KERNFORSCHUNGSZENTRUM

KARLSRUHE

April 1972

KFK 1809

Institut für Neutronenphysik und Reaktortechnik

Fast Reactor Development in Germany

K. Wirtz

GESELLSCHAFT FÜR KERNFORSCHUNG M.B.H.

KARLSRUHE

FAST REACTOR DEVELOPMENT IN GERMANY

KARL WIRTZ
Karlsruhe Nuclear Research Center
Karlsruhe, Germany

EARLY HISTORY

The German work on fast breeders originated in 1960 at the Karlsruhe Nuclear Research Center. From the very beginning the aim was an economical, commercial power plant. Earlier studies, mainly in the United States, had concentrated on highly-enriched metallic fuel. Around 1960, closer studies of the fuel cycle had led to the more diluted ceramic fuels as the preferred choice. This was adopted by the German program. The physics of a ceramic breeder are different from those of a metallic one in many ways. The Karlsruhe Center, therefore, started an extended basic research program. At the same time, the principles of the engineering design of large breeder power stations were studied, including a fuel element development program. A fairly large percentage of the Karlsruhe Nuclear Research Center was assigned to this work. Euratom became associated with these efforts in 1963 and a joint five-year research and development program was initiated. Through Euratom, links with the centers CEN Mol in Belgium and RCN Petten in the Netherlands were initiated, and also with the United States AEC. Close exchange of information with the French center at Cadarache was established. The present international affiliation of the German, Belgian, Dutch, Luxembourgian base program is shown in Fig. 1.[1,4]

RESEARCH AND DEVELOPMENT

Physics

The development of fast reactor theory and code programs[2,3] more or less followed the international path and has ultimately led to the presently mainly used Karlsruhe program systems NUSYS and KAPROS that include a large number of individual modules. Microscopic nuclear data were evaluated by a strong group in close connection with the *E*uropean *A*merican *N*uclear *D*ata *C*ommittee (EANDC). The Karlsruhe nuclear data file KEDAK was a result of these activities.[5,6]

Experimental physics research was performed with the help of several large-scale experiments:

SUAK is a bare pulsed subcritical assembly that allows flux decay measurements and spectrum determination by the time-of-flight technique.[10]

STARK is a fast thermal Argonaut reactor that has a thermal driver zone and a fast highly-enriched core. It produced the first fast neutrons on the continent and allowed the first measurements on the Doppler effect.[11]

SNEAK is a full-scale critical facility, designated for experiments with plutonium fuel comparable to the French MASURCA, the British ZEBRA and the United States ZPPR at Idaho. SNEAK allows the mockup of full-scale fast breeder power reactors up to 5000 liter cores.[9]

SEFOR, the *S*outhwest *E*xperimental *F*ast *P*lutonium *O*xide *R*eactor, is a joint venture of the U.S. General Electric Company, the Karlsruhe Nuclear Re-

Reprinted from Volume 34, Proceedings of the
American Power Conference, 1972

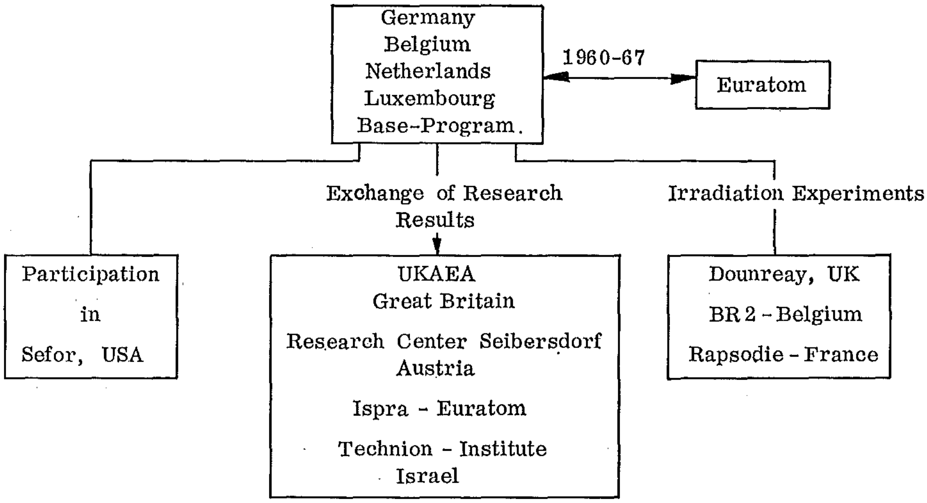

Fig. 1—International affiliations of the DEBENELUX base program, 1972.[1]

TABLE I
STATUS OF FUEL PIN DEVELOPMENT

Target	Reactor	Irradiation Equipment	Lin. Rating, W/cm max	Burnup, MWd/t	Number of Pins
		OXIDE FUEL			
Parameter testing	FR2	NaK capsule	500	90,000	23
Parameter testing	FR2	He-Loop	1000	—	40
Parameter testing	BR2	NaK capsule	500	60,000	14
Test of max. operational data	BR2	Na-Loop	650	50,000	7
Monitor test	DFR	Trefoil	500	56,000	3
Performance test	DFR	Subassembly	450	53,000	39
Performance test	DFR	Trefoils	450	65,000	9
Monitor test	Rapsodie	Cluster	460	25,000	5
Performance test	Rapsodie	Subassembly	460	15,000	68
		CARBIDE FUEL			
Parameter testing	FR2	NaK capsule	1300		25
Parameter testing	BR2	NaK capsule	1300	Under preparation	16
Parameter testing	DFR	Mini sub-assembly	1300		21

search Center together with Euratom, the Southwest Atomic Energy Associates, a group of American utilities, and the United States AEC. It is located near Fayetteville, Arkansas, became critical in 1970, and performed its famous excursion experiments in 1971. The Doppler reactivity feedback of a plutonium fueled breeder under full power was demonstrated and measured and gave the expected results, a Doppler constant of about 4×10^{-3}. This achievement was the result of detailed planning and cooperation between the United States and the European partners and has been described elsewhere,[12] and is shown diagrammatically in Fig. 2.

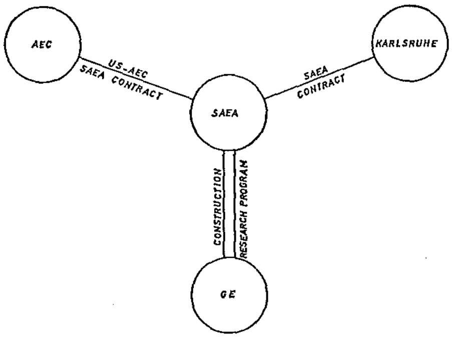

Fig. 2—Scheme of contracts between parties cooperating in building the SEFOR reactor.

Fuel and Materials

Target for fuel development was from the early beginning a burnup of 100,000 MWd/t. Irradiation tests have been and are being performed mainly in the British DFR (Dounreay Fast Reactor) and in the Belgian BR2 at Mol. Irradiations up to 80,000 MWd/t, mainly with mixed UO_2-PuO_2 fuel with stainless steel cladding ("strong pins"), have been performed, similar to the fuel element research in the United States. A survey is given in *Table I*.[4] No basic problems are expected at present for the fuel of LMFBRs.

In close contact with the Karlsruhe Nuclear Research Center the fuel company NUKEM started a subsidiary, ALKEM, for manufacturing fuel and fuel pins containing plutonium.

The main advantage expected from a breeder is a cheap fuel cycle, cheap mainly because ultimately only fertile material, i.e., U^{238}, as feed should be needed. Fissile material should be in surplus. The German program expects the cost percentages for a 1000-MWe unit with a mean burnup of 100,000 MWd/t as follows:[13]

	Percent
Fuel element fabrication	71
Fuel transport and reprocessing	14
Interest on plutonium inventory	40
Use of fissile material	−26
Feed of fertile	0.4
	100

The value of plutonium is taken as $5 per kilogram.

Fuel-cycle cost estimates have changed in recent years. They were around 0.4 Deutsche pfennig (1.2 mills) per kWh and the price of a kWh was around 2.2 Dpf (7 mills) with plant costs of 750 Deutsche Mark (DM) per kilowatt installed. These prices are of 1970 and must be considered outdated today.

Further Basic Studies

More extensive studies were or are being performed in the frame of the DEBENELUX-Association on questions of safety of LMFBRs and sodium technology.

With respect to safety, the predominant role of the Doppler reactivity effect became evident at early stages and led to the SEFOR program mentioned above.

The Doppler effect is the main factor

TABLE II
HEAVY SODIUM COMPONENT TEST FACILITIES OF DEBENELUX

5-MW INTERATOM test facility	Investigation of special aspects of steam generators	Na-Na-steam system Na: max 560 C Steam: 500-540 C/200 atm	1963 Construction 1965 Operation for KNK 1969 Operation for SNR
INTERATOM sodium pump test facility	Testing of pumps	Pump capacity 5000 m^3/h (15,000 m^3/h)	1967 Construction 1970 Operation
50-MW NERATOOM sodium component test facility	Testing of 50-MW steam generator and 70-MW intermediate heat exchanger	Na-Na-steam system Na: max 650 C Steam: 600 C/215 atm	1968 Construction 1970 Operation

limiting power excursions and stabilizing a fast reactor. The Doppler effect now is understood well, both theoretically and experimentally. Another effect, studied carefully, that influences the design of LMFBRs is the sodium void reactivity. Voiding the core from sodium can lead to a dangerous increase of reactivity. The void effect also is understood well today and can be reduced by flat core design. Core voiding can be made highly improbable, but remains a major safety problem in the design of LMFBRs.

Large-scale work on sodium technology and component development is performed by industry of the DEBENELUX countries, mainly with the help of special test facilities. *Table II* gives a rough outline of these facilities.[2]

One of the most important facilities in developing sodium technology is the prototype reactor, KNK (*K*ompakte *N*atriumgekühlte *K*ernenergieanlage—compact sodium-cooled nuclear plant) at Karlsruhe.[7] This sodium-cooled test reactor has a moderator of zirconiumhydride and operates with thermal neutrons in its first core. Later, KNK is expected to have a second fast core. The reactor was constructed by INTERATOM at the Karlsruhe Nuclear Research Center. Its characteristics are shown in *Table III*. Core I became critical in 1971; full power is expected in spring 1972.

The role of this reactor in the frame of the FBR program is:

1. To provide experience with the sodium technology under reactor operating conditions (Core I);
2. To study fuel and reactor behavior in a fast sodium-cooled core (Core II); and
3. To provide sodium reactor construction experience to industry.

The idea to build a high flux fast test reactor (similar to the United States FFTF) has been abandoned.

EARLY DESIGN STUDY

The first design study performed at Karlsruhe was concerned with the 35-MWe helium-cooled fast breeder with mixed oxide fuel (1962). Study of gas cooling was abandoned shortly after, because time was not yet ripe, and was resumed only in 1967, as will be discussed later.

This was followed by detailed research on sodium- and steam-cooled FBRs that extended until around 1969. The results were several design studies of 1000 MWe and 300 MWe with sodium and steam as coolants. The data of these designs are shown in *Table IV*.[4]

TABLE III
DATA OF KNK I AND II

	Core I	Core II
Thermal power	58 MW	58 MW
Electrical power	20 MW	21, 35 MW net 17, 75 MW
Fuel	UO_2 6% enriched	
test zone		UO_2 - PuO_2
driver zone		UO_2
enrichment in the test zone		80-90%, 30% Pu
enrichment in the driver zone		ca. 40%
Canning material	SS 1613	4981, 4988, 4970
Moderator	Zirconhydride	—
Coolant temperature:		
primary	550 C/360 C	550 C/360 C
secondary	540 C/360 C	540 C/360 C
Steam conditions:		
pressure	80 atm	80 atm
temperature	505 C	505 C
First criticality	1971	1973/74

These studies served the purpose of defining the main problem areas of further basic research and development work, as well as of components development, and provided references for the ultimate prototypes to be built. It was anticipated fairly early that these prototypes should be of about 300 MWe, similar to the British DFR and the French PHENIX.

With respect to the sodium-cooled type, Karlsruhe followed the general international trend. All Karlsruhe LMFBR types were of the "loop-type," whereas several foreign designs followed the well-known "pool-type" (core, pumping system and heat exchangers in this case are submerged in a pool of sodium) (see *Table V*).

Steam-cooling was actively developed until 1969 as an alternative to sodium, primarily because coolant technology for steam was at hand from light-water reactor power plants. Sometimes a quick development and early availability of SCFBR was hoped for in Germany. Ultimately (1969) research on steam-cooling was reduced to insignificance.[16] The German FBR program from that time on was directed almost exclusively toward the SNR 300, a follower to Na-2 of *Table IV*, but now designed exclusively by industry.

THE PROTOTYPE SNR 300

At the present status of knowledge provided by a decade of basic research, the logical next step should be the actual construction of the prototype SNR 300. The SNR is a loop-type sodium-cooled breeder with oxide fuel in stainless steel cladding of 300 MWe. In *Table V* its data are compared with those of the French PHENIX and the nearly finished British PFR (Prototype Fast Reactor) that are both of the pool-type.[2,8]

There is a time schedule for the construction of the SNR, but at present, in March 1972, the contract between the manufacturers and the future owner (Schnell - Brüter - Kernkraftwerksgesellschaft mbH. (SBK)) has not yet been signed, probably because the final cost estimates ($\approx$ 1.7 billion DM) have con

TABLE IV
KARLSRUHE STUDIES ON 1000-MWe AND 300-MWe FBRs WITH SODIUM AND STEAM COOLING

	Na-1	Na-2	D-1 (steam)	DSR (steam)
System	LMFBR, Na/Na/H_2O loop type 4 primary loops	LMFBR, Na/Na/H_2O loop type 3 primary loops	SCFBR, H_2O direct Loffler cycle 170 atm, 6 not integrated loops	SCFBR, H_2O direct Loffler cycle 120 atm, 4 partly integrated loops
Power, MWt/MWe	2500/1000	730/300	2517/1000	838/300
Fuel	PuO_2UO_2	PuO_2UO_2	PuO_2UO_2	PuO_2UO_2
Core Dimensions, H(cm), V(m^3), H/D	95/6.1/0.33	95/1.75/0.62	151/8.2/0.58	44/1.83/0.19
Core Volume fractions, % coolant, structure, fuel	50/19.6/30.4	49.6/20.6/29.7	31.6/21.9/46.5	31/28/41
Pin diameter/pitch, mm	6.7/9.3	6.0/7.9	7.0/8.15	7.0/8.2
Wall thickness of fuel pins, mm, cladding material	0.35, SS	0.38, SS	0.37, Inconel 625	0.40, Incoloy 800
Pin concept	vented to plenum	vented to plenum	vented to plenum	vented to plenum
Fuel density, ρ/ρ_{theor}	0.87	0.80	0.87	0.85
Max. nom. rod power, W/cm	560	420	390	409
Max. average burn up, MWd/t	100,000	55,000	55,000	60,000
Coolant temp. T_{in}/T_{out}, C	430/580	380/560	365/540	332/470
Inventory, kg Pu_{fiss}	2250	773	3350	1140
Breeding ratio	1.35(1.23)		1.15(1.03)	1.20
Nuclear data set	KFK 26-10	KFK 26-10	KFK SNEAK	KFK SNEAK (PMB)

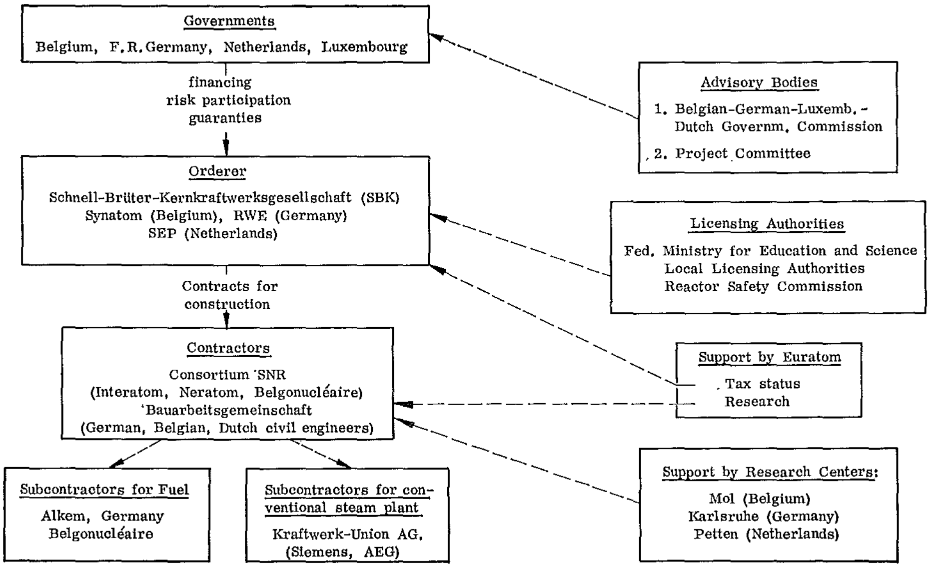

Fig. 3—Partners and participants in the SNR 300 project.

siderably surpassed the figures discussed so far.

DEBENELUX ORGANIZATION FOR CONSTRUCTION OF THE SNR 300

Industry

The Consortium SNR (INTERATOM (now mainly Siemens owned), BELGO-NUCLEAIRE, NERATOOM) is responsible for construction of SNR 300. The Consortium ALKEM-BELGONUCLE-AIRE is responsible for manufacturing the plutonium-uranium oxide fuel. INTERATOM is responsible for the construction of KNK I and II.

Utilities

Schnell - Brüter - Kernkraftwerksgesellschaft (SBK) is a consortium of RWE (Germany), N.V. *S*amenwerkende *E*lektriciteits-*P*roduktiebedrijven (Netherlands) and SYNATOM (Belgium) with an initial capital of 120 × 10^6 DM). This Consortium is responsible for:

1. Ordering of SNR 300 to the "Consortium" and to "Bauarbeitsgemeinschaft," a group of German, Belgian, and Dutch construction companies for all civil engineering work.
2. Supervision of construction,
3. Licensing procedures, and
4. Operating the plant.

The Consortium also has plans to participate in the first French 1000-MWe commercial breeder plant. The Consortium later may form a common company.

Research Centers

The research centers of Karlsruhe (Germany), Petten (Netherlands), Mol (Belgium) in cooperation with the Dutch TNO (Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek) and LUXATOM, coordinated by Karlsruhe, are responsible for the base program:

1. Physics,
2. Fuel,
3. Safety,
4. Studies of design with various coolants, and

TABLE V
THE SNR 300 COMPARED WITH PFR AND PHENIX

	UK PFR	FRANCE PHENIX	GERMANY SNR
Reactor power			
Thermal, MWt	600(670)	563	730
Electrical, MWe	250(275)	250	300
Core (reference)			
Fuel	PuO_2/UO_2	PuO_2/UO_2	PuO_2/UO_2
Core volume, l	1320	1150	1600
Fuel rating average, MWt/kg fiss	0.7	0.8	0.8
Power density average, MWt/liter	0.4	0.42	0.4
Linear rod power, max W/cm	450	430	400
Breeding ratio	1.2	1.16	1.29
Burnup, MWd/ton	70,000	50,000	55,000
Primary heat-transfer system			
Type	Pool	Pool	Loop
Coolant	Na	Na	Na
Number of coolant loops	3	3	3
Pump capacity, m^3/h	5000	4800	5100
Coolant temperature			
Core inlet, C	400-425	400(420)	380
Core outlet, C	560-585	560(580)	550
Steam conditions			
Temperature, C	510-540	510	505
Pressure at	162	167	165
Date of operation	1971/72	1973	1977

5. Strategic research on breeder economy and their introduction into the electricity market.

Governments

They formed and chaired the "Project Committee Schneller Brüter" that comprises representatives of governments, utilities, research centers, and industry. It is chaired by the German government representative.

These efforts are embedded into a framework of international contacts with governments, industries and research groups. A chart indicating these links is shown in Fig. 3.[14]

STUDIES FOR ADVANCED BREEDERS

Beyond the work on SNR 300, further studies on 1000-MWe breeders have been performed. Also, design studies on helium- and steam-cooled types were included.

In the case of helium cooling, extended evaluation of several proposals was made in the frame of the so-called German Gas Breeder Memorandum.[16] For the near future, a more conservative proposal of Gulf General Atomic, with steel cladded and vented oxide fuel pins with gas exit temperatures around 600 C and operation on a steam generator, was found to be most appropriate. Above a gas temperature of 700 C a gas turbine process in direct cycle would become economical. It seems likely that the cladding at these temperatures should not be stainless steel but rather a vanadium alloy, and the fuel a carbide. In a British proposal, coated particles were used as fuel and the coolant is streaming through the particle bed. *Table VI* shows these designs compared with an advanced 1000-MWe LMFBR.[16]

The better cost and breeding poten-

TABLE VI

MAIN PARAMETERS OF 1000 MWe HELIUM-COOLED BREEDER REACTORS COMPARED WITH ADVANCED SODIUM- AND STEAM-COOLED TYPES

	CONCEPT 1	CONCEPT 2	CONCEPT 3	Advanced Na-Breeder	Steam Breeder
Cycle	Steam turbine	Gas turbine	Steam turbine	Steam turbine	Steam turbine
Fuel	Oxide	Oxide	Oxide	Oxide	Oxide
Fuel element	Fuel pin (vented)	Fuel pin (sealed can)	Coat. particle	Fuel pin (sealed can)	Fuel pin (vented)
Max. lin. power rating in pin, W/cm	430	440	—	530	420
Mean discharge burnup, MWd/t			75,000		
Inlet coolant pressure, kg/cm²	70	100	70	10	150
Mixed mean coolant temp. at reactor outlet, C	600	706	675	580	500
Max. hot spot temp. at clad midwall, C	755	850	950	700	720
Core fissile inventory, kg Pu^{239}, Pu^{241}	3140	2770	1800	1630	2860
Breeding ratio	1.44	1.32	1.19	1.29	1.15
System lin. doubling time, years**	13.2	17.8	31.8	14.5	32.3
Specific investment, $/kWe	162	145	162	170-240	152*
Fuel cycle cost, mills/kWh	1.3	1.5	1.5	0.875	1.4*
Electricity cost, mills/kWh**	5.2	5.05	5.4	5.0-6.5	5.2*

*Estimated costs.
**Load factor 0.7.
All costs are for spring 1970.

TABLE VII

SCHEMATIC EVALUATION OF BREEDERS WITH DIFFERENT COOLANTS—PARAMETERS INFLUENCING ECONOMY

	Steam	Sodium	Gas I	Gas II
Breeding ratio	1,1	1,2-1,3	1,4	1,3
Doubling time (years of Pu inventory)	great	15	13	
Fuel pin	not yet available	available	available as far as the LMFBR pin is used	
System pressure	160 atm	< 10	70	100
Reactivity coupling with the coolant density	strong	very strong	none	
Doppler effect	big	big	medium	
Capital costs	near LWR	larger than LWR	well below LMFBR	
Fissile inventory	big	medium	big	same as LMFBR

tial of the GCFBR is obvious from these data. This raises the question, whether the concentration of the worldwide development efforts on LMFBRs is justified and whether it would not be wiser to not forget the other possibilities. If it is correct that ultimately breeding ratio and doubling time will be the decisive economical parameters, the evaluation of breeders in *Table VII* should be kept in mind.[17]

It is obvious that the development of fast breeder reactors is in its early stages. The future of nuclear power depends on its success.

SOME COSTS OF THE DEBENELUX-FBR PROGRAM

There are some cost figures available for the breeder program until the end of 1968. A few will be mentioned.

1. Base program of the Karlsruhe Center 1960-67, 10^6DM

Direct costs	100.4
Indirect costs	122.8
Fissionable material, fabrication included	60.9
	284.1

2. KNK I payments 1966-72	130.0
KNK II payments 1968-74	90.0
3. Steam-cooling; special supporting industry projects, not mentioned in the text (Superheat Steam-cooled Reactor Project (HDR)). Costs until Dec. 31, 1968, including R + D	128.6
4. Further project and development work, mainly by industry, financed by the government, until Dec. 31, 1968	
a) Sodium	29.4
b) Steam	23.2
	52.6
5. Base program Karlsruhe, 1968-72 (estimated)	
Direct costs	186.0
Indirect costs	180.0
Fissionable material, fabrication included	118.0
	484.0

Figure 4 shows a followup survey and a forecast of future costs based on 1970 data. The figure shows estimated cumulative costs, including the SNR 300, as well as a 1000-MWe demonstration plant. More recently for this demonstration plant a power of 1800 to 2000 MWe has been discussed; a plant of that size probably would not be constructed by the DEBENELUX alone, but on a broader European basis.

In Fig. 4 the SNR 300 cost appears as more than 10^9 DM, whereas until 1970 only about 0.5 billion DM was discussed. Early 1972 cost estimates were 1.075 billion DM, including plant, fuel, site preparation, etc. For unexpected changes during construction and licensing and for cost increases, 0.465 billion DM is envisaged.

In this connection a few remarks are appropriate. The DEBENELUX FBR project obviously has passed a point where return would be difficult. Different from France and the United Kingdom, but similar to the United States, it is a basic policy in Germany that actual construction of the SNR is a matter of industry only, i.e., a matter between a utility group (here Schnell-Brüter-Kernkraftwerksgesellschaft) and the manufacturers (here the Consortium and Bauarbeitsgemeinschaft). Government funds enter via SBK. The government wants fixed prices as much as possible. The manufacturer then has to bear the risks. This influences the price estimates in this unknown field so that they are very con-

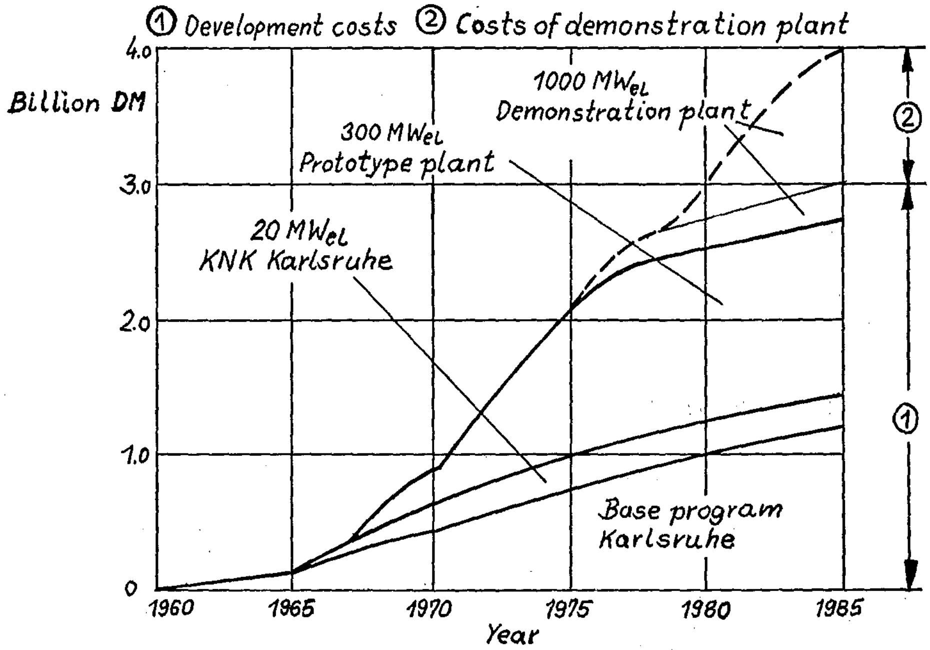

Fig. 4—Cumulative development cost of the LMFBR in the DEBENELUX countries.

servative; especially in view of the situation some six to eight years ago with light-water reactors, when optimistic cost estimates brought heavy losses to the manufacturers. True costs of the SNR 300 will be known only after its construction and if, as a consequence of the government money involved, a close examination of the construction costs has occurred. Probably the same holds for the costs of the United States demonstration plants. Presently it looks like capital costs could possibly be the major obstacle in introducing the LMFBR into the electricity market.

REFERENCES

1. Mandel, H., "The Possibilities of International Collaboration in the Nuclear Energy Field," *Atomwirtschaft,* **16,** 418-26 (1971) August/September.
2. Haefele, W., *et al.,* "Fast Breeder Reactors," *Annu. Rev. Nucl. Sci.,* **20,** 393-434 (1970).
3. Haefele, W., "Fast Breeder Reactors, Their Principles, Their Development, and Their Role in a Nuclear Economy," **KFK-480** (1966) October (German (text); "German Fast Breeder Program," **KFK-634, EUR-3678e** (1967) October; "On the Development of Fast Breeders," **KFK-881** (1968) November.
4. Engelmann, P. and Haefele, W., "Base Programme of the DeBeNeLux Fast Breeder Project," *Paper* **A/CONF. 49/P-366,** presented at the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, September 6-11, 1971.
5. Schmidt, J. J., "Neutron Cross Sections for Fast Reactor Materials. Part I. Evaluation," **KFK-120** (1966) February; Schmidt, J. J., "Organizational and Technical Aspects in the Field of Neutron Nuclear Data Evaluation," **KFK-791** (1968) July; Woll, D., "Card Image Format of the Karlsruhe Evaluated Nuclear Data File, Kedak," **KFK-880, EURFNR-611, EUR-4160** (1968) December.
6. Langner, I., Schmidt, J. J. and Woll, D., "Tables of Evaluated Neutron Cross Sections for Fast Reactor Materials,"

KFK-750; EURFNR-537; EUR-3715; Hinkelmann, B., *et al.*, "Status of the Karlsruhe Evaluated Nuclear Data File Kedak at June 1970," **KFK-1340, EURFNR-912** (1971) February.

7. Tebbert, H., *et al.*, "The Compact Sodium Cooled Nuclear Reactor of Karlsruhe," *Atom Strom,* **13,** 117-29 (1967) September/October (German text).
8. Guthmann, E. A., *et al.*, "Fast Breeder Development Program of the Consortium SNR," *Paper* **A/CONF./49P-369,** presented at the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, September 6-11, 1971.
9. Engelmann, P., *et al.*, "Construction and Experimental Equipment of the Karlsruhe Fast Critical Facility, SNEAK," **ANL-7320,** 725-36 (1966) October.
10. Borgwaldt, H., *et al.*, "SUAK-A Fast Subcritical Facility for Pulsed Neutron Measurements," **KFK-302** (1965) May.
11. Barleon, L., *et al.*, "Evaluation of Reactor Physics Experiments on the Coupled Fast-Thermal Argonaut Reactor STARK," **ANL-7320,** 137-58 (1966) October.
12. Schnurr, W. and Welsh, J. R., "The SEFOR Reactor—Aspects of International Cooperation," *Paper* **A/CONF. 28/P-533** presented at the Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1964; Haefele, W., *et al.*, "Static and Dynamic Measurements on the Doppler Effect in an Experimental Fast Reactor," *Paper* **A/CONF. 28/P-644,** presented at the Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1964; see also Steele, M. L., "Operating Experience at SEFOR," *Reactor Technol.,* **14,** 237-40 (1971) Fall; Noble, L. D., Kussmaul, G. and Pflasterer, G. R., "Sub-Prompt Critical Transients in SEFOR," *Trans. Amer. Nucl. Soc.,* **14,** 741 (1971).
13. Haefele, W. and Kraemer, H., "Technical and Scientific Position as Well as Prospect for Nuclear Energy in the Engineering of the Federal Republic of Germany. Part II.," **KFK-1430, JUL-775-RG** (1971) June.
14. German "Bundesminister für Bildung and Wissenschaft" on SNR 300, Press release, November 1971.
15. Engelmann, P., *et al.*, "Report on the Research and Development Work Carried Out in the Karlsruhe Nuclear Research Center on the Steam-Cooled Fast Breeder," **KFK-1370** (1970) December; Donne, M. D. and Wirtz, K., "Problems of Gas-Cooled Fast Breeder Reactors," *Trans. Amer. Nucl. Soc.,* **14,** 272-73 (1971).
16. Donne, M. D., Wirtz, K. and Kraemer, H., "Assessment of Gas-Cooled Fast Breeder," *Nucl. News,* **14,** 42-44 (1971) December; see also "Gas Breeder-Memorandum. Results of an Investigation of the Feasibility and Economics of a Gas-Cooled Fast Breeder," **KFK-1375, EUR-4575, JUL-744-RG** (1971) February.
17. Partly from: Engelmann, P., "What is the Position of German Fast Breeder Development? 1. The Public Discussion in Karlsruhe," *Atomwirtschaft,* **16,** 195-208 (1971) April.
18. See: "The Controversy Over the Future Development of the German Fast Breeder—A Documentation," *Atomwirtschaft,* **14,** 187-220 (1969) April.