabrication line I was designed for 10 t/a of LWR recycle fuel and 2-3 t of breeder fuel, respectively, while the highly automated line II was to attain four times that capacity. Belgonucléaire soon afterwards had given up its pilot plant at Mol and built a new manufacturing plant at Dessel with a capacity of 7.5 t/a of breeder fuel [97].

Some of the fresh fuel rods for R&D in-pile experiments were fabricated on small lines at Karlsruhe and Mol, such as the rods used in the Mol 8D and Mol 16 test groups. For quality control, an electrochemical probe had been developed for non-destructive measurements of the O/M ratio.

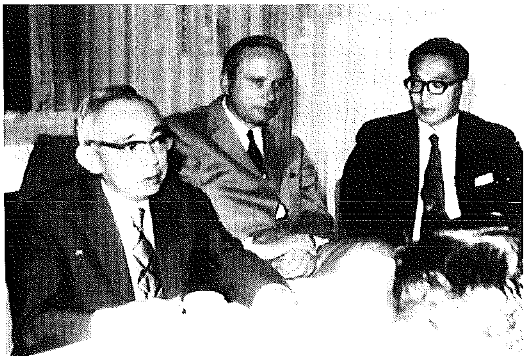
In the **fuel cycle**, the cold trial runs of MILLI had been completed in the spring of 1970. One problem had been the availability of sufficient amounts of high-burnup fuel for active operation of the plant. The SNR 300 fuel elements were to be reprocessed in WAK; a special development program had been harmonized with the SNR deadlines. The fast breeder cores were to be reprocessed in the so-called mixed core management mode, i.e., the fuel rods were to be reprocessed together with blanket rods.

5.4.2 Physics and Safety

Between the spring of 1969 and the autumn of 1970, the SNEAK 2 and 6 assemblies were studied in **SNEAK** as setups typical of sodium cooled breeder reactors. In the process, the SNEAK 2A uranium core had been incorporated, step by step, a central Pu zone and a 150° Pu sector. For this purpose, 90 kg of plutonium had to be obtained on loan from the MASURCA plant. The SNEAK 6 test series also indicated that k_{eff} could be predicted with an uncertainty of approx. 1%, and the power distribution, with approx. 3-4%.

After studies for the steam-cooled breeder (SNEAK 3), on equipping KNK with a fast core (SNEAK 4), and the sodium-related setups mentioned above (SNEAK 2, 6), the first assemblies directly tailored to SNR 300 needs were investigated between 1972 and 1975 (SNEAK 9A, B, C). Configuration 9A was an almost true-to-scale replica of the Mark I core, but already taking into account modifications for Mark Ia [98].

While experiments were being conducted on the Van de Graaff accelerator, the **database** was developed further and reached another stage of completion in 1975 when the KEDAK 3 Karlsruhe Nuclear Data Library was established. Still on the basis of a revised version of KEDAK 2, the KfKINR 01 26-group set was created in 1972 [99, 100].


German-Japanese talks about cooperation
(left to right: A. Oyama, W. Häfele, K. Mochizuki).

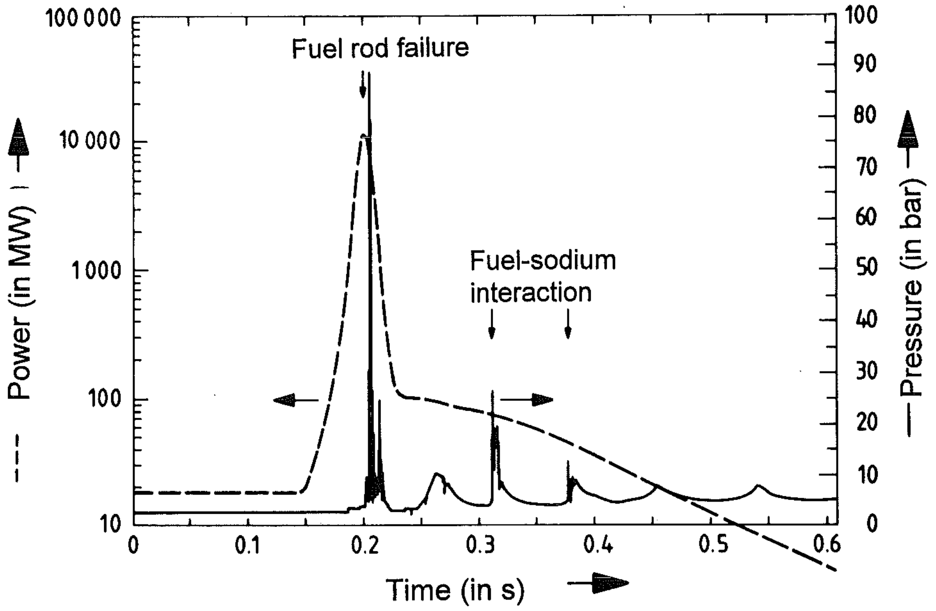
Code development progressed in accordance with the availability of effective computers. While neutron flux distributions initially could be determined only in a one-dimensional diffusion approximation, two- and three-dimensional treatment was introduced later (DIXY, KASY, D3D, D3E). In 1973, the NUSYS code was replaced by the flexible, modular KAPROS system, of which a second version came out in 1977 after virtual storage had been introduced on the central host computer [101].

Safety research followed the questions that had been raised in the expert opinions written about the SNR 300. A special problem affecting fast breeders was seen in the possibility of cooling defects giving rise to reactivity perturbations followed by power excursions. A distinction was made between losses of flow in the entire core and local losses of flow in individual fuel elements. The analyses served to identify individual links in this chain of events and to produce physical proof that this chain would not be run through from start to finish. Important problem areas quickly recognized included sodium boiling; reactivity increase by way of the positive void effect; fuel rod failure; fuel meltdown; the fuel-sodium interaction; nuclear aerosols; reactor disintegration; and the impact on the containment of the mechanical energy released. In those years, these were the main topics covered in experimental and theoretical work [102, 103, 104, 105, 106].

There was an obvious shortage of **in-pile experiments**. Consequently, participation was sought in the evaluation of ongoing programs abroad, and cooperation agreements were signed which are still valid. In the French Scarabee experiments, fuel rods were made to melt by means of throttling the coolant flow; in the HFR experiments in Petten, the temperature of the fuel rod cladding was kept constant at a level below 1000 °C, and cladding failure was achieved. In addition, the results of the American TREAT experiments were observed. An agreement was signed with CEN/SCK Mol about the Mol 7C experiments, in which 37-rod bundles with artificial coolant blockages were to be irradiated. The experiments served to study fault propagation and the reliability of instrumentation.

SEFOR had gone critical in May 1969 after 44 months of construction. During commissioning it was seen that the Pu-contents of some fuel elements were below the specified levels. That error was observed with particular attention by the Nuclear Safeguards Project founded shortly before. In January 1971, the reactor reached its full power of 20 MWth. The step-by-step program of Doppler measurements, which ran from statistical power measurements and oscillator experiments to sub- and superprompt critical excursions, had been prepared by a strong Karlsruhe team and ran smoothly. The Doppler constant, $D=T\cdot dk/dT$, was determined to be between -6.5 and -8×10^{-3}; the values predicted theoretically were between -6.6 and -7.8×10^{-3}. The SEFOR reactor was decommissioned in 1972, thus unfortunately preventing the execution of a follow-on test program.

To make up for the loss of SEFOR, the **CABRI** joint project was started with the French CEA in 1973, later to be joined by Japan, the United Kingdom, and the United States of America as junior partners. The modified CABRI reactor in Cadarache was to be used for experiments in which especially spent mixed oxide fuel rods were to be made to fail as a result of loss-of-coolant flow and reactivity perturbations. The test reactor went critical in March 1977; in the early phase, normally eight to ten scientists were delegated to Cadarache by KfK to participate in the joint research program.



Typical power transient in the CABRI program.

The CABRI program was most successful; its findings were repeatedly used in the licensing procedure of the SNR 300. Follow-on programs (CABRI-2, perhaps even CABRI-3) confirmed the success of this international cooperative venture.

Theoretical studies of the **Bethe-Tait accidents** had been started before 1970 with the compilation of the REX and FAUN-Z codes. In late 1971, KfK and Interatom, in a joint crash effort together with the Argonne National Laboratory (ANL), computed the hypothetical accidents as a basis for designing the reactor vessel of the SNR 300 in late 1971. Two chains of accidents were analyzed: pump failure, and reactivity accident accompanied by the simultaneous failure of the two independent shutdown systems. Core meltdown processes in the core disruption phase were studied by means of the SAS 2A and VENUS codes. On the basis of the model by Cho-Wright, mechanical energy releases of 50 to 200 MWs were calculated, which the SNR 300 vessel was able to withstand [107, 108, 109].

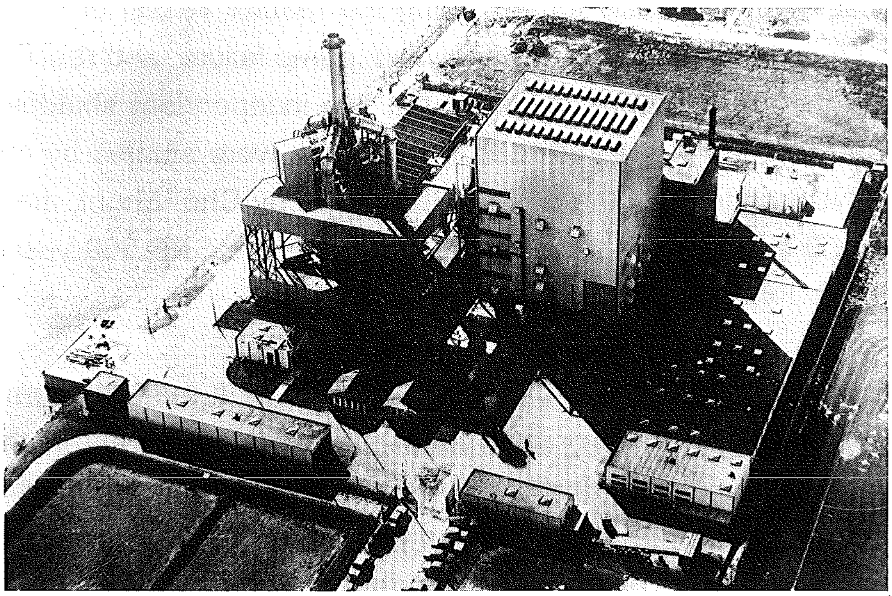
As a consequence, the studies led to the development of a modular **computer code system** at Karlsruhe which more or less corresponded to the power of the most advanced codes of ANL. From 1973 on, the CAPRI-2 code was available to analyze the phase preceding reactor disintegration. It used point kinetics and allowed thirty characteristic cooling channels to be processed. Important constituent parts of CAPRI-2 were the BREDA fuel rod module and the BLOW 3 boiling module. The KADIS code was used for the disintegration phase; it was based on an older version of VENUS and had been greatly improved at Karlsruhe. Interatom, which was responsible for analyzing the mechanical loads and stresses acting on the structures, used the HEINKO, DRAP, and ARES codes. The first calculations with these codes were conducted on the original Mark I SNR 300 core; the important Mark Ia analyses followed later [104].

5.4.3 Sodium Technology and KNK

The main points of interest in the R&D program on sodium technology were the large component test rigs and the KNK test reactor [110, 111].

At **Hengelo**, Netherlands, a 50 MW test rig for intermediate heat exchangers and steam generators had been built and commissioned in 1972 after some teething troubles. The heat exchangers of the SNR 300 were subjected to brief suitability tests and 3000 h long-term tests on a full scale; important indications of necessary modifications became manifest partly during operation, partly during subsequent inspection.

Interatom commissioned a number of experimental facilities of special importance for SNR 300 component tests, most of them true to scale. In the Breeder Pump Test Rig **(APB)**, important components of the main system were tested, such as valves, flowmeters, but also the SNR prototype pump.



The 50 MW test rig for sodium components of the SNR 300
in Hengelo, Netherlands.

In the Fast Breeder Reactor Section **(RSB)**, the rotating shield system and the most important handling facilities were tested full-scale under real operating conditions. Also the transport of sodium aerosols was studied, which had had a very negative impact on the commissioning phase of the KNK test reactor.

In the Breeder Core Elements Facility **(AKB)**, especially the fissile and fertile elements and parts of the instrumentation plate, were studied for thermohydraulic and vibration characteristics. Particular importance was attached to tests of the shutdown rods in which important parameters, such as temperature, flow, and dislocation, were imitated under reactor conditions.

In the Breeder Engineered Safeguards Experiments Facility **(ASB)**, finally, the very important experiments on sodium-water interaction were run on models of the SNR 300 steam generator. Their results constituted the base for the design of the steam generator and the pressure relief system in the Kalkar Nuclear Power Station.

At the **Nuclear Research Center**, the Compact Sodium Cooled Reactor **(KNK)** had received its permit for full power operation on February 19, 1974 and had been raised to its rated load two days later. This implied a delay by approximately two years over the original timetables due, to a considerable extent, also to the licensing procedure, which initially had been expected to be less complicated. As the experimental nuclear power plant was subjected to the same criteria under the Atomic Energy Act as a commercial light water nuclear power plant, the final permit was obtained only via ten partial permits (five construction and operating permits each) plus more than 650 conditions imposed [112].

With respect to sodium technology it was important to see that the sodium pumps and intermediate heat exchangers as large components caused no problems (during KNK I operation). On the other hand, there were difficulties with sodium aerosols in the vessel top shields, and also with temperature shocks caused by unscheduled reactor scrams.

In the commissioning phase, a major fire occurred in the secondary purification system, and one leak was detected in a steam generator unit; both accidents were managed without having any impact on the environment.

The most expensive event occurred in the trace heating system: A tiny stud screw one millimeter long, but present 8000 times, had not been protected properly and, ultimately, caused a six months' delay because of repair work.

Despite these problems, or possibly just because of them, the KNK facility with its core moderated by zirconium hydride furnished importance experience in the field of sodium technology between 1971 and 1974 [113].

5.4.4 Reorganization of the Karlsruhe Project Management

KfK adopted a **Project Statute** on December 16, 1969, in which the organization of the PSB Project Management as well as its rights and duties were defined. The Project Leader now was joined by a deputy and several Project Officers and Project Engineers for the different R&D areas. A Project Working Committee and a Project Council were established as advisory and supervisory bodies, respectively. The responsibility of the Project Leader for the definition and attainment of goals, and his rights and duties vis-à-vis the Management of the Center, the Scientific-Technical Council (WTR), the Institutes, and external partners were laid down in detail in writing in these statutes [114].

The PSB Project Statute, which was slightly modified once more on October 1, 1973 in order to meet the basic principles of Section 19 of the KfK Company Statute of 1972, proved to be most successful. It ensured closer contacts with the staff at the Institutes and also more transparency in decisionmaking, which had occasionally been missed before, for instance in the coolant controversy. As far as its objectives were concerned, it was in line with the general move "to dare more democracy" so popular at that time.

On July 1, 1972, Professor Häfele gave up his function of Project Leader. He was succeeded by Dr. Peter Engelmann, his former deputy. Engelmann was succeeded by Dr. Günter Keßler in 1975, who passed this function on to Dr. Willy Marth in 1978, who held this post until the end of the PSB Project (October 31, 1989).

The four Karlsruhe PSB Project Leaders on a rafting tour on the Isar River (left to right: W. Häfele, P. Engelmann, G. Keßler, W. Marth).

One of the duties of the Karlsruhe Project Leader and his deputy, respectively, was to chair the **"R&D Programs Working Committee."** That body was established by the Fast Breeder Project Committee in September 1970 in order to coordinate and control the Breeder Research Program in the DeBeNe area. Members of the Committee were the four national research centers (KfK; CEN/SCK, Mol; ECN; TNO) and the four industries (Interatom, ALKEM, Belgonucléaire, Neratoom) together with the Federal Ministry for Education and Science (now called Federal Ministry for Research and Technology); INB and SBK attended as observers [115].

The Committee was organized initially in four, later in ten committed working parties, which allowed the extensive R&D programs in the three countries to be kept under continuous control. The result of these efforts was documented annually by a coordinating staff in a loose-leaf folder comprising some 4000 pages, the Budget Plan ("Green Book") and the DeBeNe Annual Report.

6. START OF CONSTRUCTION AND FIRST DIFFICULTIES (1973 - 78)

6.1 Planning and Site Construction

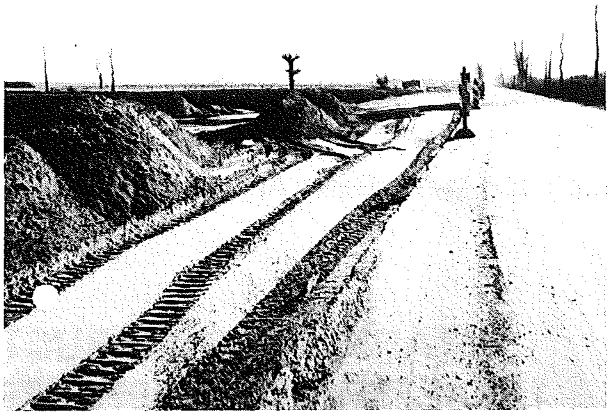
In **March 1973**, the delivery contracts had entered into force when the first partial construction permit had been granted and the governments had agreed on their financial contributions. The mood at the Bensberg **Status Report** was euphoric:

> "We have now entered into the execution phase of the Project... I hope you understand my feelings about the promising and exciting task which is to be solved by the men working for this plant and helping to complete it." [116].

The quotation reflects the optimistic expectations in those days and does not indicate the disappointment to be felt in later years.

A brief summary will be presented below of the planning activities and work on site; in addition, progress will be described with the large components and in the field of mixed oxide fabrication. The description will be based on the quarterly reports published by SBK, which constitute excellent documents of progress in the project between 1973 and 1991 [117].

Construction work on site for the Kalkar Nuclear Power Station took off quite briskly. Within three months, foundations of the baseplate of the reactor building had been prepared; a sheet metal liner was attached, and on top of this structure the steel reinforced concrete slab of 3 - 6 m thickness was to be cast.



Preparing the SNR 300 construction site in Kalkar (1973).

At the Status Report in the following year, **1974**, the Project was already two months behind schedule, but intended to recover the loss by the time the reactor vessel was to undergo pressure testing. Two extensive plant modifications had to be incorporated in the intermediate heat exchangers and the emergency core cooling system. An analysis of the intermediate heat exchangers had revealed their tube plates to be not strong enough to withstand the Bethe-Tait accident, which meant that radioactivity could have been transferred to the steam generator buildings. As it was impossible to upgrade the systems, it was decided to install not one intermediate heat exchanger per circuit, but three smaller modules per loop, which added up to a total of nine such units for the SNR 300 [80].

Very extensive replanning became necessary as a result of conditions imposed on the emergency core cooling system by the expert consultants. The capacity of the system was raised from an earlier 6 x 20% to 2 x 100%, which implied scaling up the immersion coolers and all the auxiliary systems. These modifications were incorporated also against the background of being able to submit a consistent concept of protection against external impacts.

By **1975**, the concrete structure of the reactor building had been completed about 40%, but the **delay in the timetable** had increased to four months, which could no longer be recouped. The cost associated with further conditions imposed by the licensing authorities was estimated to run up to DM 250 million. A particularly difficult problem was the suspension of the vessel top shield system in the reactor cell concrete. In a nuclear excursion, the vessel support beam probably would be subjected to dynamic loads of approximately 10,000 t. These loads had to be transmitted safely into the concrete structure, and expert opinions had to be sought to confirm the validity of the design [118].

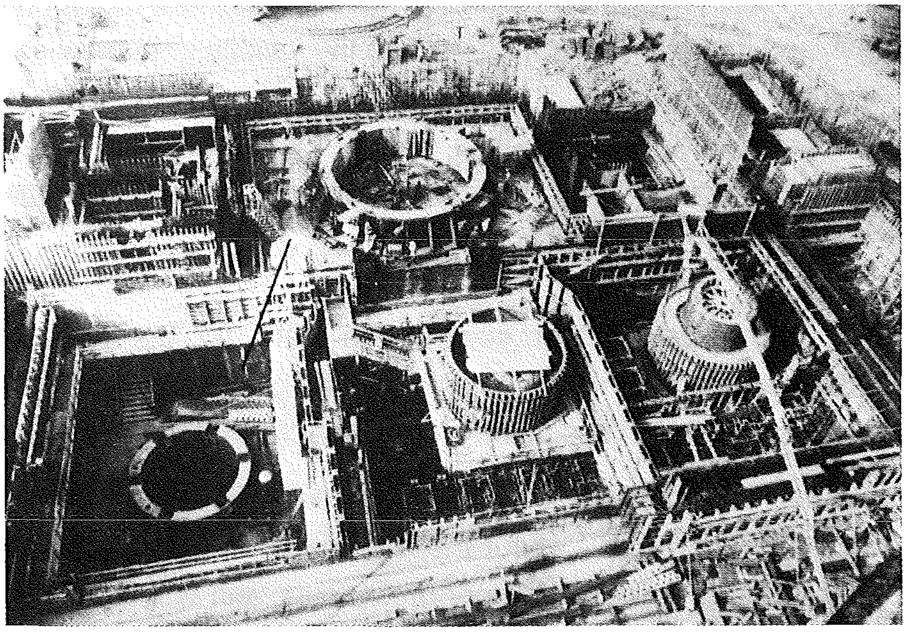
Also the design of the core catcher was quite difficult. Demonstrations had to be produced, *inter alia*, of the ability to avoid nuclear criticality of the melt and manage the high temperatures of the uranium-plutonium mix.

Formally adopting for prototype reactors, such as the SNR 300, the **licensing procedure** originally developed for commercial light water reactors turned out to be problematic. INB-CEO Klaus Traube on this point:

> "Due to the formal nature of the licensing procedure, questions are raised very early - and must be answered - about the detailed design of components which will not be installed in the plant until very much later, and whose planning status accordingly is still incomplete. This situation is causing us much more difficulties than, for instance, in the case of water reactors, as we cannot fall back upon any standardization, any precursor, or use existing answers." [80].

In **1976**, 80% of the components and systems had been ordered, but the problem of the **vessel support beam** had yet to be solved. Sophisticated calculations, for some of which the methods had to be elaborated first, seemed to indicate the existence of resonance vibrations in that component. To detune the resonance frequency, concrete bulkheads were installed, which greatly aggravated formwork and reinforcement activities and made planning of the installations difficult in the compartments concerned. On top of that, there was a sophisticated materials testing program for the reactor vessel. Large specimen tests indicated that the short-term “Bethe-Tait pressures" could be reduced to a level of 11% by strains. Finally, also demonstrations of the heating of, and absence of cracking in, the concrete took a lot of time [81].

The delay in the timetable meanwhile had increased to twenty months; the **additional cost** was estimated to run up to DM 750 million, approximately DM 450 million of which was due to price escalation. Manning strength on the construction site as an indicator of the amount of work had increased rather uniformly from the start of construction work and reached its maximum of approx. 1150 persons in early 1976. After that date, the headcount dropped just as continuously to some 300 employees for the ARGE construction consortium and INB and SBK by 1978. This drastic decline reflects the shortage of activities caused by the non-availability of important partial permits.



The reactor cell and primary cells of the SNR 300 (1975).

The difficulties in executing the SNR 300 Project persisted even beyond 1976; in fact, as will be seen below, the technical problems were augmented by many others from other areas. Approximately at that time, a special effort began to be made by the contracting parties and others involved to explain the SNR 300 problems to a broader public and try to find solutions. A first step in this direction was the resumption of meetings of the Fast Breeder Project Committee.

Also the then Federal Minister for Research, **H. Matthöfer**, showed his commitment in many ways. In interviews and discussions he tried to educate the public in matters nuclear. His discussions "Pro and Con" were addressed more to the expert public and featured even prominent breeder opponents, such as A.B. Lovins and F.v. Hippel from the United States of America [119, 120].

In September 1977, some 35,000 nuclear power plant opponents **rallied** on the site of the nuclear power station. However, the proclaimed "Battle of Kalkar" did not take place, because strong police forces controlled the approaches to the site and confiscated tons of axes, metal pipes, knives, etc., in this way making sure that the situation would not get out of hand [121].

6.2 Large-component Tests and Mixed Oxide Fabrication

From 1974 on, also the **large components** could be tested as soon as the test facilities at Bensberg and Hengelo had become available. The intermediate heat exchangers and the straight-tube and helical-tube versions of the steam generators were tested at TNO in Hengelo, Netherlands. They passed the long-term tests over 3000 hours at partial and full power relatively well; merely one straight-tube steam generator had to be examined (in vain) for a leak over a long period of time.

In the APB test facility at Bensberg, the startup of a sodium pump caused turmoil. The reason finally was found to be an uneven radial temperature distribution in the upper part of the pump; the problem was settled administratively by phrasing the operating instructions in more specific terms. This phenomenon of startup under transient loads later was observed also in pumps of PFR and FFTF [122, 123].

The RSB plant, also at Bensberg, was used to try out the entire sequence of handling steps in refueling under sodium at 250 °C. The experimental program encompassed also bowed and misaligned fuel elements. In addition, the functioning of the rotating top shield system, the fuel element transfer system, and of tracing devices and grabs was demonstrated.

From 1977 on, the AKB plant was used for lifetime tests of the prototypes of the primary and secondary shutdown systems.

In the field of fuel elements, most of the effort in 1976 was concentrated on producing **mixed oxide powder**. One important specification requirement was the low fuel density thought to be necessary for attaining high burnups. The fuel rod suppliers, ALKEM and Belgonucléaire (BN), used different ways of powder preparation: ALKEM tried to achieve low density by adding pore formers; at BN, correspondingly large amounts of inactive powder from scrap recycling were added. It was quite problematic to achieve the required fluidity of the mix for, except for the UO_2 starting substance, neither AUC nor PuO_2 were particularly fluid [124, 125].

When MOX fuel rods irradiated in the Obrigheim Nuclear Power Station were reprocessed, the bad **solubility** in pure nitric acid of the mixed oxide crystals was discovered in 1977. No special importance had been attributed to that aspect before, as in-pile irradiation was assumed to produce subsequent crystals of completely mixed components and, hence, full solubility of the mixed oxide fuel. As a consequence, therefore, the former standard fabrication technique was abandoned in favor of the so-called AUPuC process, the feedstock of which is not oxides, but Pu- and U-nitride solutions, which are adjusted to the desired fissile materials content by mixing the two components. Out of this solution, ammonium uranyl plutonyl carbonate is precipitated as a relatively coarse grained solid solution and converted into fluid U/Pu mixed oxide powder by calcination.

6.3 The Breeder before the Federal Constitutional Court

The first partial construction permit, TEG 7/1, of the Kalkar Nuclear Power Station had been the subject of litigation before the administrative courts since February 1972; its opponents sought to have it revoked. The plaintiff was a farmer, Mr. **Joseph Maas**, from the community siting the SNR 300, Kalkar-Hönnepel. The Düsseldorf Administrative Court had rejected his action in a first decision on October 23, 1973 on the grounds that the permit under the Atomic Energy Act violated no rights of the plaintiff.

In reacting to an appeal lodged by the plaintiff, the **Münster Higher Administrative Court** had suspended proceedings on August 18, 1977 on these grounds [126]:

> "A ruling by the Federal Constitutional Court shall be sought to find out whether Section 7 of the German Atomic Energy Act, to the extent in which its present version enables permits to be issued for nuclear power plants, including the fast breeder line, is compatible with the Basic Law."

In its ruling of August 8, 1978, the Second Chamber of the **Federal Constitutional Court** unanimously stated that the breeder reactor was legally covered by the valid Atomic Energy Act. It declared the issuance of permits for breeder reactors under Sec. 7 of the Atomic Energy Act to be compatible with the Basic Law and, in addition, in its guiding principles publicized on December 8, 1978, contradicted the opinion held by the Münster Higher Administrative Court that only Parliament, not the executive, had a right to take guiding decisions about the way in which the Atomic Energy Act was to be construed. Consequently, the German Federal Parliament on December 14, 1978 took the important political decision to continue to build the SNR 300 and carry on the necessary R&D work [127].

6.4 Stop Signs from the USA

Approximately around 1976 nuclear technology, and also the breeder line, increasingly moved into the focus of politicians. This happened first in the USA, where the two presidential candidates, Ford and Carter, in the presidential election campaign of 1976 argued partly opposite views about the benefits and risks of nuclear technology.

The new **U.S. President Carter** elected in 1976 took up office on January 20, 1977; already in April he announced a new nuclear program constituting a complete reorientation of the previous nuclear policy. The main points of his declaration were these:

(1) National commercial reprocessing activities will be deferred indefinitely.

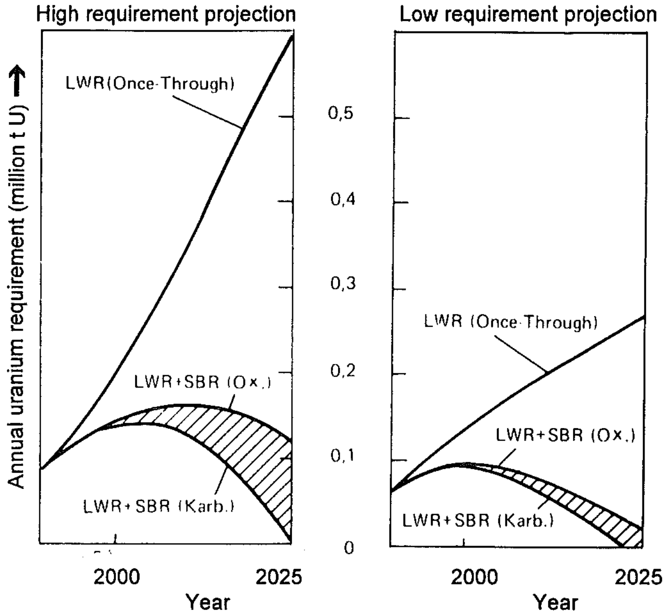
(2) The U.S. breeder program will be modified so as to avoid early commercialization of the breeder reactor.

(3) The Clinch River Project, which included the construction of an American prototype breeder power plant, will be discontinued.

(4) The breeder research programs will be reorientated towards the development of alternative fuel cycles not based on plutonium.

(5) A worldwide expert discussion will be held about the evaluation of alternative nuclear fuel cycle and reactor concepts within the International Nuclear Fuel Cycle Evaluation (INFCE) Program [128].

The scientific base used by the Carter administration for its planned **realignment** of nuclear policy was the so-called Ford-MITRE Study compiled 1976 by 21 authors on behalf of the Ford Foundation and the MITRE Corporation. Among the authors were Harold Brown, later U.S.



World uranium requirement for high and low nuclear power growth scenarios (INFCE assumptions).

Secretary of Defense, and Joseph S. Nye, later Undersecretary of State with the U.S. State Department and responsible for U.S. non-proliferation policy. The report is about 400 pages long and, in a clear and impressive style, covers the economic, safeguards, and political aspects of the most important sources of energy. In the nuclear sector, four problem areas were identified on which early decisions by politicians were deemed to be necessary: reprocessing and recycling of plutonium; breeder reactors; uranium enrichment; and nuclear export policy [129].

President Carter's invitation to the **INFCE Conferences** was accepted by 46 states and five organizations. The studies began in 1977 and were concluded in 1980 with a comprehensive report. The breeder was treated by Working Group 5 chaired by Belgium, Italy, and the USSR. The initial reservations of the Americans vis-à-vis the fast breeder finally gave way to an improved understanding of the needs of the Europeans and Japanese. On the other hand, it became evident that the political problems associated with the breeder, such as proliferation, had not been given proper attention earlier on. A few items will be singled out below from among the large number of statements contained in the final report by Working Group 5 [130, 131]:

(1) The sodium cooled breeder based on the uranium-plutonium cycle was referred to as the state of the art. Breeders with thorium in the core and in the blanket, respectively, were viewed skeptically, also because of the problems of the thorium cycle, the need for remote refabrication, and the partly doubtful breeding properties. Molten salt breeders were not taken into account because of their corrosion problems.

(2) Strategic calculations showed that the uranium requirement can be decreased considerably by 2025 even in a mixed LWR-LMFBR system. Even if the expected requirement is high, the energy requirement can be satisfied for more than 1000 years when breeders are used.

(3) The environmental impact caused by breeder reactors in normal operation and under accident conditions does not differ significantly from that of light water reactors. Besides, breeders offer advantages because of the reduced rate of uranium mining and the lower waste heat production they entail.

(4) The risks of clandestine diversions of fissile material at various stages in the breeder fuel cycle were considered to be not greater than those in the LWR with Pu-recycling (and even without). Alternative cycles involving the use of thorium and depleted uranium, a mix of U-233/U-238, were considered

technically unsatisfactory solutions to the proliferation risk. On the other hand, the proliferation risk was expected to be diminished as a consequence of co-conversion, co-location, and multinational management of the plutonium stockpiles.

(5) The capital costs of the breeder reactor were considered to be higher throughout than those of the LWR. This would be offset by advantages in the nuclear fuel cycle as a result of expected increases in the price of uranium. A number of countries expected the breeder to break even in 1990. The Americans were more skeptical, anticipating a breakthrough of the breeder line not before the year 2000.

6.4.1 Individual Critics: Riemer, Traube, Keck

Even in the early phase of the Breeder Project, there were a number of critics in the Federal Republic of Germany who reached a broad public through the media and in politics. The Frankfurt journalist, Kurt Rudzinski, has already been referred to above. The first really significant critic probably was the SPD Member of Parliament, Professor Karl **Bechert**, Full Professor of Theoretical Physics at the University of Mainz and, between 1962 and 1965, Chairman of the Parliamentary Committee for Atomic Energy. He untiringly drew attention to, what he felt, were underestimated problems of radiation protection, stating that the construction of nuclear reactors had been begun much too early [132]. From among the number of individual critics who came in later, Riemer, Traube, and Keck will be mentioned in this report as representatives of the areas of **politics**, **technology**, and **science**.

Dr. Horst-Ludwig Riemer was a Member of the State Parliament and, as State Minister of Economics in North Rhine-Westphalia, responsible for licensing the SNR 300 when, in September 1978, he expressed an idea about a modification of the SNR 300 which caused a lot of excitement. Riemer proposed to modify the core of the SNR 300 in such a way that the reactor could henceforth be used as a "plutonium annihilator." For this purpose, the uranium in the blanket, and later also in the core, should be replaced by thorium. Riemer's proposals must be seen against the background of the INFCE assessment at that time, and also against the influence of American groups [133].

Had this idea been put into practice, it would have meant starting both the U-Pu - and the thorium-uranium-233 cycles - a huge, nearly futile enterprise. The safety characteristics and the fuel element behavior of the reactor would have been unknown, quite aside from the fact that the proliferation hazards of U-233 are hardly inferior to those associated with U-235 and Pu. And then, this modified SNR 300 would have been able to "annihilate" not more than 5% of the plutonium arising from light water reactors in the Federal Republic. Riemer's "reactor design" has never been put into effect, but nevertheless intrigued the German public for quite some time and clearly hindered progress in the SNR 300 licensing procedure.

Dr. Klaus Traube, a graduate mechanical engineer and thermodynamicist, had a large audience especially because, after having held leading posts with the AEG Boiling Water Reactor Division in Frankfurt, he was Managing Director and Project Officer responsible for the SNR 300 with Interatom and INB in Bensberg 1972 - 76. In 1976 he resigned his post, supposedly because of a wire tapping affair by the Secret Service. Over one year later, his book "Müssen wir umschalten?" (Do We Have to Change our Mind?) appeared in which he bitterly criticized nuclear technology [134].

K. Traube.

Traube's book turned out to be a perfect surprise especially to his former colleagues, for they had known and experienced him as a committed proponent of breeder technology for many years. For this reason, many thought it incredible that he should have changed his mind about this technology, do an about-face within only one year, and then articulated his new opinion so eloquently on more than 300 pages of a book. He probably must have harbored his doubts for quite some time, but he never seems to have talked about them.

A basic tenor in his book is "small is beautiful," an opinion expressed by just about everybody in the seventies. Traube untiringly praises the simplicity and usefulness of a "collector on the roof," the advantages of thermal insulation as a means of energy conservation. He finds a few positive words even about the "medium-sized technology" of the Chinese. On the other hand, he relentlessly condemns big science and technology, nuclear power in particular. His sentence,

> "I think that big technical developments, by and large, cannot be controlled rationally; big technology mostly develops in an anarchic, unforeseeable, irrational way," [133]

also contains the gist of his personal experiences. He certainly must have had a hard time, for instance at the 1976 Status Report in Utrecht, Netherlands, when he had to tell a top-level international expert audience that the SNR 300 Breeder Project under his responsibility had failed technically, in its deadlines, and financially.

In citing reasons for his aversion to big technology, Traube in his book points especially to the high temperature reactor. In later publications, he ceases to protect his former project and also aims his criticism against the SNR 300. Finally, Traube also emphatically attacked microelectronics, an attitude which seems highly antiquated at a time when every point of sale is computerized [135].

Dr. Otto Keck, who had studied theology (in addition to philosophy and economics), was probably the first scientist to choose the SNR 300 fast breeder reactor as a subject for a Ph. D. thesis. On the basis of memoranda and records of the German Advisory Committee on Atomic Energy, the Breeder Project Committee, and the files of the German Federal Ministry for Research he investigated the decisionmaking processes in the German SNR 300 Breeder Project in a doctoral thesis submitted at the English University of Sussex [136].

In his book, Keck analyzed the Breeder Project from its beginnings approximately up to the late seventies. For this purpose, he also conducted many interviews with participants in the Project from government, research, and industry. Quite a number of persons he talked to were irritated by the fact that he seemed to know the outcome of his research even before he had conducted the interviews.

The results of his studies seem to indicate that government subsidies of industrial development activities close to the market normally are inefficient. He criticizes insufficient controlling in the early phase of the Fast Breeder Project, in particular the absence of any parliamentary control. In his view, the economic analyses conducted by the Nuclear Research Center were not sufficiently based on reality and were not criticized by the industrial partners either, probably in order not to endanger their government funding. Moreover, the government set the level of financial participation by manufacturers and power utilities in the SNR 300 too low. He also criticizes that the uranium reserves were estimated to be much too low and, hence, the fast breeder was prematurely elevated from a research project to a big-science project, with all the negative consequences, such as extra cost, etc.

In his book, Keck finds that an introduction of the breeder line on a large scale will hardly be meaningful and necessary before the middle of the next century. Should industry nevertheless engage itself in this development, the government should only make a limited contribution to the research program, if any. O. Keck may be regarded as an early representative of Technology Assessment. His competence, and the amount of effort he invested in penetrating the jungle of technology, economics, and politics in the breeder field, is admirable.

6.5 German-French Cooperation

On May 11, 1977, the agreement about founding the **"Fast Breeder Development Association"** was signed at Karlsruhe by KfK, Interatom, and ALKEM. It constituted one of the administrative preconditions of German-French cooperation as agreed upon later. In particular, it was meant to express the broad and harmonized base in the Federal Republic in its relations with its future contracting partner, France.

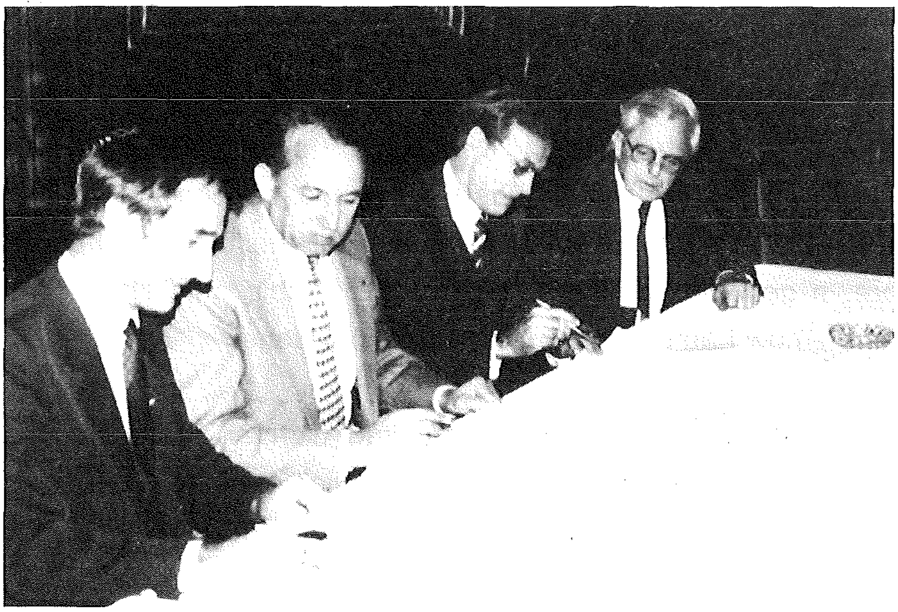
In addition to its external effect, the Fast Breeder Development Association was very important also for the relations among the partners in Germany. This was apparent already from its objectives: regular harmonization and joint execution of all R&D efforts in the fast breeder sector, including exchanges of the findings made in this way. The annual research programs were to be adapted to the technical and timing needs of the fast breeder construction schedules and also become integral parts of German-French cooperation.

Already in the early seventies, conditions seemed to be ready for European cooperation above and beyond the level of the three countries, Germany, Belgium, the Netherlands. On the vendors' side, a contract had been formulated ready for execution in 1972 between Interatom and the British **TNPG** about the establishment of a joint company for the production and marketing of fast breeders. However, these intentions came to nothing, as the structure of the nuclear power industry in Britain was rearranged at that time [82].

At the level of the utilities, RWE, the French EdF, and the Italian ENEL agreed in May 1971 to cooperate in the construction and operation of two large breeder reactors. More details were defined within the so-called **Nice Agreement** in December 1973. The NERSA consortium was to launch the 1200 MWe Superphénix (which it did), while the ESK consortium was to launch the 1500 MWe SNR 2 (which it failed to do) [78, 79].

In February 1976, finally, also German-French cooperation was completed at the level of vendors and national research centers. The basis was constituted by a joint declaration by the German Federal Minister for Research, Matthöfer, and his French colleague, d'Ornano, in which the Ministers advocated close cooperation between the two countries in fast breeder development. Along these lines, research centers and the industrial partners in May 1976 agreed on the general principles of cooperation within the framework of guidelines and memoranda.

On July 5, 1977, a number of contracts on **German-French cooperation** were signed in Paris in which comprehensive cooperation was foreseen in the development and industrialization of sodium cooled fast breeders. On the German side, Dr. Hans-Henning Hennies, KfK, was instrumental in getting the contracts accepted; later, he was Chairman of the Steering Committees for a long time and - together with G. Vendryes from CEA and others - did a lot to foster cooperation in a spirit of confidence among the partners [137].



Signing the German-French Cooperation Agreement
(left to right: H. Wagner, H.-H. Hennies, both KfK;
J.-P. Sieveking, H. Mausbeck, both Interatom).

The German-French R&D Contract was signed by KfK/Interatom and the French CEA; associated partners under a consortial agreement were Neratoom, TNO, ECN (Netherlands); CEN/SCK, Mol and BN (Belgium), and CNEN (Italy). The subject of the contract was the complete exchange of know-how generated in R&D work in the fast breeder area; in addition, future R&D programs, and the use of facilities, were to be harmonized and coordinated. A Steering Committee was set up to supervise cooperation, into which the French and the German sides delegated two representatives each.

In October 1978, **SERENA** was founded, a company whose purpose since has been to collect and utilize commercially the know-how existing in the participating countries, especially by granting licenses. The DeBeNe partner of SERENA is the Kenntnisverwertungsgesellschaft Schnelle Brutreaktoren mbH (KVG), in which the Nuclear Research Center holds a 19% interest; other shareholders are Interatom with 51%, and Belgonucléaire and Neratoom with 15% each. Planning and building breeder power plants was the subject of a contract on cooperation among the industrial groups, INB and Novatome. Exempt from this exchange is know-how in reprocessing and manufacturing components and fuel elements. The agreements run for twenty years.

In the field of plant construction, the exchanges of experience between INB and Novatome had been greatly intensified before. Delegations of staff members and exchanges of documents achieved detailed mutual exchanges of the experience accumulated with KNK and SNR 300, and Rapsodie, Phénix and Superphénix, respectively.

Cooperation among the industrial groups was concentrated on a detailed comparison of the conceptual design features of the two primary systems, the so-called **Pool-Loop Study**. It is well known that France pursued the pool concept, while Germany favored the loop concept. Although comparative studies of the two concepts had been conducted before, a genuine comparison became possible only after the barriers to exchanges of know-how had been removed by associations.

In 1984, also the British were incorporated into German-French cooperation on the R&D side. In 1988/89, this cooperation converged into the project of the European Fast Reactor (EFR), in which the three countries held equal shares.

7. COMMITTEES, COMMISSIONS, EXPERT OPINIONS (1978 - 82)

7.1 The Project at the Crossroads

Around 1979, the Project had almost reached a dead end. Some 300 people were still engaged in work **on site** in Kalkar, approximately half of them assembly workers - a dramatic decline from the more than 1000 people who had worked on the spot as late as in early 1976. Most of the work on the building shell had been completed, while activities dealing with the reactor cell had suffered a considerable delay. For the biological shield, time-consuming demonstrations of the integrity of the overall system in an assumed energy release of 370 MWs in case of the Bethe-Tait accident had to be conducted before construction work was cleared [138, 139].

Component fabrication in the shops of the subcontractors had moved ahead considerably. The large components, such as the reactor vessel, the grid plate, the gas bubble separator, the fixed plug ring, the reactor cover, and the core catcher, were either finished or about to be finished. The reactor vessel arrived in Kalkar in mid-1976 but, in the absence of an installation permit, had to be kept in intermediate storage in a separate storage building together with the bottom collecting tank. Problems were associated with the missing **partial permits** for the auxiliary systems and the main and emergency core cooling systems. They were expected to be issued "very soon," but in actual fact it took another one or two years for them to materialize. Comparison with the situation at the date of the last Status Report (Utrecht, 1976) showed that "delivery" as one of the key points had not been approached any more closely. Partial permit 7/5 for the nuclear main system was the key item on the critical path. Analyses of the timetables conducted by the manufacturers indicated that delivery of the power plant could be expected, at the earliest, three years after the permit would have been granted. As seen from 1979, this could not be before the autumn of 1984.

The licensing procedure entailed a tremendous administrative expense bordering on **red tape**. Merely for prechecking the 72 bottom troughs, some 2300 drawings, 5500 bills of materials, and 10,000 pages of stress analyses had to be completed. The biggest flood of paper had to be coped with for documentation purposes. Experts estimated that one complete set of documents covering the entire plant would require some 10,000 files. Putting these files side by side would result in 800 meters of documents containing 50 to 100 million official seals and 3 million signatures.

The delays in project execution, and the completion of licensing criteria, in the meantime had raised the **costs** of the Kalkar Nuclear Power Station to DM 3.2 billion. A large fraction, namely DM 1.1 billion, was due to price escalation, i.e., the general price increases coupled with the delays in project completion.

It is easy to understand the responsible Executive Officer and Managing Director, A. Brandstetter, who had succeeded K. Traube in the executive project management function in 1979. With an audible sigh, he had uttered at the end of his 1979 Status Report in Karlsruhe:

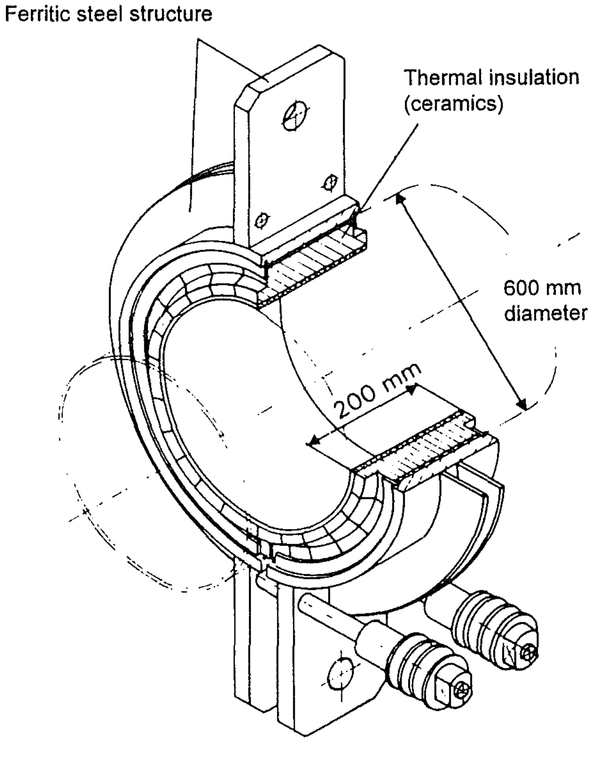
> "It has become very difficult in this country to build a prototype plant."

7.2 The ad hoc Group of the Project Committee

The lack of progress in the Kalkar Nuclear Power Station had alarmed the Project Committee, the group of high-level representatives of government, the industrial partners, and the R&D centers. At its meeting on September 23, 1979, it commissioned an **ad hoc Group** to list the problems encountered in the SNR 300, evaluate them, and draft proposals for solutions. The Group was composed of representatives of Interatom, Neratoom, SBK, and KfK, and was chaired by Dr. W. Marth, KfK. Merely six months later, in February 1980, the report by the Group was submitted to the Project Committee [140, 141].

The Group had identified roughly half a dozen problems which it considered to be responsible for the unsatisfactory state of affairs with the SNR 300. At the top of the list was the **Bethe-Tait complex**, which had assumed proportions moving this, initially hypothetical, accident in the close vicinity of a classical design basis accident. More and more extensive individual evidence not based on any physically credible accident scenario made the licensing criteria rise far beyond the internationally customary level. The Group therefore suggested that the existing evidence of integrity be accepted and sensitivity analyses be tolerated even if they occasionally exceeded the set limits by a slight margin.

In the field of **strength analyses**, the problem was found to be in the lack of precise definitions in the design basis, the American ASME code. The licensing authority kept demanding more and more conservative steps, for instance in upgrading and limiting load cycles. Far reaching effects were produced by the pessimistic assumptions the expert consultants made about leaktightness, which were almost impossible to harmonize with the existing containment concept. Even when excluding inelastic analyses, the computation expense for the pipes was gigantic, reaching almost 3000 man-months.



Support structure of the main pipe in the SNR 300.

The assumption of a **prompt pipe break** was made in analogy with LWR practice, although sodium reactors, because of their low systems pressure, thinwalled pipes, relatively low loads, and the tough austenitic material, exhibit quite different conditions than those prevailing in highly pressurized light water reactors. Ensuring emergency core cooling under conditions of an extreme loss of flow associated with a double-ended (2F) break of a main coolant pipe, and deflecting the jet forces, required protective devices which took up much space, and also armor-plate-like bottom troughs. The Group therefore recommended to accept the internationally recognized leak-before-break criterion. Obviously, there would be detectable amounts of leakage long before critical crack sizes could develop.

Also the **external impacts**, i.e. the design basis earthquake and airplane crashes, escalated the amount of computation expense associated with the evidence of such protective provisions. Almost worse were the huge number of dampers, hangers and supports to be installed, all of which was bound to reduce accessibility to the plant area. The Group therefore proposed that manufacturers be allowed to use a computationally less sophisticated rigid body model, and evidence be limited to the crash of an airplane on the building structures.

The absence of **rules** specific to the SNR was a constant source of uncertainty; consequently, the expert consultants analogously applied the existing body of rules about light water reactors, i.e. KTA Rules, BMI Directives, RSK Guidelines, etc. Frequently, the positive generic properties of sodium cooled reactors were not even taken into account. Also the expert opinions written about plant components were tightened up all the time: Instead of the original 39 electronic systems, 117 such systems were included in the licensing procedure under the Atomic Energy Act in 1980. Also preliminary testing up to clearance for assembly had become very cumbersome, causing lengthy, costly holding times on site [142].

The ad hoc Group therefore proposed that the expert consultants and the licensing authorities establish an **Oversight Group**. A small group of people experienced in the Project should be empowered to determine the scope of expert consultancy and handle conflicting targets in the interest of a balanced engineered safeguards approach. The decisions by that group should be binding upon all the expert consultants involved in the licensing procedure. The Group explained the reasons for this approach as follows:

> "If the present expert consulting and licensing practice continued, the nuclear power plant, which was to have been started up in 1979 according to original plans, certainly will not be delivered in 1985, the date now foreseen. We even believe that completion of the SNR 300 may not be expected before 1990 - perhaps even considerably later."

The study by the ad hoc Group was later requested for discussion by the Committee of Inquiry of the German Federal Parliament. In the covering letter to the Chairman of that Committee, H.B. Schäfer, Federal Minister for Research **von Bülow** added:

> "A large part of the proposals listed in the working document were felt to be unfeasible, the fears expressed were considered in part to be exaggerated or capable of being resolved. The extrapolation of the completion date to 1990 or even later was considered untenable." [143].

This is where Mr. von Bülow was mistaken.

7.3 Appointing Committee of Inquiry 1

After the December 8, 1978 Kalkar ruling by the German Federal Constitutional Court, the way seemed to have been paved for the overdue 3rd Partial Construction Permit which, among other items, covered the control room and the inerting systems. However, the fast breeder at Kalkar in the meantime had also reached the German Federal Parliament. A dramatic **energy debate** revealed that six FDP Members of Parliament (among them MPs Haussmann and Matthäus) of the Social Democrat-Liberal government coalition intended to vote against the continued construction of Kalkar. Only after the then FDP Ministers Genscher, Lambsdorff, and Baum indicated that they would resign in that case, the six Members of Parliament and breeder opponents were willing to abstain and, in this way, allow the Energy Report to be adopted [144].

On December 14 of that year, the **German Federal Parliament** thus agreed on the updated Energy Program and, hence, on continuing construction of the SNR 300. There was one important string attached to that decision: Prior to commissioning that nuclear power plant, another decision by the Federal Parliament was to be sought in a political debate.

In preparation of that decision, a Parliamentary Committee of Inquiry on Future Nuclear Energy Policy was set up, which consisted of seven Members of Parliament and eight experts. The Chairman was the SPD Member of Parliament, R. Ueberhorst. Under its mandate, the Committee was to work out the lines along which future decisions could be taken about energy problems in the light of ecological, economic, and other aspects. Moreover, it was to establish criteria for the acceptance of nuclear power, and study possibilities of alternative nuclear fuel cycles. Finally, it was expected to prepare the decision by the German Federal Parliament about possible commissioning of the SNR 300.

Seven of the total of 24 **meetings of the working groups** were devoted to breeder reactor technology. Individual deliberations mostly revolved around reactivity coefficients, the plutonium economy, the Bethe-Tait accident, and risks. The well-known fact that breeder reactors the size of the SNR 300 have a positive sodium void coefficient was discussed widely with respect to its consequences. It was not recommended to lay down in a rule the magnitude of this coefficient, let alone its sign, as such intervention easily could have led to a "suboptimization" of the overall system. The Committee also concluded that construction and operation of the Kalkar Nuclear Power Station would not yet raise any problems of a plutonium economy [145, 146].

After lengthy deliberations, the Committee accepted the development of breeder reactor technology "for research policy purposes." This included construction of the SNR 300. In addition, the requirement was imposed that the safety level of the Kalkar Nuclear Power Station must not be below that of a modern pressurized water reactor. Two studies were commissioned for further evaluation of these problems [147] :

1. The so-called **Upper Bound Study** was to contain a literature survey of the scientific work about Bethe-Tait accidents with a high mechanical energy release potential. In addition, those studies were to be evaluated which maintained a mechanical energy release above the limit of 370 MWs in the SNR 300. The literature survey was to include comments by scientists with different attitudes towards nuclear power.
2. Moreover, a so-called **Risk-oriented Analysis** was to be drafted along the lines of the "German Nuclear Power Plant Risk Study" carried out for the Biblis B pressurized water reactor. The term, "risk-oriented," was meant to indicate that the comparison between the two reactor systems could also be qualitative in part. Also the Risk-oriented Study was to be conducted by scientists with different attitudes towards the fast breeder.

In March 1981, KfK was commissioned to conduct the Upper Bound Study; the Risk Study was to be completed by the Gesellschaft für Reaktorsicherheit (GRS) as commissioned in August 1981. On June 27, 1980, the Committee of Inquiry produced an interim report, as the parliamentary term came to an end; at the same time, it suggested that the points still open, especially those on commissioning the SNR 300, should be clarified in an immediate continuation of the Committee's work in the 9th German Federal Parliament.

7.3.1 The Findings in the "Upper Bound Study"

For the Upper Bound Study, **KfK**, with the assistance of the FIZ 4 Specialized Information Center, listed and evaluated all accessible publications as well as other known, but unpublished, reports about energy releases in sodium cooled fast breeders. In particular, the question was pursued whether these documents provided any indication that barely credible accident scenarios, with the SNR 300 conditions taken into account, could give rise to mechanical energy releases beyond 370 MWs [148].

The **conversion** of thermal energy into mechanical energy acting on the primary system is a very complex process of fluid dynamics and thermodynamics because of the presence of materials other than fuel (sodium, steel, fission products). Thus, effects of self-mixing, heat transfer, friction, and condensation, among others, greatly reduce the energy calculated from isentropic fuel expansion. If these phenomena are taken into account in the SNR 300, even a pessimistic (i.e. conservative) estimate arrives at a release of mechanical energy below 100 MWs.

In a separate chapter, the Upper Bound Study dealt with the unpublished hypotheses of the American, **R.E. Webb**, quoted at length in a presentation to the Committee by a "Critical Working Group" (University of Bremen). The KfK study maintained that Webb's assumptions contained drastic errors in calculation and unrealistic accident conditions. Moreover, his scenarios violated physical conditions.

The staff of the Nuclear Research Center involved in the study were unable to find any new accident aspects not already used as a design basis for the SNR 300. International expense just to deal with the Bethe-Tait problem was estimated to run up to approximately 10,000 man-years.

The KfK study arrives at this **finding**:

> "With a probability bordering on certainty, i.e. to all practical intents and purposes, it can be excluded for the SNR 300 that major accidents occur whose release of mechanical energy would go beyond the design level of 370 Mws."

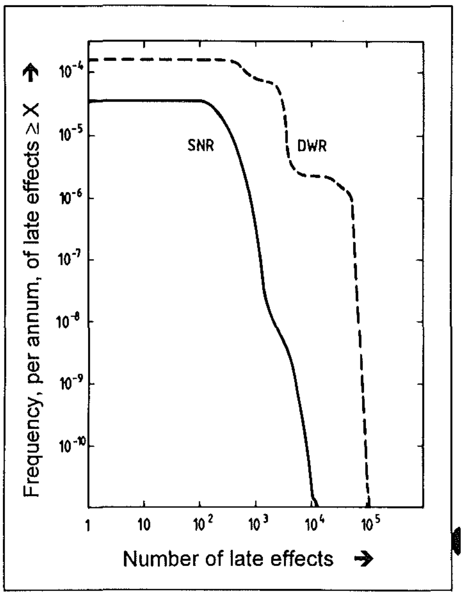
7.3.2 The Findings in the "Risk Study"

The Risk Study, as the Risk-oriented Study was abbreviated, was written under the responsibility of **GRS**, and with the participation also of KfK and of SAI (Palo Alto, USA). A subcontract was awarded to Professor J. Benecke, Munich, to perform parallel studies of selected risk-related problems. For this purpose, Benecke and a few free-lance scientists from Bremen and Heidelberg set up the "Forschungsgruppe Schneller Brüter e.V." **(FGSB)**, which intended to deal "critically" with the SNR 300 accident problems.

The most important **findings** of the Risk Study were the absolute upper limits to damage, as far as early and late deaths were concerned, in connection with the severest radionuclide releases caused by an uncontrolled loss-of-flow accident. For gaseous fission products, such as noble gases, no retention mechanisms had been assumed; for volatile radionuclides, however, sedimentation, diffusion, and thermophoresis were taken into account as removal processes [149; 150].

The **calculations of accident consequences** were based on Kalkar as the plant site. They arrive at the conclusion that early damage by acute radiation injuries will not occur even in the severest accidents, as the threshold dose required for this to happen will not be reached. (For pressurized water reactors, in 1979, the "German Risk Study" still expected a maximum number of 14,500 persons to be killed immediately). The maximum of somatic late damage was almost one order of magnitude lower in the breeder than the consequences to be expected from pressurized water reactors [151].

The accident consequences determined by the FGSB for the SNR 300 showed a smaller number of early deaths, compared with the findings about the pressurized water reactor, but a larger number of cases of somatic late damage. In addition, that study was based on a considerably larger area of radioactively contaminated soil. The FGSB did not include any information about the probabilities of occurrence and, consequently, was unable to provide any quantitative statements about the risk which, after all, is the product of accident frequency and the extent of damage.



Frequency distribution of somatic late effects caused by fast breeders and pressurized water reactors.

7.4 The Findings of Committee of Inquiry 2

The "Future Nuclear Power Policy" **Committee of Inquiry** of the next, the 9th, German Federal Parliament was reconstituted in May 1981, now under the new Chairman, Harald B. Schäfer, SPD. Because of the earlier deadline demanded by Parliament for a recommendation about potential commissioning of the SNR 300, the Committee members began to concentrate on their first activity, the fast breeder, from the spring of 1982 on [152, 153].

The **Upper Bound Study** was submitted in time by KfK on January 22, 1982 and deliberated by the Committee one week later. Afterwards, experts from various camps, Germans and foreigners, were invited, among them the Munich physicist, Professor Maier-Leibnitz, and the nuclear power critic, Dr. Cochran of the Natural Resources Defense Council. Especially the statements made by the American physicist and Nobel prize winner, Professor Hans **Bethe**, were of interest; his research conducted together with the physicist, J.A. Tait, constitutes the theoretical basis of the nuclear power excursion in breeder reactors, an effect now bearing his name. In his letter of March 1982 to the Committee of Inquiry, Bethe writes:

> "The early paper by Bethe and Tait of 1956 was far too conservative. We did then not understand many of the physical factors which mitigate a possible core disruptive accident... Everything the Karlsruhe group says seems to me well founded and I have great confidence in their conclusions." [154]

The **Risk Study** was submitted by Professor Birkhofer, GRS, on the official date of April 30, 1982. However, the contribution by the FGSB was missing and did not materialize until September 1982 in various interim reports. Because of the tight schedule, it was not possible to write a common final report.

In the GRS study, particular engineered safeguard advantages of the SNR 300, for instance, result from the fact that the insertion of a single shutdown rod already interrupts the nuclear chain reaction; in addition, decay heat removal has fivefold redundancy. In addition, even for the molten core cooling remains feasible by technical provisions. The nuclides released are retained largely in the reactor vessel and, should the vessel fail, in the double containment. The probability of the design basis level of 370 MWs being exceeded was made the topic of an assessment invited from fifteen leading international personalities and institutions, and used as a basis for the calculations by GRS [155].

In contrast to these findings, the **FGSB** postulated an immediate containment failure, for instance as a result of the cell cover acting as a missile, as well as a 50% release of all sparingly volatile nuclides. The relative biological effectiveness of α-radiation was assumed to be a factor of 5 higher than the internationally valid ICRP levels, and the body intake of plutonium was increased by a factor of 10. If these extremely pessimistic, in part even arbitrary, assumptions by the FGSB are corrected, the results of the FGSB study revised in this way are seen to differ only slightly from those of the GRS study. A member of the Committee then found:

> "In the light of all this, it must be said that the experiment of a parallel investigation of the fast breeder by scientists of different opinions has failed." [156, 157]

The study by the FGSB was not regarded as a sound scientific document by the majority of Committee members.

After twenty Committee and Subcommittee meetings merely on the subject of the SNR 300, the following **recommendation** was put to a vote on September 23, 1982:

1. The long-term use of nuclear power requires a major conservation of natural uranium resources. For this reason, the breeder reactor technology must be made available. It is in the light of this aspect that commissioning the SNR 300 is important.
2. The licensing procedure under the Atomic Energy Act for the SNR 300 is carried out correctly and with great care, as the Committee has had occasion to ascertain.
3. In the required comparison of the safety of the SNR 300 and that of a 1300 MWe light water reactor of the Biblis B type, the Committee based its opinion on scientifically established, quantitative findings, dealt with the problem of absolute upper bounds to damage, and also looked at consequences of external impacts. In doing so, the Committee has come to the conclusion that "the risk arising from the operation of the SNR 300 is in the **same bandwidth** as the risk associated with the light water reactors now in operation. The Committee therefore considers commissioning the SNR 300 a step reflecting political responsibility."
4. The Committee recommends to commission the SNR 300 in several steps, to make a particular effort in training the personnel, and to develop carefully and carry out the programs for checking systems and components.

5. Consequently, the parliamentary reservation should be lifted.

The pro-side scored a tremendous success: eleven out of sixteen, that is, more than two thirds of the members of the Committee of Inquiry, voted in favor of this recommendation, i.e., in favor of **lifting the parliamentary reservation**; only five out of sixteen members voted against [158].

The report by the Committee of Inquiry, and its recommendation, were immediately passed on to Parliament, which deliberated the documents as early as in late September. After parliamentary committees had dealt with the problem, the final deliberation and decision was scheduled for the 134th sitting of the German Federal Parliament on December 3, 1982. The **vote** turned out a clear majority in favor of lifting the parliamentary reservation, which had existed since 1978, also because SPD Members of Parliament in favor of the breeder from the beginning did not attend the voting ceremony, i.e., did not vote against lifting the reservation. The majority of the SPD group voted against the breeder, probably as a reflex to the change in the domestic situation, the so-called **"Wende,"** after September 17 and October 1, 1982.

7.5 The Opinion by Kearney/Motor Columbus

In summer 1981, the German Federal Ministry for Research and Technology (BMFT) commissioned the US-Swiss industrial group, A.T. Kearney-Motor Columbus, to write an expert opinion about the "causes of cost increases and delays in construction of the SNR 300." In May 1982, the brief was extended to include a critical review of the new "overall cost estimate" made by the operators and vendors in mid-1982. The opinion by the group was submitted in September 1982 as a 268-page study [159].

In the **technical analysis**, the study found that the licensing procedure had required complete evidence to be produced under very pessimistic assumptions about accident management, as had not been the case in any other country with comparable breeder projects. Moreover:

> "There was the tendency to strive for absolute safety, irrespective of the resulting costs."

By way of example, the continuously escalating demands in connection with the Bethe-Tait accident, airplane crashes, and protection again seismic effects were mentioned. The operators' decision in 1970 to change over to a square containment was considered problematic. Because of the stiff anchorage concept and subsequent stringent requirements of protection against an airplane crash, a completely new, costly solution of the steel sheet containment had become necessary. That these opinions were correct, was confirmed also at the International Breeder Report held at Kalkar in October 1981 instead of the usual Status Report [160].

In the analysis of the **licensing and supervisory procedures**, the lack of rules specific to fast breeders as well as the complex licensing structure was criticized, with its partly conflicting rules and competing experts dealing with the same problems (for example: fire protection, ventilation, radiation protection). Developments in the political and legal environments resulted in a volume of documents almost impossible to handle and impossible to fathom. Moreover,

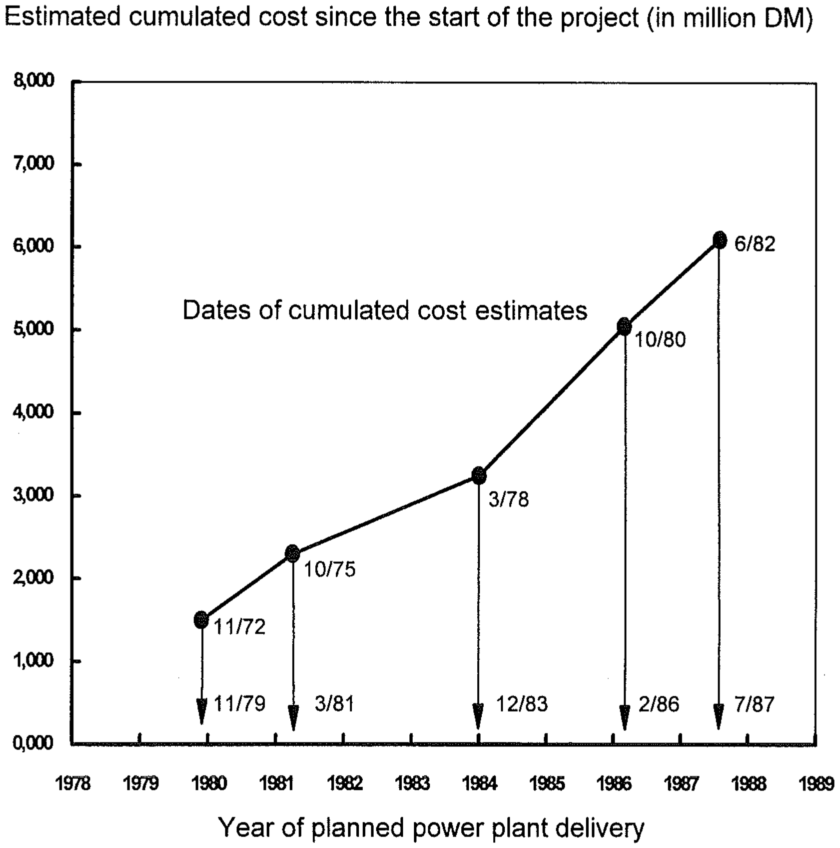
> "the lengthy procedure required to match expert opinions and documents in terms of format, style and editing indicates that the need to make everything watertight for a court case plays a major role."

In its **management analysis**, the opinion continued its recommendation to increase the personnel capacity at BMFT, MAGS, SBK, INB, and TÜV. Especially the main source of funds, BMFT, had been understaffed and short of real possibilities to influence developments and, as a consequence, had not been able to control the Project firmly also under the unexpected interfering influences. SBK pointed out that the flood of requirements to be met, and the massive political resistance, were developments not to be anticipated at the onset of construction, which could have been met only inadequately even by an increased project management staff.

The study also suggested to hold so-called **"Top Level SNR 300 Project Talks"** among the vendors, SBK, and BMFT, to deal with such general problems as definitions of strategy for the licensing procedure (the similarity with the "Oversight Group" of the ad hoc Committee was evident). This proposal was later taken up by the BMFT; such talks were held every four or six weeks, and in the meantime, a small group of Project Officers monitored progress in the Project on behalf of the Federal Ministry for Research.

Important items in the opinion were the **total cost estimate** and the delay in construction of the Project. In mid-1982, the SNR 300 costs had reached DM 6050 million; including the DM 1535 million earmarked at the start of construction, extra costs had arisen of three times this amount, namely DM 4516 million. The latter figure is composed of four main types of costs: non-personnel costs, DM 1301 million (29%); engineering costs, DM 571 million (13%); builder's costs, DM 537 million (12%), and price escalation, DM 2087 million (46%).

Nearly half of the **extra cost** thus had been caused by the additional price escalation resulting from the delays in the Project. The expert consultants largely agreed with the overall cost estimate by INB/SBK, merely suggesting that an amount of DM 650 million be incorporated into the future financial plan for contingencies in technical development and in the timetable.



SNR 300 cost development between 1972 and 1982
(according to Motor Columbus opinion).

Power plant delivery, originally scheduled for November 1979, now was planned for July 1987. This implied a delay in construction by 7.5 years. Completion of the plant (prior to commissioning) now was fixed for November 1985. In the opinion of the expert consultants, the cause of the Project delay so far had exclusively been the nuclear plant components. Managing the Bethe-Tait accident had caused a delay by some two or three years solely in the structural part, and by another three or four years in the primary and secondary systems.

8. A TURNING POINT AND AN UPSWING (1982 - 85)

After four years of stagnation, a number of important events occurred in late 1982 which took the SNR 300/Kalkar Nuclear Power Station Project out of its lethargy. On September 22, 1982, the very important 5th Partial Construction Permit, **TG 7/5**, was issued. It covered mainly the primary and secondary systems, the reactor vessel with its internals, the reactor protection system, the emergency power Diesel plants, and the reventing system. TG 7/5 also implied a comprehensive, positive, stable evaluation of the Bethe-Tait complex. This meant an almost complete license for construction of the Kalkar Nuclear Power Station. Shortly before, a supplement to the 4th Partial Construction Permit had been granted, which covered the ventilation systems, and also the important permit of the new steel sheet metal containment concept had been issued.

The positive decision taken by the German Federal Parliament on December 3, 1982, in the light of the recommendations by the Committee of Inquiry, has been referred to above. It put the Project on safe political grounds, as far as the federal level was concerned.

An event of particular political importance was the **change in government** in Bonn from a Social Democrat-Liberal coalition to a Christian Democrat-Liberal Coalition in October 1982, the so-called "Wende." The new Federal Government had inherited, above all, the problems of financing the Project: Construction costs in the meantime had been extrapolated to DM 6500 million. There was an absolute need for an interim financial contribution of DM 600 million by the planned election date in April 1983. That there was no reliance any more on the former initiators and proponents of the SNR 300, was evident from some statements made by the former SPD Federal Minister for Research, Dr. von Bülow. In July 1982, when he was still Minister for Research, he stated in a comment on the draft budget of his Ministry [157]:

> "The important rank of the advanced reactor lines [SNR 300 and THTR] was recognized by the Federal Government in the additional provision in the budget of DM 120 million."

A few months later, as a former Minister for Research, he said in an interview published in "Der Spiegel:"

> "Immediately after the Wende I stated publicly that both projects [SNR 300 and THTR] had become insignificant from the point of view of energy policy. At the end of a learning process completed despite great resistance I think it is necessary to mothball both projects, despite their advanced stages of completion."

8.1 The Financial Rehabilitation of the Project

Dr. v. Bülow's successor as Federal Minister for Research, **Dr. Heinz Riesenhuber**, immediately took up the case of the two ailing projects, THTR 300 and SNR 300, and, first of all, commissioned a **re-evaluation** from the point of view of the power economy. The result indicated that the breeder continued to be important even against the background of a reduced role of nuclear power. At this advanced state of construction, moreover, the only alternatives were to discontinue or continue the Project. In view of the long-term potential of the breeder, and the support by important industrial partners, the Federal Government therefore had decided to go on with the Project [161].

Federal Minister for Research H. Riesenhuber, CDU, initiated the turnaround in the Kalkar Project in 1982.

In **financing** the Kalkar Nuclear Power Station, before the "Wende" only DM 3738.5 million out of the total costs of DM 6500 million had been secured and spent to meet the obligations incurred by that date. The sum total of unsecured expected contributions, and the budgetary gap, respectively, had risen to DM 2761.5 million by September 30, 1982. The gap was closed, mainly by higher financial contributions by industry, after quick and successful negotiations by the new Government. The share in financing the total SNR 300 construction costs to be contributed by the German Federal Ministry for Research and Technology was reduced from 59.2 to 48.5%. The table below shows the financial situation of the SNR 300 before and after the "Wende" [162]:

Cost estimates and cost allocations for the SNR 300 before and after the 1982 political turnaround

	State as of Sep. 30, 1982:		State as of April 21, 1983:	
	DM million	approx. %	DM million	approx. %
BMFT	2215.0	59.2	3162.5	48.5
Investment grant	572.0	15.3	572.0	9.0
Belgium	333.0	8.9	470.0	7.0
Netherlands	333.0	8.9	470.0	7.0
SBK, operator	265.5	7.1	265.5	4.0
German utilities	0.0	0.0	1160.0	18.0
INB, vendor	20.0	0.6	300.0	5.0
Loan	0.0	0.0	100.0	1.5
	3738.5	100.0	6500.0	100.0

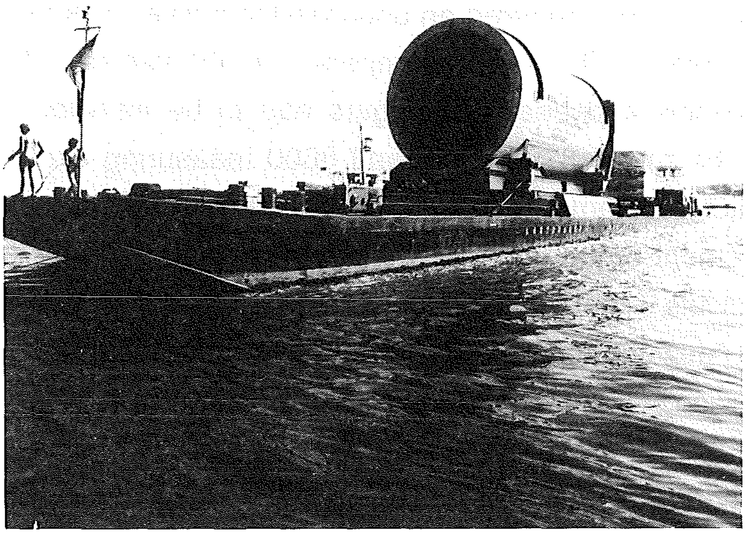
As a new element designed to keep within the cost limits, a highly progressive **vendor's share** was agreed upon with the Vendors' Consortium, which was to become due at between DM 5 to 6.5 billion. In addition, an independent company (Lurgi) was commissioned to monitor costs and schedules as a permanent "watchdog." Regular talks about progress in the Project were to be organized with all contracting parties as well as the licensing authorities and expert consultants, and were to be directed by the BMFT.

For the THTR, which had suffered a similar cost increase, a comparable balanced financing scheme was agreed upon. As a result of contributions by industry, the expenditures to be made by the BMFT to finance the two reactor lines were to remain below 10% of the annual budget.

8.2 Completion of the Kalkar Nuclear Power Station

After the permits under the Atomic Energy Act had been received, and the Project was back on the rails in terms both of national policy and of finance, **activity on the construction site**, preparatory planning, and shop fabrication assumed a breathtaking pace.

One case in point is the **steel shell**, which surrounds the containment of the Kalkar Nuclear Power Station as a pressure resistant, tight outer safety enclosure. It had been finished roughly one third in 1976, when the need appeared to change to a new concept with a tougher steel variety and, above all, increased permissible relative movement. In mid-1982, assembly of the redesigned steel shell began, and after some 2 1/2 years of construction, the pressure test and the leak rate test were completed successfully in 1984. The steel shell - designed according to German licensing criteria! - cost nearly as much as the whole of the Phénix and PFR breeders, respectively [163].



The reactor vessel being unloaded at Kalkar.

Since 1976, the **reactor vessel** had been kept ready for installation on the power plant site. After the TEG 7/5 Permit had been received, it was moved to its final position in the reactor cavity still in the autumn of 1982 and, less than a year later, one of the important items on the critical path, "completion of the reactor vessel connections," was finished [164].

Also the reactor parts and large components were manufactured speedily in **shops** in Germany and abroad. In late 1982, the first Mark Ia fuel element of the reactor core was completed. In April 1985, Belgonucléaire had assembled the last Mark Ia fuel element; RBU/ALKEM was still short of 16 items as, by decree of the Hesse State supervisory and licensing authorities, manufacturing operations had had to be discontinued for a brief interval, pending instructions from Bonn. But even in Hanau, all fuel rods had been manufactured in the meantime. Occasionally, manufacturing problems arose, such as the observance of specific density, stoichiometry, impurities, etc., but they were overcome in an extensive R&D program at the two manufacturing sites.

The sodium pumps, intermediate heat exchangers, and steam generators for the SNR 300 were made in the Netherlands by Neratoom and its industrial partners, Royal Schelde and Stork Boilers. All 33 **large components** had arrived at the construction site between 1983 and 1985 and were installed on the spot. In the manufacturing process, increasingly tighter licensing criteria had resulted in frequent changes in planning and, of course, entailed cost increases. In particular, the accidents assumed in connection with the Bethe-Tait effect and the presumed earthquake and airplane crash impacts had far reaching ramifications. On top of that, the so-called Basic Safety Rules had to be observed, though they had reached the manufacturers relatively late in the fabrication process. Despite these problems encountered between 1976 and 1982, it was finally possible to deliver the components in time [163].

The large number of **components** delivered triggered an unparalleled activity at Kalkar. Here are some figures: 70 km of pipes with 30,000 hangers, 21,000 valves, 1100 pumps and blowers, and 1500 vessels and heat exchangers had to be installed. In addition, 5000 km of cable had to be run to 8700 loads and 8600 measuring circuits. The 300,000 **dowels** caused major problems especially in the reactor building. Because of the high level of reinforcement of the concrete containment, it was nearly impossible in some cases to place dowels without hitting steel bars. Also this difficulty was overcome at last by a specialized "dowel team," the use of improved detection equipment, and refined statistical evidencing.

The faster pace of **assembly activities** at Kalkar is reflected in the rapid rise of personnel on site. In 1982, some 800 persons worked on the construction site; already next year, the team had to be increased to 3300 in order to meet assembly requirements. More than 900 enterprises, most of them small and medium sized, from the Federal Republic, the Netherlands, and Belgium participated in the construction work. Cooperation among planning engineers, vendors, assembly personnel, and the supervisory and licensing authorities succeeded thanks to the extraordinary **management performance** by Interatom-INB Managing Director **Wulf Bürkle**, who was responsible for the Project. He even managed, in this period of time, to keep within the cost limits and deadlines [165, 166].

W. Bürkle, INB Managing Director, advanced the Kalkar Project.

The installation of major components in 1982/83, and the construction of the extensive piping system, covered the milestones on the critical path step by step. When, in late 1983, the successful **pressure test** of the primary system was completed one month ahead of schedule and, one year later, also the pressure test of the containment was finished with a positive result, the timetable of the Project was shortened by seven months - an unparalleled event in the history of the Kalkar Nuclear Power Station. Unfortunately, this lead was lost again later as a result of some technical setbacks, but this will be reported in one of the next chapters.

Commissioning was initiated in mid-1984, when the first sodium volumes were delivered; the total quantity of approx. 1100 tons was filled into the cooling systems without major problems. After the reactor vessel and the primary systems had been filled, construction of the Kalkar Nuclear Power Station as specified in the delivery contracts was formally completed in early May 1985 [167, 168].

In the subsequent **pre-nuclear commissioning stage**, the sodium systems were cleared of potential impurities in a high-temperature cleanup at 400 °C. Moreover, the primary systems compartments were inerted with nitrogen in the same period of time. The sodium pumps showed excellent running characteristics; some problems were encountered with the new type of Viscoseal on the pump shafts.

The fuel element handling devices in a fast breeder are particularly complicated, as they are required to permit remote, angle-oriented handling of hexagonal core elements at pre-programmed positions. But even these tests, which took about ten weeks, were completed successfully [169].

Finally, also pipe movements should be mentioned. Temperature shifts from room temperatures to operating temperatures cause major displacements between the attachment points on the containment and the hangers, as the Japanese were to learn when they commissioned their MONJU prototype. When these displacements were measured in the SNR 300, luckily an optimum was found between the stress contribution affecting the pipes and the loads acting on the supports.

8.2.1 Technical Setbacks

As was to be anticipated in a prototype facility the size of the SNR 300, there were also some technical setbacks in the course of completion, which did not endanger the Project, but still need to be classified as **"experience accumulated in contingencies."** Some of these difficulties caused the time lead which had been accumulated to be lost again. These events, which differed greatly in terms of technical importance, will be briefly outlined below in the sequence in which they occurred [170].

1. Corrosion of the Reactor Vessel.

   The reactor vessel made of X6 CrNi 1811 type stainless steel had been delivered on site in the spring of 1976 and, for lack of an installation permit, stored in a special depot. In 1980, the outer surface of the vessel displayed intergranular corrosion caused by moisture and corrosive dust. The damage was repaired by milling off the entire surface. Continued storage up to installation in 1982 involved no further problems because the air was filtered and dried [171].

2. Sodium Fire.

   In November 1984, some 200 kg of sodium particles were ignited on the roof of the reactor building; they accidentally had been carried upward through depressurization pipes from the basement of a steam generator building in the commissioning tests. The commissioning staff and the fire brigade on the spot were able to control the fire very quickly. Repetitions of the event were precluded by a technical modification in the secondary sodium system [172].

3. Sodium Leakages from Dump Tanks.

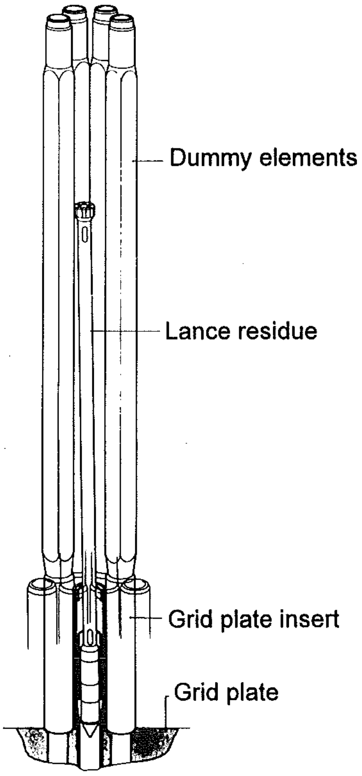
   In August 1985, leakages were found in the ferritic sodium dump and leakage collection tanks. Inspection showed cracked welds through which sodium was able to penetrate. Corrosion studies revealed an increased sensitivity to hydrogen-induced cracking of the stressed, unannealed filler metal; hydrogen release in the reaction between sodium and the corroded material was demonstrated. The decisive mistake probably had been the lack of heat treatment after the original welding had been completed. All tanks, irrespective of their showing cracks or not, were rewelded and annealed and, at least some of them, were available again already in December of the same year [173].

4. Separation for Electrical Redundancy.

In the autumn of 1984, the supervisory authority criticized the insufficient extent of physical separation of plant components and their associated cablings, especially with a view to fire protection. It should be noted at this point that the design of the Kalkar Nuclear Power Station incorporates fivefold redundancy to control decay heat removal, and that the need to continue this redundancy in electric cabling is open to some doubt. However, in its very special style of proceeding in Kalkar the authority again had its way, the consequence being that the SNR 300 features a comprehensive level of fire protection unparalleled by any other breeder power plant in the world [166].

5. Break of a Lance for Vibration Measurement.

In January 1986, a lance for vibration measurement broke when handled. It had been installed in the central position of the reactor vessel to check on the gas bubble separator. Subsequent recovery of the lance part and some loose bits and pieces was a difficult job, but was finished within two months. Specially made tools for illumination, detection and manipulation at 12 m distance allowed the work to be completed successfully in this short span of time. Moreover, it had become apparent once again that trained and experienced personnel is a decisive factor in running sodium plants [174].



The broken lance surrounded by dummy elements.

6. Drying Closure Head Granulate.

In April 1986, the centering tube displacement mechanism of the control rods was found to stick; this was attributed to coatings. The cause was seen to be residual moisture in the basalt granulate boxes shielding the reactor closure head. That residual moisture was released when temperatures rose (e.g., when sodium was filled) and penetrated into the cover gas compartment of the reactor vessel through openings. As a consequence, a moisture removal system was installed which, in a number of campaigns, took the moisture out of the reactor vessel by way of higher basalt temperatures and sweeping with fresh argon. At the end, the hydrogen content in the cover gas, in the power mode, was demonstrated to be below 10 ppm, an absolutely uncritical level [175].

8.2.2 The Mark Ia Reactor Core

A public inquiry about the licensing procedure under the Atomic Energy Act for the so-called **Mark Ia core** of the Kalkar Nuclear Power Station was held in Wesel on December 4 - 6, 1984. As the two core versions, Mark I and Mark Ia, are being mixed up again and again, the cause for, and the history of, this decision about the core configuration should perhaps be highlighted at his point.

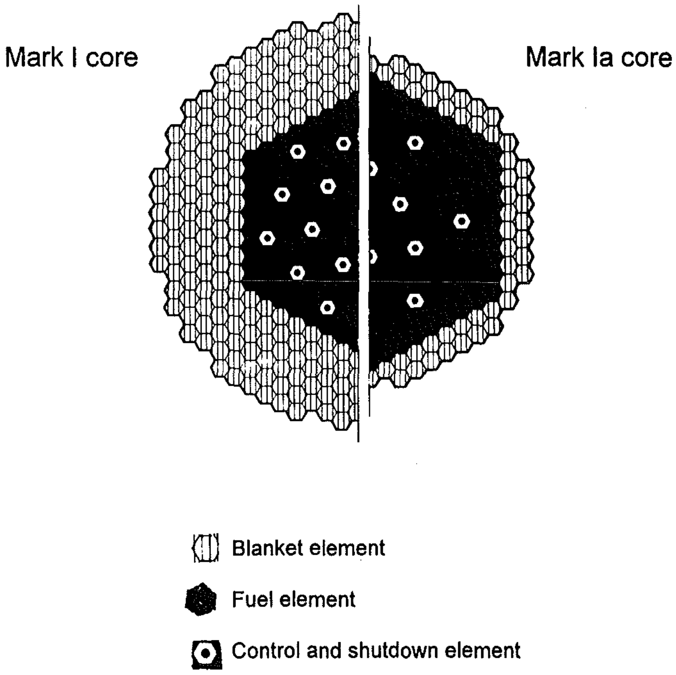
In 1972, the Mark I core version served as a basis for the first partial construction permit of the Kalkar Nuclear Power Station. A number of parameters, such as the geometry of the core and of the radial and axial blanket zones, were to be defined permanently in a later phase of detailed planning.

Subsequent studies of the economics of power plant operation had indicated a possibility to clearly decrease the operating costs by, initially, running the SNR 300 prototype power plant without the breeding capability. This was communicated to the licensing authority in March 1973.

The new core, Mark Ia, had one row of fuel elements more in the core, while the radial blanket had been reduced from five to two rows. Unlike the Mark I core, the Mark Ia core had a slightly higher thermal power of 762 MWth. All subsequent calculations were based on the Mark Ia core version, also the extensive Bethe-Tait calculations and the risk analyses conducted for the Committee of Inquiry.

The nuclear design of the Mark I core had been based on the use of plutonium generated in the reprocessing of fuel from gas-cooled graphite-moderated reactors (of the

MAGNOX type), which has a typical isotopic composition and is called MAGNOX plutonium. Later, however, only 34% of the total amount of plutonium required could be obtained from MAGNOX inventories for the first Mark Ia core. The balance was made up for by purchasing plutonium from light water reactors which, however, differs in isotopic composition. This change to a different fuel composition, of course, would have been necessary also for the original Mark I reactor core.



The Mark I and Mark Ia reactor cores side by side.

In 1983, the Mark I core was formally withdrawn from the licensing procedure and replaced by the Mark Ia first core. The licensing authority took this core modification, especially the change in the plutonium vector, as a reason for demanding a **public inquiry** for the objectors; that inquiry was held in Wesel in 1984. Despite the three days of discussions the inquiry did not produce any fundamentally new aspects even to the authority [176].

Nevertheless the authority later, in the wake of the discussion about opting out of nuclear power, emphasized two **objections** in the TG 7/4(3) Partial Permit:

1. The applicant was accused of "economic" unreliability for having ordered and manufactured the reactor core before it had been licensed under the Atomic Energy Act. That had been tantamount to the negligent use of public funds.

   The representative of the Federal Ministry for Research and Technology (BMFT) which, as a grantgiver, has to approve the way in which SBK uses public funds, opposed the argument by stating that that procedure had been known and approved of. Incidentally, for reasons of time management, this was common practice in the construction of nuclear power plants.

2. Doubt was expressed about the manageability of an overprompt critical power excursion (Bethe-Tait accident), after Donderer and Tränkle, authors critical of nuclear power, had calculated much higher energy releases in 1984, on the basis of the American SIMMER code, than had been used as a basis for Partial Permit 7/5. Their calculations were opposed by detailed analyses by W. Maschek, D. Struwe, R. Fröhlich, P. Royl of KfK and H. Hübel, W. Roßbach, G. Friedel, H. Vossebrecker, U. Wehmann of Interatom. According to them the calculations mentioned above were based on numerical instabilities caused by errors and inconsistencies in modeling and in phenomenology.

   Incidentally, the work by Donderer has never been published and never been submitted to any nuclear conference. Consequently, no public peer review was possible. This also applies to horror scenarios invented by the American, Webb. Scientifically, it was hard to understand why the Düsseldorf licensing authority relied on those persons for years and even awarded contracts to them [177, 178].

After the inquiry, the Karlsruhe Nuclear Research Center, on behalf of the Düsseldorf State Ministry for Labor, Health, and Social Affairs, wrote an **expert opinion** about the neutron physics design of the Mark Ia core. On the basis of intercomparison calculations, mainly by the KfK Institute, INR, under the leadership of G. Keßler and E. Kiefhaber, the evaluation arrived at showed that the methods of computation and the results elaborated by the vendor were not to be criticized [179].

9. DECLINE AND THE END (1985 - 91)

9.1 Political Clouds Appearing on the Horizon

The political change in government in the autumn of 1982, and the loss of the federal elections in the spring of 1983, caused the Social Democratic Party of Germany (SPD) as the biggest opposition party to redefine its program and look for new areas of conflict with the coalition parties in government, CDU/CSU and FDP. Nuclear power, especially the fast breeder, was an obvious choice.

The first steps in this direction were taken at the 1984 Federal Convention in Essen. That Convention decided on a **coal-first policy**, on opting out of nuclear fuel reprocessing, and on adding no more nuclear power plants. The breeder was not yet mentioned explicitly.

Before the elections to the State Parliament of North Rhine-Westphalia, the Minister President and candidate for reelection, Johannes Rau, wrote a letter to Federal Chancellor Kohl asking for a reassessment of breeder technology. Bonn refused, referring to its policy document of the spring of 1983.

State Minister Farthmann, SPD.

The May 1985 **State Parliamentary election** again returned an absolute majority for the SPD and, consequently, exacerbated the breeder debate. Professor Farthmann, now Head of the SPD Parliamentary Group and, as former Minister for Labor, Health, and Social Affairs (MAGS) responsible for granting roughly a dozen partial permits for the SNR 300, made a complete about-face in his argumentation, now expressing himself in strong language against commissioning the Kalkar Nuclear Power Station ("Do not kindle this hell fire." [180]). He made the interesting statement that

> "one was prepared to go to court, if necessary, until the breeder had died a peaceful death." [181].

It may be recalled that his Social Democratic Party colleague, von Bülow, when still Federal Minister for Research, had declared in 1982:

> "Kalkar will not become a ruin of Social Democrat research policy." [182].

In the new government, **Professor Jochimsen** had taken over the State Ministry of Economics (from Riemer), the nuclear supervisory function of the MAGS (from Farthmann) and, as Head of the new Ministry for Economics, Small and Medium-sized Businesses, and Technology (MWMT), had exclusive responsibility for the licensing procedure of the Kalkar Nuclear Power Station. He, too, was no friend of nuclear power. At a hearing before the **Economics Committee** of the North Rhine-Westphalian State Parliament in October 1985 he indicated that the current policy of immediate execution of partial permits might be discontinued in the future. The reason was the increased risk suffered by potential plaintiffs as a consequence of the hazard potential inherent in the plant.

However, Jochimsen was contradicted by one of the experts he had invited, the Frankfurt lawyer, Professor Steinberg. Steinberg described the **discretion to withhold** further permits as being very limited, for "the seventeen partial construction permits granted earlier assume a legally binding character." Moreover, Steinberg regarded the discretion of the State to be limited by the right of the Federal Government to issue instructions. These legal arguments played a major role in the subsequent development of the licensing procedure for the Kalkar Nuclear Power Station [183, 184].

Eighteen months later, the **Energy Advisory Board** of the SPD Federal Executive Board under its Chairman Jochimsen decided on April 28, 1986 - shortly after the Chernobyl accident, but without yet having learned about it - on an amendment to the German Atomic Energy Act. In that amendment, the support granted to nuclear power was to be deleted, and the liability limit was to be increased drastically; furthermore, reprocessing and the use of plutonium were to be banned. For the breeder, this meant in concrete terms: "Even if the operator, against all expectations, were to succeed in coming to grips with the technical problems, this type of reactor will be stopped by law." [185].

The accident in the fourth unit of the Chernobyl Nuclear Power Station provoked a drastic change in the situation: For the first time the public realized, no longer on the basis of theoretical risk analyses but as a hard fact, that large-area contamination and enforced evacuation of the population is possible as a consequence of a grossly deficient way of handling nuclear power. The breeder now came under severe attack, especially because its opponents suggested a technical relationship between the Kalkar Nuclear Power Station and the Chernobyl unit, which had been of the RBMK 1000 type, for instance by referring to the burnable substances, sodium and graphite.

For the line of arguments pursued by the SPD at that time it was only logical that the largest opposition party, at its **Party Convention** in Nuremberg on August 27, 1986, followed a proposal by a Preparatory Committee under Hauff and Jochimsen and decided to opt out of nuclear power within ten years. Hesse State Minister President Börner was one of the few people who dared oppose this trend, albeit in vain, by confessing: "I have always been in favor of nuclear power, and I will remain that way." [186].

The political uncertainty engulfing the breeder finally also extended to the FDP coalition partner. In March 1987, after the federal elections (which had been won), the FDP demanded in the government negotiations that the benefit to research policy of the SNR 300 be ascertained. The Swiss company, **Motor Columbus**, was commissioned to write the expert opinion; its recommendations were submitted six months later [187, 188]:

(1) From the point of view of research policy, the SNR 300 should be commissioned speedily, because the real R&D benefit can be derived only from its normal operation.

(2) The SNR 300 should be operated over a long period of time so that all systems and components can be tested for endurance.

(3) The R&D program should be expanded to include also the burning of longlived nuclides.

The expert opinion by Motor Columbus thus had confirmed the main arguments raised by the Federal Government in its Energy Report of September 1986 [189].

In this connection, a **scandal** was created by a letter written by the Chief Executive Officer of the Badenwerk utility, Professor Guck, to the Minister President of the State of Baden-Württemberg, Lothar Späth, on August 11, 1988. In that letter Guck not only refused, on behalf of his utility, to make any contribution towards the costs of financing the holding phase for the SNR 300, but also vehemently argued against that Project's benefit to research policy [190].

Of course, the CEO could have expressed any opinion on the SNR 300, but Mr. Guck then happened to be the President of the Deutsches Atomforum, the German Atomic Industrial Forum, of many years. In that capacity, he had been untiring in convincing the participants in the Annual Nuclear Technology Conferences of the necessity to build the Kalkar Nuclear Power Station. Many engineers, especially the members of the Kerntechnische Gesellschaft (KTG), felt deceived by these written statements of their officer, Guck, and it is certainly no coincidence that participation in the Conferences showed a marked decline from then on.

Many dark clouds of party politics had obscured the Project in 1984 - 87. However, there was a silver lining on the horizon in the legal field: In the **ruling** by the Düsseldorf Administrative Court in April 1984, the actions brought by the farmer, Josef Maas, of Kalkar-Hönnepel against all licensing decisions up until 1982 were dismissed in the first instance. Oral proceedings revolved around the question of the potential development of an assumed excursion accident and the resultant release of mechanical energy. The experts invited (W. Maschek, KfK, and A. Scharfe, GRS) convinced the court with their consistent statements. The explanation of the court ruling consequently reads:

> "To demand more, a consistent mechanistic description not relying on probabilistic assumptions with uncertain estimates at any point, would be ignoring the limits to human perception and, consequently, cannot be demanded by a court of law either." [191].

9.2 Permit Refused at Press Conference

The increasingly more difficult **political situation** had clearly negative impacts upon the granting of the remaining partial permits under the Atomic Energy Act approximately from 1984 on. In accordance with the speedy completion of construction work at Kalkar, the following partial permits were expected:

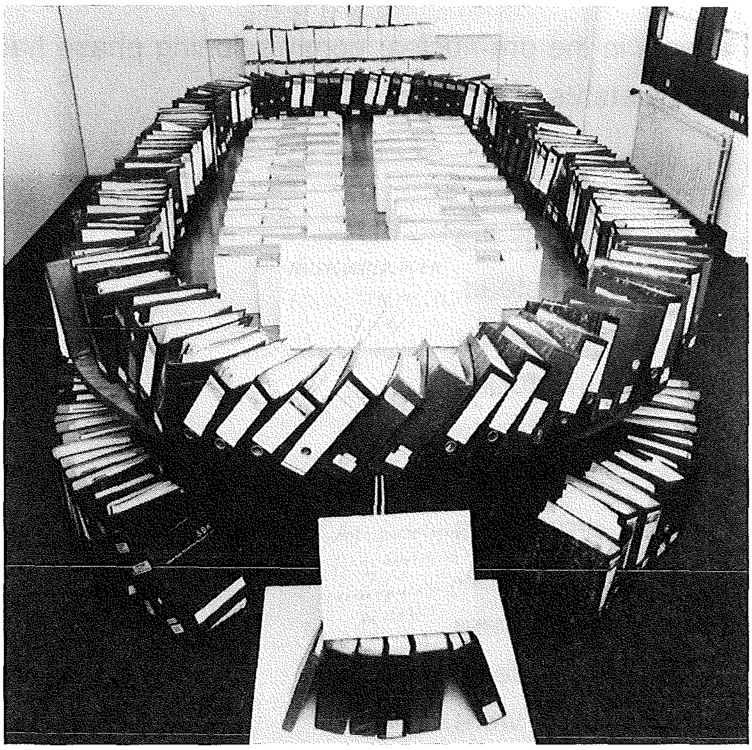
(1) Mid-1983: Partial Permit TG 7/4(2) for minor supplementary construction measures.

(2) Early 1985: Partial Permit TG 7/6 for storage of the core elements.

(3) Mid-1986: Partial Permit TG 7/7 for nuclear commissioning and permanent operation.

Already the relatively minor TG 7/4(2) turned out to be very lengthy in processing and, for practical reasons, had to be subdivided into two permit decisions, TG 7/4(2) and 7/4(3). TG 7/4(2) was granted in June 1984; activities concerning the other part extended into the time of the North Rhine-Westphalian State Parliamentary elections in which the ability, or willingness, of the authority to act appeared to be clearly diminished [192].

In October 1985, finally, also Permit 7/4(3) was granted, albeit with a rider of seven pages of very politically sounding reasons for **immediate execution** and the preliminary **positive overall assessment**. This seemed to be indicative of a stronger political influence on the way in which future licensing procedures would be handled. For the reasons explained below, the 7/4(3) decision has remained the last permit granted to the Kalkar Nuclear Power Station.



The documents filed with the application for Partial Permit 7/4
(in the foreground, the corresponding documents for Partial Permit 7/1).

The application for Partial Permit **TG 7/6** for storage of the core elements had been filed in June 1983; the positive expert opinion had been submitted in the spring of 1984, and a permit decision was expected to come forth in the autumn of the same year. However, this timetable was delayed because of the public inquiry held in Wesel, as described above, and - a new experience - because the authority allegedly was unable to process it alongside TG 7/4(3). In the course of the deliberations resumed in late 1985 it became more and more apparent that the MWMT considered this licensing step an operating permit and, consequently, demanded broader-based preconditions, also in the fields of fire protection and sodium leakages.

In mid-1986, Minister Jochimsen, who was responsible for the proceedings, surprisingly stated at a **press conference**, before informing the applicant, that the preliminary positive overall assessment required for any permit could no longer be expressed for the Kalkar Nuclear Power Station. Nine months earlier, this had still been possible. The reasons he cited included these:

(1) There were similarities between the Chernobyl reactor and the SNR 300.

(2) Earlier Bethe-Tait analyses were not reliable.

(3) Technical events in the pre-nuclear commissioning phase had raised doubts about the quality status of the plant [193].

State Minister Jochimsen, SPD, refused to grant the operating permit for the SNR 300.

The applicants were never able afterwards to discuss these points with the authority in an unbiased way. Instead, the same Minister organized another **press conference** in April 1987, telling the public about his intention to even refuse Partial Permit TG 7/6 [194]. He more or less used the same arguments as before; on top of that, the installations protecting against sabotage were to be raised to the final operational level even before any fuel elements were stored. Administrative interim solutions, such as intensified surveillance - a customary practice during revision outages in all nuclear power plants -, were not permitted. As in the case mentioned above, the formal letter from the MWMT arrived a few days after the press conference, when all the media had long since published their reports, and the applicant, SBK, had no chance of achieving comparable publicity with its comments [195, 196].

In the subsequent stage, SBK, in agreement with BMFT and BMU, took the **storage of fuel elements** out of the application volume for Permit 7/6 and instead made it part of Operating Permit TG 7/7, hoping that the procedure might be restarted in this way. Downsized TG 7/6 now was a mere construction permit; its volume amounted to 1 - 2% of the total construction volume.

Nevertheless, the authorities did not go ahead in examining the subject matter. They had taken nearly eight years to move from the application date (1983) to the discontinuation of the Project (1991); this was more than the expert examination of the entire process engineering part of the SNR 300 had taken, including the decisive engineered safeguards problems, which had been covered in six years prior to 1982. This dragging of feet over Partial Permit TG 7/6, together with the Bethe-Tait complex, was the final reason why the Federal Minister for the Environment issued an instruction in April 1988, against which the State, in turn, had filed suit with the Federal Constitutional Court.

Only for the sake of completeness, mention should also be made of Operating Permit **TG 7/7** which, of course, was never issued either. It had been applied for in April 1984; the expert opinion had been submitted in the spring of 1986 together with a positive overall assessment.

A major reason for the long time taken for expert evaluation after the political change in the State of North Rhine-Westphalia was the ineffective way in which the authority now commissioned its experts. The **commissioning procedure** frequently took many months before the expert thus hired was allowed to start working. When an expert opinion had been completed, there was an acceptance procedure just as cumbersome, the so-called reading, which covered several months or even years, as the MWMT often asked for a large number of so-called amendments.

Also the switch from experienced experts to relative newcomers ordered by the authority contributed to the long delays. For example, the Gesellschaft für Reaktorsicherheit **(GRS)** should be mentioned which, for many years, had been the expert consultant investigating the difficult problems associated with the Bethe-Tait accident. When GRS in the autumn of 1986, after the political change in North Rhine-Westphalia, had arrived at a clearly positive evaluation of this accident in the expert opinion about operation of the SNR 300, it abruptly ceased to be the expert consultant called in, and further expert opinions were commissioned from Elektrowatt-Ingenieurunternehmung Zurich/Mannheim **(EWI)** which, at that time, had hardly any expertise in the field it had been invited to. The new expert consultant took almost one year to familiarize with the complex subject matter new to them. Other experts, coming from an anti-nuclear group associated with the University of Bremen, were of dubious scientific qualification and reputation, quite aside from the superfluous, expensive duplication of effort caused by the licensing authority.

9.2.1 Comments by TÜV and RSK

The negative public comments made by Minister Jochimsen about the technical safety of the SNR 300 had aroused the attention of the CDU, the opposition party in the North

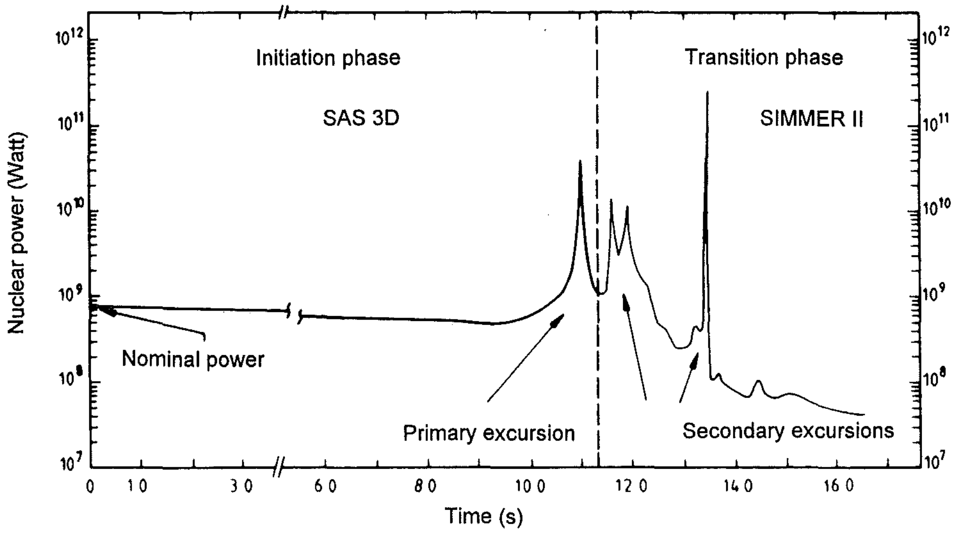
Rhine-Westphalian State Parliament. Its Chairman, Worms, asked the Chief Expert Consultant, the Rhineland Technical Inspectorate (Technischer Überwachungs-Verein Rheinland e.V.), for information. The Chairman of the Board of that TÜV, **Professor Kuhlmann**, followed the request in a personal letter of six pages in August 1986 with a clear comment on the five main points of contention, namely the Bethe-Tait accident, in-service inspections, a quality assurance system, the Chernobyl accident, and the waste management aspect [197].

On the Bethe-Tait accident, it was stated in the letter that the manufacturer had taken a number of additional technical measures, although that accident had no impact on the design basis because of its low probability. The author of the letter found the comparison of the SNR 300 with the Chernobyl reactor "superficial," because of the very different physical modes of operation and the technical state of both reactors. In summary, Kuhlmann arrives at the assessment that

> "no reasons of technical safety exist which would oppose commissioning the SNR 300 ... In my view, this no longer is a technical matter; it is a political decision."

Also the German **Advisory Committee on Reactor Safeguards** (Reaktorsicherheitskommission, RSK) in April 1987 duly investigated the comparison of the RBMK 1000 Chernobyl reactor with the SNR 300. It found major differences between the two reactors in nearly all design aspects. This was true especially of the reactivity behavior: The SNR 300 was characterized by its good controllability, while the RBMK 1000 showed unstable behavior and complex physical dependencies. In all major safety-related respects, such as redundancy, diversity, level of automation, and safety margins, the protection and scram systems of the SNR 300 were found to be clearly superior. In the **RBMK 1000**, there were no measures which could be taken to contain the damage in case of an excursion, while the SNR 300 had the primary system and the containment with high protective functions. Finally, the consequences of the Chernobyl accident were aggravated by the exothermic process of the graphite fire while, in the Kalkar Nuclear Power Station, the inerted containment and the steel liner would reliably prevent major fires. Finally, the RSK found that an accident in which all barriers would be destroyed, as in Chernobyl, could never happen in the SNR 300 [198, 199].

The **Bethe-Tait accident** was the subject on which the RSK organized a special meeting on September 30 - October 1, 1987 attended by national expert consultants and international experts from France, the United Kingdom, Japan, and the United States of America. The meeting was called because, despite the positive opinion about commissioning the SNR 300 the RSK had expressed in February 1986, the licensing authority had felt that there were still some open questions about the initiation phase and about recriticalities. The **international** experts agreed that Bethe-Tait accidents of the type discussed for the SNR 300 were attributed to the residual risk in their countries. They also confirmed the experimental verification of the SAS 3D computer code used to treat the initiation phase (D. Struwe and P. Royl, KfK). With regard to the recriticality accident, the RSK experts stated that its mechanical energy potential remained far below the design level of 370 MWs. As far as the use of the **SIMMER code** was concerned, the participants argued that, at its present state of development, this computer code was not yet a suitable instrument to be used in a licensing procedure under the Atomic Energy Act. Consequently, the hearing of international experts confirmed earlier statements by the RSK on this subject[200, 201, 202].



Typical curve of nuclear power in a loss-of-flow accident.

9.3 Stagnation on Site

Construction of the Kalkar Nuclear Power Station, for purposes of contractual definition, was completed in May 1985 after the primary system had been filled with sodium. By mid-1986, the functional tests of all systems individually (F1 phase) and the functional tests of the systems combined (F2 phase) had largely been concluded. The plant status, i.e. construction and commissioning activities, had reached a 95% level of completion [203].

Also most of the major unplanned additional activities recognized to be necessary in the phase of pre-nuclear commissioning had been completed by late 1986. Under this heading, the **events** already mentioned above should be recalled:

- Recovery of the broken vibration measurement lance.
- Upgrading of the sodium dump tanks.
- Redundant cabling and fire protection measures.
- Removal of granulate moisture.

They had had a major impact on the speedy decrease of personnel originally planned [204].

When it became evident in the spring of 1986 that Partial Permit TG 7/6 for the delivery and storage of fuel elements, which had been applied for in mid-1983, would not come forth in the near future, the owner, SBK, and the main contractor, INB, took decisive measures to reduce **Project costs**. As the delays in the permit procedure clearly were not based on technical reasons, the BMFT made available interim funds of DM 84 million to cover the so-called "delay phase" between mid-1986 and the spring of 1987, during which no money was spent out of the Project budget.

But even after that period was over, the licensing situation had not improved; it was still not possible to see when TG 7/6 would be issued. The parties to the Project now decided on drastic cuts in current Project costs. Within the framework of a "minimum model phase" a **plant operations pool** was set up under the leadership and responsibility of INB, to which staff members of the plant operations group of SBK and of the commissioning team of INB were delegated. The clear separation of duties of the owner and the prime contractor, normally observed very strictly, had been given up in this area. This measure allowed personnel on the construction site to be reduced and, in this way, operating costs to be cut. The plant operations pool, above all, was required to run the main heat transfer systems in the recirculation mode; these systems made up nearly 80% of the whole plant. Draining or even freezing the sodium could not be risked, as the resultant systems state would not have been under sufficient technical control because of corrosion and shock stresses.

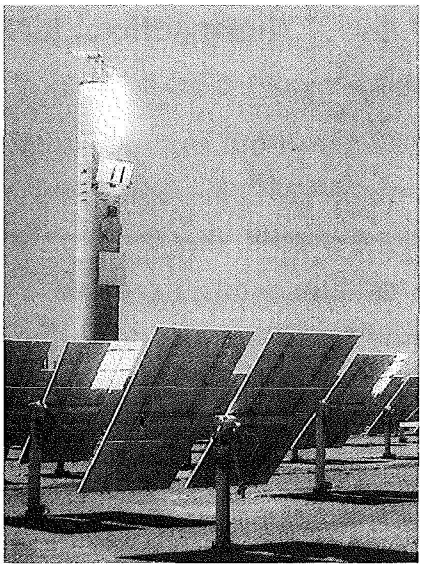
In early 1988, a **"holding phase"** (1988) and, from 1989 on, an **"extended holding phase"** till the end of 1991 were defined, which were financed one third each by the BMFT, various German electricity utilities, and Siemens. The necessary funds amounted to DM 105 million a year. The financial participation by the utilities (RWE, Bayernwerk, PreußenElektra) and by Siemens AG was made in the expectation that it would be possible again, in a foreseeable time frame, to meet with the licensing authority for factual debates with a certain objective in mind, at which the questions raised could be solved without external pressures [205, 206].

9.3.1 Events in Kalkar and in other Plants

Judged by the complex structure of the SNR 300 prototype facility and the comparatively narrow background of experience, only very few major disturbances arose in pre-nuclear commissioning between 1985 and 1991. As a consequence of the sodium fire on the roof of the reactor building in November 1984 and the ensuing public and political criticism, special reporting criteria and procedures were agreed upon with the Supervisory Authority. Besides major events, such as the break of the vibration measurement lance, now also the fire of a refuse container or the damage to the outer fence caused by a protest campaign of nuclear opponents were reported to the authority.

Much more important were special **events in other plants**, which were collected and passed on by GRS and had to be analyzed for their relevance to the Kalkar Nuclear Power Station by INB and the Technical Inspectorate [204].

At the experimental solar power station in **Almería**, Spain, a sodium fire had occurred during an inexpert repair of the sodium system in August 1986, as a consequence of which the plant was practically destroyed. The main reason for the impact of the fire was the intense spraying of sodium ejected from the system and the relatively large surface area this produced. The reaction with oxygen generated very high temperatures (above 1000 °C), which caused the surrounding steel structures to melt down.



The Almería solar power plant with a tower and radiation collectors.

The phenomena to be expected in the Kalkar Nuclear Power Station were quite different. Extensive analyses showed that a comparable accident would have taken a very different turn, with regard both to its origins and to its development, in the Kalkar Nuclear Power Station and would have been controlled with the measures and means available.

Another major external event was the steam generator accident in a superheater of the British **PFR** prototype reactor, which had caused 40 bundle tubes to fail. As the intermediate heat exchanger, as a containment boundary, had not been damaged, no direct hazard to plant safety had arisen. Later studies showed that the event had been caused primarily by vibrations of a few bundle tubes, which had given rise to steam leakages, producing pronounced superheating of the adjacent tubes and, finally, overpressure failure.

For several reasons, this cause of an accident could not be extrapolated to the Kalkar Nuclear Power Station. On the one hand, prototype experiments in the test facility at Hengelo had shown that the SNR 300 steam generators were not susceptible to vibrations. On the other hand, the Kalkar equipment was monitored for leakages more reliably, which would have caused early shutdown on the steam side. Also the in-service inspections demanded at Kalkar would have indicated any attrition of wall thicknesses reliably and in time.

9.4 Instruction, Litigation, Judgment

It had become evident finally, after the two press conferences held by Minister Jochimsen, MWMT, in June 1986 and May 1987 and the letters by the authorities following those events, that the project of the Kalkar Nuclear Power Station had bogged down in a profound crisis created by political forces. The licensing preconditions had been broadened considerably, the preliminary positive overall assessment was jeopardized, and the storage of fuel elements had been delayed indefinitely. In addition, the comparison of Kalkar with Chernobyl, and the "recalculations" of the Bethe-Tait accident by nuclear opponents upon invitation of the authority increasingly developed into bones of contention between the MWMT and the applicant.

On April 27, 1988, the Federal Minister for the Environment, Professor Töpfer, sent a **letter of instructions** to the MWMT with these statements, among others:

> "... In the supervisory statements by the Federal Government you were informed of certain legal viewpoints in the licensing procedure for the Kalkar Nuclear Power Station. In view of the failure to reach agreement on these issues I feel compelled to instruct you, pursuant to Article 85, Sec. 3 of the Basic Law, to observe the following points in the continued licensing procedure:
>
> My views about the preliminary positive overall assessment and the justified interest pursuant to Sec. 18 of the Regulations on Nuclear Proceedings as well as about the binding effect and the guarantees for continued existence shall constitute the basis of the licensing procedure.
>
> The Advisory Committee on Reactor Safeguards evaluated the Chernobyl accident with a view to its importance to the SNR 300; I concur with that evaluation. As a consequence, no more expert opinions shall be commissioned ..."

In issuing these instructions, the BMU had told the State authority how to continue the licensing procedure. The instructions had the character of guiding principles determining further proceedings and constituted the framework for further decisions on the subject matter. The actual licensing procedure was to be continued, not cut off. A federal supervisory statement was announced in connection with the treatment of the Bethe-Tait accident [207, 208].

The proponents of the Kalkar Nuclear Power Station welcomed these instructions to the MWMT; there were quite a few who felt they should have been issued a year earlier. However, the initial assumption that this would speed up the licensing procedure was erroneous. Proceedings dragged on for nearly six months, and one day before the legal deadline for raising objections had expired, the North Rhine-Westphalian State Government responded by bringing **action** before the Karlsruhe Federal Constitutional Court. In its application for a declaratory judgment it argued that the Federal Government, in issuing instructions, had violated the independence of the State; the instructions were out of proportion, not sufficiently well defined, and unduly backed the opinion expressed by the Advisory Committee on Reactor Safeguards.

On February 20, 1990, the parties met for **oral proceedings** before the Second Chamber of the Federal Constitutional Court under Vice President Mahrenholz. Minister Jochimsen as the first speaker felt that the inviolable core of the independent status of the states in a federation was at stake, and emphatically argued the point of his State Government. Federal Minister Töpfer, in turn, invoked the danger that the practical execution of the Atomic Energy Act could develop in different directions. These proceedings had to determine a way for the Federal Minister of the Environment to enforce his decision by federal supervision; otherwise the instrument of instruction was a blunt sword.

The 2nd Chamber of the Karlsruhe Federal Constitutional Court
decided in favor of the SNR 300
(4th from left: Vice President E. G. Mahrenholz).

The interest of the judges concentrated on the specific ban on commissioning another Chernobyl expert opinion, which the State described as a ban on thinking, while the Federal Government referred to it as a measure taken to prevent duplication of expert consultant effort. The agitated arguments by an official from the middle level of the MWMT who, repeatedly interrupting the presiding judge, tried to connect all and sundry technical features of the SNR 300 with the Bethe-Tait accident and, when asked to give factual reasons for commissioning another Chernobyl expert opinion, made a most helpless impression, were noted with surprise by experienced court observers [209].

The **judgment** by the Federal Constitutional Court was pronounced on May 22, 1990 and was impressive in its clarity. The result, in a nutshell, was this: The action brought by the State was dismissed in all respects; the Federal Government had been correct in exercising its power to issue instructions; the instruction had been clear and contained a reliable guidance of proceedings; in addition, the Federal Government had given the State ample opportunity before to express its comments.

The Karlsruhe judges based their decision mainly on the character of federal administration by commission pursuant to Article 85 of the Basic Law. This allows the Federal Government at any time to intervene in proceedings and instruct the State to do or omit certain things. The responsibility in substance for assessing the subject matter, which the court called **technical competence**, can be claimed by the State only subject to its being exercised by the Federal Government; this implies that the Federal Government may, at its own discretion, exercise this competence at any time. On the other hand, the so-called **competence of performance** rests with the States, i.e., acting against third parties, such as applicants or objectors. Administration by commission of the Federal Government thus moves in a strict hierarchical relationship: The State is bound to obey the instructions by the Federal Government, unless the Federal Government were to make absolutely irresponsible demands. Whether such instruction is useful, appropriate or legal, is not for the State to comment on; this is the sole responsibility of the Federal Government [210], [211].

The SNR 300 judgment by the Federal Constitutional Court soon acquired fundamental importance in the relationship between the Federal Government and the State Governments also in other licensing procedures under the Atomic Energy Act.

9.5 Kalkarization according to the Letter of the Law

Anybody believing that the licensing procedure for the SNR 300 would be afloat again after the BMU instruction of April 1988, soon had to admit failure. Processing of Partial Permit **TG 7/6**, though that permit had been shrunk to a minimum, did not make headway at all. However, precisely this partial permit was of major strategic importance, less so because of its technical contents, but rather because of the preliminary positive overall assessment renewed in this way. Even a scaled-down 7/6 Permit would have demonstrated that the political blockage had been overcome.

The delays in the licensing procedure resulted from daily **activities at administrative level**; a few examples will illustrate this point [212] :

1. Points long since decided in earlier permits were reopened as a result of "general concern" and used as an excuse to commission new, extensive expert opinions. (One of the applicants aptly called this "mice playing games of tennis.")

2. Technical events in Kalkar and in other facilities (such as Almería, Dounreay, Chernobyl, etc.) were used as a pretense for reopening the debate about the basic principles of the SNR 300 safety design and justifying further commissioning of expert opinions.
3. Expert consultants were chosen who, up to that point, were not sufficiently familiar with the licensing procedure of the SNR 300 (such as EWI); as a consequence, much time was needed for familiarization, which delayed the Project even further.
4. Persons were even nominated as experts who, in past court proceedings, had acted as consultants on the plaintiffs' side and had publicly appeared as agitators against nuclear power; consequently, their neutrality and seriousness in writing expert opinions about the Kalkar Nuclear Power Station could be seriously doubted.
5. Finally, the expert opinion phase proceeded without any traceable checks of management or timetables; MWMT kept adding more and more new problems, thus causing enormous delays.

Under the German Atomic Energy Act, the licensing authority has practically unlimited scope of discretion in decisionmaking. Consequently, the MWMT was right in maintaining again and again that it acted **"in accordance with the letter of the law."** The weekly "Die Zeit" more aptly called this feet dragging technique **"kalkarization"** [213, 214].

It is not really worthwhile speculating whether this approach by the administration was the result of a political directive or whether the civil servants were merely unwilling or perhaps even incapable. Anyway, the practical results achieved at the MWMT working level were quite in line with the political intentions of that authority and of the whole State. The corresponding decisions to halt the Kalkar Project had been taken by political bodies of the State of North Rhine-Westphalia in 1985/86.

In German legal terminology, this is now described by the term "execution of the law with the intention to opt out" (ausstiegsorientierter Gesetzesvollzug) [215]. Professor Horst Sendler, the former President of the Federal Administrative Court in Berlin, defines it in this way:

> "The application of law in a way which results in non-applicability ... Or, in a nutshell: non-execution through execution."

He compares this attitude with the "go-slow policy" occasionally adopted in collective bargaining issues in the public sector, and continues:

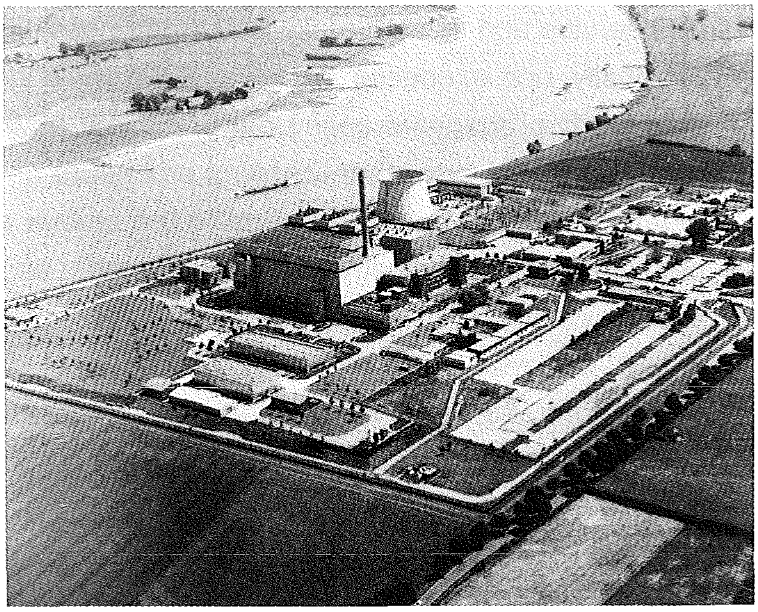
> "But in contrast, execution of the law with the intention to opt out means that the civil service and its staff make use of the possibility to bypass execution of the law by busily non-executing it ... Therefore, it is not necessarily a contradiction if somebody propagates opting out of nuclear power, openly declaring the intention to not complete any other licensing procedure and, at the same time, asserts that, legally speaking, one was bound to the criteria of the Atomic Energy Act ... coupled with the announcement, probably meant as a threat, ... that the law would be applied strictly." [216].

Fritz Ossenbühl, a colleague of Sendler's, calls a spade a spade in formulating his definition:

> "Obstruction under the guise of legality." [217].

But let us return to the SNR 300 Project. The possibility was considered repeatedly to take **legal steps** against the State authority in order to regain the initiative in the licensing procedure. Among the few possibilities available to do so, an action for inactivity pursuant to Sec. 75 of the Administrative Court Rules of Procedure could have been brought (followed by stipulating an appropriate deadline), or an action against the costs charged for expert opinions not actually required. In the latter case, steps could have been taken against a specific decision. However, for discretionary reasons none of these legal steps could be taken before the Federal Constitutional Court had ruled. And even afterwards, lengthy court proceedings of more than two or three years had to be expected, which would be accompanied by a *de facto* standstill of the licensing procedure.

Even now, outsiders failed to detect a general concept of the BMU in managing the licensing procedure as an act of **federal supervision** it had been entrusted with. Although the Karlsruhe court had handed the Minister for the Environment an effective instrument ("Töpfer's Sharp Sword" - see [211]), no visible progress was made in the Project. Many parties expressed the wish that the BMU establish a competent technical working party in order to be able, in this way, to exercise tighter control, technical and also of the timetable, over the corresponding groups at the MWMT. This would have had the advantage of indicating in the very early stages whenever a point of fact was about to become the nucleus of an inflated problem, for instance, by being handled by more than one expert consultant and the like.



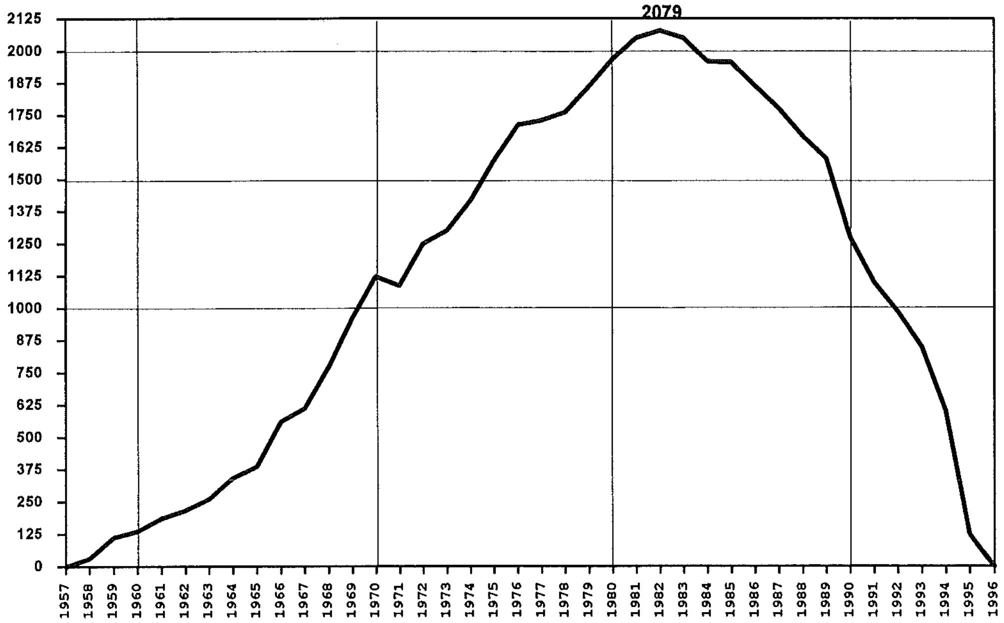
View of the Kalkar Nuclear Power Station
after completion of the prenuclear commissioning phase.

Unfortunately, there was no such support by federal supervision. Consequently, the parties to the Project met again in mid-1990 to strike a balance. The lawsuit before the Federal Constitutional Court had been won, but the Project nevertheless had not progressed in any way. No further instructions by the BMU in points of dispute were to be expected in the near future, and probably would not have helped anyway. After all, it is impossible in the long run for the Federal Government and the executive to communicate by instructions. Conversely, there is every reason to make sparing use of the right to issue instructions.

Meanwhile, the **financial problems** of the SNR 300 had become more and more urgent. As the funds tiding over the holding phase expired in 1991, the way had to be paved for further financing, if any, as early as possible and not later than by the end of 1990. But in the absence of any progress in the licensing procedure, and in the absence also of a firm commissioning date, the providers of funds could hardly be expected to make available another amount in excess of DM 100 million per year mainly for waiting, all the more so since residual financing of the Project was still open.

Another, political problem emerged: Federal elections had been scheduled for December 1990. In view of the recognizable volume of funds required for German unity, it was not at all certain whether the FDP, even the CDU/CSU, Members of Parliament would vote in favor of spending more millions on Kalkar - provided, of course, that the present government coalition was reelected.

The SNR 300 was doomed.



Personnel development at Interatom (and Siemens, respectively), Bensberg, between 1957 and 1994.

9.6 The End

After a preparatory round of discussions on January 9, 1991, Federal Minister for Research Riesenhuber invited the representatives of the three electricity utilities, RWE, PreußenElektra, and Bayernwerk, as well as Siemens to the decisive round of talks on March 20. In the light of the situation, the parties agreed that, because of the attitude of the State of North Rhine-Westphalia, a successful completion of the licensing procedure for the Kalkar Nuclear Power Station no longer was to be expected. To avoid unnecessary additional costs, therefore, it was decided in accordance with the rules of the Holding Phase Agreement to provide no more funds; this meant the end of the Project. Discussions with the Governments of the Netherlands and Belgium were to be held immediately.

The participants agreed in their finding that the breeder option was to be preserved by continuing the European Breeder Association within the European Fast Reactor, EFR [218].

Although construction and prenuclear testing of the SNR 300 had generated important knowledge for fast breeder development, the most significant goal, operation of the SNR 300, was not achieved for political reasons. Effective April 10, 1991, SBK and the main vendors terminated their delivery contracts as a consequence of that decision.

A press release by the BMFT on March 21, 1991 succinctly notes:

> "The responsibility for the end of Kalkar,
> thus the participating utilities, the vendor, and the BMFT,
> clearly lies
> with the **State of North Rhine-Westphalia."** [219].

1993: The remnants of the experimental sodium facilities at Interatom, Bensberg described on pages 69 and 70.

Veniet tempus, quo posteri tam aperta nos nescisse mirentur [220].

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Translation:

The time will come
when our descendants will be surprised
that only now we have recognized
such foregone conclusion.

CHRONOLOGY

1955

Aug.	First United Nations Conference about the Peaceful Uses of Atomic Energy held in Geneva.
Oct.	German Federal Ministry for Atomic Affairs (BMAt) established; F.J. Strauß (CSU) appointed Minister.

1956

July	Karlsruhe Reactor Center established; Kernreaktor Bau- und Betriebs GmbH founded.
Oct.	S. Balke (CDU) succeeds F.J. Strauß as Minister for Atomic Affairs.
Dec.	State Parliament of North Rhine-Westphalia decides to establish a research center; later, Jülich is chosen as site.

1957

March	Agreements founding the European Atomic Energy Community signed.
Aug.	Construction of FR 2 begun.
Oct.	Federal Ministry for Atomic Affairs renamed Federal Ministry for Nuclear Energy and Water Management.
Dec.	Topics associated with the fast breeder reactor begin to be taken up in the Federal Republic of Germany at a seminar held at the Institute for Neutron Physics and Reactor Engineering (INR) of the Karlsruhe Nuclear Research Center.
Dec. 13	Interatom GmbH founded; Head Office: Duisburg.

1958

Jan.	European Atomic Energy Community (Euratom) founded; members are Belgium, Federal Republic of Germany, France, Italy, Luxemburg, the Netherlands.
Dec. 15	Interatom moves to Bensberg (Old Castle).

1959

June	Gesellschaft für Kernforschung (GfK) founded by Federal Government and State of Baden-Württemberg.
July	Soviet BR-5 experimental reactor attains full power.

1960

April 1	Fast Breeder Project (PSB) founded at the Karlsruhe Nuclear Research Center.
April	German Advisory Committee on Atomic Energy adopts Advanced Reactor Program.
May 15	Supervisory Board of the Nuclear Research Center approves Fast Breeder Project (PSB).
Dec.	Working Party III/1, "Nuclear Reactors," of the German Advisory Committee on Atomic Energy approves preliminary Fast Breeder Project at Karlsruhe for a period of three years.

1961

May	Supervisory Board of the Nuclear Research Center decides to intensify activities within Fast Breeder Project.
Oct.	EBR II (25 MWe) goes critical.
Nov.	Federal Ministry for Nuclear Energy and Water Management renamed Federal Ministry for Nuclear Energy.

1962

Nov.	In a report to the U.S. President, U.S. Atomic Energy Commission suggests long-term development program for fast breeder reactors.

Dec.	German Federal Ministry for Nuclear Energy renamed Federal Ministry for Scientific Research (BMwF); H. Lenz (FDP) appointed Minister after S. Balke.
Dec.	FR 2 reactor (12 MWth) at the Karlsruhe Nuclear Research Center begins full power operation.

1963

March	Construction of 5 MWth plant started at Interatom (sodium filling completed in late 1964).
May	Association Agreement with Euratom of the Karlsruhe Nuclear Research Center signed. It provides for expenditures for Karlsruhe Fast Breeder Project of DM 185 million over five years.
Aug.	Enrico Fermi fast breeder reactor (200 MWth, 60 MWe) goes critical.
Dec.	General Electric (US) awarded contract for Oyster Creek Nuclear Power Station; first commercial order for a light water nuclear power plant.

1964

Jan.	Gesellschaft für Kernforschung and Kernreaktor Bau- und Betriebs-GmbH merged.
May	Agreements on construction of SEFOR reactor signed, joint project of U.S. Atomic Energy Commission, General Electric (GE-USA), and Karlsruhe Nuclear Research Center (KfK).
Sep.	U.S. company, General Electric, declares publicly its confidence to be able to offer commercial fast breeder by 1974.

1965

June	Construction of 23 MWe Superheated Steam Reactor, HDR, begun, a boiling water reactor with nuclear steam superheating.
Oct.	G. Stoltenberg (CDU) succeeds H. Lenz as Federal Minister for Scientific Research (BMwF).

1966

March	Construction of 20 MWe sodium cooled zirconium hydride moderated KNK experimental power plant started at Karlsruhe Nuclear Research Center.

Oct.	Accident in Enrico Fermi fast breeder reactor (fuel meltdown).
Nov.	BMwF appropriates funds for project design of 300 MWe sodium cooled breeder by Siemens/Interatom, and 300 MWe steam cooled breeder by AEG, GHH, MAN consortium.
Dec.	SNEAK and MASURCA facilities go critical.

1967

Jan.	Project Committee established in Bonn.
July	German-Belgian-Netherlands-Luxemburg R&D Agreement (Government Agreement) signed.
Oct.	British scientists report about new measurements of plutonium alpha value.
Oct.	Na-2 Study presented by KfK (with contributions by industry).

1968

Jan.	Siemens/Interatom-Belgonucléaire-Neratoom Consortial Agreement signed.
April	AEG proposes to Fast Breeder Project Committee to terminate design activities for steam cooled breeder.
April	GfK-Siemens/Interatom Cooperation Contract for project design and R&D on 300 MWe sodium cooled prototype breeder signed.
June	Deliberations begin at Karlsruhe about possibility to discontinue Steam Cooled Breeder Project.
July	General Electric and East Central Nuclear Group (USA) announce discontinuation of 50 MWe steam cooled prototype fast breeder design work.
Dec.	Agreement signed with Belgium about joint German-Belgian use of BR 2 test reactor.
Dec.	Working Party III/1, "Nuclear Reactors," proposes to discontinue all work on steam cooled breeder.

1969

Jan.	Karlsruhe studies about technical and economic conditions of steam cooled breeder published.

Feb. 5	Industrial activities for steam cooled fast breeder reactor discontinued by order of Federal Minister for Research, Stoltenberg; Karlsruhe work on this reactor line scaled down.
April	AEG and Siemens pool power plant activities in joint subsidiary, Kraftwerk Union (KWU); because of existing licensing agreements, nuclear power plant activities initially excluded from merger.
Oct.	6th German Federal Parliament, SPD/FDP coalition (Chancellor: W. Brandt).
Oct.	Federal Ministry for Scientific Research (BMwF) renamed Federal Ministry for Education and Science (BMBW).
	H. Leussink (unattached) succeeds G. Stoltenberg as Minister.
Oct.	HDR reactor in Kahl (Main) critical.
Nov.	Future SNR 300 operators establish Projektgesellschaft Schneller Brüter (PSB).
Dec.	Soviet BOR 60 experimental breeder reactor goes critical.
Dec. 31	Presentation by SNR Consortium of SNR 300 Safety Report.

1970

March/Oct.	Application, under the Atomic Energy Act, for construction and operation of SNR 300 Nuclear Power Station at Weisweiler and Kalkar, respectively.
April	Fast Reactor Coordinating Committee (FRCC) established by Euratom.
May	Successful irradiation in DFR of 39 fuel rods typical of SNR completed; other joint German-British breeder research projects agreed upon.
Sep.	R&D Programs Working Party established.
Oct.	Memorandum about the prospects of gas cooled breeder reactors compiled by GfK, KFA, and industry; preceded in 1969 by agreement about exchange of gas breeder know-how between Siemens and Gulf General Atomic.
Oct.	Projektgesellschaft Schneller Brüter announces Kalkar as new site.
Nov.	Bundle irradiation tests for SNR 300 in French RAPSODIE experimental breeder reactor begin.

Dec.	Preliminary concluding report about Karlsruhe R&D activities on steam cooled breeder.

1971

Feb. 15	Status Report at Karlsruhe; public debate about reasons for abandoning steam cooled breeder line.
April	HDR reactor decommissioned because of fuel element failure.
May/Dec.	Revised Safety Report of Kalkar Nuclear Power Station presented by SNR Consortium.
May	First Agreement on Cooperation in the Breeder Field with Japan signed.
July	Memorandum of Understanding signed among manufacturers of SNR 300.
Aug.	SEFOR transient experiments conducted successfully.
Aug.	KNK reactor goes critical.
Oct.	Project Committee, after examination of technical maturity, recommends to build SNR 300.

1972

Jan.	K. v. Dohnanyi (SPD) succeeds H. Leussink as Federal Minister for Education and Science.
Jan.	German-Belgian-Netherlands Operators' Consortium, Schnell-Brüter-Kernkraftwerksgesellschaft mbH (SBK), founded.
Feb.	Federal Cabinet approves funding of SNR 300.
March 20	Public inquiry under the Atomic Energy Act about SNR 300 held in Kleve.
March	Governments of the Federal Republic of Germany, Netherlands, and Belgium decide to build SNR 300.
March/Nov.	First grants-in-aid paid to SBK.
May	Technical Inspectorate (TÜV) writes positive general opinion on SNR 300.
June	Advisory Committee on Reactor Safeguards takes positive final vote on SNR 300.
July	Bid for Kalkar Nuclear Power Station sent out to operators.
Aug.	KNK reactor generates electricity for the first time.

Oct. 12	Internationale Natrium-Brutreaktor-Bau-Gesellschaft (INB) founded as German-Belgian-Netherlands Vendors' Consortium.
Nov. 10	SBK awards power plant contract to INB.
Nov. 23	BMBW decides on grants-in-aid for Kalkar Nuclear Power Station.
Nov.	7th German Federal Parliament, SPD/FDP coalition government (Chancellor: Schmidt).
Dec.	Federal Ministry for Education and Science (BMBW) split into Federal Ministry for Research and Technology (BMFT) and Federal Ministry for Education and Science (BMBW).
	Responsibility for nuclear power rests with Federal Ministry for Research and Technology under H. Ehmke (SPD).
Dec. 18	Partial Permit TG 7/1 issued for basic concept and for reactor building up to ±0.00 m.

1973

March 19	Application filed under the Atomic Energy Act to obtain license for Mk. Ia reactor core in addition to Mk. I core.
April	Start of construction in Kalkar of SNR 300.
April	Nuclear Reactor Divisions of AEG and Siemens merged with Kraftwerk Union.
Oct. 30	Action before Administrative Court in Düsseldorf against 1st Partial Construction Permit.
Dec. 11	Partial Permit TG 7/1(1) issued for bottom sheet of steel shell.
Dec.	Convention signed by utilities in France, Germany, and Italy about construction of Superphénix and SNR 2.

1974

May	H. Matthöfer (SPD) succeeds H. Ehmke.
May 22	Partial Permit TG 7/2 issued for reactor building, remainder of the steel shell, D 2 steam generator building, building for auxiliary plants.
July 14	French PHENIX 280 MWe prototype breeder starts commercial operation.
Sep.	KNK reactor shut down for conversion into fast reactor, KNK II.

Dec. 12	Partial Permit TG 7/2(1) issued for cable ducts between steam generator buildings.

1975

May 5	Partial Permit TG 7/2(2) issued for auxiliary plants building (modification).
Aug. 1	Partial Permit TG 7/2(3) issued for D 0 and D 4 steam generator buildings, switching systems buildings, cooling water intake and discharge structures, secondary cooling water pipe, cavities, bottom troughs, platforms, and crane systems.

1976

Feb.	German-French Government Agreement signed on cooperation in breeder field.
April 15	Partial Permit TG 7/2(4) issued for reactor emergency cooling stack, cooling water pump structure.
Oct. 3	8th German Federal Parliament, SPD/FDP coalition government (Chancellor: H. Schmidt); H. Matthöfer reappointed BMFT.
Oct.	Construction activity reaches first peak: approx. 1200 persons work on site (700 persons in engineering).

1977

Jan.	Siemens takes over AEG interests in Kraftwerk Union.
Feb.	British 250 MWe PFR prototype breeder operated at full power.
April	U.S. President Carter announces new atomic energy program (no reprocessing, reduced breeder activities).
July	German-French Breeder Agreements signed.
Aug. 18	Münster Higher Administrative Court rules that Federal Constitutional Court be invoked to determine applicability of the Atomic Energy Act also to breeders.
Sep.	Report by BMFT about SNR 300 reevaluation published; confirmation expressed in September 1985.
Sep. 24	First major rally at Kalkar.
Oct.	Federal Parliamentary committees recommend political reservation about commissioning Kalkar Nuclear Power Station.

Oct.	KNK II goes critical.
Dec. 15	Partial Permit TG 7/2(5) issued for biological shield, crane facility for auxiliary plants wing, and for redundant Diesel air intake system.

1978

Feb.	V. Hauff (SPD) succeeds H. Matthöfer as BMFT.
March	New cost estimate of Kalkar Nuclear Power Station results in DM 3.2 billion.
Sep.	H.-L. Riemer, NRW MWMV, recommends to run SNR 300 as plutonium annihilation plant.
Dec. 8	Federal Constitutional Court finds licensing regulations in the Atomic Energy Act constitutional, and dismisses Münster court decision; file No.: BVerfG 2 BvL 8/77 ("Kalkar Ruling").
Dec. 14	Federal Parliament decides on reservation about commissioning SNR 300; Committee of Inquiry established to prepare decision.
Dec. 20	Partial Permit TG 7/3 issued for inerting systems, fuel element storage and handling (in part) including the associated instrumentation and control systems, electrical power installations, control room, reactor cell cover.

1979

March	8th Germany Federal Parliament establishes Committee of Inquiry 1, "Future Nuclear Energy Policy," to draft also recommendations on commissioning SNR (Chairman: R. Ueberhorst).
March	KNK II in full power operation (20 MWe).
July 18	Partial Permit TG 7/2(6) issued for the façades.
July	Lowest point in activity on construction site: < 400 persons.
Dec.	RSK recommends that reactor vessel be suspended in concrete structure.

1980

Feb.	American 400 MWth FFTF experimental breeder goes critical.
March	BMI Principles on Waste Management Provisions promulgated.
April	Report by ad hoc Group to Project Committee (causes of project delays).
April	Soviet BN 600 (600 MWe) breeder delivers electricity.
June	First report by Committee of Inquiry on Future Nuclear Energy Policy.

June 10	Partial Permit TG 7/3(1) issued for sodium secondary systems, gas systems, fuel element storage and handling (in part), cooling water systems, supply systems, treatment and disposal systems, electrical systems and instrumentation and control systems, reactor cell internals.
Oct. 5	9th German Federal Parliament, SPD/FDP coalition government (Chancellor: H. Schmidt).
Oct.	New cost estimate of Kalkar Nuclear Power Station results in DM 5 billion.
Nov.	A. v. Bülow (SPD) succeeds V. Hauff as Federal Minister for Research and Technology (BMFT).
Dec.	A. v. Bülow demands higher financial involvement of industry in Kalkar Nuclear Power Station.

1981

Jan.	Intergranular corrosion found in reactor vessel.
April	Federal Parliament establishes Committee of Inquiry 2, Future Energy Policy (Chairman: H.B. Schäfer).
Oct. 9	Partial Permit TG 7/4 issued for ventilation systems (excluding reactor building), core catcher, decay heat removal systems and secondary cooling water system for specific trains, reactor emergency cooling system, handling device.
Oct.	Federal Minister for Research v. Bülow appropriates additional DM 166 million, thus avoiding impending halt of construction of Kalkar Nuclear Power Station.
Oct.	International Breeder Report at Kalkar.

1982

Jan.	Upper Bound Study delivered to Committee of Inquiry by KfK.
April	Risk-oriented Study delivered to Committee of Inquiry by GRS.
April 30	Partial Permit TG 7/2(7) issued for steel shell.
July 28	Partial Permit issued for cooling tower.
July 30	Partial Permit TG 7/4(1) issued for well building, ventilation systems in reactor building, radiation protection instruments.

Sep.	New cost estimate for Kalkar Nuclear Power Station results in DM 6.5 billion.
Sep.	Positive vote by Committee of Inquiry; second report on completion and recommendation for commissioning submitted.
Sep. 22	Partial Permit TG 7/5 issued for reventing system, emergency power systems, reactor vessel with internals, rotating shield system, primary and secondary systems, reactor protection system.
Oct.	Switch of government in Bonn ("Wende"); H. Riesenhuber (CDU) succeeds v. Bülow as Federal Minister for Research; Chancellor: H. Kohl.
Dec. 3	Reservation about commissioning SNR 300 as expressed by Federal Parliament lifted with CDU/CSU and FDP votes.
Dec.	Interim financing by new Federal Government.
Dec.	Considerably increased activity on site.

1983

Jan.	Lurgi hired for project control.
Jan. 28	Mk. I core withdrawn from proceedings under the Atomic Energy Act for Kalkar Nuclear Power Station.
April 4	New Federal Cabinet decides to increase funding for construction and commissioning SNR 300 (and THTR).
June	Documents filed for storage of core elements.
June	ARGO Study Group established in Paris.
Oct.	Belgian and Netherlands partners limit their financial contribution to Kalkar Nuclear Power Station.
Dec.	Peak activity on site: 3300 persons.
Dec. 31	Accident Directives promulgated by BMU.

1984

Feb.	Documents filed for operating permit for SNR 300.
March	Positive expert opinion presented on fuel element storage.

March 14	SPD motion to amend Atomic Energy Act.
April 10	Düsseldorf Administrative Court: Action by Maas against TG 7/1-7/5 dismissed.
May 17	SPD Convention in Essen: Nuclear power to be used only for limited interim period.
June 6	Government Agreement about Cooperation on Sodium Cooled Breeder Reactors signed by Germany, France, and the United Kingdom.
June 20	Partial Permit TG 7/4(2) issued for various technical plant modifications.
Oct.	SPD State Convention in Oberhausen: Commissioning SNR 300 refused.
Oct.	Positive result of SNR 300 containment pressure test.
Dec. 4-6	Public inquiry in Wesel about Mk. Ia modification.

1985

May	Construction of Kalkar Nuclear Power Station completed, sodium filled into the main system.
May	Non-nuclear commissioning begins.
May	NRW Minister President J. Rau writes to Federal Chancellor H. Kohl: fundamental objections to breeder technology and SNR 300.
May 12	State Parliamentary elections in NRW; absolute SPD majority; Minister F. Farthmann, hitherto responsible for SNR permits, becomes Chairman of SPD Parliamentary Group; Minister of Economics, R. Jochimsen (MWMT), is given responsibility for licensing the Project.
May	Brief halt of SNR 300 fuel element fabrication at Alkem/RBU.
June	SBK and CEA sign reprocessing agreement for SNR 300 fuel elements.
July	Farthmann demands to refrain from kindling "hell fire of Kalkar" ("Spiegel" interview).
Aug.	Vessel upgrading in Kalkar.
Aug.	All fuel elements for SNR 300 fabricated.
Sep. 7	1st criticality of Superphénix.

Sep.	Comment by Federal Government to NRW State Government: Kalkar operation feasible from safety point of view, spent fuel and waste management ensured.
Sep. 28	SPD State Convention in NRW opts for terminating development of fast breeder technology.
Oct. 3	Partial Construction Permit TG 7/4(3) issued "according to letter of law" by NRW Minister Jochimsen; strange comments on immediate execution and preliminary positive overall assessment.
Oct. 8	SPD Executive Council against continuation of breeder technology; at the same time, refusal of construction of Wackersdorf Reprocessing Plant.
Oct. 16	Expert hearing before North Rhine-Westphalian State Economics Committee.
Oct.	SNEAK facility at Karlsruhe decommissioned and converted into tritium laboratory.
Dec. 12	Münster Higher Administrative Court dismisses action for cancellation.
Dec.	Cables rerouted in SNR 300.

1986

Jan.	Expert opinions (12/1 and 12/2) about operation of SNR 300 published.
Jan. 13	All Permits (7/1 to 7/4(3)) legally binding with waiver of appeals proceedings by plaintiff.
Feb.	Positive RSK recommendation of first step in operation (loading).
April 26	Chernobyl accident.
May	German Federation of Labor (Deutscher Gewerkschaftsbund, DGB) votes against Kalkar.
May	Kalkar Nuclear Power Station ready to take in core elements, and for loading.
May 26	SPD Party Executive in Hanover: SNR not to be commissioned; R&D activities to be stopped.
June	W. Wallmann (CDU) appointed Federal Minister for the Environment (BMU).
June	Non-nuclear commissioning activities completed 90%.

July 17	NRW State Parliament votes against Kalkar.
July 18	Under chairmanship of Minister Jochimsen, Advisory Energy Board to SPD Executive Council recommends opting out of nuclear power.
July 21	Jochimsen press conference: preliminary positive overall assessment of SNR 300 no longer possible.
Aug.	Moisture removal in Kalkar begun.
Aug. 10	SPD Convention in Nuremberg demands opt-out of nuclear power within ten years (proposed by Hauff Committee).
Sep. 24	Energy Report by Federal Government: main arguments in favor of developing breeder technology continue to be valid.

1987

March	K. Töpfer (CDU) replaces W. Wallmann as Federal Minister for the Environment (BMU).
March 6	FDP demands independent expert opinion within coalition agreements.
April 1	Jochimsen press conference: no storage permit possible.
April 15	Positive RSK vote on document about incomparability of Chernobyl and Kalkar.
June	THTR 300 delivered to operator.
Sep. 30	International expert hearing about Bethe-Tait accident.
Oct.	Motor-Columbus expert opinion about research policy benefits of SNR 300 presented on behalf of BMFT: Kalkar to be commissioned speedily and operated over long period of time.
Nov. 11	Positive RSK comment on Bethe-Tait accident.
Dec. 12	Core element storage taken out of 7/6 application.
Dec.	MWMT report on licensing and supervisory proceedings after BMU quest of Feb. 5, 1987.

1988

Feb.	Kalkar complete except for minor points; pre-nuclear commissioning activities completed approximately 95%.
Feb.	Decision about financing holding phase.

April 21	SPD applies to Federal Constitutional Court to ban plutonium use.
April 27	BMU instructs MWMT in guidance of proceedings.
May 19	Supervisory comment by Federal Government about Bethe-Tait accident.
Aug. 24	SPD motion to Parliamentary Budget Committee to stop breeder development.
Oct. 31	State of NRW sues Federal Government before Federal Constitutional Court because of instruction.
Nov. 25	MWMT remonstration after Bethe-Tait comments.
Dec. 7	Budget Committee of Federal Parliament lifts freeze of DM 35 million for SNR 300.

1989

Feb.	Agreement on financing holding phase (DM 105 million annually) secured until 1991.
Feb. 16	Agreements signed in Bonn by United Kingdom, France, and Federal Republic of Germany about Breeder Cooperation for European Fast Reactor, EFR.
April 30	SBK writ against action for unconstitutionality brought against Federal Government by State of North Rhine-Westphalia.
Sep. 8	BMU report to Budget Committee about status of SNR 300 licensing procedure.
Oct.	THTR 300 decommissioned.
Oct. 31	Fast Breeder Project (PSB) in Karlsruhe terminated; LWR and LMFBR Safety Programs combined in Nuclear Safety Research Project (PSF).
Nov. 1	Management Group for Research and Development (MGRD) founded for European Fast Reactor (EFR).

1990

Feb.	BMFT presents Third Energy Research and Energy Technologies Program; importance of breeder reactor development, specifically SNR 300, confirmed.
Feb. 20	Oral proceedings before Karlsruhe Federal Constitutional Court.

May 22	Federal Constitutional Court dismisses as unjustified on all points action brought by State of North Rhine-Westphalia; file No. 2 BvG 1/88 ("SNR 300 Ruling").
Oct. 3	Reunification of Germany.

1991

Jan.	CDU/CSU-FDP coalition government repeated (Chancellor: H. Kohl); H. Riesenhuber confirmed as BMFT.
Jan. 9	Partners in the holding phase financing agreement discuss project situation with BMFT.
March 20	Contracting partners and BMFT decide to terminate SNR 300/Kalkar Nuclear Power Station Project.
March 21	Press release by Federal Minister for Research and Technology attributing cause for termination to State of North Rhine-Westphalia.
April 10	Delivery contracts for SNR 300/Kalkar Nuclear Power Station terminated by SBK.