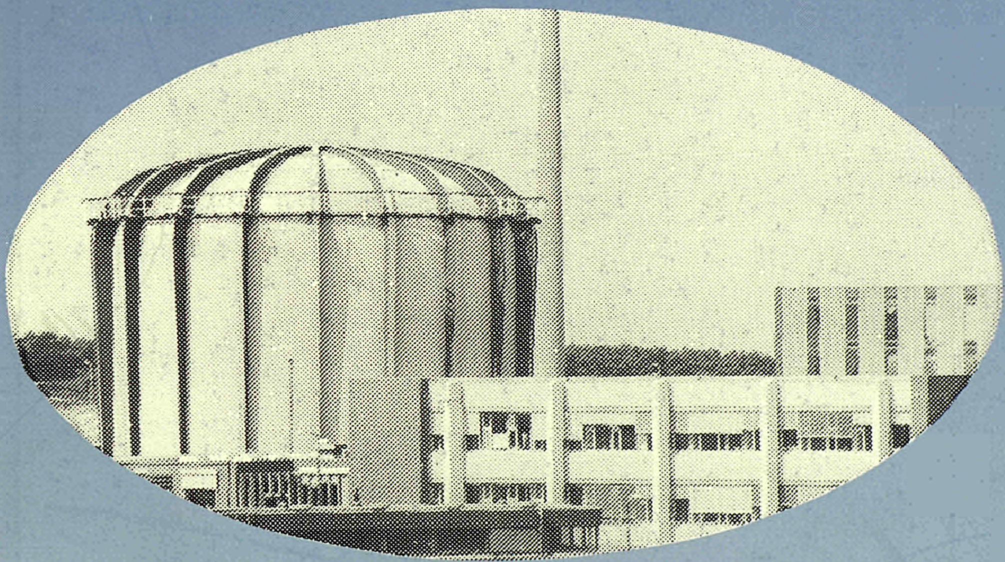
Commission of the European Communities

ANNUAL PROGRESS REPORT 1988
OPERATION OF THE HIGH FLUX REACTOR



Report
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Commission of the European Communities
Institute of Advanced Materials
Petten Site

ANNUAL PROGRESS REPORT 1988
OPERATION OF THE HIGH FLUX REACTOR

J. Ahlf, H. Röttger, editors

Directorate-General
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PETTEN SITE

HFR Division

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In 1988 the High Flux Reactor Petten was routinely operated without any unforeseen event. The availability was 99% of scheduled operation.

Utilization of the irradiation positions amounted to 80% of the practical occupation limit. The exploitation pattern comprised nuclear energy deployment, fundamental research with neutrons, and radioisotope production. General activities in support of running irradiation programmes progressed in the normal way. Development activities addressed upgrading of irradiation devices, neutron radiography and neutron capture therapy.

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PROGRAMME PROGRESS REPORT JANUARY-DECEMBER 1988

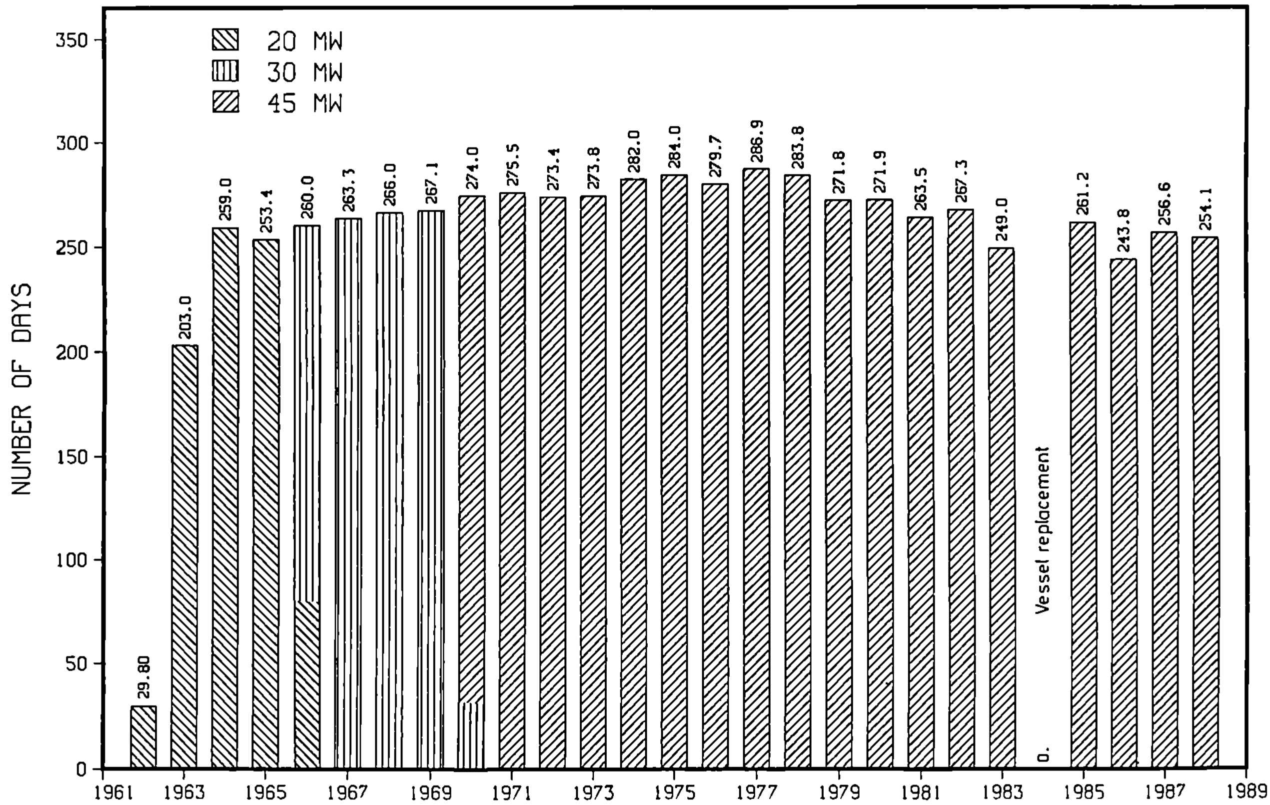
1. INTRODUCTION TO THE HFR PROGRAMME

Following the reorganization of the Joint Research Centre of the European Communities in 1988, the High Flux Reactor Petten became a division within the Institute of Advanced Materials. The objectives for exploiting the HFR as set in previous multi-annual programmes of the JRC continues into the 1988/1991 programme. The reactor is operated and exploited in support of research programmes of the European Community and of its Member States.

The expenses for the HFR are covered to a large proportion by a supplementary programme funded by the Governments of the Federal Republic of Germany and the Netherlands, with a considerable addition from the common programme of the JRC. Although the contribution of public funding will continue to be by far the largest, the services of the HFR are increasingly offered to third parties inside and outside the European Communities.

As in the past the HFR Petten is operated and exploited as a multi-purpose research reactor. The programme covers the fields of nuclear fission energy with special regard to safety aspects, thermo-nuclear fusion, fundamental research with neutrons in the fields of nuclear and solid state physics, large scale radioisotope production for medical, agricultural and industrial applications, neutron activation analysis, development and application of neutron radiography and application of neutrons to cancer treatment. Safe operation of the reactor is in itself an expressed programme objective.

Since the first criticality of the HFR in 1961 it has been continuous policy to keep the installation up-to-date by implementing technical developments and by refurbishing or replacing all components and equipment which approach the end of their useful life.
In addition, the facilities and the ancillary experimental equipment were continuously adapted and kept versatile by responding to changing requirements from the experimental programmes.



HFR operation days 1961-1988

Performance upgrading comprised increase of the initial power of 20 MW in two steps to 30 MW, and now 45 MW, accompanied by improving the core loading pattern in order to provide an increasing number of high flux irradiation positions. These improvements were rendered possible by adopting more recent technology in fuel element design and manufacture. The phase of optimizing operational performance ended in about 1984 with the replacement of the old reactor vessel by a new one offering much improved irradiation possibilities, for example, the pool-side facility was enlarged and the former thermal column was replaced by two large cross-section beam tubes. Major refurbishment actions after the restart of the reactor early in 1985 were the replacement of the primary and pool heat exchangers, the beryllium reflector, the nuclear instrumentation channels, and a number of other important components. A full upgrade of the control room is under preparation, and will be carried out within the next few years. When this has been completed, the HFR Petten can be regarded as a fully modernized facility.

Upgrading and refurbishing actions followed a carefully planned strategy in order to avoid unplanned outages due to component failure. This policy maintained a high plant availability (see figure on page 7) and a high level of occupation of the irradiation facilities. At the same time the modernization of the plant has led to a reduction of the irradiation dose of the reactor personnel, now at a level far below internationally accepted norms.

Projects

2. PROJECTS

2.1. HFR Operation, Maintenance and Upgrading

o **Objectives**

In 1988 the goals set for reactor operation were:
- increase of the reactor power from 45 to 47.5 MW,
- high availability and full occupation, in order to continue the good result of the past years,
- use of a reactor stop in March for maintenance, training and retraining of personnel,
- use of the long summer stop for the In-Service Inspection of the reactor vessel and for maintenance,
- continuation of upgrading projects,
- improvement of quality control and quality assurance.

***Table 1* Revised HFR operating calender 1988**

		operating days	shut-down days
Jan. 01 - Jan. 04	Cycle 87.11 cont.	3.7	
Jan. 05 - Jan. 06	Core reloading		2.3
Jan. 07 - Febr. 01	Cycle 88.01	25.7	
Febr. 02 - Febr. 03	Core reloading		2.3
Febr. 04 - Febr. 29	Cycle 88.02	25.7	
March 01 - March 27	Maintenance		27.3
March 28 - March 30	Core reloading		3.0
March 31 - April 25	Cycle 88.03	25.7	
April 26 - April 27	Core reloading		2.3
April 28 - May 23	Cycle 88.04	25.7	
May 24 - May 25	Core reloading		2.3
May 26 - June 20	Cycle 88.05	25.7	
June 21 - June 22	Core reloading		2.3
June 23 - July 15	Cycle 88.06	23	
July 16 - Sept. 04	Maintenance,		
	Reactor holidays		51.0
	In-service inspection	(ISI)	
Sept. 05 - Sept. 07	Core reloading		3.0
Sept. 08 - Sept. 28	Cycle 88.07	21	
Sept. 29 - Oct. 03	Core reloading		5
Oct. 04 - Oct. 24	Cycle 88.08	21	
Oct. 25 - Oct. 27	Core reloading		3
Oct. 28 - Nov. 17	Cycle 88.09	21	
Nov. 18 - Nov. 21	Core reloading		4
Nov. 22 - Dec. 12	Cycle 88.10	21	
Dec. 13 - Dec. 15	Core reloading		3
Dec. 16 - Dec. 31	Cycle 88.11	16	
		255.2	110.8
Jan. 01/89 - Jan. 05/89	Cycle 88.11 cont.	5	

NB: The nominal power of 47.5 MW will be reduced to 45 MW beginning with cycle 88.06. The reactor will be stopped the last day of the cycle at 24.00 h

o **Methods**

The original annual schedule for reactor operation at 47.5 MW had to be revised in the middle of the year.
For reasons of fuel economy, necessitated by the delay in the supply of fuel elements, the operation at 45 MW had to be resumed; for the same reasons the length of the operation cycle had to be decreased. The revised operating calender is shown in **Table 1**.
The summer stop of 7 weeks was partly used for the execution of the programme of the first three-yearly In-Service Inspection of the new reactor vessel after its installation, as was prescribed by the licensing authority.

o **Results**

The reactor was in operation during 69.4% of the year and 94% of the original planned programme.
Nearly 100% of the aimed operation time of the revised schedule was reached.
Also a reasonably high level of experimental occupation was achieved. In-Service Inspection was executed successfully and within the scheduled time.
Good progress was made in the upgrading projects.

2.1.1. HFR Operation

2.1.1.1. Operation Parameters

At the beginning of 1988 the HFR was operated at nominal power of 45 MW for the continuation of cycle 87.11.
The reactor power was increased as planned to 47.5 MW for the first 5 complete reactor operation cycles of 1988.
For the remaining 5 reactor cycles and cycle 88.11 (continued in 1989) the reactor power had to be reduced to 45 MW.

The actual operating periods and basic operating data for 1988 are given in **Table 2**, which, for comparison, also gives data for 1987.
The experimental loading of the reactor, the reactor power history and the mean control rod movement for the full 10 cycles completed in 1988 and the continued cycle in January 1989, are shown in **Figs. 1 to 11.**

Table 2 Survey of reactor operation and basic operating data

Dates	Program	Generated reactor energy	Operating time		Planned shut-down				Unscheduled shut-down			Fuel consumption	Stack release (Ar-41)
			cycles	various	cycles	various	shut-down	power decrease		shut-down	power decrease		
1988		MWd	h.min	h.min	h.min	h.min			h.min			g U-235	GBq
01.01-04.01	Cycle 87.11'	165.00	88.00		8.00		-	-		-	-	206.09	
05.01-01.02	Cycle 88.01	1223.66	619.00		53.00		-	-		-	-	1528.35	628.00
02.02-29.02	Cycle 88.02	1208.29	612.14		59.42		-	-	.04	1	-	1509.15	557.30
01.03-03.03	Training			20.04		51.56							
04.03-27.03	Maintenance					575.00							
28.03	Fluxmapping			2.38		21.22							
29.03-25.04	Cycle 88.03	1211.80	615.31		52.37		1	1	3.52	3	-	1513.54	749.30
26.04-23.05	Cycle 88.04	1214.44	616.34		55.20		-	2	.06	1	-	1516.84	548.60
24.05-20.06	Cycle 88.05	1197.56	608.00		64.00		-	1		-	-	1495.75	576.30
21.06-22.06	Measurements			6.31		41.29							
23.06-15.07	Cycle 88.06	935.19	502.30		14.12		-	-	35.18	1	-	1168.05	461.80
16.07-04.09	Maintanance					1224.00							
05.09-28.09	Cycle 88.07	946.76	507.23		69.37		-	-		-	-	1182.50	598.80
29.09-24.10	Cycle 88.08	964.64	515.30		108.30		-	1		-	-	1204.84	527.20
25.10-17.11	Cycle 88.09	956.71	514.11		61.49		-	-		-	-	1194.93	576.20
18.11-12.12	Cycle 88.10	941.31	503.39		96.10		-	-	.11	1	1	1175.70	437.80
13.12-31.12	Cycle 88.11'	738.02	393.50		62.10		-	-		-	1	921.79	386.90
Total 01.01-31.12.1988 :		11703.38	6096.22	29.13	705.07	1913.47	1	5	39.31	7	2	14617.52	6048.20
Percentages of total time in 1988 (8784h) :			69.4%	0.3%	8%	21.8%			0.5%				
Total 01.01-31.12.1987 :		12021.78	6487.25	38.50	789.51	1280.10	2	6	163.44	14	1	14969.34	6387.39
Percentages of total time in 1987 (8760h) :			74.1%	0.4%	9%	14.6%			1.9%				

Remark: For cycles 87.11 and 88.11, only figures are taken in account of the 1988 part.

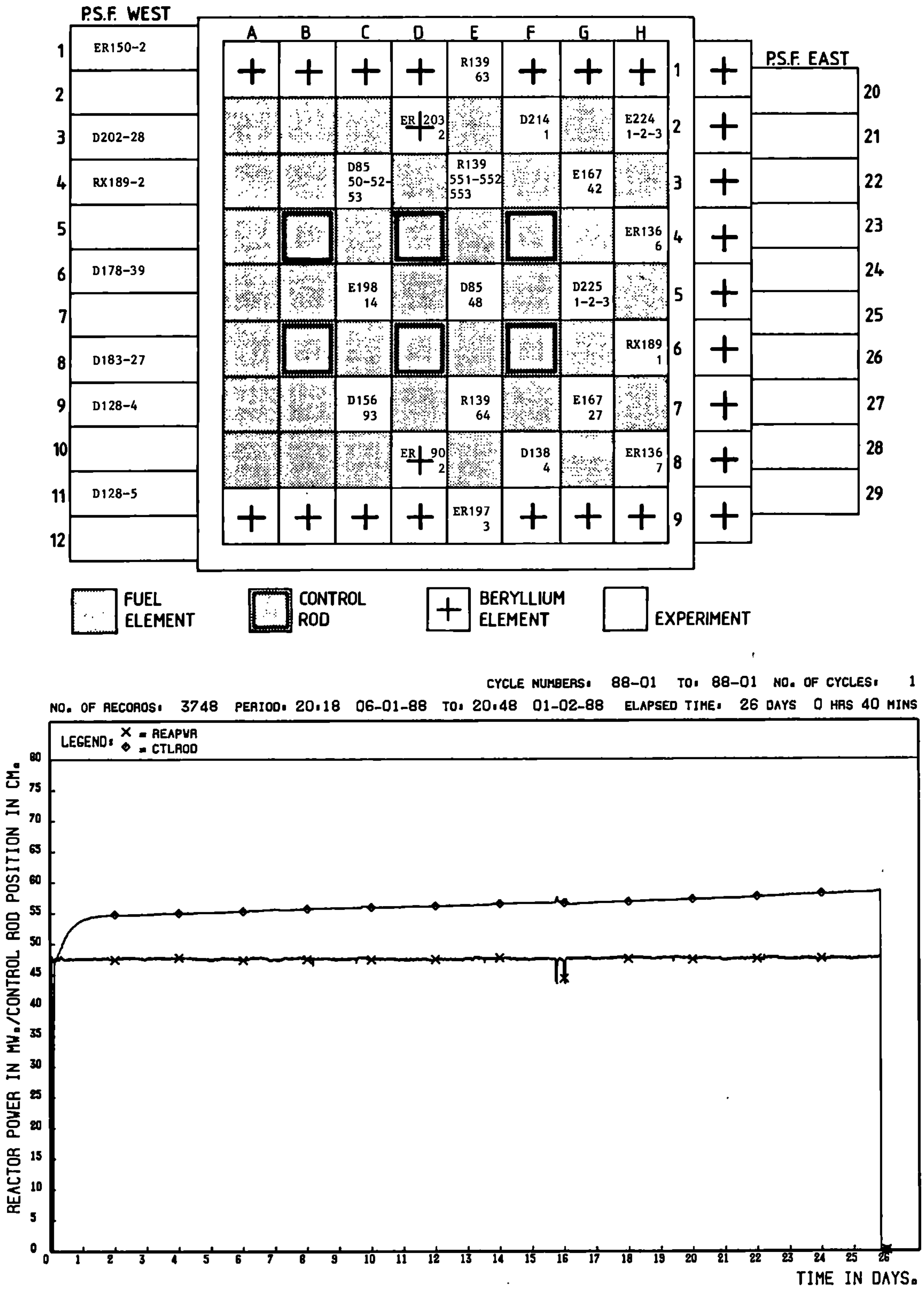


Fig. 1 HFR cycle 88.01. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.

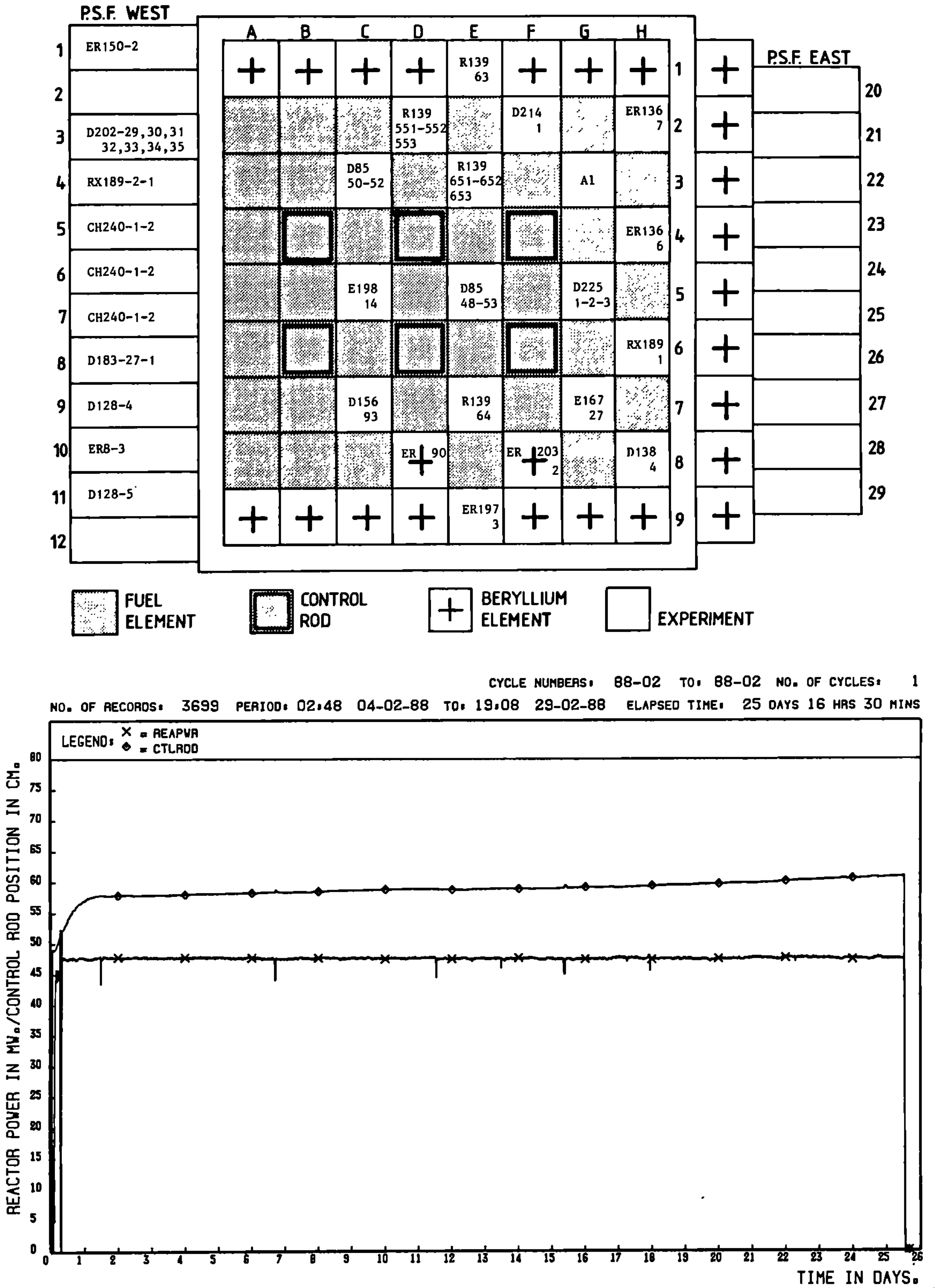
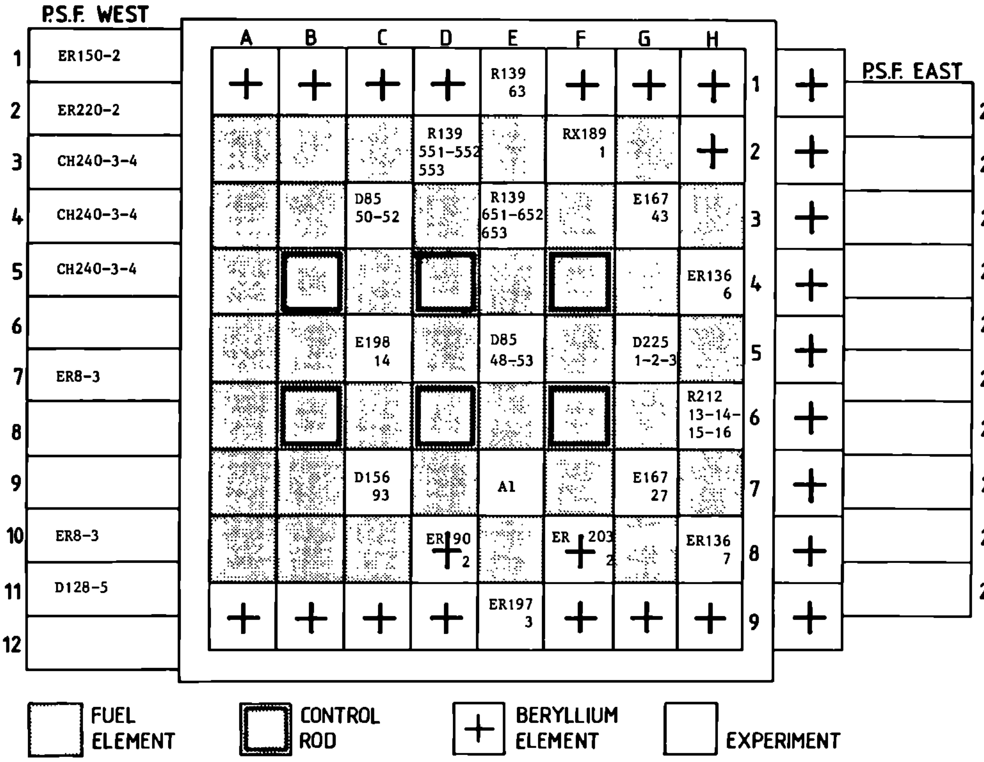


Fig. 2 HFR cycle 88.02. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.



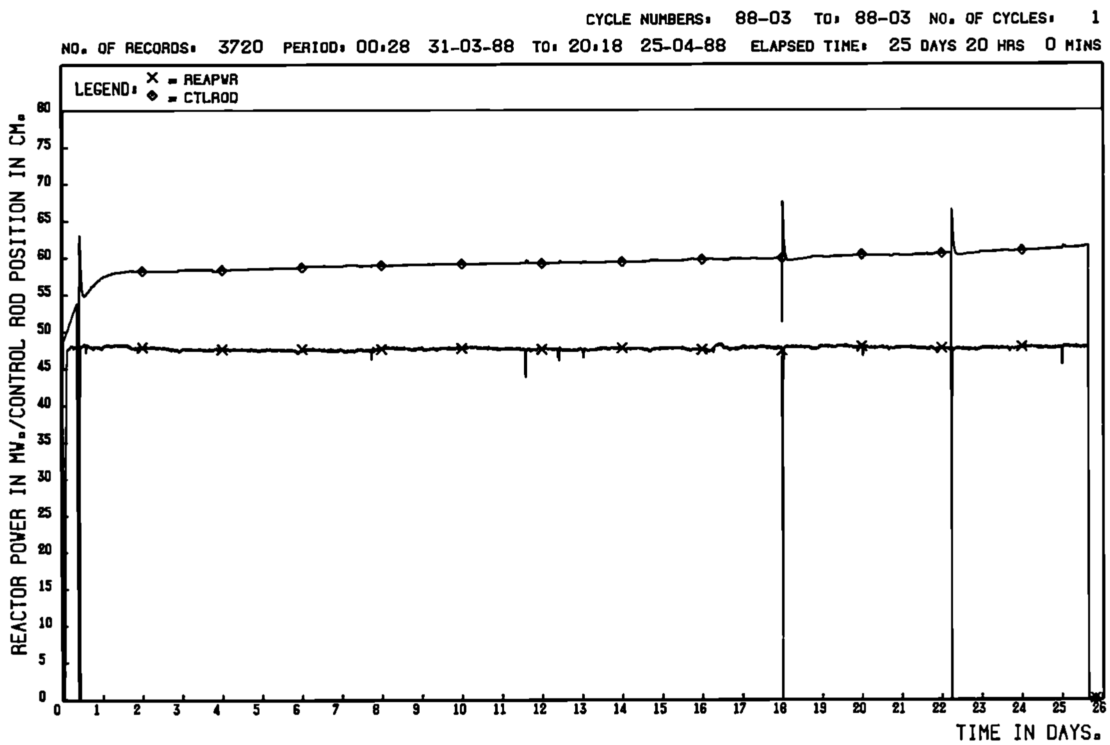


Fig. 3 HFR cycle 88.03. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.

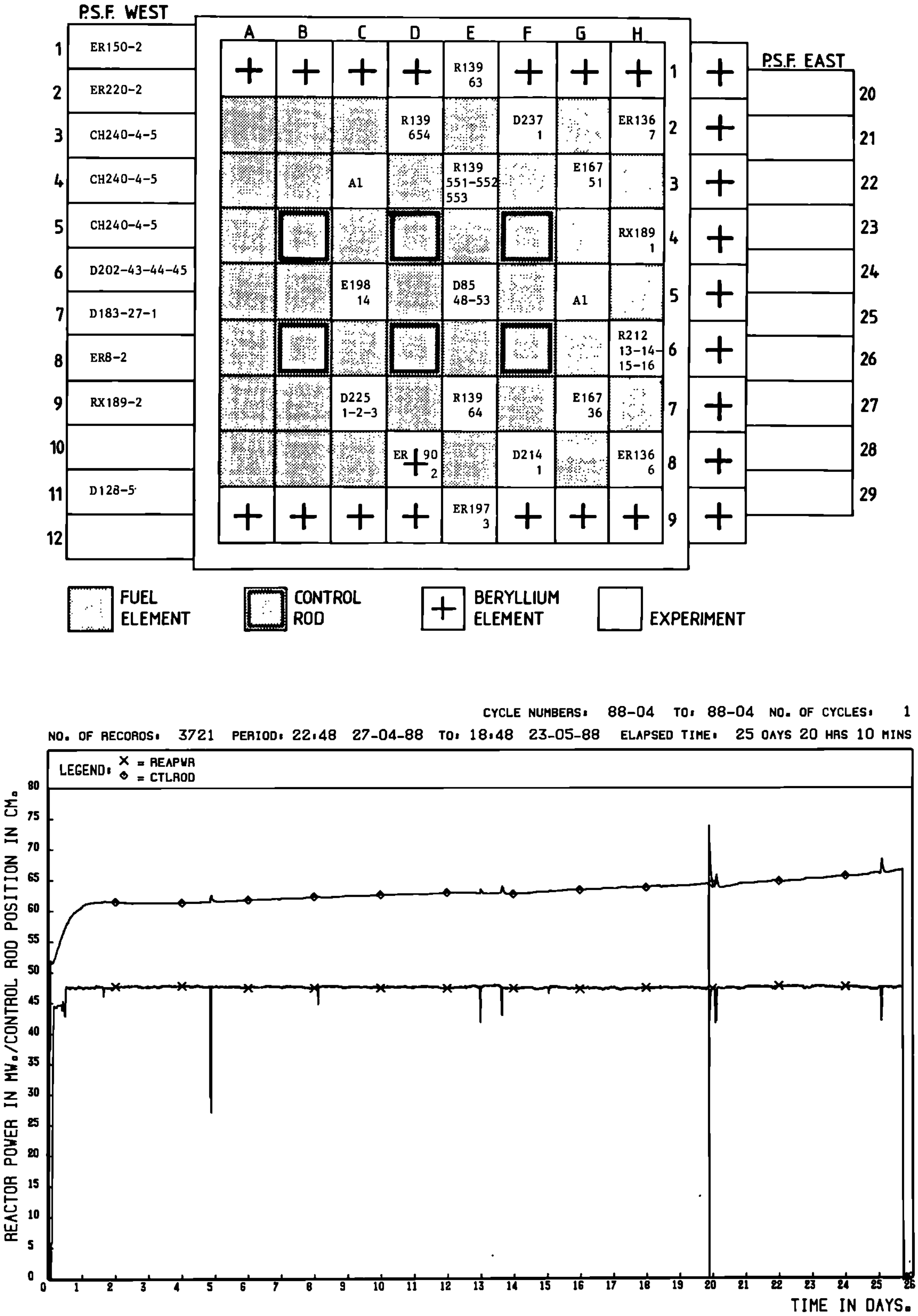


Fig. 4 HFR cycle 88.04. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.

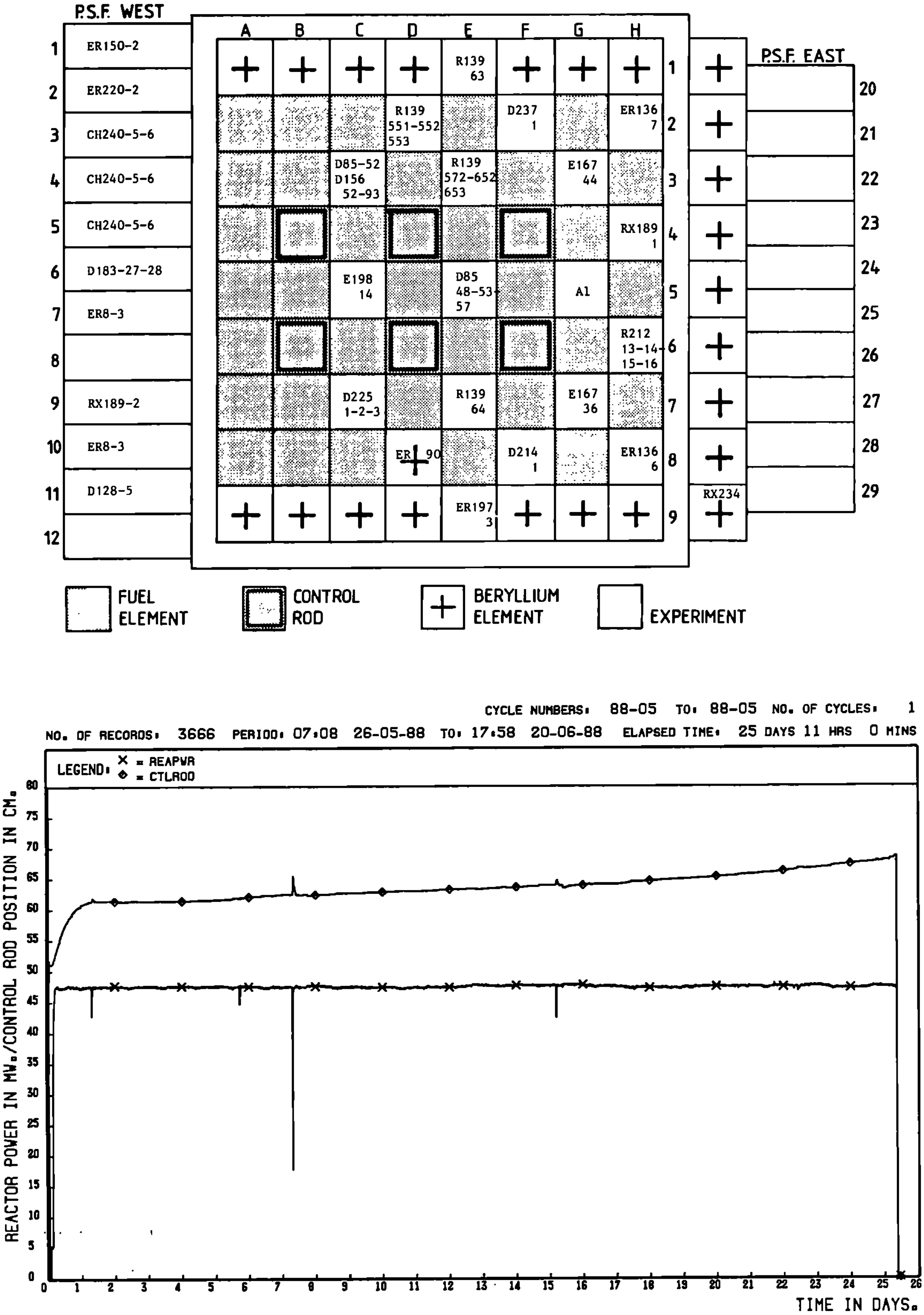
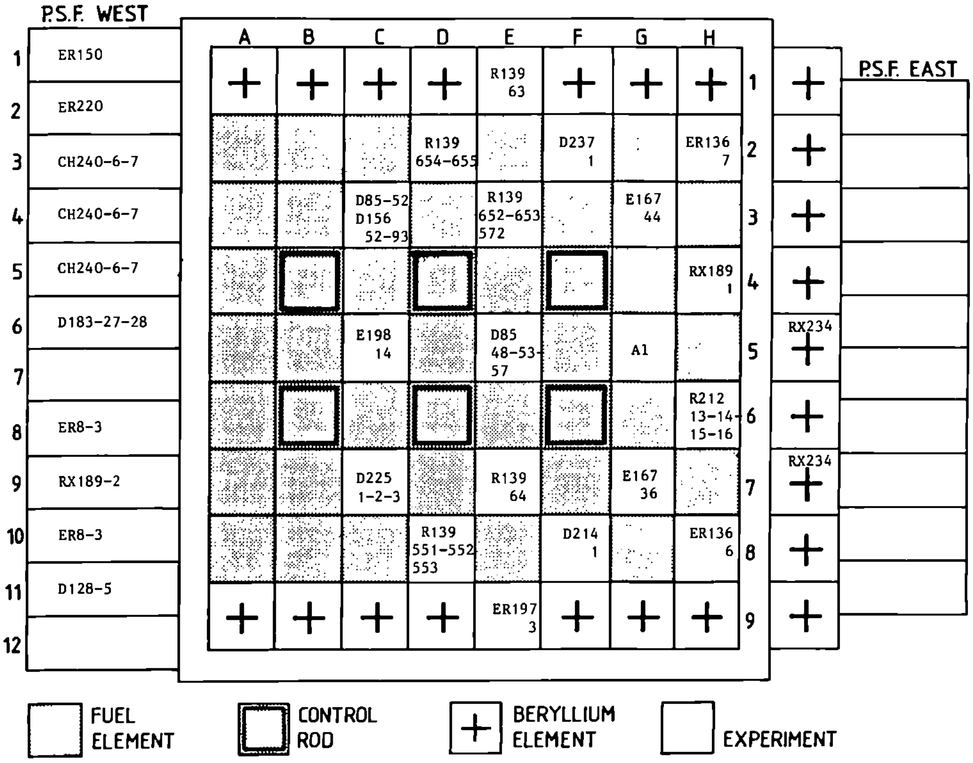


Fig. 5 HFR cycle 88.05. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.



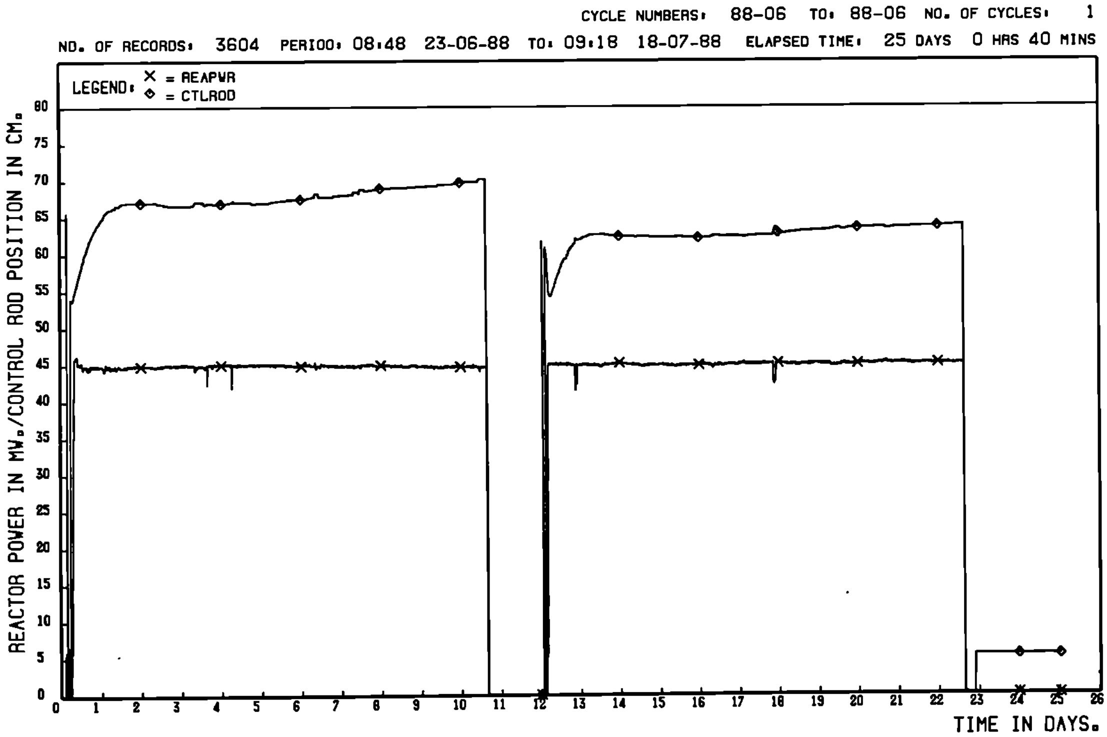
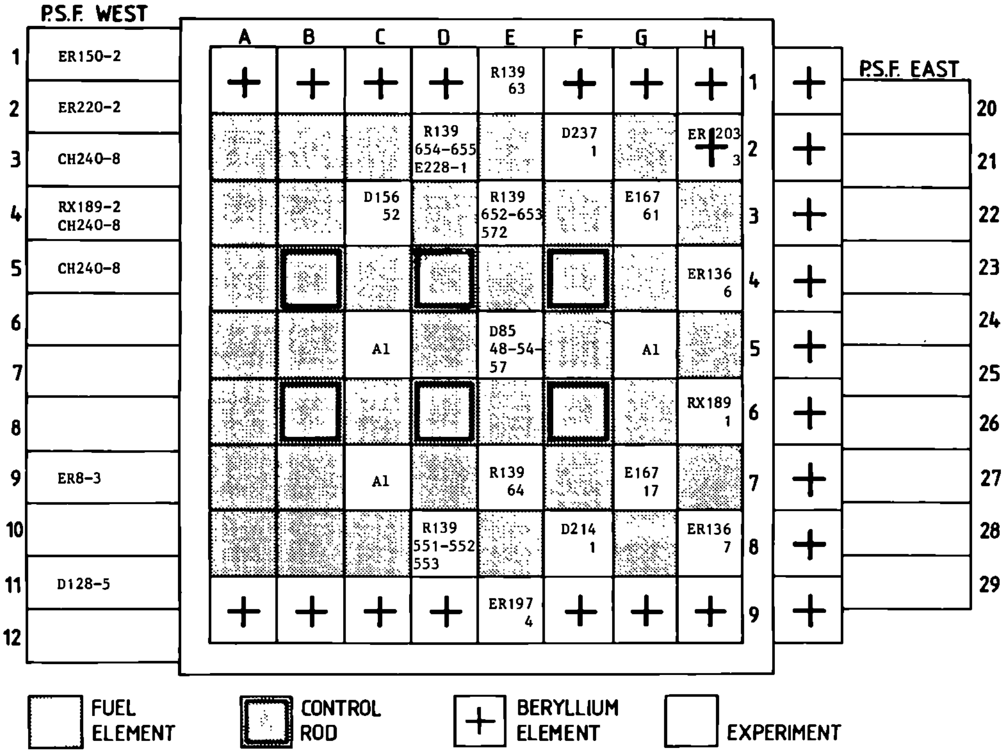


Fig. 6 HFR cycle 88.06. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.



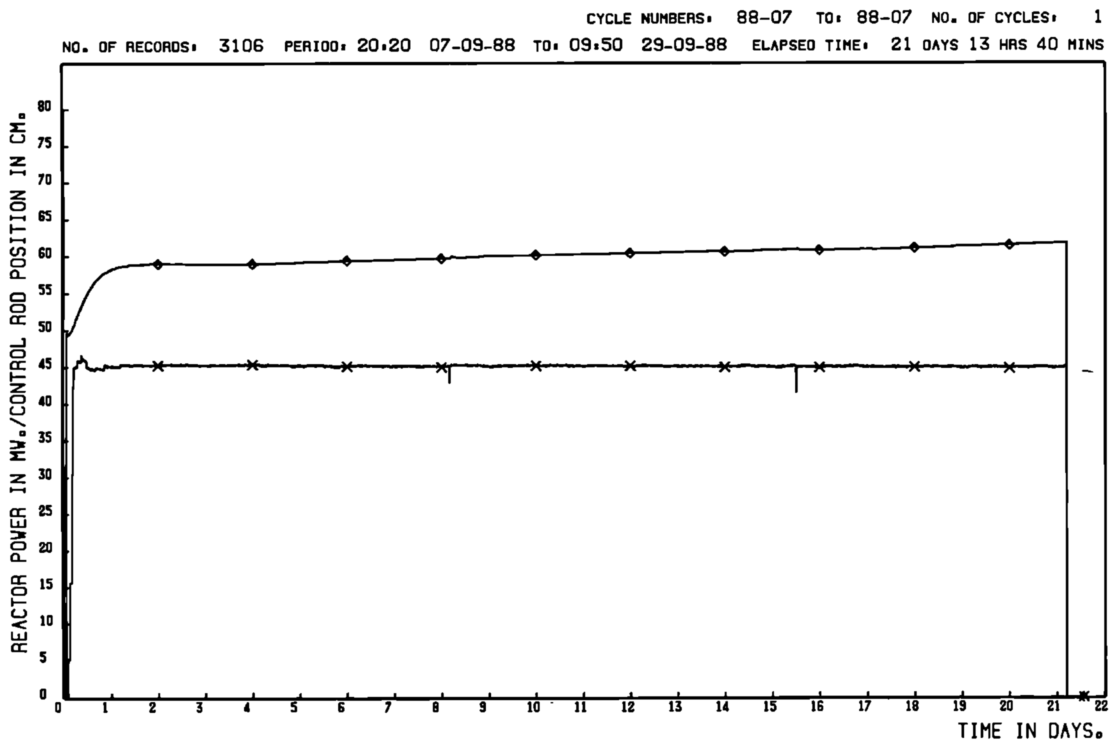


Fig. 7 HFR cycle 88.07. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.

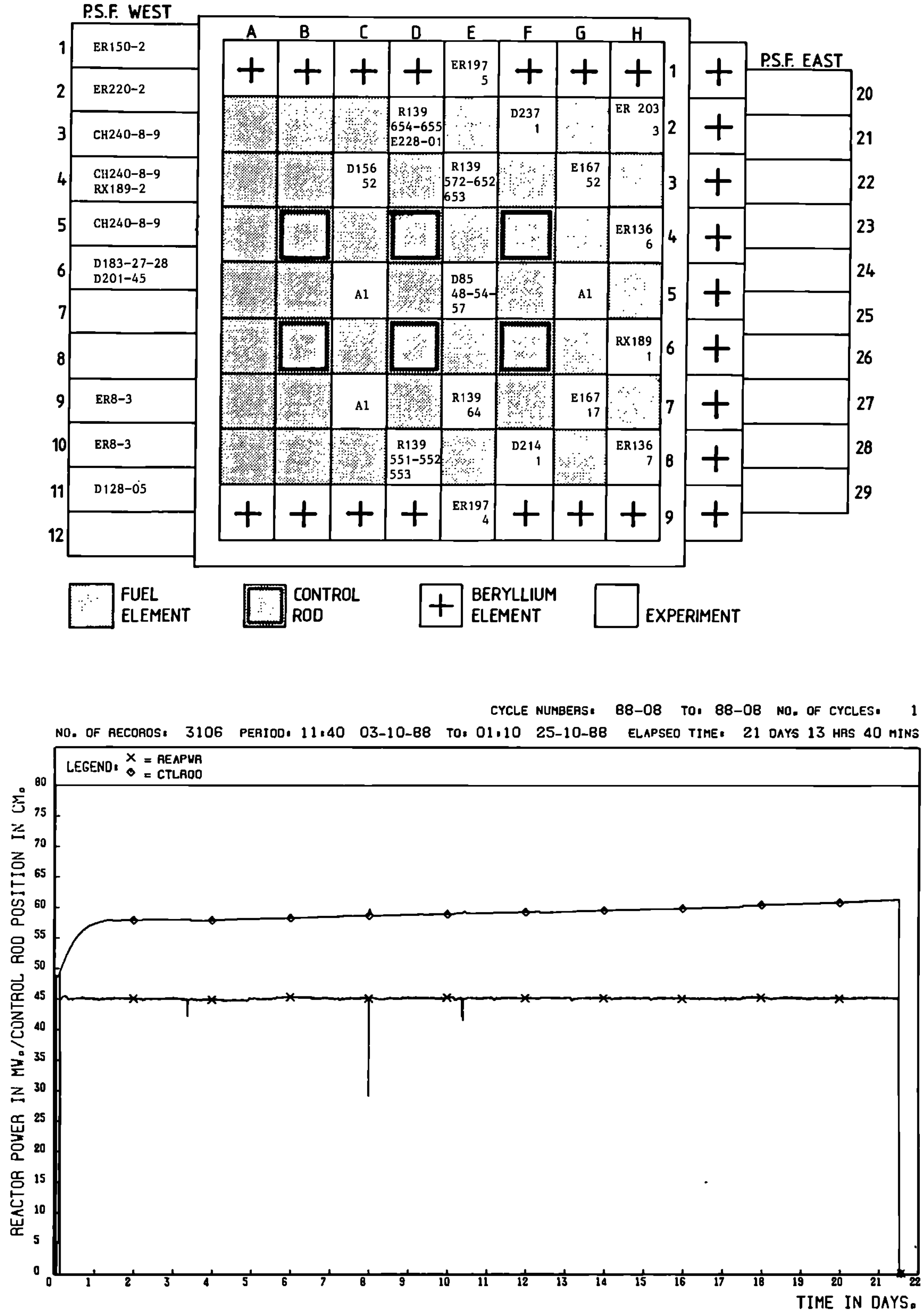
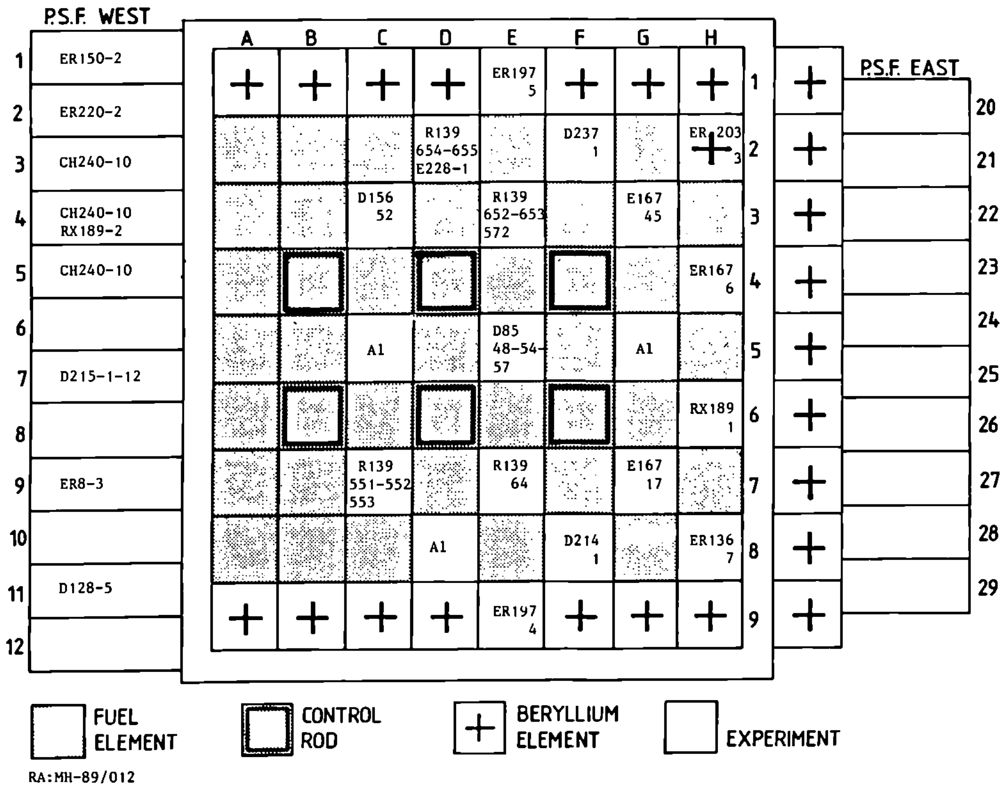


Fig. 8 HFR cycle 88.08. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.



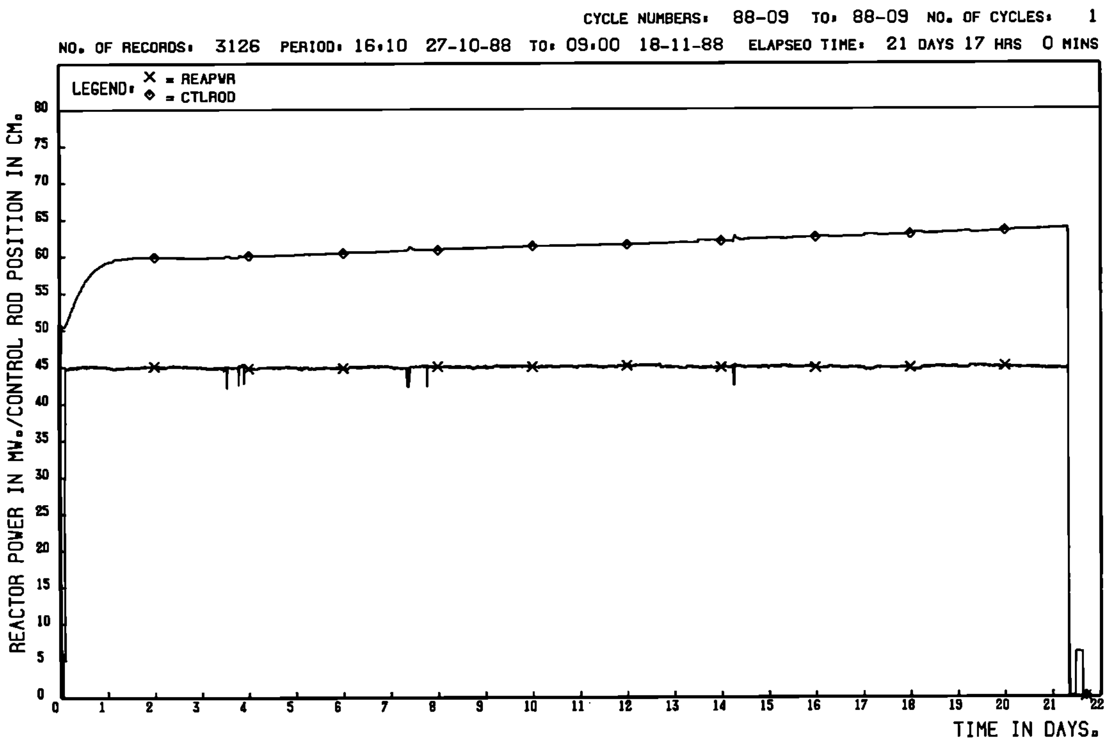
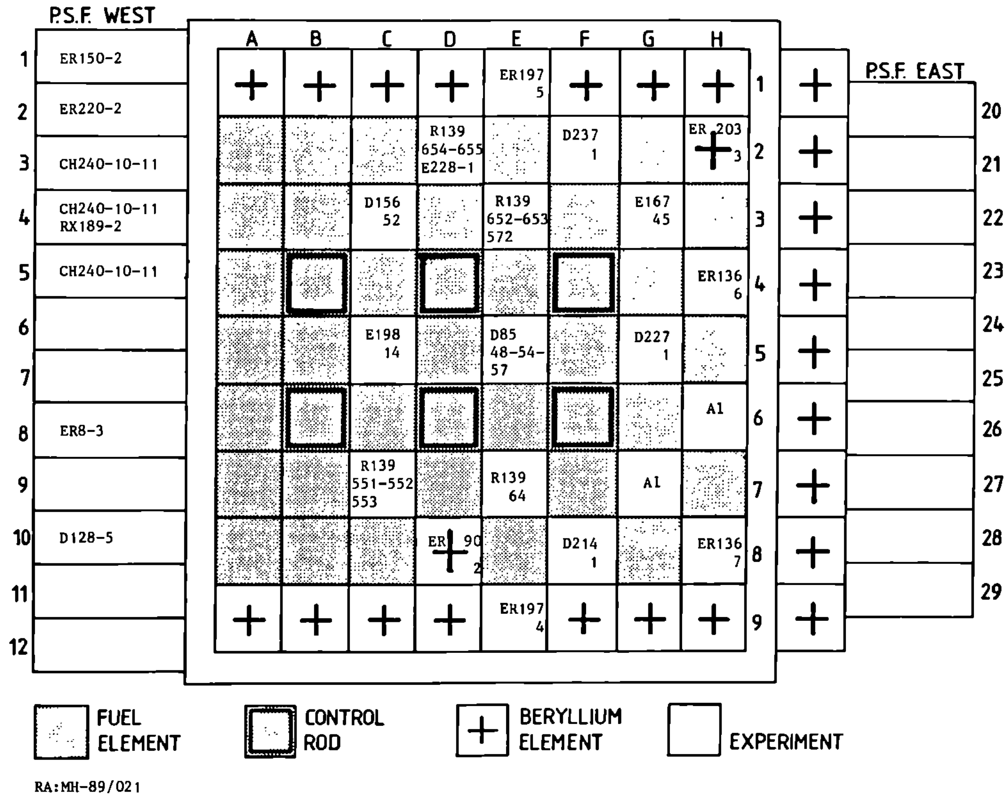


Fig. 9 HFR cycle 88.09. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.



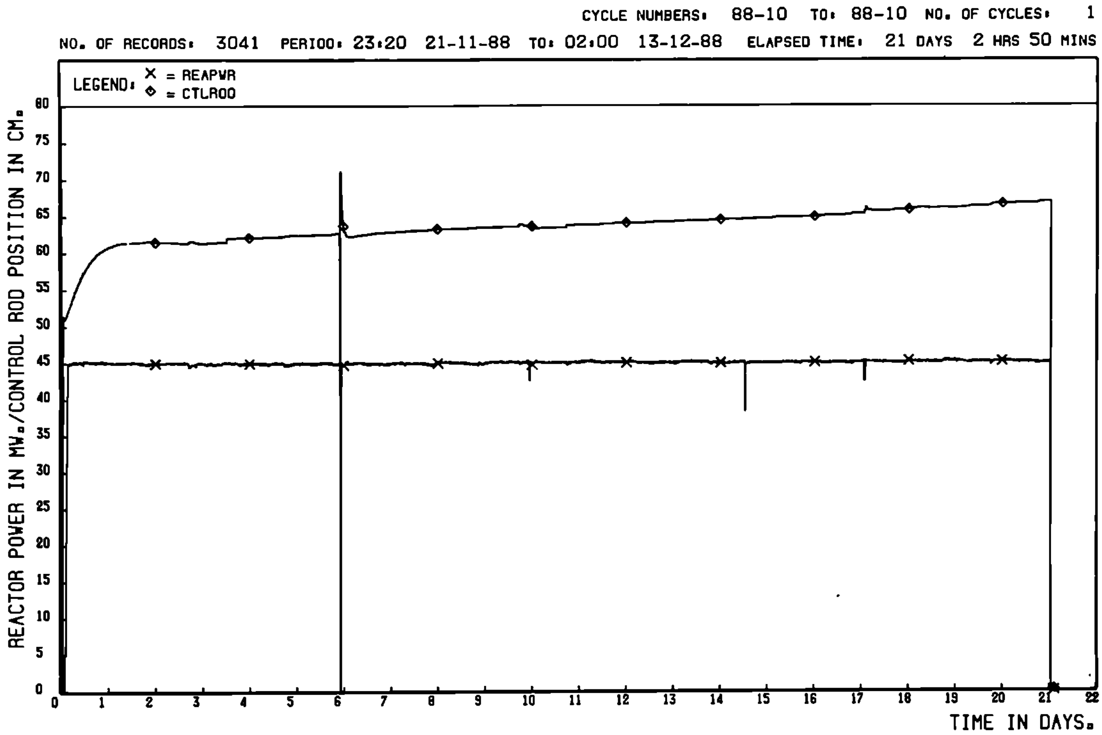
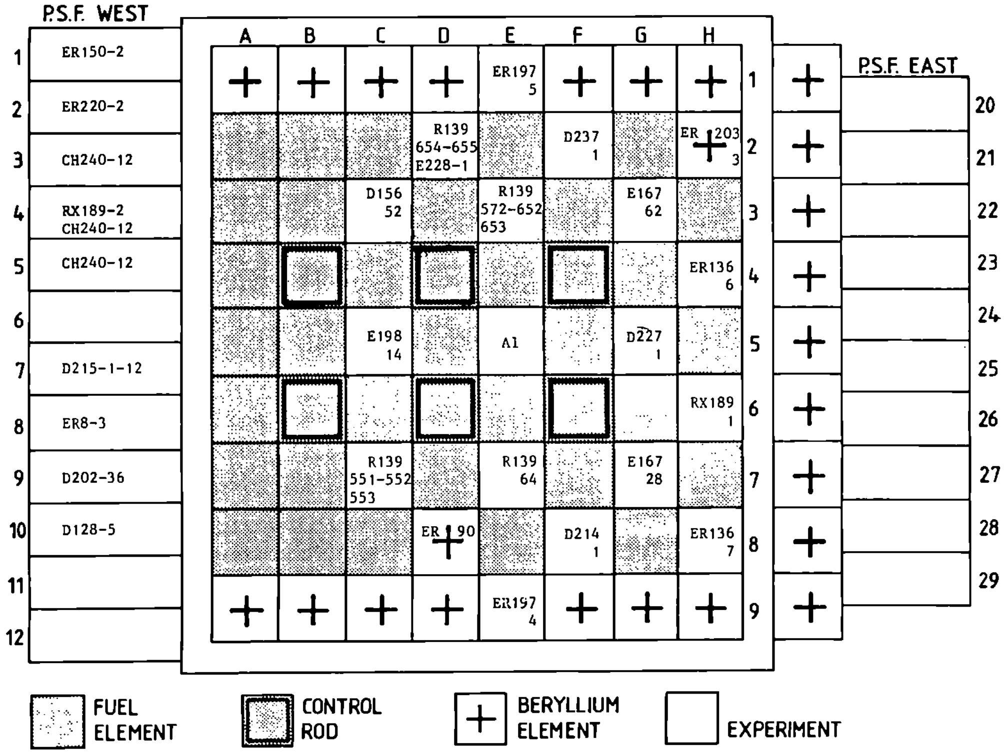


Fig. 10 HFR cycle 88.10. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.



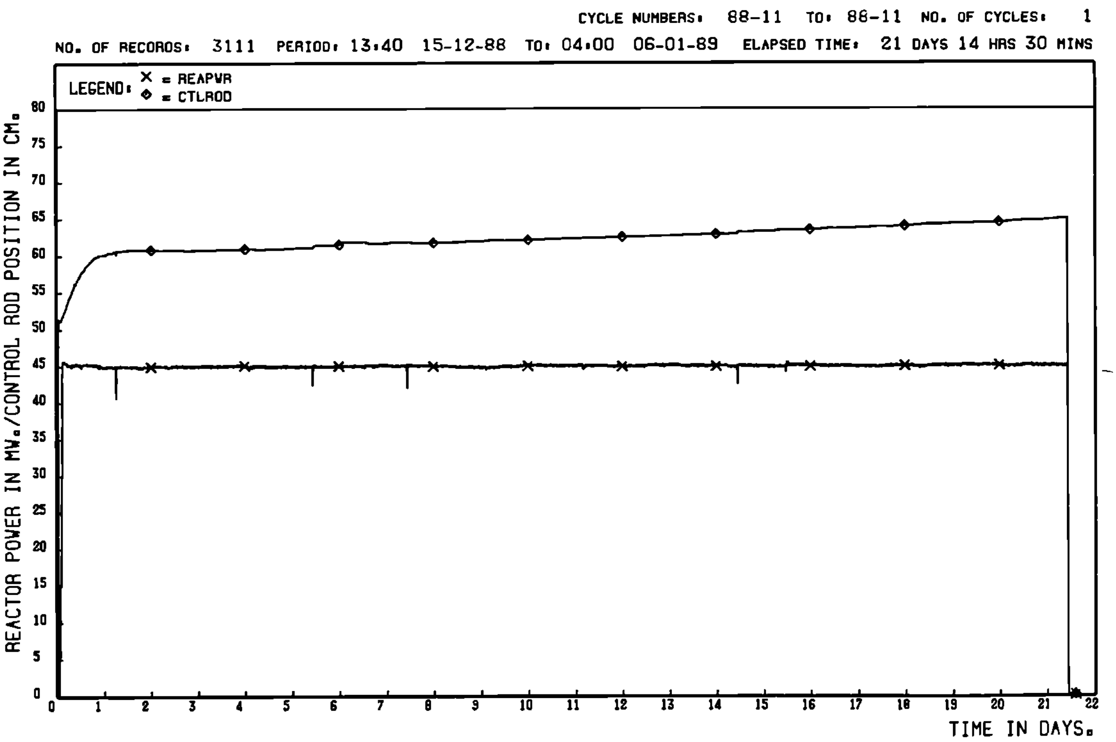


Fig. 11 HFR cycle 88.11. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Used experiment codes are explained in Table 5.

2.1.1.2. Operational Disturbances and Incidents

Table 3 shows the scheduled and unscheduled deviations from normal operation, together with an indication of type and origin of each disturbance. The number of disturbances (15 in 1988) was lower than in previous years (23 in 1987 and 34 in 1986).

There were 5 scheduled power production interruptions and 1 scheduled power decrease, all for reasons of handling of experiments or isotope facilities. Of the 7 automatic shut-downs, 5 were by "human" origin, 3 were caused by isotope facility handlings and 2 during or after repairs. Of the automatic shutdowns 2 were initiated by mains power supply disturbances. Two human errors caused power decreases during manipulations with water systems. One manual shut-down during the reactor start was necessary for the removal of the reactor vessel material surveillance rig.
There were five manual reactor power decreases for experimental or isotope facility handling.

2.1.1.3. Radiation Exposure of HFR Personnel

In **Fig. 12** a survey is given of the registered annual dose equivalent for HFR operators.
The picture clearly shows that in the last few years the doses to personnel are significantly lower than in the past. The values are much lower than the officially permissable level (50 mSv).

2.1.1.4. Fuel Cycle

- o HEU Supply
  After some delay the USA authorities granted an export license for 38 kg of HEU which was delivered in October 1988. This supply, together with existing stock will assure HFR operation until spring 1991.

- o Fuel Management
  During the year 1988, 47 new elements have been delivered and a consignment of 42 fuel elements and control rods has been shipped to the Savannah River plant for reprocessing. The

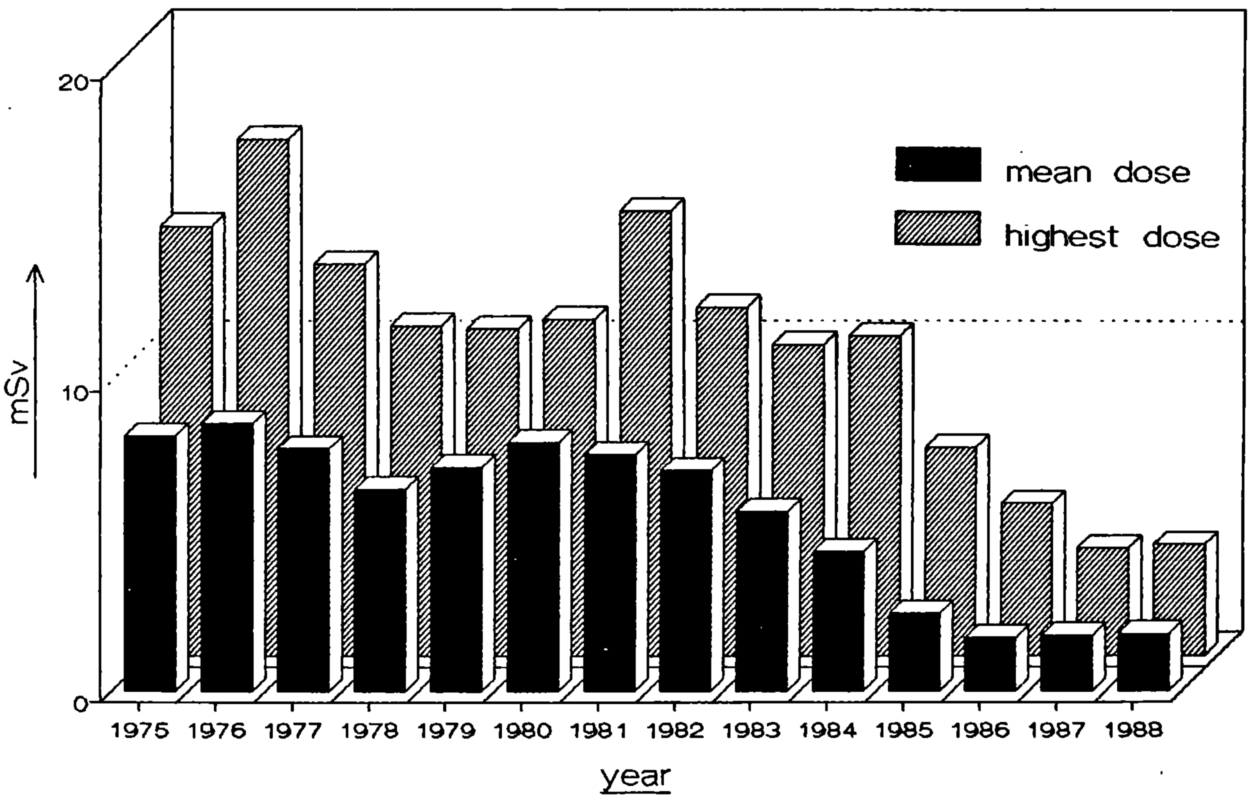


Fig. 12 Dose equivalents HFR-operators for the period 1975-1988

Table 3 Disturbance during full power operation

Date 1988	Hour	Duration h.min.	Disturbance code 1	2	3	Reactor system or experiment	Comments	Core no.
04.02	09.12	00.04	AS	R	H	Safety channel	Too fast reset of the automatic power control unit after repair.	88.02.01
30.03	22.00	02.44	MS	E	H	RX189-2	Removal of the target from poolside facility.	88.03.01
31.03	09.23	00.57	AS	E	H	HB11/12	High gasactivity alarm, due to the removal of a malfunctioning gasreducer.	88.03.01
07.04	18.15	-	MP(40MW)	E	S	ER136-07	Precaution for isotope handling.	88.03.01
18.04	00.20	00.05	AS	E	H	ER136-07	Safety channel trip during isotope handling.	88.03.01
22.04	05.50	00.06	AS	E	H	ER136-07	Ibid.	88.03.01
02.05	19.00	00.07	MP(25 MW)	E	S	D183-27	Removal of experiment from the poolside facility.	88.04.01
02.05	19.45	00.08	MP(25 MW)	E	S	D183-27	Installation of experiment in the poolside facility.	88.04.01
17.05	19.52	00.06	AS	R	E	Power supply	Main power supply dip.	88.04.01
02.06	14.25	00.13	MP(20 MW)	E	S	D183-27	Installation of experiment in poolside facility.	88.05.01
04.07	00.10	23.50	AS	R	H	ER 136-07	Safety channel trip during handling.	
05.07		11.30						88.06.02
11.10	11.30	00.08	MP(20 MW)	E	S	D183-27/28	Experiment removed from poolside facility.	88.08.01
27.11	21.21	00.11	AS	A	E	Power supply	Short-circuiting on mains transformer connections.	88.10.01
06.12	11.26	00.04	AP	A	H	Pool	Pool level lowered during pump action.	88.10.01
16.12	19.40		AP(40 MW)	R	H	Secundary cooling	Increase of primary temperature during backflushing of primary heat exchanger.	88.11.01

DISTURBANCE CODE

1. LEADING TO
- Automatic shut-down AS
- Manual shut-down MS
- Automatic power decrease AP
- Manual power decrease MP

2. RELATED TO
- Reactor R
- Experiment E
- Auxiliary system A

3. CAUSE
- Scheduled S
- Requirements R
- Instrumentation defect I
- Mechanical defect M
- Electrical defect E
- Human error H

transport was performed by Nuclear Cargo and Services who have taken over the Transnuklear contracts. A survey of the HFR fuel status is given in **Table 4.**

- o Fuel Fabrication
  Due to the decision of Nukem to give up MTR fuel element fabrication future delivery of fabricated fuel elements and control rods is uncertain. In order to prolong HFR operation fuel has been conserved by reducing the cycle length from 26 to 21 days and reducing power from 47.5 MW to 45 MW. It is expected that all fuel fabrication can be taken over by CERCA and that the normal HFR cycle can be resumed in 1989.

- o LEU Testing
  LEU test elements have been delivered from CERCA and B & W. Low power flux measurements were performed prior to the start of HFR cycle 88.07. Irradiation proper is scheduled to start in January 1989.

2.1.1.5. Audit Inspection

The national licensing authority made a comprehensive quality audit (during one week) in order to assess the procedures for reactor operation and irradiation experiments. The audit was conducted according to the INSAR model as applied by the IAEA (Integrated Safety Assessment of Research Reactors).

It was noted that a quality assurance manual was in an early stage of preparation; the auditing team recommended that a formal quality system should be introduced in the near future.
The final report of the auditors is not expected to reveal any major shortcomings.

2.1.2. Maintenance and Modifications

2.1.2.1. Mechanical Installations

- o The first phase to renew the demineralised water supply system was executed. The new reverse osmosis system was installed.
- o Progress was made with the up-date of the as-built drawings for various components.
- o Various actions necessary for the execution of the In-Service Inspection were carried out.

2.1.2.2. Instrumentation Systems and Informatics

- o Good progress was made with the improvement of the gas monitoring system. Modules with pumps and flow meters have been installed in the monitor area. The delivery of the required monitoring materials suffered some delay.
- o The project for the replacement of the start-up channels has been finished.
- o The equipment for the replacement of the fuel

Table 4 Status of HFR fuel elements

	1987	1988
Transfer of depleted fuel elements	67	33
Transfer of depleted control rods	17	9
Average burn-up of transferred fuel elements	49%	47%
Average burn-up of transferred control rods	53%	49%
Delivery of new fuel elements	25	47
Delivery of new control rods	10	-
New fuel elements available for use at the end of the year	30	23
New control rods available for use at the end of the year	13	1
New fuel elements charged to the core	71	54
New control rods charged to the core	16	11
Fuel elements depleted	58	54
Average burn-up of depleted fuel elements	48%	49%
Control rods depleted	14	11
Average burn-up of depleted control rods	48%	59%

rupture monitor was received and tested.

- Equipment for the water level monitoring in the three pools was received at the end of the year.

2.1.2.3. Electrical Installations

- Much time was spent on the renewal of the intercom and the emergency warning system.
- The fire alarm was integrated into the physical protection warning system.
- Some 102 new technical drawings were made, and a further 120 were revised.
- 106 operationally relevant motors were maintained.

2.1.3. HFR Upgrading Projects

2.1.3.1. Replacement of Pool Cooling Heat Exchanger

Objective: To increase the heat removal capacity of the pool cooling system in order to maintain an acceptable (< 38^{0}C) pool temperature during summer conditions and especially in the case of a HFR power increase.
Progress: Minor technical problems at the manufacturers and the the possible impact of higher and non-constant pool water temperatures during In-Service Inspection led to the decision to postpone the installation until the next long maintenance stop, i.e. March 1989.

2.1.3.2. Replacement of Beryllium Reflector Elements

Reason: Replacement of the original elements became necessary due to mechanical damage and local deformations caused by a combination of handling and of irradiation induced embrittlement.
Progress: 15 internal and 13 external beryllium reflector elements have been fabricated and checked at the manufacturer. The delivery of all elements has taken place. The safety report is nearly finished.

2.1.3.3. Extension of the Reactor Power Safety Protection System

Objective: To provide redundancy and diversification for the present 3-channel flux protection system. Through the presence of two such systems both working in a 2-out-of-3 mode the vulnerability to detector failures and other spurious events can be decreased.
Progress: The order has been placed and the equipment (comprising a second set of safety channels) has been manufactured, inspected and accepted by TUV. After some modifications in the documentation the equipment will be shipped. Installation is expected in March 1989.

2.1.3.4. HFR Control Room Upgrading

Objective: Reconfiguration and upgrading of HFR control room functions and apparatus in order to replace outdated components and to introduce modern ergonomic principles with regard to information access and display.
Progress: A report prepared on this project by KEMA has been received and studied. It is expected that the upgrading process will be executed in steps over several years, in order not to interrupt the normal operation of the HFR. Detailed considerations have to be made to computerized data collection, presentation and calculation systems and to alarm annunciations.

2.1.3.5. Revision of HFR Design and Safety Report

Objective: Updating of the HFR Technical and Safety Documentation to modern structural and technical requirements, such as to form the basis for a re-issue of the present HFR Operating License.
Progress: Many sections of the final document have now been prepared by the main author. The process of review by experts present on the site suffered some delay due to several technical and personnel reasons.

2.1.3.6. Extension of HFR Building Complex

Objective: The extension of the building complex which, as a first step, will comprise an enlargement for the installation of better cloakroom accomodation.

As second step the enlargement and renovation of the high construction hall is envisaged.

Progress: The first step comprising the construction of a few offices and new washing and changing facilities for the reactor personnel was finished early 1988.
No action was taken with respect to the second step.

2.1.3.7. HFR Silicide Fuel Evaluation

Objective: Evaluation of the applicability of silicide fuel elements in materials testing reactors, by means of experimental verification of the irradiation characteristics of this type of fuel, and determination of the nuclear and operational characteristics of fuel elements with special composition.
Progress: The project comprises the study of the behaviour of (UxSiy-Al) test elements supplied by different manufacturers. Two test elements of French origin have undergone a hydraulic testing procedure, and passed the dimensional check after this test. At low reactor power, neutron fluence rate measurements have been performed. Measurement results are being compared with calculational results. The safety report has been written and the full power irradiation is expected in January 1989. The two elements from the USA were received on site; progress of testing etc. was delayed as accompanying documentation was missing. This has now been received.

2.1.3.8. HFR In-Service Inspection

The first full in-service inspection of the HFR vessel was performed during July and August in accordance with procedures previously agreed with the Netherlands licensing authorities. The techniques used were ultrasonic, eddy current, dimensional, visual and surface penetrant.
The conclusion drawn from the inspection was that there have been no changes in the vessel since its installation in 1984.

2.1.3.9. Leakage of HFR Pool Liner

This project studies the development and application of a method to stop further corrosion of the pool liner.

One of the measures to stop the corrosive action on the aluminium liner is the application of an inhibitor.

In 1987 it was recommended to inject CO_2 gas at the concrete side via the leakage water drain, in order to reduce the alkalinity of the water near the concrete. Detailed working procedures for the reactor operations staff are being written.

A system for CO_2 injection is available. Its use is delayed as a consequence of unexpected new discussions about the effects expected from CO_2 injection.

2.1.3.10. Uninterrupted Power Supply

Objective: Improvement of the reliability and continuity of the power supply system, in order to prevent disturbing effects on reactor operation if a main power failure occurs.
Progress: A new uninterrupted power supply has been installed, in order to replace the rather old installation and to improve the situation with respect to location (both physical protection and cabling) and reliability. The installation comprises two static uninterrupted power supply sets of 40 kVA in parallel. At full load the batteries of each set can operate for 10 minutes.
Since the input power required for the installation is supplied by the emergency power installation with diesel motors, the new installation has to function only during the start-up time of these diesel motors. When there is a failure in the emergency power station, it is guaranteed that the uninterrupted power supply can operate for 20 minutes.

2.1.3.11. HFR Vessel Material Surveillance (RX189)

The in-core facility was irradiated in core position H6, except for 2 cycles in H4 and 1 cycle in F2. It became necessary to change the dosimetry monitors, because they had reached saturation. During a reactor stop period an attempt was made to dismantle the facility, but the cover could not be released, due to corrosion. A new facility was fabricated at the JRC workshop. During cycle 88.10 the old facility was cut open using the fuel element saw, after which the samples with new flux monitors were re-loaded into the new facility. The irradiation in the PSF-facility was continued in position 4 without any problems.

2.1.3.12. Automatic Gas Supply System for Irradiation Devices (AUGIAS)

A study of a system for automatic temperature control in irradiation capsules was made in 1987. The mechanical design of the system has been accepted by the parties involved, but some concern was expressed on the concept of fully automatic temperature control. It has now been decided to change to a semi-automatic system. This means that when the capsule temperature deviates only an alarm will be given. The experiment operator then decides whether or not to change the gas mixture. Safety limits will prevent wrong gas mixing, increasing pressure, wrong operation with radioactive gases, etc.

There is not much progress to report on this project. Drawing office capacity was not available until December. Then the design of the connection boxes was started. Furthermore some offers have been made for mechanical parts. It was planned to have the assistance of a computer expert at JRC; one of his tasks was the AUGIAS computer system. Unfortunately this plan has been cancelled and a solution for this part of the project has not yet been found.

2.1.3.13. Horizontal Beam Tubes

Since the reactor vessel replacement there is a leakage on beam tube 7.
In this beam tube, a so called inner shutter is installed, which was originally designed for water. Since the total beam tube system has been filled with helium, the sealing gives a problem. A design is made for another sealing construction. For financial reasons the manufacture of the mechanical parts has been postponed until 1989.
During the summer stop a new shielding construction has been installed at HB 11/12. At the same time the gas supply system has been modified.
All gas supply systems and leak detection systems are assembled at a general panel. The water security locks were replaced by safety valves.

2.1.4. Analytical and Experimental Support

2.1.4.1. HFR Core Characteristics

o Neutron Fluence Rate Measurements

The characterization of all HFR irradiation facilities and standard devices took place during irradiations in November 1986 and September 1987 (FLUX-86B). The evaluation was done in 1988. The results are reported in /1/ and /2/. Some characteristic distributions are given in **Figs. 13 to 17**.
Comparisons have been made with the results of the former metrology programmes FLUX-83 and FLUX-84. In nearly all experiment positions, in-core as well as PSF-I, lower thermal and fast fluence rates have been measured compared with the data presented in EUR-5700 /3/.
Differences up to 15% have been observed, dependent on the core position and the fluence rate type (thermal or fast).
Thermal and intermediate neutron fluence rate calculations for all in-core experiment positions, for positions 2 and 4 of PSF-I and positions 22 and 27 of PSF-II, at different distances from the reactor vessel wall, are given in /4/. For all these locations the thermal fluence rate $\phi 2200$ and the intermediate fluence

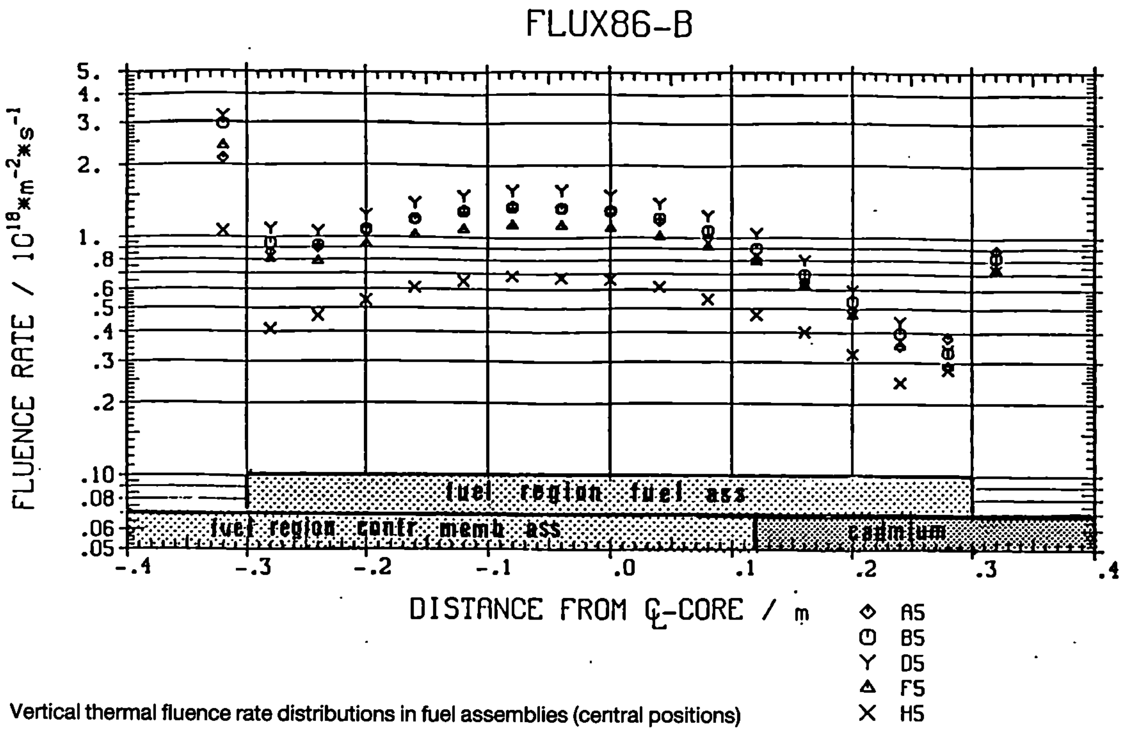


Fig. 13a Vertical thermal fluence rate distributions in fuel assemblies (central positions)

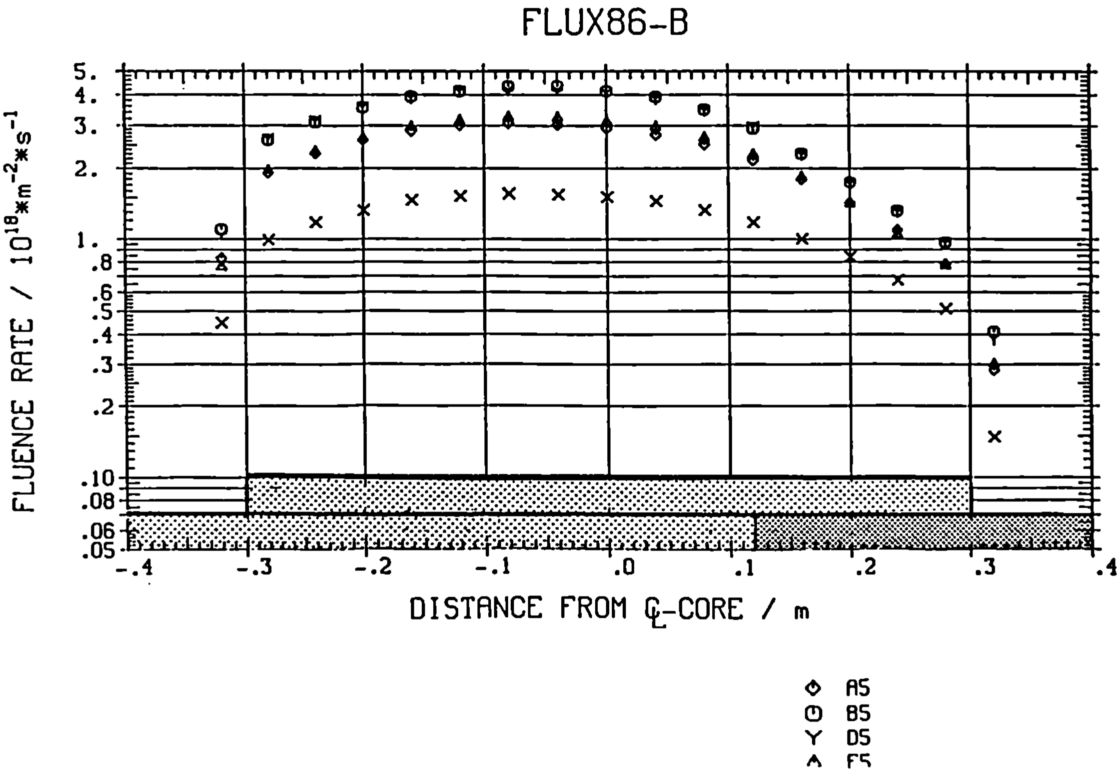


Fig. 13b Vertical fast fluence rate distributions in fuel assemblies (central positions)

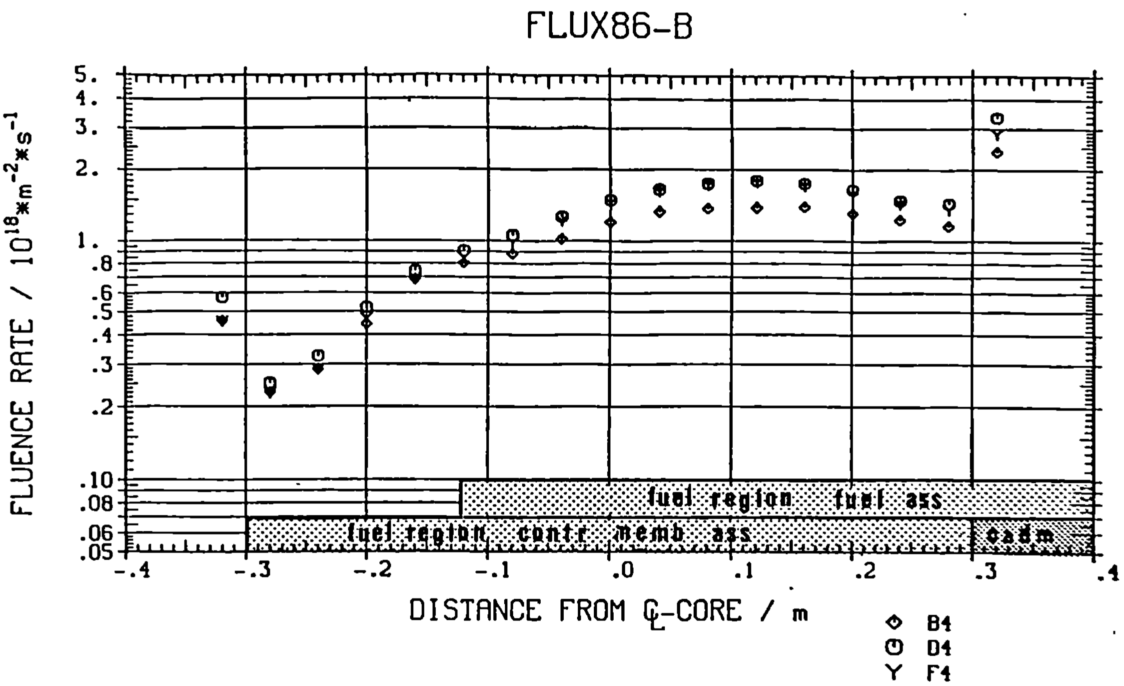


Fig.14a Vertical thermal fluence rate distributions in control-member assemblies (central positions)

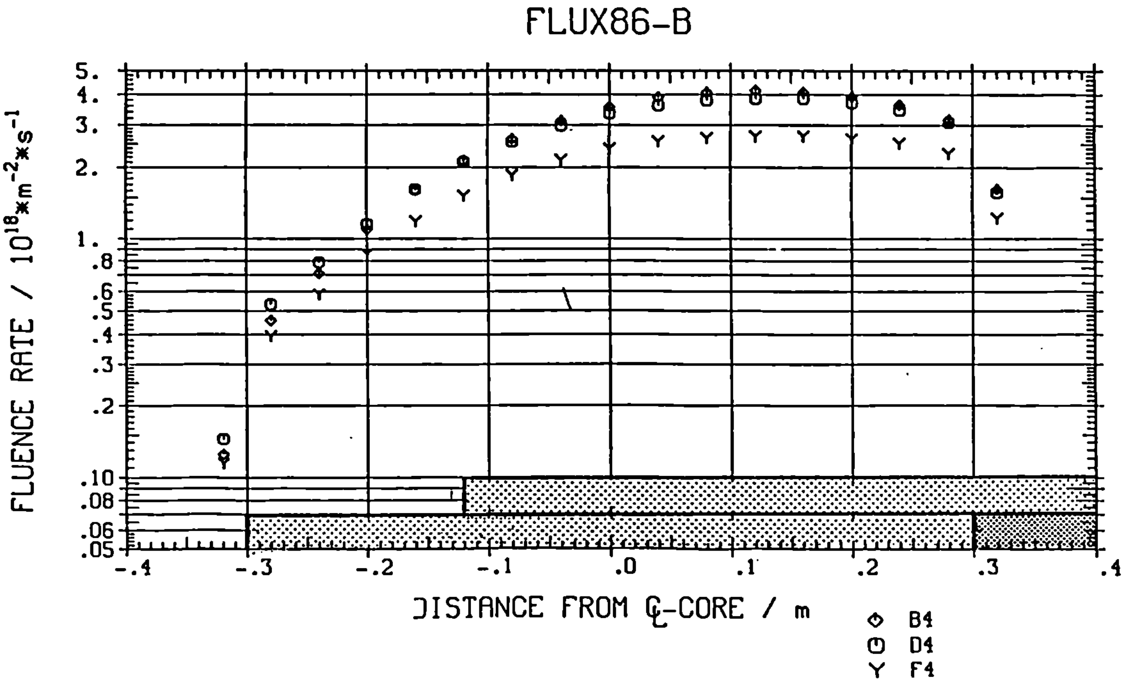


Fig. 14b Vertical fast fluence rate ditributions in control-member assemblies (central positions)

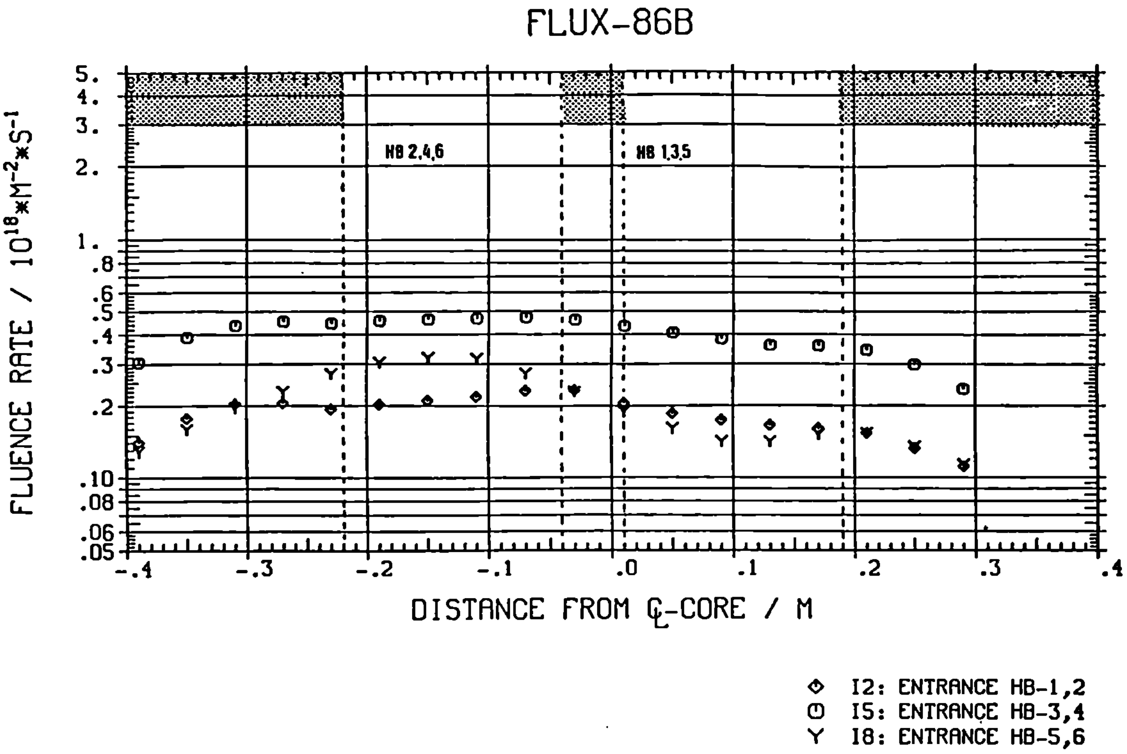


Fig. 15a Vertical thermal fluence rate distributions in front of the entrances of the HFR beam tubes

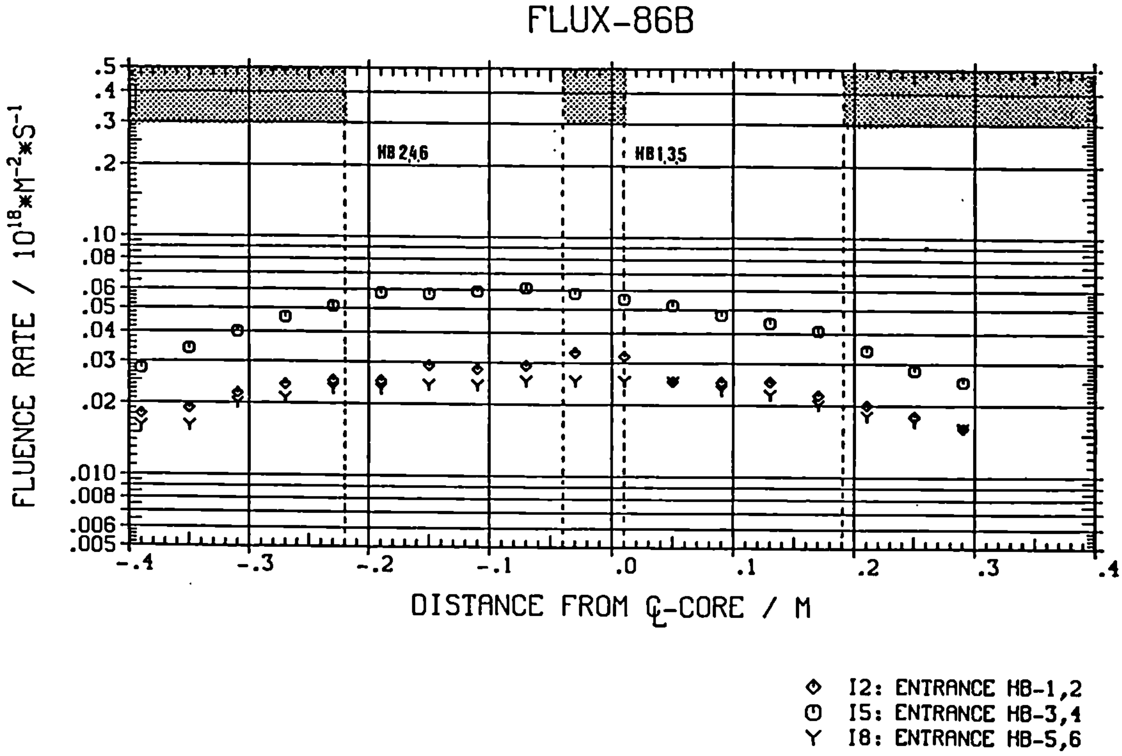


Fig. 15b Vertical fast fluence rate distributions in front of the entrances of the HFR beam tubes

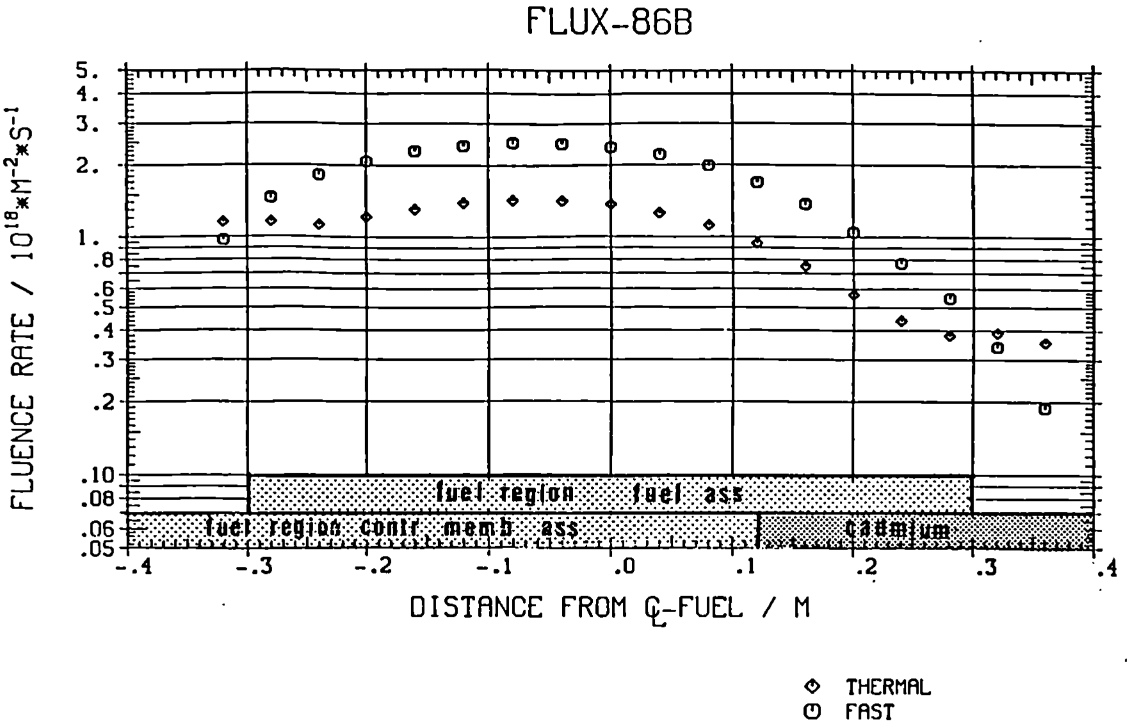


Fig. 16 Vertical thermal and fast fluence rate distributions in S-assembly E5

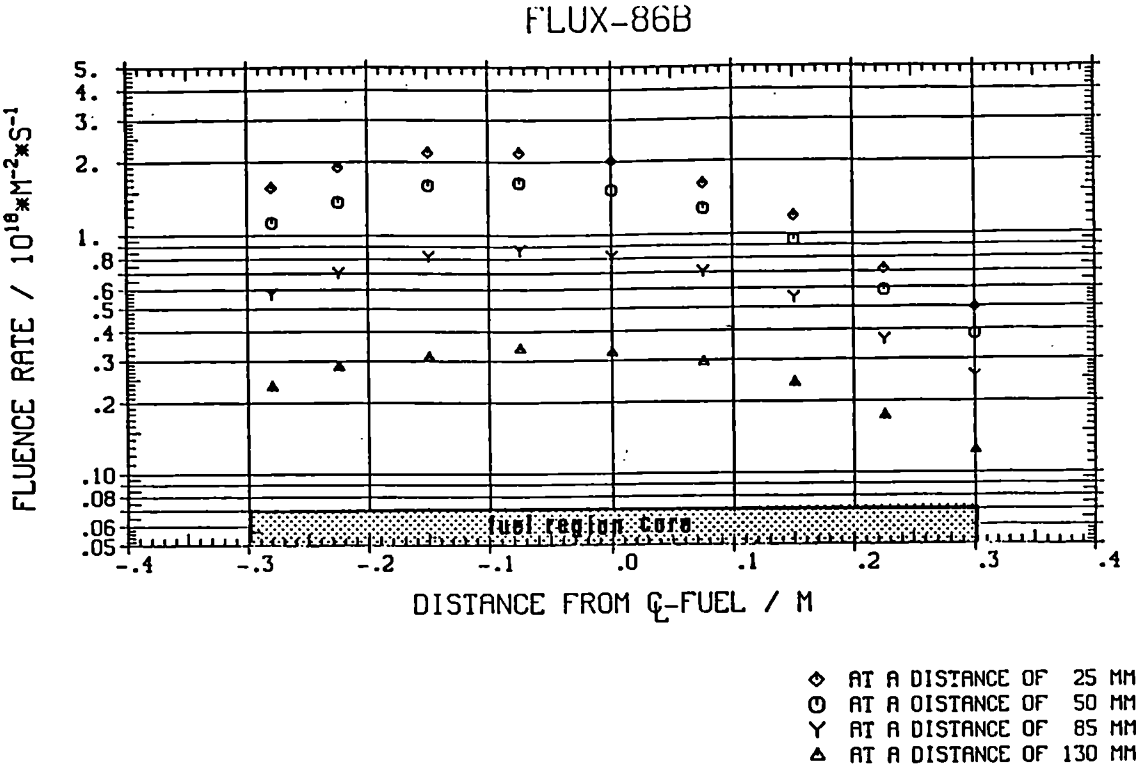


Fig. 17a Vertical thermal fluence rate distributions in position 9 of PSF West

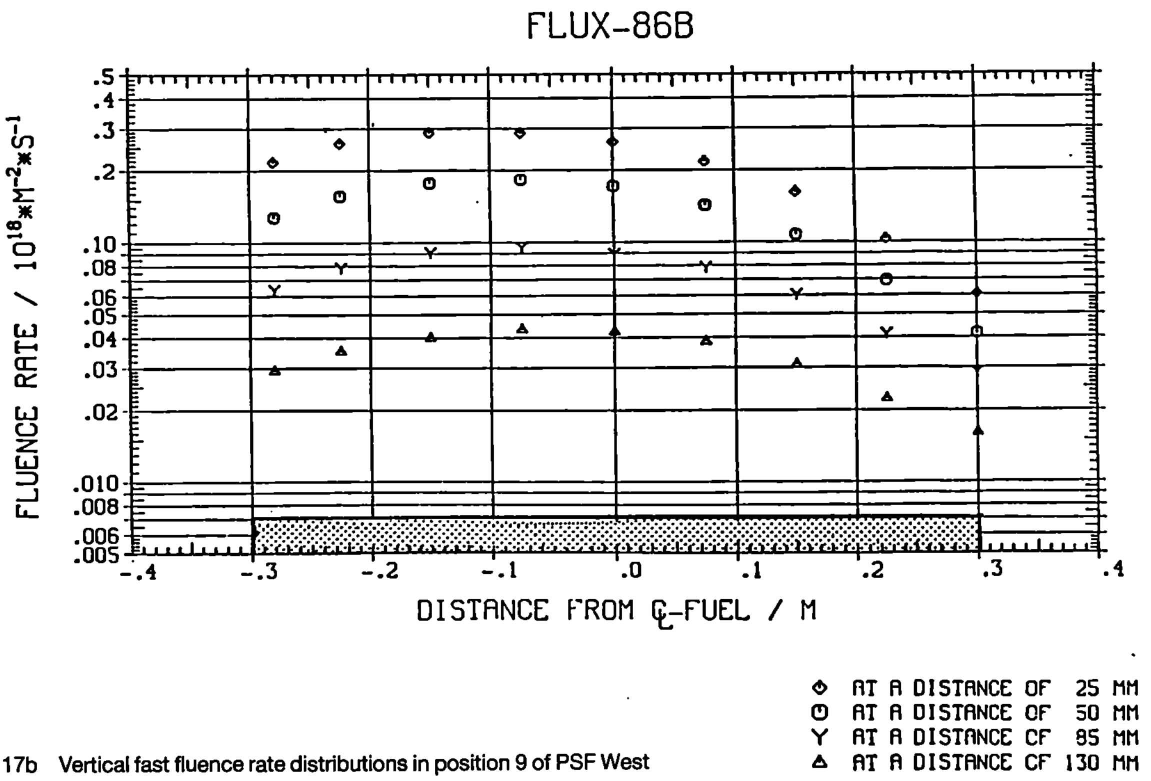


Fig. 17b Vertical fast fluence rate distributions in position 9 of PSF West

rate per unit lethargy θ are measured for the position at centre line fuel. A survey of the ratio between both types of fluence rate data is given in **Fig. 18**.
The sources of uncertainty present in the reported fluence rate values have been summarized in /5/.
The yearly fluence rate measurements in all fuel assemblies have been carried out on March 28, 1988, during an irradiation of 2 hours at 180 kW (core 88031). These measurements are needed to fulfil conditions set by KFD (Kern Fysische Dienst) to operate the reactor. The results are used to check the HIP-TEDDI calculations.

o Nuclear Heating Measurements, TRAMP, RX161

A series of measurements of nuclear heating in several in-core- and PSF-positions has been reported in ECN-88-104. For the users of the HFR and the experimental facilities a shortened version is produced under ECN-88-105. With reference to these measurements an important remark can be made. In the in-core positions it is found that the nuclear heating level in graphite is 17% higher than in aluminium and 26.5% higher than in stainless steel. In the PSF positions the values are about the same.
Last year the measuring probe of the TRAMP facility has been damaged beyond repair. Before the manufacture of a new measuring probe, the design has been simplified. In the new measuring probe only 6 calorimeters will be installed and the probe can be removed easily from the drive unit. The mechanical parts for the new probe have been manufactured, but the assembly has not been finished. The available calorimeters have been recalibrated in order to be sure that they were still in a good order. The assembly of the measuring probe has been started.

References to paragr. 2.1.4.1.

/1/ Paardekooper, A. and Voorbraak, W.P. "Neutron Metrology in the HFR Annual fluence rate measurements FLUX86-B; Part A : Fuel, in-core experiment positions, beam tubes and PSF-I (west)" ECN-88-161 (Petten, October 1988)
/2/ Hoving, A.H. and Voorbraak, W.P. "Neutron Metrology in the HFR Annual fluence rate measurements FLUX86-B; Part D : Pool Side Facility II (east)" ECN-89-012 (Petten, January 1989)
/3/ Röttger, H. et al. "High Flux Materials Testing Reactor HFR Petten" Characteristics of facilities and standard devices" Report EUR 5700 (Revised edition 1986/1987)

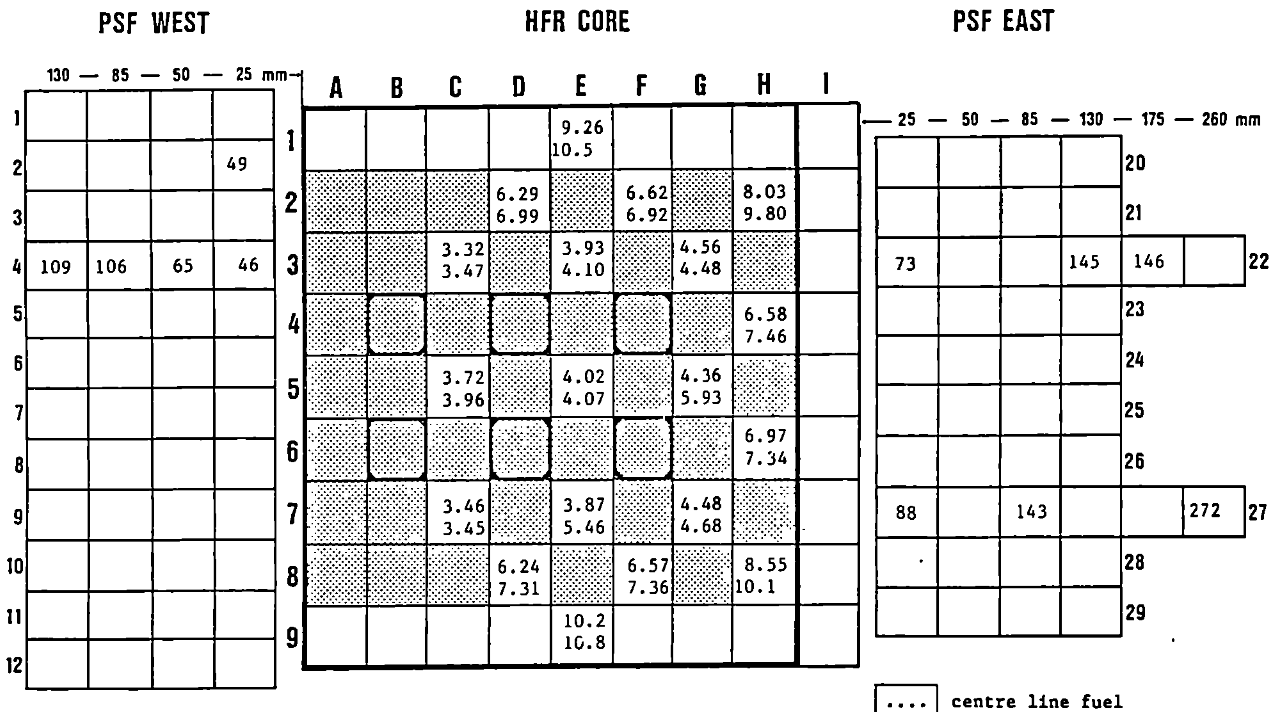


Fig.18 Ratios of the thermal to the intermediate fluence rate per unit lethargy

/4/ Freudenreich, W.E.
"Neutron Metrology in the HFR
Annual fluence rate measurements FLUX86-B;
Part B : Intermediate fluence rate values in experiment positions inside the core, PSF-I and PSF-II"
FYS/RASA-88/34 (Petten, December 1988)

/5/ Paardekooper, A. and Voorbraak, W.P.
"Neutron Metrology in the HFR
Annual fluence rate measurement FLUX86-B;
Part C : Uncertainty of presented values"
FYS/RASA-88/27 (Petten, October 1988)

2.1.4.2. Core Characterization Methods Development

- o Development and Testing of Techniques for Neutron Metrology in the HFR

Irradiation History HFR experiments

The irradiation history of an experiment in the HFR, which is necessary for the calculation of the fluence and fluence rate, consists of numerical values for the reactor power and for the date and time at which this power level was reached. In the past, the irradiation history was derived from the HFR cycle logbooks and typed into the computer. This time-consuming method has been replaced by two computer programs. The first part, the update of the power history file with data of the new cycle, is done by means of the program MOTOR. The program MOTOR condenses a detailed HFR reactor power history from DACOS into a new power history with larger intervals of a constant reactor power.
From this extended history the program HISTOR selects the history for a particular experiment. This selected history can be condensed again by HISTOR in the case of long irradiations. Both programs are described in /1/.

- o Counting and Data Treatment of Fluence Rate Detectors

A start was made with the development of a system of programs for the treatment of counting results to give fluence, dpa and helium production sequentially. Until now each program runs independently and many manual interactions are necessary. In the new system all programs will operate as single, independent, modules interfacing the essential input and output data to a data base, the so called "work base", which escorts the complete calculation process.

To increase the counting effort, a robot has been installed which transfers an irradiated activation monitor from a lead surrounded storage facility to a counting position at a certain distance from a Ge(Li) detector. After the counting, the robot returns the monitor to the storage facility. The right counting position (dependent on the counting rate) is selected by the robot itself. A start has been made with the development of the software for the robot.
The fluence measurement and data processing for neutron activation detectors irradiated in an HFR experiment (from detector preparation to damage parameter calculation) is schematically shown in **Fig. 19**. For each step in the process sequence a number of possible sources of perturbation, leading to uncertainties in the resulting data, is given. In addition three tests are indicated, which are used to check the quality of the results. The data treatment procedure has been described in /2/.

For long irradiation periods niobium activation detectors are very suitable due to the large half-lives of the product nuclides. The fast and thermal fluences can be measured with the activation reactions $^{93}Nb(n,n')\,^{93}Nb^{m}$ and $^{93}Nb(n,\gamma)\,^{94}Nb$, respectively. Previously, difficulties were met in the activity deter-

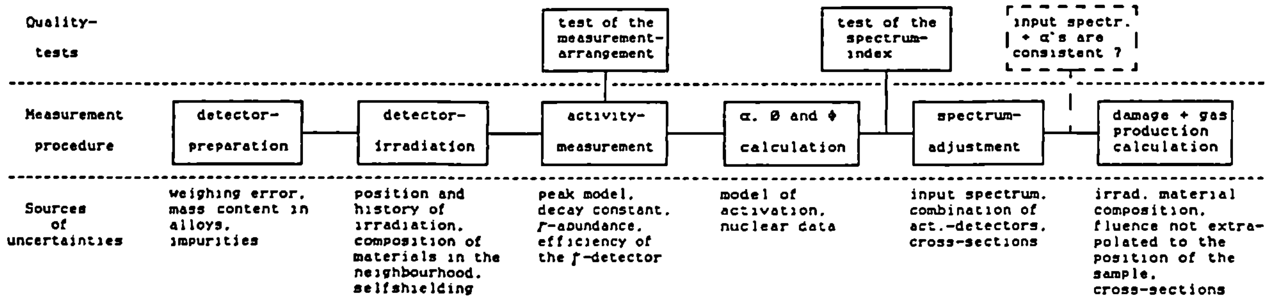


Fig. 19 Scheme of the measurement procedure

α : saturation activity per target atom
Ø : neutron fluence rate
Φ : neutron fluence

mination of $^{93}Nb^m$, caused by the self-absorption of the Nb X-rays (16.5 and 16.6 keV) in the metal foil and the generation of Nb X-rays by scattering of gamma-rays with various energies from other activated nuclides of the irradiated detectors. To reduce the above problem another technique has been applied to determine the activity of $^{93}Nb^m$. In this case the niobium metal foils have been dissolved in a fixed amount of acid (mixture of HNO_3 and HF). The solution has been counted with a 1000 mm^2 X-ray detector. The results of the activity determination, using this technique of dissolved foils, give better results than the counting procedure with solid metal foils. The technique has been described in /3/.

Damage in Ceramic Materials

The number of displacements for the ceramic material irradiated in experiment D 217-13 (CERAM) had to be calculated using a damage cross-section for graphite. At present, no recommendation on how to report damage in ceramic materials, or damage cross-sections for ceramic materials is available.
The Radiation Damage sub-group of the European Working Group (EWGRD) initiated an action to solve this problem during their 53rd meeting in Ispra (26/27 April, 1988).

o Nuclear Data

A draft of the new edition of the "Nuclear Data Guide" has been presented at the 53rd meeting of the EWGRD /4/. The final edition of this report will replace the first edition of the "Nuclear Data Guide", distributed in 1979.
The main features of the new edition are:
- an updating of the nuclear data,
- an extension of the number of reactions.

During the last quarter of 1988, the contents have been revised, taking into account some of the comments on the draft report.

References to paragr. 2.1.4.2.

/1/ Kraakman, R.
"Program description of the programs MOTOR and HISTOR"
FYS/RASA-88/13, May 1988

/2/ Freudenreich, W.E., and Nolthenius, H.J.
"Quality control on neutron fluence rate measurements at ECN"
ECN-88-075, April 1988

/3/ Appelman, K.H.
"Counting of Nb foils (reaction $^{93}Nb(n,n')$ $^{94}Nb^m$)"
FYS/RASA-88/06, February 1988

/4/ Baard, J.H., and Zijp, W.L.
"Draft. Nuclear Data Guide for Reactor Neutron Metrology (1988 edition)"
ECN-88-071, April 1988

2.1.4.3. Users' Services

Nuclear analyses have been performed for a number of experiments:
The radioactivity of irradiated material has been calculated for the (old) beryllium reflector elements /1/ and the CERAM (D 217) experiment. For the SIMONE (ER 231) experiment a number of calculations have been carried out to obtain the nuclear constants of the LEU fuel elements at several burn-up levels /2/. The derived nuclear constants are used in the HFR HIP-TEDDI calculations for the cycles in which the test elements are going to be irradiated.

References to paragr. 2.1.4.3.

/1/ Thijssen, P.J.M.
"Berekening van de radioactiviteit van beryllium reflectorelementen na 25 jaar bestraling in de HFR"
RA memo 88-21, ECN, Petten, 1988

/2/ Mérelle, E.Ch., and Thijssen, P.J.M.
"Berekening van de nucleaire constanten van het splijtstofdeel van SIMONE testelementen"
RA memo 88-.., ECN, Petten, in voorbereiding

2.1.4.4. Other Reactor Support Activities

A computer code has been written on a PC to process the measured values during the "HFR containment building leakage test" /1/. The code has been used successfully during the test in March.
The code is an important debugging tool during the leakage test: the response of all measuring devices can be plotted, as well as intermediate and final results. While using this tool the basic scanning and processing system (datalogger and PDP11/73) continues its work. Formerly, the basic scanning system had to be interrupted for debugging purposes, with a loss of some scans.

In June, reactivity measurements were performed in support of the safety analysis of the HFR core and for verification of the calculational methods used /2/.

The activities that are related to the procedure for HFR fuel transfers have been analyzed and written in a report /3/.

The conversion of the MICROFLUX code from ALGOL-5 into FORTRAN-77 started in August. The project will take approximately eight months and is performed by ENR.

References to paragr. 2.1.4.4.

/1/ Thijssen, P.J.M.
"Beschrijving van de verwerkingsprogramma's voor de lekdichtheidsbeproeving op de Tulip PC"
Restricted Distribution ECN-88-140, ECN, Petten, 1988

/2/ Hendriks, J.A., and Thijssen, P.J.M.
"Reactiviteitsmetingen in de HFR-kern"
Restricted Distribution ECN-88-155, ECN, Petten, 1988

/3/ Thijssen, P.J.M.
"Beschrijving van de werkzaamheden met betrekking tot de totstandkoming van verplaatsingsformulieren voor HFR splijtstof"
RA memo 88-10, ECN, Petten, 1988

2.2. REACTOR UTILIZATION

2.2.1. Objectives

The reactor is essentially a neutron source. It is operated as a multi-purpose research reactor. The programme makes use of a variety of interactions between neutrons and matter.

- Fission: Fissile materials testing
- Elastic scattering of energetic neutrons: Radiation damage to structural materials
- Scattering, diffraction of slow neutrons: Solid state physics, materials science
- Neutron capture: Radioisotope production, activation analysis
- All kinds of nuclear reactions induced by neutrons: Nuclear physics, nuclear structure
- Special nuclear reactions: $^{10}B(n,\alpha)\,^{7}Li$ for neutron capture therapy
- Imaging with neutrons: Neutron radiography.

The following statistical information on the experiments [1] performed gives an impression of the size of the programme:

- start of new experiments	39
- continued irradiation throughout 1988	33
- unloading after end of irradiation	42
- short term transient irradiations	8
- horizontal beam tubes in permanent use	7-12
- isotope facilities in permanent use	10
- isotope facilities in intermittent use	1

2.2.2. Project Management

Irradiation projects originate from requests by experimentors. They then pass through the following main stages:
- design study (feasibility study), preliminary planning
- detail design and calculations, detailed planning
- safety analysis and assessment
- purchase of material, machining, preparation of instrumentation
- assembly
- testing and commissioning
- loading and connection in HFR
- irradiation, surveillance, data acquisition
- post-irradiation examinations (PIE)
- data processing
- reporting

More detailed project management schemes have been elaborated, featuring about 100 steps per project. Considering that about 40 irradiation projects are handled simultaneously, the volume of work involved can easily be judged.

For non nuclear energy applications (solid state and nuclear physics experiments, radioisotope production and activation analysis) the project stages follow a somewhat simplified procedure. Usually, fixed installations and long-term facilities are used (which do undergo the complete development cycle) with minimum amount of technical and administrative preparation.

2.2.3. Results

The experimental utilization of the reactor positions in 1988 is presented in **Fig. 20**. The reactor occupation was kept at a high level, namely 80% of the practical limit of occupation (1986: 75%, 1987: 84%). The objectives of the individual irradiation experiments were met in nearly all cases due to the good performance of the irradiation facilities.

2.2.3.1. Light Water Reactor (LWR). Fuel and Structural Material Irradiations

The LWR irradiation programmes in the HFR address primarily fuel irradiation experiments with the pre-irradiated fuel rod segments (rodlets) emanating from commercial power reactors (BWR and PWR). Approximately 250 pre-irradiated LWR fuel rods have been tested in the HFR within the period 1976/1988 in various programmes, representing approximately 30 tests per year. The earlier, relatively large test programmes have gradually been replaced over the last 3 years by smaller programmes with higher complexity. The basic theme of the investigations of the fuel rods concerns, in most cases, the behaviour of the fuel rod under power transients and/or power cycling. The newer test series address the dynamics of transient effects. They therefore involve utilization of more and better instrumentation, as well as more refined techniques for operation in the HFR and for the pre- and post-irradiation examinations (HFR pool and Hot Cells). The major topics of the 1988 LWR fuel irradiation programmes are:
- extended burn-up behaviour of MOX fuel rods
- transient fission gas release
- transient behaviour of BWR fuel rods of extended burn-up
- restructuring of fuel at constant power operation
- irradiation behaviour of PHWR fuel
- iodine release under simulated in-pile LOCA conditions

[1] Definition: Each sample holder which can be irradiated indepedently is considered as one experiment.

CORE

YEAR 1988

Position	Experiment	Capsule	J 01	F 02	M 03	A 04	M 05	J 06	J/A 07	S 08	O 09	N 10	D 11	Operator
C3	D.085	50	TTTT	TTTT	TTTE									Sch
	D.085	52	TTTT	TTTT	TTTT		TTTT	TTTE						Sch
	D.085	53	TTTT											Sch
	D.156	93					TTTT	TTTT						Cun
	D.156	52					(F)TTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	Cun
C5	E.198	14	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX				XXXX	XXXX	Sch
C7	D.225	01				TTTT	TTTT	TTE						Sch
	D.225	02				TTTT	TTTT	TTE						Sch
	D.225	03				TTTT	TTTT	TTE						Sch
	D.156	93	TTTT	TTTT	TTTT									Cun
	R.139	551									TTTT	TTTT	T TTE	Tso
	R.139	552									TTTT	TTTT	T TTE	Tso
	R.139	553									TTTT	TTTT	T TTE	Tso
D2	R.139	551		TTTT	TTTT		TTTT							Tso
	R.139	552		TTTT	TTTT		TTTT							Tso
	R.139	553		TTTT	TTTT		TTTT							Tso
	R.139	654				(F)TTT		TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	Tso
	R.139	655						(F)TTT	TTTT	TTTT	TTTT	TTTT	TTTT	Tso
	E.228	01							(F)TT	TTTT	TTTT	TTTT	TTTE	Mos
	ER.203	02	XXXX											Hol
D8	ER.90	02	XXXX	XXXX	XXXX	XXXX	XXXX					XXXX	XXXX	Hol
	R.139	551						TTTT	TTTT	TTTT				Tso
	R.139	552						TTTT	TTTT	TTTT				Tso
	R.139	553						TTTT	TTTT	TTTT				Tso
E1	R.139	63	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXE					Tso
	ER.197	05								[F]XXX	XXXX	XXXX	XXXX	Hol
E3	R.139	551	TTTT			TTTT								Tso
	R.139	552	TTTT			TTTT								Tso
	R.139	553	TTTT			TTTT								Tso
	R.139	651		(F)TTT	TTTE									Tso
	R.139	652		(F)TTT	TTTT		TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	Tso
	R.139	653		(F)TTT	TTTT		TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	Tso
	R.139	572					(F)TTT	TTTT	TTTT	TTTT	TTTT	TTTT	TTTT	Tso
E5	D.085	48	TTTT	TTTT	TTTT	TTTT	TTTT	TT	TTTT	TTTT	TTTT	TTTE		Sch
	D.085	53		TTTT	TTTT	TTTT	TTTT	TE						Sch
	D.085	54							(F)TTT	TTTT	TTTT	TTTT		Sch
	D.085	57					(F)TTT	TT	TTTT	TTTT	TTTT	TTTT		Sch
E7	R.139	64	XXXX	XXXX		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXE	Tso
E9	ER.197	03	XXXX	XXXX	XXXX	XXXX	XXXX	XXXE						Hol
	ER.197	04							[F]XXX	XXXX	XXXX	XXXX	XXXX	Hol

CORE

YEAR 1988

Position	Experiment	Capsule	J 01	F 02	M 03	A 04	M 05	J 06	J/A 07	S 08	O 09	N 10	D 11	Operator
F2	RX.189	01			XXXX									Hol
	D.214	01	XXXX	XXXX										Hol
	D.237	01				[F]XXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXE	Co
F8	D.138	04	XXXX											Hol
	D.214	01				XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	Co
	ER.203	02		XXXX	XXXE									Hol
G3			42		43		44				45			Cun
	E.167	40	[F]XE		[F]XE		[F]XXX	XXXE			[F]XXX	XXXE		Cun
						51				52				Cun
	E.167	50				[F]XE				[F]XE				Cun
									61				62	Cun
	E.167	60							[F]XE				[F]XE	Cun
G5	D.227	01										[F]XXX	XXXE	Mar
	D.225	01	TTTT	TTTT	TTTT									Sch
	D.225	02	TTTT	TTTT	TTTT									Sch
	D.225	03	TTTT	TTTT	TTTT									Sch
G7									17					Cun
	E.167	10							[F]XXX	XXXX	XXXE			Cun
			27										20	Cun
	E.167	20	[F]XX	XXXX	XXXE								[F]XX	Cun
						36								Cun
	E.167	30				[F]XXX	XXXX	XXXE						Cun
H2	E.224	01	QQQE											Co
	E.224	02	QQQE											Co
	E.224	03	QQQE											Co
	ER.136	07		XXXX		XXXX	XXXX	XXXX						Ko
	ER.203	03							[F]XXX	XXXX	XXXX	XXXX	XXXX	Hol
H4	ER.136	06	XXXX	XXXX	XXXX				XXXX	XXXX	XXXX	XXXX	XXXX	Ko
	RX.189	01				XXXX	XXXX	XXXX						Hol
H6	RX.189	01	XXXX	XXXX					XXXX	XXXX	XXXX	XXXX	XXXX	Hol
	R.212	13			(F)QQQ	QQQQ	QQQQ	QQQE						Co
	R.212	14			(F)QQQ	QQQQ	QQQQ	QQQE						Co
	R.212	15			(F)QQQ	QQQQ	QQQQ	QQQE						Co
	R.212	16			(F)QQQ	QQQQ	QQQQ	QQQE						Co
H8	D.138	04		XXXE										Co
	ER.136	06				XXXX	XXXX	XXXX						Ko
	ER.136	07	XXXX		XXXX				XXXX	XXXX	XXXX	XXXX	XXXX	Ko
C1														
B1														

PSF

YEAR 1988

Position	Experiment	Capsule	J 01	F 02	M 03	A 04	M 05	J 06	J/A 07	S 08	O 09	N 10	D 11	Operator
01	ER.150	02	XXXX	XXXX	XXXX	XXXX	XXXX		XXXX	XXXX	XXXX	XXXX	XXXX	Lee
02	ER.008	02	S	S										Hol
	ER.220	01	S S	S S	S S	S S	S S	S S	S S	S S	S S	S S	S S	Vis
03	D.202	28	(S)SSS											Sch
	D.202	29		(S)SSS										Sch
	CH.240	01			(P)P	PP	PPPP	PPPP	PPPP	PPPP	PP	PP	PP	Cun
04	RX.189	02	PPPP	PPPP					PPPP	PPPP	PPPP	PPPP	PPPP	Hol
	CH.240	01			(X)X	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	Cun
05	CH.240	01		(P)P	PP	PPPP	PPPP	PPPP	PPPP	PPPP	PP	PP	PP	Cun
06	D.201									S				Mar
	D.178	39	(X)X											Mar
	D.183	27					HHHH	HHHH		H				Mos
	D.183	28					HHHH	HHHH		H				Mos
	D.202	40				(S)S								Sch
	CH.240	01		(X)X										Cun
07	D.183	55/56										(S)		Mos
	D.183	27				HHHH								Mos
	D.215	01									HH		HHHH	Mos
	D.215	12									(F)H		HHHH	Mos
	CH.240	01		(P)P										Cun
	ER.008	03			(S)		S							Hol
08	D.183	27	HHHH	HHHH										Mos
	ER.008	03				SSSS		S	S	S	S	S		Hol
09	D.128	04	XXXX	XXXE										Mar
	D.202	36											(S)	Sch
	RX.189	02				PPPP	PPPP	PPPP						Hol
	ER.008	03											SSS	Hol
10	D.128	05										XXXX	XXXX	Mar
11	D.128	05	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX			Mar
12														
SW														
HW	ER.070	02	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	Wij

BEAM TUBES

YEAR 1988

Position	Experiment	J 01	F 02	M 03	A 04	M 05	J 06	J/A 07	S 08	O 09	N 10	D 11
HB 1	R.9	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 2	R.10	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 3	R.11	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 4	R.159	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 5	R.13	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 6												
HB 7	R.14	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 8	ER.169	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 9	R.107	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 10	ER.95	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
HB 11	R.130	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX		XXXX	XXXX	XXXX	XXXX
HB 12	R.221	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX				X	X

Fig. 20 HFR Petten. Occupation of reactor positions in 1988

Table 5 Experiment codes used in Figs. 1-11 and Fig. 20

IRRADIATION PROJECTS — Situation: 20.04.1988 KH/gp

Exp. Code	Filler element Ø	Type	Description	Inst.	Person in charge	Irradiation 88	89	90	ECN/GCO proj. nr.	Remarks
ER 8	—	P	HF-PIF	ECN	Nolten	X	X	X	—	
R 9	—	HB1	Triple axis spectrometer	ECN	van Dijk	X	X	X	260	
R 10,12,14	—	HB2,4,7	N-G-research	ECN	Abrahams	X	X	X	261	
R 11	—	HB3	Time-of-flight spectrometer	ECN	van Dijk	X	X	X	260	
R 13	—	HB5	Neutron diffraction	ECN	van Dijk	X	X	X	260	
ER 70	—	spec.	PROF	ECN	Wijtsma	X	X	X		
D 85	72/74/76	C	Intermed. + high temp. graph.	GCO	Scheurer	X	X	X		
ER 90,95	52	C/HB 10	RIF, FASY	ECN	Nolten	X	X	X	—	
R 107	—	HB9	Single crystal diffraction	ECN	van Dijk	X	X	X	260	
RX 117	—	P/C	Reactor noise studies	ECN	Turkcan	1)	1)	1)	1417	
E 121	—	P	Development LWR irrad. dev.	GCO	Markgraf	X	X	X		
D 125	—	P	Power ramp experiments	GCO	Markgraf	X	X	X		
D 128	—	P	Fuel stack displacement	GCO	Markgraf	X	X	X		
R 130	—	HB11	Mirror-system	ECN	Abrahams	X	X	X	261	
ER 136	74	C/P	FIT	GCO	Konrad	X	X	X		
D 138	74	C	BEST	GCO	Conrad	X	X	X		
R 139	72/76	C	SINAS/AKTINES	GCO	Tsotridis	X	X	X		
ER 144	72	A	HIFI	GCO	Konrad	X	X	X		
ER 150	—	(P)	Neutrografie kamera	ECN	Leeflang	X	X	X		
D 156	72	C	DISCREET	GCO	Cundy	X	X	X		
E 157	72	C	CRISP	GCO	Cundy	X	X			
R 159	—	HB4	γ-capture measurement	ECN	Wijkstra	X	X	X		
RX 161	52	C/P	TRAMP	ECN	Nolten	X	X	X	0013	
E 167	72	C	TRIESTE	GCO	Cundy	X	X	X		
ER 169	—	HB8	ILONCA	ECN	Leeflang	X	X	X		
D 170	—	P	POCY	GCO	Moss	X				
D 176	—	P	Power ramp experiments	GCO	Markgraf	X	X	X		(see also D125)
D 178	—	C	Power ramp experiments	GCO	Markgraf	X	X	X		(see also D125)
D 183	—	P	KAKADU	GCO	Moss	X	X	X		
ER 185	—	C	AUGIAS	GCO	Nolten		X	X		
E 188	—	P	BWFC without fuel	GCO	Markgraf	X	X	X		
RX 189	72	C/P	SURP	ECN	Nolten	X	X	X		
D 192	72	C	OPOST	GCO	Moss	X				
D 195	—	P	Power Ramp BWR-Fuel	GCO	Markgraf	X	X	X		(see also D125)
ER 197	—	A	COBI	ECN	Nolten	X	X	X		
E 198	74/76	C	FRUST	GCO	Scheurer	X	X	X		
D 201	—	P	Power PWR-fuel	GCO	Markgraf	X	X	X		
ER 203	72	A	CORRI	ECN	Nolten	X	X	X		
D 206	—	P	ISOLDE	GCO	Markgraf	X	X			
ER 209	—	-	GIF	ECN	Wijtsma	X	X	X		
ER 210	—	-	PR	ECN	Wijtsma	X	X	X		
R 212	74	C	EXOTIC	ECN	Conrad	X	X			
D 214	72	C	"GA-rods"	GCO	Conrad	X	X			
D 215	72	P	RELIEF	GCO	Moss	X	X	X		
D 217	—	C	CERAM	GCO	Tsotridis	X	X	X		
ER 220	—	P	SIP	ECN	J.F.J. Visser	X	X	X		
R 221	—	HB12	24 keV-neutron facility	ECN	Abrahams	X	X	X	261	
E 224	74	C	LIBRETTO	GCO	Conrad	X	X			
D 225	72/74	C	CEFIR	GCO	Scheurer	X	X			
E 226	—	P	POMPEI	GCO	Moss	X	X			
D 227	72	C/P	MOKA	GCO	Markgraf	X	X			
E 228	72	C	BUMMEL	GCO	Moss	X				
E 230	72	C	PROFI	GCO	Conrad		X	X		
ER 231	—	fuel elem.	SIMONE	ECN	Pruimboom	X	X			
ER 233	—	spec.	SIDO	ECN	J.F.J. Visser	X				
RX 234	—	-	TIBER	ECN	Wijtsma	X				
D 235	—	P	TRAGA	GCO	Moss	X	X			
E 236	74	C	LOTUS	GCO	Scheurer		X	X		
D 237	52	C	ELIMA-2	GCO	Conrad	X				
ER 238	—	C/P	FACIT	GCO	Konrad	X	X			
D 239	—	P	ROSI	GCO	Markgraf	X				
CH 240	—	3(5) x P	IRMA	GCO	Cundy	X	X	X		
D 241	—	P	GRIPS	GCO	Scheurer	X				
S 242	—	-	CIEMAT	GCO	Husmann	X			Spanish	MTR fuel handling

1) = Short time irradiation; P = Poolside irradiation; C = in core irradiation; HB = beam tube; A = in core without extension tube

AUGIAS = AUtomatic Gas supply system for IrrAdiationS
AKTINES = AKTI (Greek for irradiation) NEutrons Steel
BEST = Brenn-Element SegmenT
BUMMEL = fiss-gas BUbbles (M) Mobility study (EL)
BWFC = Boiling Water Fuel Capsule
CEFIR = CEramic Fusion IRradiation
CERAM = net CERAMics
CIEMAT = CIemat-Elements MAnipulations for Transport
COBI = COBald Isotope production
CORRI = CObald ReflectoR Irradiation
CRISP = CReep In Steel sPecimen
DISCREET = DISposable CREEp in Trio
ELIMA = Exp. for LI-materials
EXOTIC = EXtraction Of Tritium In Ceramics
FASY = FAst rabbit SYstem
FIT = Fissile Isotope Target
FRUST = Fusions Reaktor; Untersuchung an STahl
GIF = Gamma Irradiation Facility
GRIPS = GRaphite Irradiation in PSf
HF-PIF = High Flux Poolside Isotope Facitily
HIFI = HIgh Flux facility for Isotopes
IRMA = IRradiation of MinerAls
ILONCA = Installation of a Long Object Neutron CAmera
ISOLDE = Iodine SOLubility and Degassing Exp.
KAKADU = KAmin KApsel-DUo
LIBRETTO = LIquid BReeder Experiment with Tritium Transport Option
LOTUS = LOw temp. TUkomak Specimens
MOKA = Misch OXyd-brennstäbe
NAST = NArrium STaal bestraling
OPOST = Over POwer Steady state exp.
POCY = POwer CYcling experiment
PR = Pneumatic Rabbit in reactor Facility
PROF = Poolside ROtating Facility
PROFI = FIssion PROduct release exp.
RIF = Reloadable Isotope Facility
ROSI = ROtative Silicium Irradiation Facility
SIDO = SIlicon DOping
SINAS = SImplified NAST
SIP = Silicium Investigation Philips
SURP = SURveillance Program
TIBER = Temp. 1-row BEryll. Reflector
TRAGA = TRAnsient GAp conductance measur.
TRAMP = TRAvelling Measuring Probe
TRIESTE = TRio Irrad. Exp. of Steel sampl. under TEnsion

As most of the above programmes require new test techniques, most of the work in 1988 was related to the development of new test facilities. During the next reference period an increase of the HFR utilization by the LWR programmes is anticipated.

D125, D176, D178, D201. Power Ramp Tests of Pre-irradiated LWR Fuel Rods

The main purpose of these tests is to investigate the PCI (Pellet-Cladding Interaction) phenomena, which may lead to a fuel rod failure when an irradiated fuel rod is exposed to a fast power increase and large power step.
The test scenario for a single fuel rod comprises the following steps:

- fabrication and characterization at the fuel production plant
- assembly of seven fuel rodlets to one full length fuel rod and insertion in a standard power reactor fuel element
- base irradiation in a commercial nuclear reactor for one or several years
- fuel rod withdrawal from the standard fuel element, and inspection and characterization at the NPP storage pool
- segmentation and further inspections at the hot cells
- preparation and non-destructive characterization of the fuel rod for the HFR test at the Petten hot cells
- neutron radiography, eddy current check of cladding and determination of the outer diameter prior to the HFR test
- conditioning irradiation for several days (mostly 3 days) and eventually intermediate characterization of the fuel rod condition by non-destructive techniques
- transient testing
- non-destructive characterization at the HFR pool after the transient test, and later at the Petten hot cells
- destructive investigations of the fuel rod at the hot cells (of the client in most cases).

In 1988 only one ramp test was performed in the HFR with a PWR fuel rod. This test completed an earlier test programme on MOX fuel rods.

The post-irradiation examinations on two more PWR fuel rods and one BWR fuel rod were finalized at the Petten hot cells.

One "Fachausschuss KFA/KWU Rampentests"-meeting was held in May in order to review the current programmes and to decide on the future programme. The 1988/1989 programme contains approximately 10 fuel rod tests.

The development of a "low power" BWFC-capsule for fuel rods of both reactor lines was nearly finished at the end of the reference period. This device is designed to irradiate fuel rods from linear powers of 150W/cm upwards, with typical LWR system fuel rod surface temperatures.The time schedule for transient tests on high burn-up fuel rods depends on the availability of these test devices. It is expected that the new test device, **Fig. 21**, will be available in the beginning of 1989.

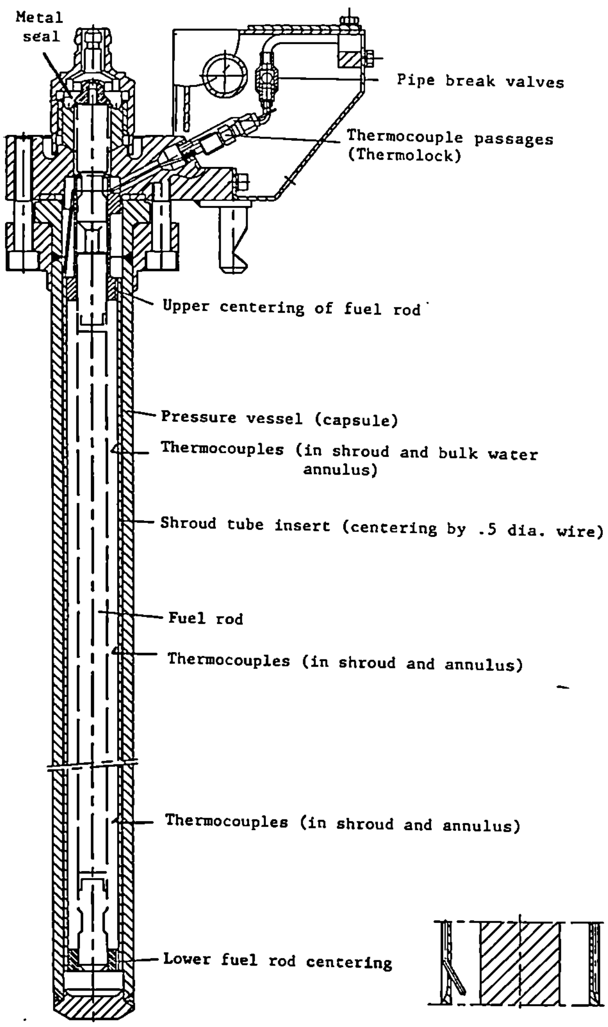


Fig. 21: Lay-out of the low power capsule for LWR fuel rod testing at HFR Petten

A pending test programme on transient fission gas release studies depends on the availability of the re-instrumentation technique at the Petten hot cells. Here also the development phase is approaching an end. An application on a BWR fuel rod is anticipated for the beginning of the next reference period.

Further development activities are related to a device where the fuel rod can be loaded axially with a load of up to 1500 N (**Figs. 22, 23**).
Another irradiation device for in-pile profilometry will be commissioned after determination of the first two programmes mentioned above.

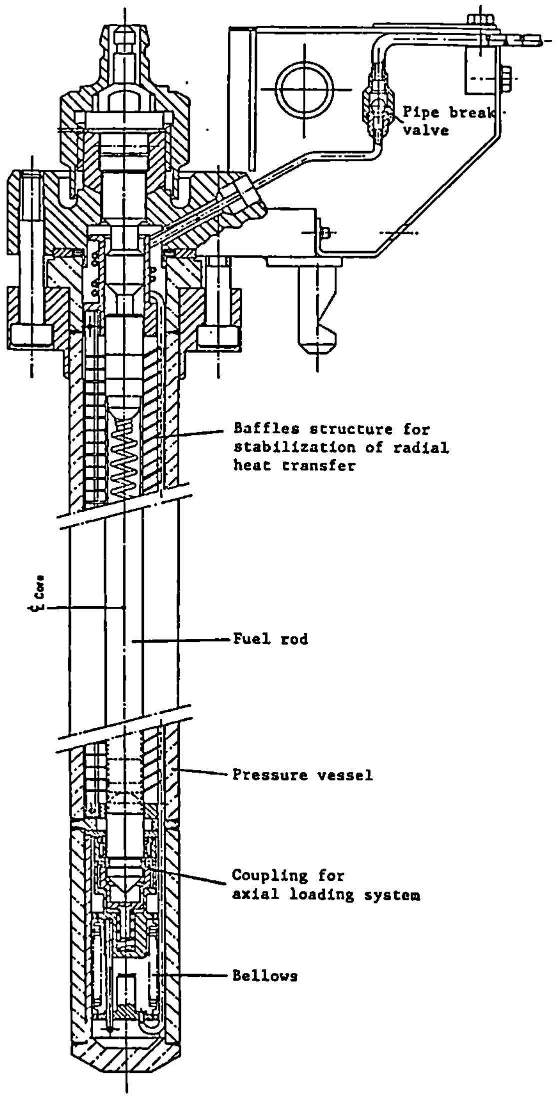


Fig. 22 Reloadable BWFC-irradiation capsule with axial loading device

D128. In-pile Measurements in LWR Fuel

The three D128 experiments each use a pressurized BWR fuel rod which is instrumented with a central thermocouple and two pressure transducers for pressure monitoring.

Two of the irradiation tests are already terminated and are at the hot cells for PIE. The third test is still in the phase of burn-up accumulation.

D128-03

The objective of this test is the investigation of transient fission gas release and fuel restructuring.
This experiment was irradiated between 1983 and mid 1987 up to a burn-up of approximately 19 GWd/t(U). Two transient tests were performed at approximately 6.3 GWd/t(U) (just before the renewal of the HFR vessel) and at the end of the irradiation period. The D128-03 test is one of the few HFR tests which was irradiated before and after the HFR vessel renewal.

During 1988 all non-destructive PIE was completed. Towards the end of the reference period the destructive PIE was started with a punturing test and fission gas analysis. Further PIE will include metallographic and ceramographic investigations, all being performed in the Petten hot cells.

D128-04

The task of the D128-04 experiment is to provide data on the fuel restructuration behaviour when the fuel rod is operated at a constant temperature level. Therefore this test was operated at a constant central fuel temperature of 1523 K (1250°C).

This irradiation experiment started in 1985 and finished in February 1988 with a burn-up of 18 GWd/t(U).

During the reference period all non-destructive PIE and puncturing including fission gas analysis has been performed.

The destructive PIE programme will be similar to the D128-03 programme and will also probably be performed in the Petten hot cells (in 1989).

D128-05

The objective of the D128-05 test is comparable to

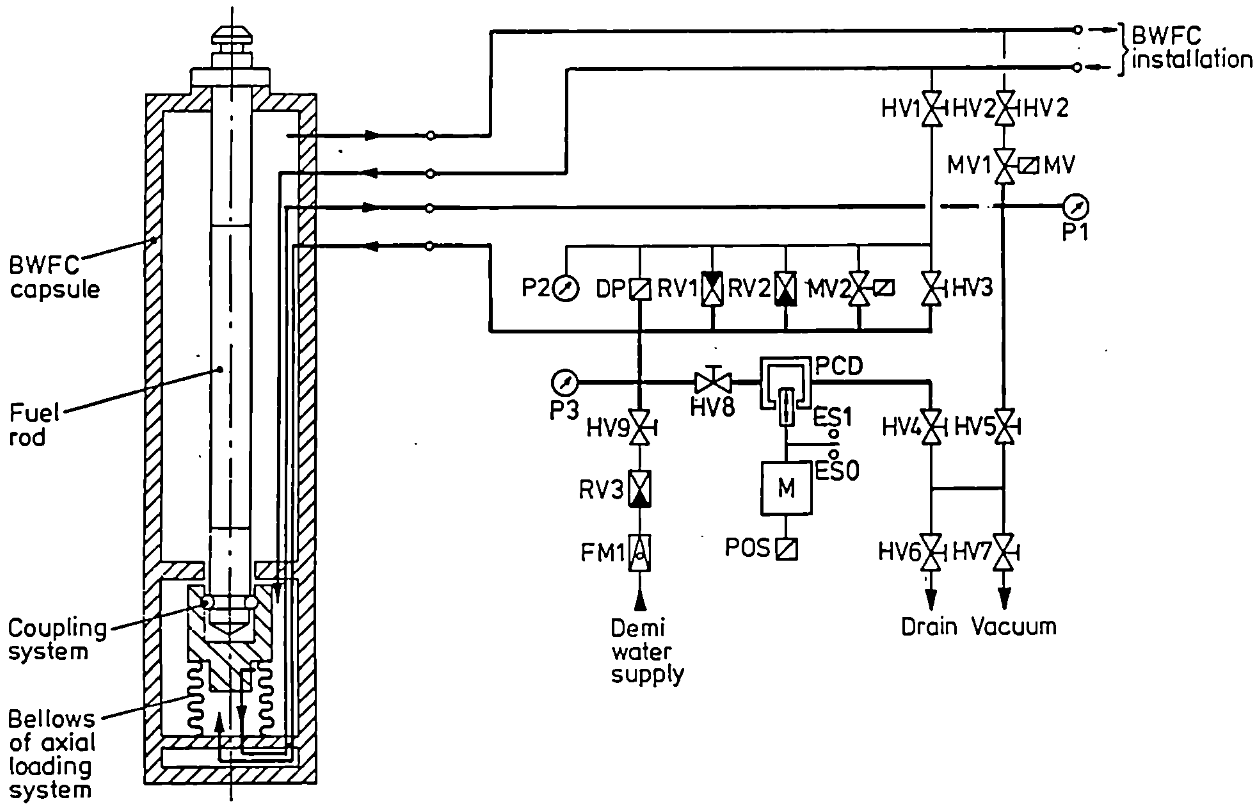


Fig. 23 Schematics of the mechanical part of the control systems for axial loading of the LWR fuel rods

the D128-04 test. However, the central temperature is kept constant at 1348 K (1075°C). Furthermore, at the end of irradiation a transient test to a final temperature of 1973 K (1700°C) is planned.

The D128-05 test was started in 1987 and will be continued until mid 1989 when a burn-up of 15GWd/t(U) will be attained. At the end of this reference period a burn-up of approximately 12 GWd/t(U) has been accumulated.

D206 ISOLDE. Iodine Solubility and Degassing Experiment with pre-irradiated PWR fuel rods

A test programme for the determination of the rate of iodine release from PWR fuel rods and its solution in steam and water for a LOCA-scenario is under realization. The test programme consists of two main branches:
- hot cell tests with re-conditioned fuel rods
- in-pile tests.

The experimental programme related to the hot cell tests has already been performed during 1983 and 1984. Twenty PWR fuel rods have been re-irradiated in the HFR for one HFR-cycle and then been transferred to the KFA hot cells. At the KFA hot cells the fuel rods were subjected to a heating test in flowing steam which simulated the steam phase of the LOCA-scenario. During these tests all fuel rods lost their cladding integrity. The results from the hot cell tests confirmed in general an iodine behaviour as experienced during the TMI-2 incident (very low iodine release into the biosphere).

The preparations for the in-pile tests with five PWR fuel rods were continued with commissioning and out-of-pile testing of the entire ISOLDE experimental equipment (**Fig. 24**). At the end of the reference period full scale simulation testing of in-pile LOCA-scenario was demonstrated with the first irradiation device. Two more irradiation devices became available for similar tests.

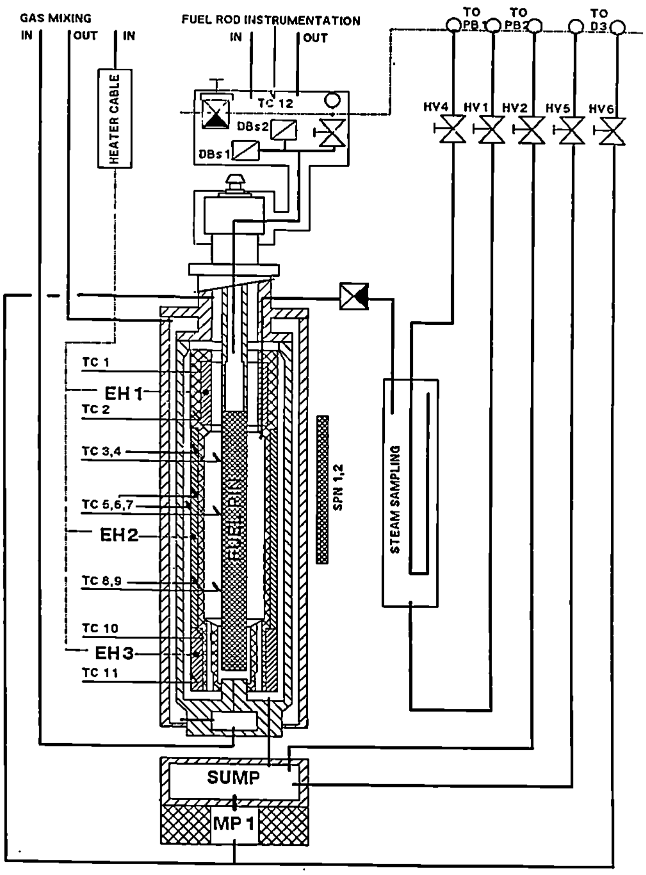


Fig. 24 ISOLDE. Lay-out of in-pile test rig

Several meetings with the programme sponsors and KFA were held in order to review the progress of the development of the ISOLDE project.

The test technique and equipment were presented in a communication to the 1988 meeting of EWGIT in Mol.

D227. Irradiation Testing of PHWR MOX Fuel Rods

Two irradiation experiments, each involving two short unirradiated MOX fuel rodlets, are being performed within the KfK-International Co-operation Agreement Irradiation Programme.

The first test, a simulated End of Life (EOL) test, has been performed in 1986 in the HFR. At the end of 1987 the fuel rods have been shipped to KfK for further PIE.

The second test programme (BU15) consists of a burn-up accumulation phase to 15 GWd/t(M) and a transient test with one of the two rodlets.

The irradiation device for the pre-irradiation phase of the BU15 test in the HFR core has been commissioned. The irradiation testing was started in December with irradiation of the empty rig for determination of the gamma-heating in the rig.
It is anticipated that the fuel rod irradiation will commence in January 1989.
The burn-up accumulation phase will be performed in the in-core position G5 and last approximately 20 HFR cycles (at 45 MW). The in-core irradiation position is chosen because it provides a typical LWR spectrum.

References to paragr. 2.2.3.1.

/1/ Fischer, G., Sontheimer, F., Ruyter, I. and Markgraf, J.
"Experiments on the load following behaviour of PWR fuel rods"
Nuclear Engineering & Design 108 (1988), 429-432

/2/ Kennedy, D., Markgraf, J., McAllister, S. and Ruyter, I.
"Thermohydraulic Studies related to the development of an LWR fuel rod testing capsule"
30th EWGIT Plenary Meeting, Mol, September 28/30, 1988

/3/ Fischer, B., Kwast, J., Markgraf, J. and Perry, D.
"An LWR fuel rod irradiation device for the investigation of axial load effects on the fuel rod behaviour"
(ibid)

/4/ Ruyter, I., Reichardt, K., Thöne, L. and Markgraf, J.
"LWR Safety Experiments in the HFR Petten
(ibid)

2.2.3.2. Fast Breeder Reactor (FBR). Fuel and Structural Material Irradiations

Internationally several R & D programmes, mainly safety related, are pursued with the goal of qualifying various FBR fuels in the normal and abnormal conditions and to study the response of neutron irradiated structural material (stainless steel) to mechanical stresses including vibration and shock.
In the frame of these programmes a number of irradiations have been carried out in the HFR since the late 1970's.

a) Fuel irradiations

In recent years, experimental requirements have become so complex and rigourous, such that standard facilities for LMFBR irradiations are used less and new innovations in design, instrumentation, and data acquisition are necessary.

Objective: Fast reactor fuel experiments carried out in the HFR Petten currently fall into two categories:

- Transient Tests

The investigation of fast reactor fuel pin behaviour under transient reactor conditions is the aim of the SNR Operation Transient Programme, which comprises a series of experiments carried out in the reactors BR2 (Belgium) and HFR (The Netherlands). The programme is executed in co-operation with Interatom (D), Belgonucléaire (B), SCK/CEN Mol (B), ECN Petten (NL), and JRC Petten. The features investigated include start-up behaviour, power cycling and ramping, fuel melting, transient overpower (TOP) and simulated loss-of-flow (LOF) behaviour. This group of testing is sponsored by KfK Karlsruhe.

- Advanced Fuel Irradiations

These concern investigations into the operational behaviour of dense (nitride) fast breeder fuels and more fundamental research on fission product kinetics in UO_2 fuel. This group of irradiations is sponsored by the JRC Karlsruhe (Trans Uranium Institute).

A review of the FBR experiments was presented at the IAEA Symposium at Grenoble /1/. More recently, a paper describing the design and specialist instrumentation features of the experimental rigs was presented at the EWGIT at Mol /2/.

Progress:
Transient Tests

During the reporting period two transient experiments were irradiated over a total of 9 reactor cycles. Development of the new experiments TRAGA and HYPERKAKADU continued with irradiation planned for 1989-1990. The status of the full programme of transient experiments is as follows:

D170 POCY (MEDINA)

The POwer CYcling experiment, POCY, began irradiation in October 1985. The experiment is designed to carry out measurements of changes in fuel pin diameter at intervals of irradiation. A brief description of the facility was given in PPR 85/2.
The irradiation was completed at the end of 1987, having achieved almost 9 at.% burn-up. Due to a malfunction of a neighbouring irradiation, which affected the good working order of POCY, the experiment did not complete its intended irradiation programme. Nevertheless, some useful cladding diametral measurements were recorded and are presently being analysed. A computer enhanced drawing of a typical measurement is shown in **Fig. 25**.

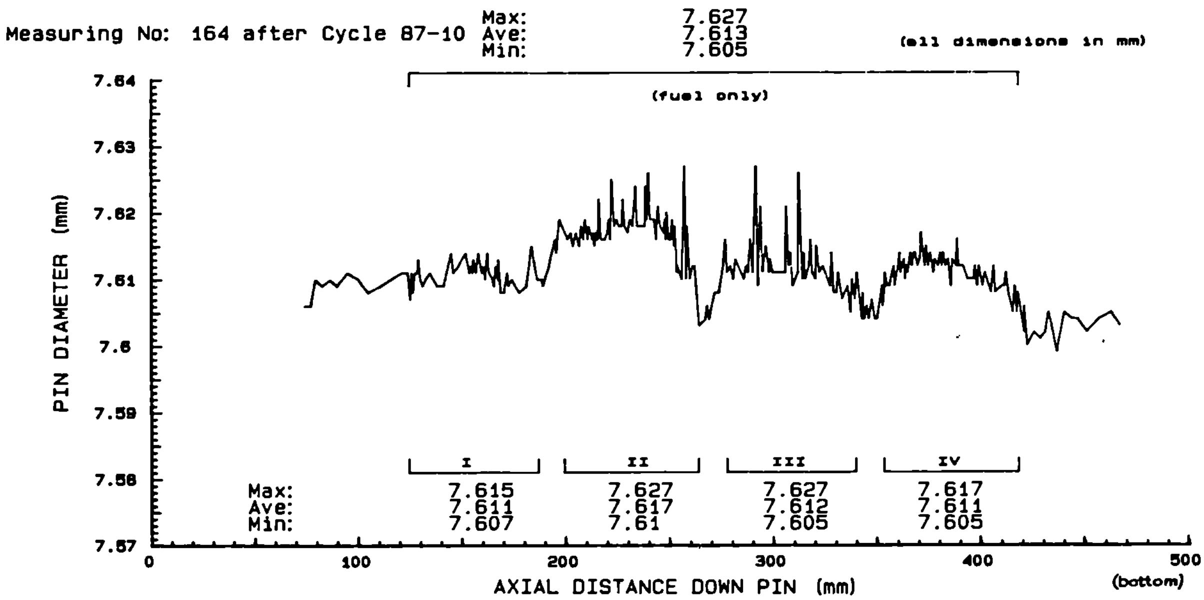


Fig. 25 D170 POCY. Computer enhanced plot of measured diametral displacement

D183 KAKADU

The KAKADU experiment 27/28, also referred to as OPEQU i.e. Over-Power EQUilibrium, continued irradiation throughout most of the year.
The experiment aims to study the effect of fuel transport in the central hole. At present, one fuel pin (no. 27) has achieved approximately 5 at.% burn-up.
The fresh fuel pin (no. 28) has recently started irradiation together with no. 27.
The irradiation will continue at a steadily increasing power of O.5% per day up to 140% of nominal power.

D183 HYPERKAKADU

A new KAKADU series of experiments consisting of 15 pre-irradiated (in PHENIX) fuel pins in under consideration.
The extra long pins necessitated, a re-design of the special α-tight EUROS cell.
This new series of irradiations is expected to start at the end of 1989.

D184/D192 POTOM/OPOST

No further irradiation in this series were carried out. Evaluation of the previous irradiations continues. The following experiment (OPOST) will take place in 1989.

D215 RELIEF

The concept, design and aim of the series of RELIEF experiments have been reported in previous progress reports and also presented at the IAEA Symposium at Grenoble /3/. Succintly, the experiment aims to study, by means of in-pile measurement, the differential and absolute fuel and cladding axial displacements during operational transients. It was reported in the last report (PPR 1987), that RELIEF 10, after just one full cycle, was stopped due to a bellow's failure. Subsequent dismantling in the ECN hot cells indicated no obvious failure by fracture or other phenomena. The second RELIEF experiment, no. 11, ended after 100 days irradiation at the end of 1987. This time, a suspected rupture of an inner bellow forming part of the cladding system, enforced another premature stop due to safety reasons. The fuel pin, however, again remained intact. Nevertheless during the 4 cycles, almost 2 at.% bu was attained. 4 transients were carried out and added to the gain in experience on both operation and interpretation of results. The means to interpretate the results have since been improved, by the completion of a new software package, which can, within minutes of a transient, produce plotted results of the event. An example is shown in **Fig. 26**. The next RELIEF experiment, no. 12, began irradiation in cycle 88.11. It should be noted that the earlier failures in the bellows system occurred in different types of bellows and at different positions in the bellows system. Hence, the error or failure is not systematic.

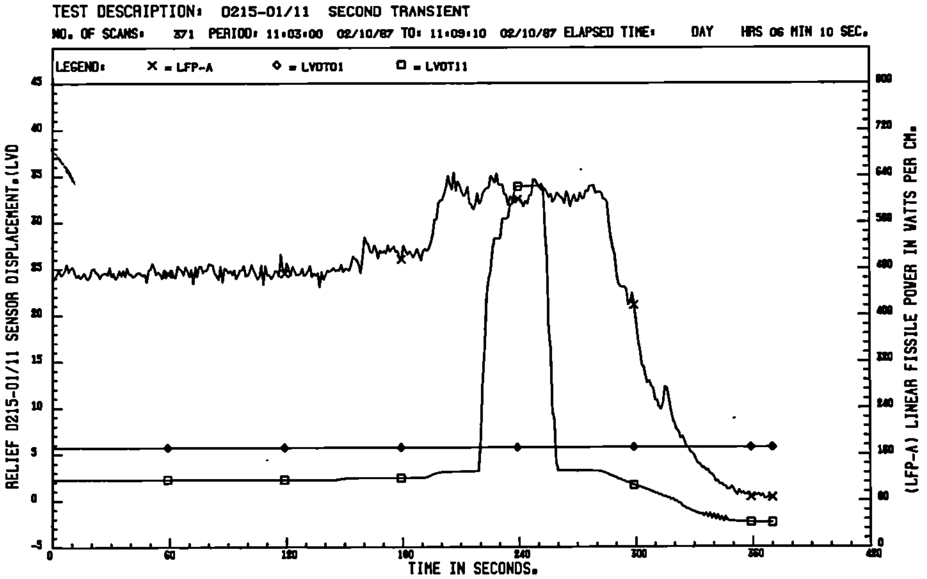


Fig. 26 D215-11 RELIEF. Example plot of transient data

D235 TRAGA

The development of the TRAGA experiment continued through 1988. The experiment aims to determine, by means of noise analysis, the change in the fuel cladding gap heat conductance during simulated transients. No significant design modifications were made. However, the central thermocouple has been improved by laser welding of the thermocouple connection to the cladding.

The development of the noise analysis technique continues, with the RELIEF, KAKADU and NILOC experiments, all having been exploited to gain a greater insight and more confidence in this important technique.

Advanced Fuel Irradiations

E 211 NILOC

Preparations have begun for the third and fourth NILOC experiments, which will take place in 1989. The experiments again irradiate 3 mixed nitride fuel pins simultaneously. The fuel pins are currently being manufactured by JRC, Karlsruhe.

E 226 POMPEI

Due to a delay in the complex process for manufacturing the special pellets of mixed nitride fuel, the POMPEI experiment will now commence irradiation during 1989.

E 228-00 VOLEX

The VOLEX irradiation was completed in February 1988. Eight small fuel capsules containing 3 to 4 fuel tablets of monocrystal UO_2 pellets, monocrystal UO_2 discs and polycrystal pellets, were irradiated in the reloadable facility, RIF, at different temperatures and burn-ups, ranging from 473-873 K (200-600°C) and 0.2-10 x 10^{18} fission/cm^3. The irradiation conditions specified, and those actually achieved are summarized in **Table 6**.

E 228-01/02 BUMMEL

The first stage (01) of the BUMMEL irradiation began in cycle 88.07. The fuel pins consisting of 10 UO_2 discs each will be irradiated to 0.5 at.% burn-up during 5 reactor cycles. Thereafter, both fuel pins will be withdrawn and transferred to the HFR hot cells, where a specially-equipped oven will heat the 2 fuel pins at 1573 K (1300°C) for 3 hours. This heat treatment serves to ensure complete precipitation of the fission gases. Thereafter, one fuel pin will be prepared for transport to Karlsruhe. The second will be reloaded into a second capsule, specially designed to achieve an axial temperature distribution of 1273 to 2073 K (1000 to 1800°C) along the fuel.

b) Structural Material Irradiations

The bulk of these HFR experiments presently fall within the scope of fast reactor safety programmes. Irradiations in the HFR Petten are carried out to stringent specifications concerning specimen temperature information of material embrittlement by helium formation and fast neutron displacement.

R139-55

Objective: The purpose of this irradiation experiment of miniature 316 CT-blocks is to study the crack propagation in LMFBR, structural steel.
Progress: The irradiation started in June 1986 in various reactor positions and terminated in cycle 88.11. The irradiation temperature was 700 K and the target dose 10 dpa. A typical statistical analysis of the temperature distribution during a reactor cycle is presented in **Table 7.**

Table 6 E 228-00 VOLEX. Irradiation conditions

fuel capsule	Required conditions		Achieved conditions	
	dose (x10^{18}fiss/cc)	temp. in K	dose (x10^{18}fiss/cc)	temp. in K
a	0.2	473	0.205	478-520
b	0.5	473	0.529	478-520
c	1.0	473	1.069	478-520
d	10.0	473	9.750	478-520
e	100.0	473	81.780	478-520
f	10.0	473	9.750	565-610
g	10.0	727	9.750	709-762
h	10.0	873	9.750	872-926

Table 7 R139-553. Typical statistical analysis of a temperature distribution in a reactor cycle (88.06)

CYCLE NO: 88-06 "D A C O S S Y S T E M" DATE: 17:47:11 5-OCT-88

ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 08:48:00 23-JUN-88 TO 09:08:00 18-JUL-88

EXPERIMENT NO. : R139-553
NAME : SINAS
START DATE : 12-06-86
REACTOR LOCATION: D8
GAS PANEL USED : TRIO-G

NOMINAL DEGREES "C": 425.00
SAMPLE :
STRESS MODE :
DATA LOGGER NUMBER : 1
RECORD INTERVAL : 10 MINUTES

CHAN NO.	MEASUR'G POINT NAME	ENG'RING UNIT	ANALYSIS OF MEASURING POINT (BY ENGINEERING UNITS) AVERAGE	MINIMUM	MAXIMUM	STANDARD DEVIATION	ERROR	TOTAL RECORD	ANALYSIS OF DATA RECORDS (BY PERCENTAGE) REACTOR < 43.MW	NO DATA	< LOW LIMIT	> HIGH LIMIT	WITHIN LIMITS
128	TC10	DEG. C	432.34	325.80	445.63	12.042	0.221	3603	17.32	0.00	2.39	0.00	80.29
127	TC9	DEG. C	433.89	326.77	447.04	12.064	0.221	3603	17.32	0.00	2.33	0.00	80.35
126	TC8	DEG. C	425.54	333.79	435.88	9.156	0.168	3603	17.32	0.00	2.19	0.00	80.49
124	TC6	DEG. C	430.21	357.07	442.77	6.697	0.123	3603	17.32	0.00	2.03	0.00	80.66
123	TC5	DEG. C	423.79	349.05	436.35	6.869	0.126	3603	17.32	0.00	2.05	0.00	80.63
122	TC4	DEG. C	424.25	361.46	442.40	5.776	0.106	3603	17.32	0.00	2.03	0.00	80.66
121	TC3	DEG. C	423.30	360.37	442.30	5.898	0.108	3603	17.32	0.00	2.03	0.00	80.66
107	TC2	DEG. C	424.67	364.32	449.48	7.285	0.133	3603	17.32	0.00	1.28	0.00	81.40

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.

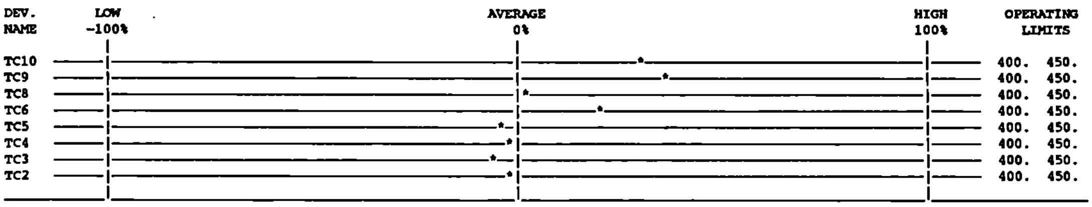


Table 8 R139-572. Typical statistical analysis of a temperature distribution in a reactor cycle (88.06)

CYCLE NO: 88-06 "D A C O S S Y S T E M" DATE: 18:14:36 5-OCT-88

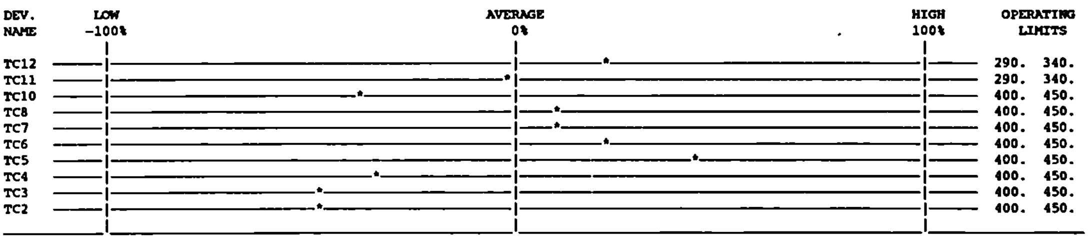
ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 08:48:00 23-JUN-88 TO 09:08:00 18-JUL-88

EXPERIMENT NO. : R139-572
NAME : SINAS
START DATE : 25-05-88
REACTOR LOCATION: E3
GAS PANEL USED : TRIO-B

NOMINAL DEGREES "C": 425.00
SAMPLE :
STRESS MODE :
DATA LOGGER NUMBER : 4
RECORD INTERVAL : 10 MINUTES

CHAN NO.	MEASUR'G POINT NAME	ENG'RING UNIT	ANALYSIS OF MEASURING POINT (BY ENGINEERING UNITS) AVERAGE	MINIMUM	MAXIMUM	STANDARD DEVIATION	ERROR	TOTAL RECORD	ANALYSIS OF DATA RECORDS (BY PERCENTAGE) REACTOR < 43.MW	NO DATA	< LOW LIMIT	> HIGH LIMIT	WITHIN LIMITS
429	TC12	DEG. C	320.74	244.71	367.63	9.114	0.167	3603	17.32	0.00	0.92	1.11	80.66
428	TC11	DEG. C	314.67	240.57	360.23	8.961	0.164	3603	17.32	0.00	0.94	1.05	80.68
427	TC10	DEG. C	415.34	325.24	458.53	8.744	0.160	3603	17.32	0.00	1.11	0.14	81.43
425	TC8	DEG. C	427.59	343.04	451.40	6.150	0.113	3603	17.32	0.00	0.89	0.08	81.71
424	TC7	DEG. C	427.48	342.71	451.07	6.091	0.112	3603	17.32	0.00	0.89	0.08	81.71
423	TC6	DEG. C	430.60	351.91	443.52	4.344	0.080	3603	17.32	0.00	0.06	0.00	82.63
422	TC5	DEG. C	435.97	355.04	448.73	4.343	0.080	3603	17.32	0.00	0.06	0.00	82.63
421	TC4	DEG. C	416.58	334.26	431.00	6.031	0.110	3603	17.32	0.00	1.25	0.00	81.43
420	TC3	DEG. C	412.84	331.19	427.30	6.062	0.111	3603	17.32	0.00	3.08	0.00	79.60
419	TC2	DEG. C	413.09	326.81	428.24	7.900	0.145	3603	17.32	0.00	4.02	0.00	78.66

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.



R139-57

Objective: This experiment is part of a fast reactor materials testing programme. The aim of the irradiation experiment is to study the crack propagation characteristics in small CT-block systems of LMFBR materials, SS 316 and 304.
Progress: The R139-57 experiment contains 2 specimen holders with 10 miniature CT-blocks and 8 tensile blocks. Irradiation of the first sample holder started in cycle 88.02. A typical temperature distribution during a reactor cycle is shown in **Table 8**. Irradiation of the second leg will start in cycle 89.02.

R139-58

Objective : This new irradiation programme will provide sufficient specimens for continuous cycling and creep-fatigue post-irradiation testing. The irradiation and testing conditions will be as close as possible to the conditions of the EFR (European Fast Reactor) above-core structures. The objectives of this work are to provide data on creep-fatigue properties of irradiated stainless steel type 316 L(N) for the EFR design data-base, and to verify the creep-fatigue interaction models.
Progress: The irradiation conditions of this experiment will be 823 K at a very low dpa (one reactor cycle in the H8 position) and the irradiation will take place in a TRIO-131 with a double container. This is required in order to obtain the temperature of 823 K at a peripherical reactor position.
Two legs of the TRIO will contain fatigue specimens and the third leg tensile-creep specimens.
Design of the sample holders has already finished and irradiation will take place in cycle 89.03.

E177 FANTASIA - Fracture Toughness Irradiation (Austenitic Stainless Steel)

Objective: To evaluate the neutron enhanced degradation of fracture toughness characteristics in austenitic stainless steels for the JRC Ispra Reactor Safety Programme (JRC Ispra Project IDEAS), the irradiation experiment E 177 FANTASIA has been designed. A total of 144 3PB samples and the same number of tensile samples have been irradiated in a sodium environment at 623K (350°C) and 823K (550°C). The irradiations were carried out in the HFR Petten between 1980 and 1987. PIE was performed at Ispra.
Progress: The results of the neutron fluence and fluence rate measurements of the E 177/31-33 irradiations and the gammaspectrometry results of irradiations E 177/31-36 are presented in references /4/, /5/ and /6/, respectively. Irradiation temperature histories and neutron metrology results of irradiations E 177/1-12, E 177/13-24, E 177/25-30, E 177/31-33 and E 177/34-36 are summarized in irradiation reports /7, 8, 9, 10, 11/.

E 208 SISSI

Sponsored by the Materials Department of JRC Ispra, SISSI is an experiment series to investigate the behaviour of austenitic stainless steel of the 316 L type, under irradiation at certain temperature and neutron fluence levels. In 1983, a first experiment was performed at 823 K (550°C) and to a damage of 1 dpa. This programme, which was discontinued in 1983 for budgetary reasons, has been taken up again. Four irradiations were performed, according to the following table:

E 208-02	2.5 dpa	623 K	350°C
E 208-03	2.5 dpa	823 K	550°C
E 208-04	1 dpa	623 K	350°C
E 208-05	1 dpa	823 K	550°C

The samples are of the cylindrical tensile type, 45 mm long, with a diameter gange length.
During the reporting period, the 4 rigs were dismantled after irradiation, and the samples were recovered. PIE started at ECN Petten.
Due to a change of emphasis in the JRC programme, this PIE work is actually progressing at a low priority rate.

References to paragr. 2.2.3.2.

/1/ Moss, R.L., Tsotridis, G. and Beers, M.
"Fast Breeder Reactor Fuel Pin Experiments in the High Flux Reactor, Petten"
IAEA International Symposium on the Utilization of Multi-Purpose Research and Related International Co-operation, Grenoble, October 1987

/2/ Moss, R.L., Beers, M., Korko, A.R. and Tsotridis, G.
"Fast Breeder Reactor Fuel Pin Experiments in the High Flux Reactor Petten : Specialist Design and Instrumentation, and Ancillary Activities"
EWGIT, Mol, September 1988

/3/ Moss, R.L., Tsotridis, G. and Beers, M.
"RELIEF: An Experiment to measure the differential fuel/cladding axial displacement of Fast

Breeder Reactor fuel pins under simulated operational transients in the High Flux Reactor, Petten"
(ibid)
/4/ Neutron Metrology in the HFR E 177/31-33 FANTASIA
ECN-Report 88-65
/5/ Neutron Metrology in the HFR E 177/34-36 FANTASIA
ECN-Report 88-82
/6/ Gammaspectrometry of FANTASIA experiments E 177/31-36
ECN-Report 88-50
/7/ FANTASIA E 177/1-12 Irradiation Report
Technical Note P/F1/87/6
/8/ FANTASIA E 177/13-24 Irradiation Report
Technical Note P/F1/87/7
/9/ FANTASIA E 177/25-30 Irradiation Report
Technical Note P/F1/87/12
/10/ FANTASIA E 177/31-33 Irradiation Report
Technical Note P/F1/88/14
/11/ FANTASIA E 177/34-36 Irradiation Report
Technical Note P/F1/88/32

2.2.3.3. High Temperature Reactor (HTR). Fuel and Graphite Irradiations

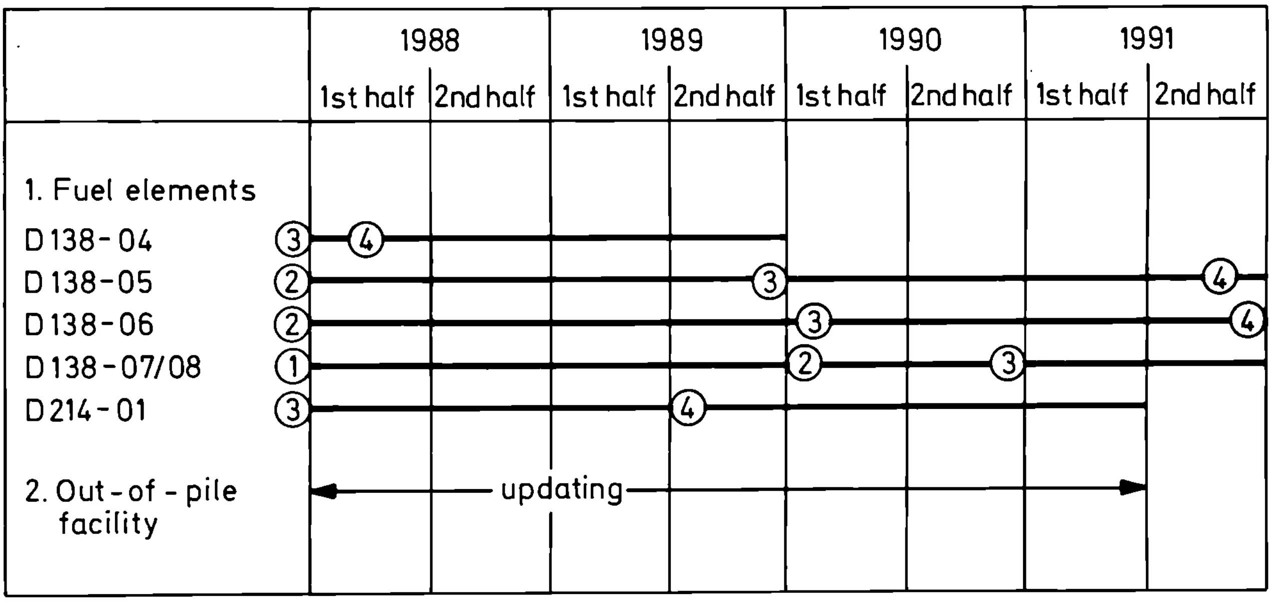
The High Temperature Reactor is being developed in the Federal Republic of Germany for nuclear process heat and direct cycle applications. In this frame, test irradiations aree being performed in the HFR on two materials which are typical for the HTR:

- coated particle fuel elements
- graphite as a predominant core structural material

a) Fuel Irradiations

High Temperature Reactor (HTR) fuel testing is performed in the HFR Petten on reference coated particle systems and production fuel elements for the German UO_2 low-enriched uranium (LEU) fuel cycle and for the TRISO-LEU fissile/TRISO-ThO_2 fertile US reference fuel system. These experiments include temperature cycling/transients and water vapour injections during the irradiation campaign. On-line measurements of volatile fission products under a

Table 9 HTR fuel irradiation experiments. Survey of present and future activities



Legend:
1 Design and calculation
2 Manufacture and commissioning
3 Irradiation, cycle reporting
4 Dismantling, evaluation

Circles indicate start of activity

wide range ($10^{-9} < R/B < 10^{-1}$) are performed, as well as on-line gas chromatograph analysis of the downstream carrier gas with the specially designed Sweep Loop installation. A survey of these activities is given in **Table 9**.

o Irradiation of Spherical Fuel Elements for the German HTR Programme

D138-04. Temperature Control Test

Two spherical fuel elements and two graphite spheres were irradiated in all peripheral in-core positions which are relevant for the forthcoming reference tests on low-enriched uranium (LEU) fuel elements for future High Temperature Reactors (e.g. HTR-Modul and HTR-500), and also for previous HTR LEU fuel element irradiations. The test samples were instrumented with thermocouples located in the centre and on different radii to measure the temperature field under irradiation. This experiment, the first of its kind, provides a representative data set with respect to the knowledge of temperature fields as a function of neutron fluence and burn-up. This data set is urgently needed, since the samples of the reference tests must remain undamaged prior to irradiation start. The temperature control was successfully completed after 667.37 full power days with cycle 88.02 /1/. The achieved irradiation parameters are compiled in **Table 10**. Only 10 out-of 82 thermocouples (type "K"), which were located in the samples without any protection and operated at temperatures of up to 1330 K, failed. The full required temperature control range of > 300 K could be maintained throughout the irradiation period by helium/neon gas mixture technique (**Fig. 27**). The thermal conductivities of the four samples were determined by measured temperature gradient data and by calculated power data for a sphere of 2.5 cm radius. The results are given in **Fig. 28**. The data are plotted against the neutron fluence. The slope is in agreement with existing data. The absolute data are 20% lower than the existing data measured in out-of-pile tests. The post-irradiation examinations (PIE) at JRC Petten consisted of neutron-radiography, recovery of the four samples, visual inspection, metrology of the graphite structure parts /2/ and gamma scanning of the capsule tubes /3/.

The neutron-radiograph showed that the capsules parts were undamaged and that the gas gap between the spheres and the structural graphite parts was < 0.15 mm. The visual inspection of the dismantled samples showed no damage of any capsule part. The outer diameters of the structural graphite parts were measured by JRC Petten with a specially developed device (**Fig. 29**). The results are given in /2/ and in **Table 10**. The relative axial and radial neutron fluence distribution was determined by gamma scanning of the capsule tubes. **Fig. 30** shows the axial fast neutron distribution and **Fig. 31** shows a rotation scan at centre line capsule. The flat radial neutron fluence distribution has been achieved by

Table 10 D138-04. Irradiation conditions and results

Sample	AK 1	BK1	BK2	CK1
Core positions	D 2 F 2 H 2 H 4 H 6 H 8 F 8			
Full power days	667.37			
Fission power in W BOL / EOL	-	2345/110	2345/110	-
Gamma power in W Max./ Min.	560/172	1097/340	1127/344	693/219
Burnup in % FIMA	-	13.2	13.2	-
Neutron fluence in $10^{25} m^{-2}$ (E>0.1MeV)	6.74	10.0	10.2	8.47
Average centre line temperature in K	935	1269	1265	1063
Average temperature gradient in K	20	142	140	22
Temperature control range in K	300	330	330	300
Thermal conductivity in W/cmK BOL/EOL	0.48/0.18	0.26/0.10	0.25/0.10	0.33/0.20
Shrinkage in % of :				
. sample (equator)	- 1.26	- 1.5	- 1.4	- 1.34
. graphite structure	- 0.78	- 1.2	- 1.1	- 0.80

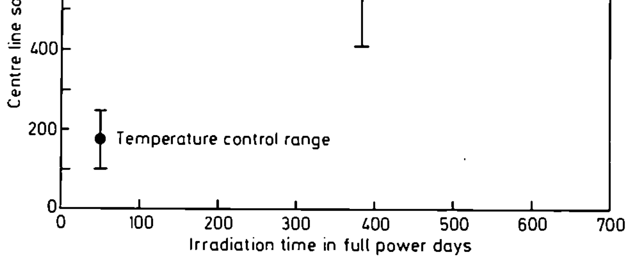


Fig. 27 D138-04. Irradiation temperatures and temperature control range

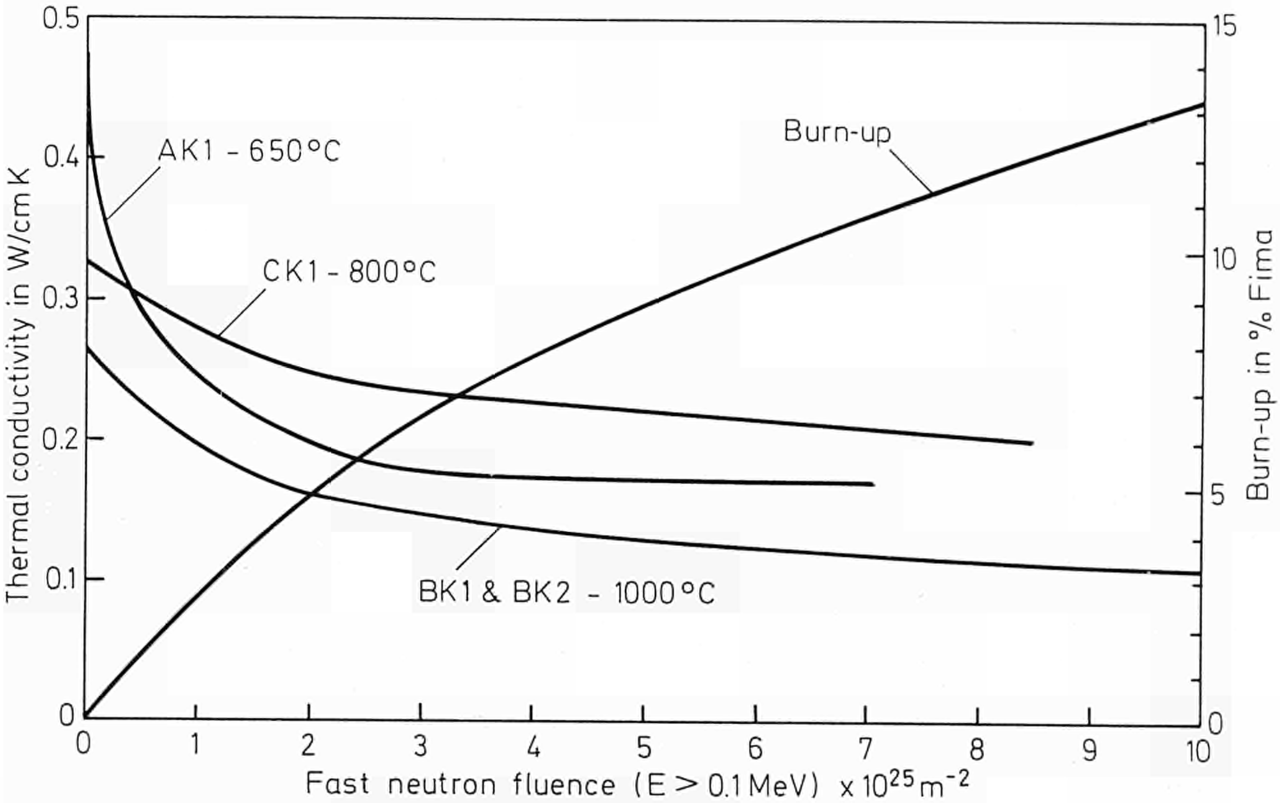


Fig. 28 D138-04. Thermal conductivities and burn-up vs. fast neutron fluence

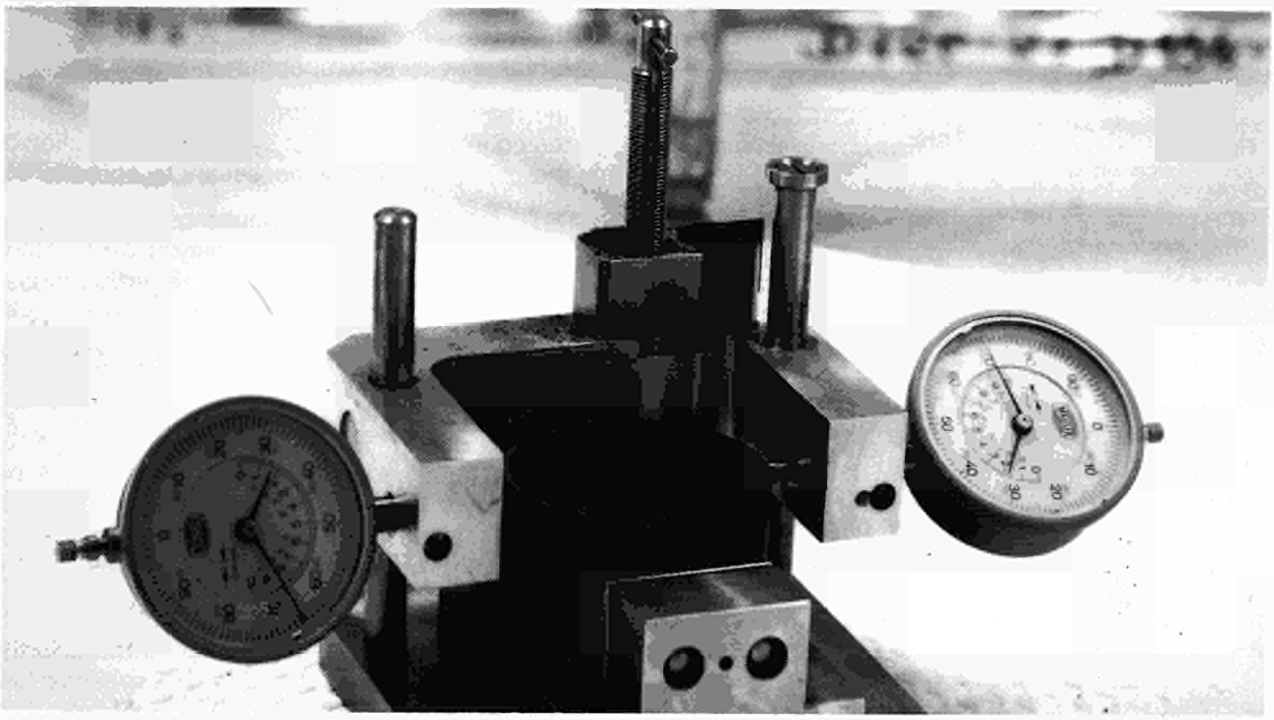


Fig. 29 D138-04. Measuring jig for structural graphite parts

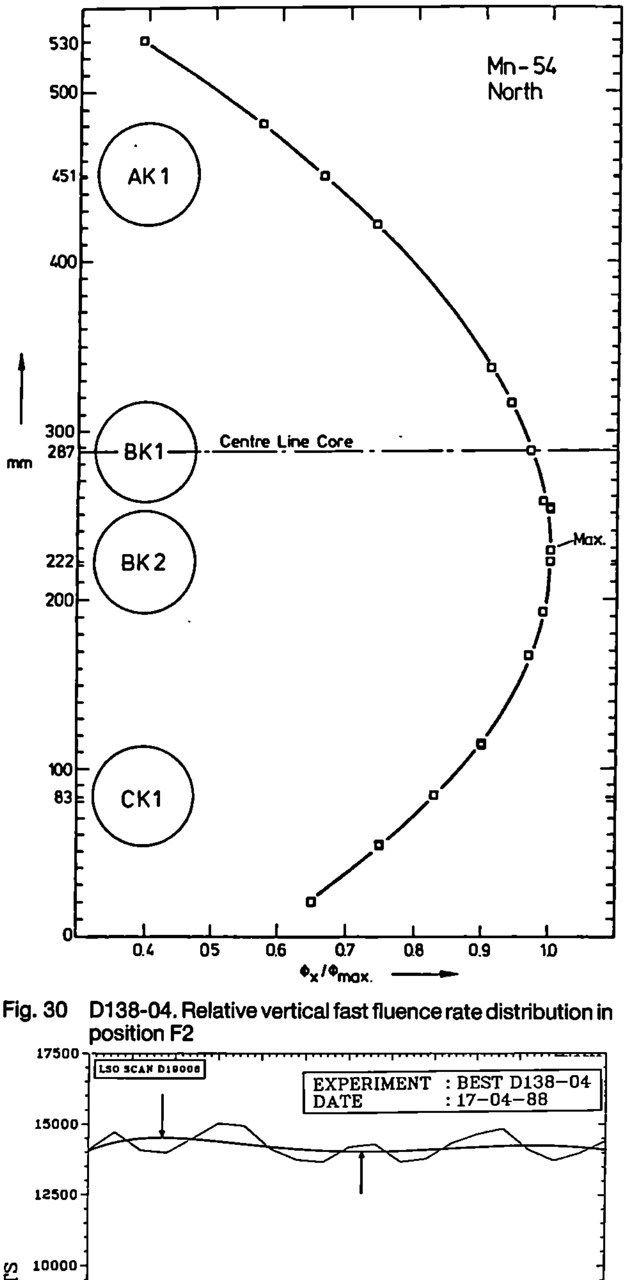


Fig. 30 D138-04. Relative vertical fast fluence rate distribution in position F2

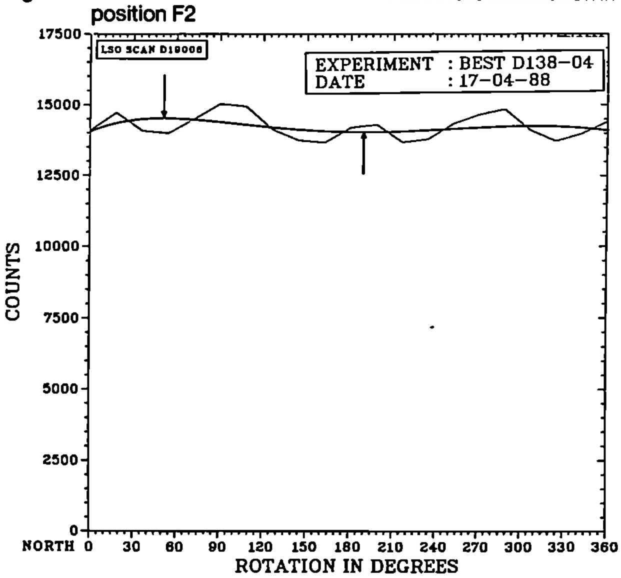


Fig. 31 D138-04. Radial thermal neutron fluence distribution on centre-line of sample BK1

achieved by turning the rig cycle-wise by 180^0 with respect to core North side.

There was no evidence of 137Cs contamination of the inner capsule wall.
The samples were shipped in 1988 to KFA for further PIE.
The final irradiation report is currently being prepared.

The conclusions of the irradiation and PIE results are:

The temperature control of spherical HTR fuel elements, the first of its kind, was successfully conducted in the HFR Petten. The results after an attained neutron fluence of 10.2 x $10^{25}m^{-2}$ provide consistent data:

- to understand the results of previous tests
- to design the forthcoming reference tests of the LEU-HTR fuel element testing programme
- to evaluate reference test results with respect to the description of the LEU-HTR fuel element temperature field in the specific MTR neutron spectrum

The findings are:

- the relative decrease of the thermal conductivity is higher at lower temperatures
- the iso-thermal temperatures in a fuel element, tested in a MTR, are not symmetrical; rotation of the capsules remains necessary to equalize the volume averaged damage
- a vertical displacement possibility of the capsules should be applied, to accomodate vertical movement of the neutron fluence rate
- central HTR fuel element temperatures can be calculated with the available data set
- the necessary temperature control range of ≈300K for the complete irradiation period can be maintained by the coincidence of decrease of thermal conductivity, fission power decrease and increase of the temperature control gas gap by graphite shrinkage
- representative irradiation conditions for the forthcoming reference tests of LEU-HTR spherical fuel elements can be realized in the HFR Petten with the existing irradiation facilities.

Table 11 D214-01. Water vapour injections in capsule 3 during 1988

Run	Cycle	Duration in hours	Water vapour concentration µatm.	Fuel temperature in °C	Fission gas release for the 85m x 10³ Pre	Dummy	Post
05	88.01	96	900	925	0.4	0.8	0.5
06	88.05	168	1320	880	0.35	0.6	0.4
07	88.06	135	1360	830	0.4	1.0	0.8
08	88.07	120	1220	865	0.7	0.8	0.7
09	88.08	192	1180	860	0.76	0.8	0.75
10	88.09	241	1305	880	1.5	1.6	1.2
11	88.10	172	1230	1040	2	2.3	1.8

Table 12 D 214-01. Achieved irradiation parameters in 1988

Irradiation Parameters	Specimen/Capsule 1	2	3
Duration in fpd	320.35	320.35	320.35
Fast neutron fluence E > 0.1 MeV in m^{-2}	4.2×10^{25}	4.7×10^{25}	3.8×10^{25}
Burn-up in % FIMA	15.7	15.9	14.4
DPA (dpa) graphite	3.618	4.072	3.247
Temperature °C	930	910-1170	810-1040
Fission gas release R/B for ^{85m}Kr	4.8×10^{-4}	1.2×10^{-3}	2.2×10^{-3}

D138-05/07. Reference Test for HTR MODUL

Objective: This reference test should confirm the design fission product release data set of HTR Modul production fuel elements under realistic irradiation conditions. The burn-up/fluence correlation and the power/temperature history considering the HTR Modul fuel loading is here understood as realistic irradiation performance (see also Fig. 15 on page 34 of PPR-1985/2).
Progress: The design has been performed in co-operation with Interatom, KFA Jülich and the HBK project.

The fuel elements were fabricated in 1988 and sent to KFA for characterization. The thermal design will be performed during the first half of 1989. The manufacture of the structural graphite parts will be done by KFA. Assembly of the rig will be carried out by JRC Petten. Irradiation start-up is planned for the second half of 1989.

D138-06/08. Reference Test for HTR-500

Objective: This reference test will supply final data to licence spherical fuel elements for the planned HTR-500, a successor plant of the THTR-300.
The main objective in this frame is the test of production fuel elements under conditions which simulate as far as possible the irradiation history of a HTR-500 core (see Fig. 16 on page 34 of PPR-85/2).
Normal and extreme operating parameters must be realized in this test to cover uncertainties in the fuel element design. The test should also demonstrate the coated particle stability, the mechanical fuel element integrity and the restrain capability for fission products of LTI (Low Temperature Isotropic)-TRISO coated particles.
Progress: The design of the irradiation experiment has been performed in co-operation with HRB, KFA Jülich and the HBK project.
The status of this experiment is similar to the D138-05 experiment.

Irradiation start-up is planned for 1990.

Parallel tests are planned for D138-05 and D138-06, which will be carried out with identical rigs, each containing three independently controlled capsules with continuous monitoring of fission gas release and gas impurities.

o Irradiation of Fuelled Block Segments for the US HTGR

D214-01. Irradiation of GA fuel rods

Objective: This experiment is a joint effort involving GA Technologies (Ca, USA), KFA Jülich, HBK project and JRC Petten under the auspices of the U.S./FRG Umbrella Agreement for Co-operation in Gas-Cooled Reactor Development.
Besides the co-operative nature of the experiment, its importance lies in the fact that it will contribute metallic fission product transport data and in-pile fission gas release from HTGR fuel under dry and hydrolyzing conditions in a near real-time irradiation with geometry and at exposure levels closely simulating those in a HTGR. GA provided the primary fuel samples and fuel bodies, KFA provided project management, "piggyback" samples and post-irradiation characterizations, while JRC Petten designed the capsule, operated and monitored it during the in-reactor phase of the experiment in the HFR Petten, performed non-destructive PIE and the dosimetry, and compiled the final irradiation report.
The overall objective of this experiment is to obtain in a configuration and time frame, simulating expected HTGR operating conditions, experimental data on metallic fission product transport in and from matrix and graphite and the effects of temperature cycling and fuel hydrolysis on fission gas release rates. These data will be used in the verification and refinement as necessary, of current normal conditions'fuel performance models.
The design of the irradiation rig is similar to the D138 rigs.

The three independent capsules are purged continuously by a helium-neon mixture. Process parameters such as temperature, gas flow, gas pressure, downstream radioactivity, up- and downstrean water vapour content in the purge gas and neutron fluence rate are recorded at two minute intervals. On-line fission gas release measurements and gas chromatograph measurements are performed at 8 hourly intervals.

Progress: The irradiation of the D214 experiment with three independent capsules continued in 1988. The irradiation was interrupted for one cycle (88-03) due to personnel shortage. Capsule 1 was operated at a constant fuel temperature of 1203 K (930^{0}C). The fission gas release rate remained constant. The R/B data for ^{85}Kr was 4.8 x 10^{-4}.

The fuel temperatures in capsule 2 varied from cycle to cycle between 1183 and 1443K (910 and 1170^{0}C), in order to obtain data on fission gas release as a function of temperature. The temperatures were increased during cycle 88.10 in two steps from 1213 to 1313 K (940 to 1040^{0}C) and to 1443K (1170^{0}C). The fission gas release rate increased during this run from initially 3 x 10^{-4} to 4 x 10^{-4} and finally to 1.2 x 10^{-3} for ^{85}Kr^m.

The water vapour injections with variation of duration and quantity were continued in capsule 3. In total, seven runs were performed (**Table 11**). The fuel temperatures were kept constant at 1153K (880^{0}C) in most cases. Only during cycle 88.10 the fuel temperature was increased from 1083 to 1313K (810 to 1040^{0}C). It was demonstrated that the fuel hydrolysis has an effect on fission gas release. The increase of release is by a factor of 2 approximately. The fission gas release decreases to the former value within a couple of days after shut down of the water vapour in the purge gas to the former value. The effect of fuel hydrolysis is shown in **Fig. 32**. The fuel hydrolysis data were presented in /4/ and in a seminar /5/.
The achieved irradiation parameters during 1988 are summarized in **Table 12**.
The irradiation is planned to continue until cycle 89.06.
A draft quality assurance report was issued /6/.

b) Graphite irradiations

In the frame of a graphite development and qualification programme a large number of graphite samples have been irradiated during more than 25 years in the HFR at Petten and in the HFR at Oak Ridge (USA). The HFR graphite irradiation programme supplies the necessary design base for the nuclear process heat and the direct cycle concepts of the High Temperature Reactor Programme of the German Federal Republic.
The irradiation capsules contain unstressed samples (fundamental properties programme) or creep specimens under tensile or compressive stress. They are irradiated in three to four fluence steps,

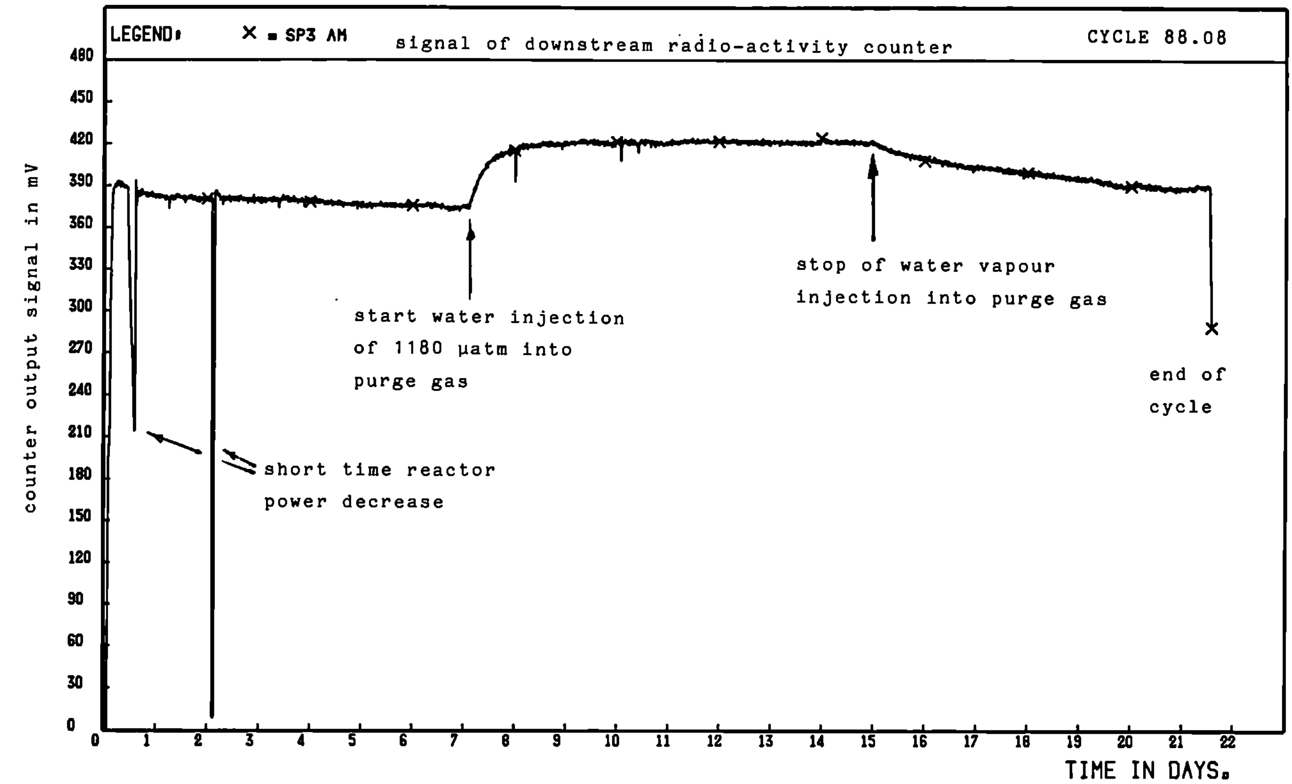


Fig. 32 D214-01. Effects of fuel hydrolysis on fission gas release

with intermediate measurement of their physical properties. For the range between 573 and 1473 K (330 and 1150°C), the neutron fluences have reached 2 x 10^{22} cm^{-2} (EDN)* for the most highly exposed samples.

o Unstressed Graphite Experiments

D85-47/48/50/51. Fundamental Properties Graphite Programme (see **Table 13**)

Objective: Characterization of reflector and matrix graphites covering all relevant material properties:
- reflector material, aiming at very high neutron fluences, in the order of 2 x 10^{22} cm^{-2} (EDN), at relatively low temperatures between 573 and 873 K (300 and 600°C)
- matrix material, for lower neutron fluences, in the order of 4 x 10^{21} cm^{-2} (EDN), at higher temperature, ranging from 773 to 1473 K (500 to 1200°C)

Progress: These are experiments on reflector graphite, at temperatures of 573, 673, 773 and 873 K (300, 400, 500 and 600°C), respectively. They are a continuation of irradiation of samples which have already been irradiated in previous experiments.

*) traditional graphite exposure unit (Equivalent DIDO Nickel)

D85-47, 573 K (300°C) and D85-51, 873 K (600°C) were terminated in 1987; they have been reported in the previous PPR.

D85-48, 673 K (400°C) which had started in 86.03, had to be interrupted after only two cycles, due to the failure of all thermocouples. An identical sample holder was built and loaded with the same samples. Irradiation recommenced in cycle 87.05, in position C3.
Because nominal temperature was not attained, it was operated with a gas mixture of He and Ar, for one cycle. From 87.06 it was placed in position E5, and 673 K (400°C) was reached. During the remaining part of the scheduled irradiation period, it continued operation without problems. However, when after cycle 88.05 the HFR power was brought back to its original value of 45 MW, it was again necessary to use argon in D85-48.

This irradiation ended with cycle 88.10. Distmantling and recovery of the samples and dosimeters is planned for January, 1989.

The irradiation report has been written and is actually being printed /7/.

D85-50 773 K (500°C) started in 86.03 and continued operation until its scheduled end, after cycle 88.02. It was then dismantled and the samples returned to KFA Jülich for PIE.
The irradiation report has been published /8/.

D85-54/55/56/57

These are the follow-up irradiations to the previously described reflector experiments. They are planned for the same temperatures (573, 673, 773 and 873 K; 300, 400, 500 and 600°C), and the same neutron fluence steps, i.e. between 4 x 10^{21} cm^{-2} for the 873 K (600°C) rig, and 8 x 10^{21} cm^{-2} for the 673 K (400°C) and 773 K (500°C) rigs.
Since they will be loaded with samples of the previous series, D85-47 to -51, their time schedule has been arranged in function of the corresponding pre-irradiation experiments.

D85-54 573 K (300°C), the follow-up experiment of D85-47, started irradiation in cycle 88.07, with a scheduled running time of 19 cycles.
The temperatures are as specified; there are no problems.

D85-55 and -56 673 and 773 K (400 and 500°C) are planned to start in 1989, according to the irradiation terminations of the corresponding D85-48 and -50.
D85-57 873 K (600°C) started irradiation in cycle 88.05. Its running time is scheduled to be 14 cycles. All temperatures are within the specified limits, the experiment is running smoothly and without problems.

D85-64/65/66/67

These are the next series of reflector graphite experiments, again at temperatures of 573, 673, 773 and 873 K, respectively. They are to pursue the irradiation of samples that have been irradiated in the previous experiments D85-54/55/56/57 and, earlier, D85-47/48/50/51.
Start-up of these irradiations is planned 1990/1991, see also **Table 13.**

D85-58/59/60

These are three irradiations at 1023, 1173 and 1323 K

Table 13 Graphite Fundamental Properties Programme. Survey 1988/1993

Experiment number D85-	Irradiation period	Irradiation temperature k	Actual state
48/2	May 87 - Dec. 88	673	irradiation ended
50	Mar. 86 - Febr. 88	773	irradiation ended
52	Oct. 87 - Jul. 88	773	irradiation ended, but dosimetry report still pending (ECN)
53	Oct. 87 - Jul. 88	1173	same as 85-52
54	Aug. 88 - Dec. 89	573	under irradiation
55	Mar. 89 - Aug. 90	673	SH ready, waiting for samples
56	Jan. 89 - Jul. 90	773	same as 85-55
57	Jun. 88 - Mar. 89	873	under irradiation
58	Jun. 89 - May 90	1023	in fabrication
59	Jun. 89 - Mar. 90	1173	under preparation
60	Sept. 89 - Mar. 90	1323	under preparation
61	Jun. 89 - Jul. 89	673	under preparation
62			number not assigned
63	Feb. 90 - Feb. 91	873	planned
64	Sept. 90 - Aug. 92	573	planned
65	Sept. 91 - Jul. 93	673	planned
66	Okt. 91 - Dec. 93	773	planned

respectively, for "new" (i.e. not previously irradiated) reflector material samples.

D85-58 (1023 K) will use the sample holder previously designed for D85-53, the type 31. This sample holder was designed for 1173 K and for a reactor power of 55 MW. With only minor modification, it is now possible to use this sample holder for lower temperatures, since the reactor power has not been increased.
The rig is being fabricated; the irradiation is planned to start around the middle of 1989 and will last for 10 cycles.

D85-59, 1173 K (900°C) will use a new sample holder, the type 41, which has been calculated and designed for a temperature range of 1173-1273 K (900-1000°C) and a reactor power of 45 MW.
The rig is presently under preparation and the irradiation is planned to start around the middle of 1989, lasting for 8 cycles.

D85-60, 1323 K (1050°C) will also use a new sample holder, the type 51, since the required temperature hass never been reached in a TRIO 129 capsule.
This rig is also under preparation and the irradiation is planned to start in the second half of 1989, lasting for 6 cycles.

D85-52/53

These were two experiments to irradiate matrix graphite. As a result of standardization in sample testing techniques, and thus sample geometries, it is possible to use the same standard sample carriers for both the reflector and the matrix experiments, as long as the specified irradiation temperatures correspond.

D85-52, 773 K (500°C) used the standard carrier type 21, in a version slightly adapted to the envisaged HFR power increase by 10 MW (type 21A). This type 21A will not be used in future because the reactor power will not be increased.

D85-52 started in cycle 87.09 in position C3, together with D85-53. The rig operated smoothly and within the specified limits of 770-773 ±25 K, until its scheduled end after cycle 88.06, when it had accumulated a fast neutron dose of 3.6 x 10^{21} cm^{-2} (EDN).
It was then dismantled and the samples sent to KFA Jülich for PIE.
The irradiation history has been reported in /9/.

D85-53, 1173 K (900°C) used a new sample holder type, called 31. Graphite at 1173 K had never been irradiated in a TRIO 129 geometry, therefore it was necessary to calculate and design a new sample holder, able to cope with the planned HFR power increase.
The irradiation started, together with D85-52, in cycle 87.09 in position C3. The planned neutron dose being the same, the two rigs were to be withdrawn at the same time, after cycle 88.06.
During the first cycles, D85-53 operated exactly at the scheduled 1173 ±45 K. Starting cycle 87.11, however, the temperatures decreased somewhat, probably due to growing carbon deposits on the surface of the carrier and, hence, growing heat losses by radiation. At the end of the year, the average temperature was about 1123 K and, since the heat transfer gas was, from the beginning, pure neon, no control margin was left. To increase the temperatures back to their nominal values, the rig was loaded into another TRIO, after cycle 88.01, which was placed in the somewhat hotter position E5. In E5, D85-53 reached its 1173 K and was operated until cycle 88.06.1, when it had accumulated the planned dose of 4 x 10^{21} cm^{-2}.
It was dismantled and the samples sent to KFA Jülich for PIE.
The irradiation history has been reported in /10/.

D85-61

In this irradiation samples of a new type and geometry will be irradiated, The samples are of CFC (Carbon Fibre Compound), and they have a rectangular shape of 3.2 x 8 x 90 mm.
The required irradiation temperature is 673 K (400°C) and the irradiation will last 1 cycle.
The thermal layout and design have been completed; the detailed drawing work is planned for January, 1989. The fabrication will start in March 1989 and the irradiation around middle 1989.

A summary of all planned and/or current D85 irradiations is presented in **Table 13**.

o Graphite Creep Experiments

Objective: The graphite used for structural components of a High Temperature Reactor is subject to thermal and neutron flux gradients which generate stress. Irradiation creep, which relieves stress, is thus an important parameter in the design of these structures. Various grades of graphite are being irradiated under stress in the HFR up to very high fluences and over the temperature range 570 K to 1170 K (300^0 to 900^0C). Creep measurements are taken out-of-pile at intervals of irradiation.

Progress:

D156 DISCREET

During the reporting period the following activities have taken place.

D156-90 Series ASR-1RS, 770 K, 5MPa tensile stress. Sample holder D156-93 continued irradiation until cycle 88.06 and was then discontinued due to a failure caused by an operational error. A new sample has been prepared and irradiation is scheduled to start in cycle 89.02.

D156-50 Series ASR-1RG, 770 K, 5MPa tensile stress.
D156-52 started irradiation in cycle 88.05 and continued uneventfully for the remainder of the reporting period.

D156-70 Series 770 K and 1170 K

Agreement has been reached with KFA Jülich and ORNL on a new experiment in which samples will first be irradiated under compression in the HFIR at Oak Ridge and then under tension in the HFR. This sequence is believed to be more representative of the real service conditions. The irradiation in the HFR is scheduled for the second half of 1990. A temperature change experiment (770-1170 K) is under consideration at Petten. This could start somewhat earlier (September 1989) because a reserve sample holder is already available.

D156 Post-Irradiation Examination

PIE of samples from earlier graphite experiments have been completed and the results reported. The samples have been transported to KFA Jülich and ORNL for further evaluation.

D156 Evaluation of Results

A new model relating graphite creep to volume change has been developed and a paper on the topic presented to the 1988 Carbon Conference in Newcastle (UK) /11/.

References to paragr. 2.2.3.3.

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HFR/88/2455, June 1988

/2/ Conrad, R., Debarberis, L., Timke, Th. and Doré, J.
Progress report no. 8 for D138-04
HFR/88/2442, April 1988

/3/ Dassel, G.
Gammaspectrometry of experiment D138-04
ECN-89-03, January 1989

/4/ Burnette, R.D.
Hydrolysis of HTGR fuel
Technical Memorandum HFR/88/2464, October 1988

/5/ Burnette, R.D.
HTR fuel hydrolysis
Seminar held on October 13th, 1988

/6/ Burnette, R.D., Conrad, R. and Timke, Th.
Q/A report on experiment D214-01
HFR/88/2478, December 1988

/7/ Scheurer, H.
Graphitbestrahlung D85-48; Abschlussbericht
Technical Note P/F1/88/..., (being printed)

/8/ Scheurer, H. and Sciolla, C.
Graphitbestrahlung D85-50; Abschlussbericht
Technical Note P/F1/88/9, Petten, August 1988

/9/ Scheurer, H.
Graphitbestrahlung D85-52; Abschlussbericht
Technical Note P/F1/88/15, Petten, September 1988

/10/ Scheurer, H.
Graphitbestrahlung D85-53; Abschlussbericht
Technical Note P/F1/88/16, Petten, September 1988

/11/ Kennedy, C.R. (ORNL), Cundy, M.R. (JRC Petten) and Kleist, G. (KFA Jülich)
The Irradiation Creep Characteristics of Graphite to High Fluences
Carbon 88, Newcastle-Upon-Tyne, UK, September 1988

2.2.3.4. Fusion Reactor Material Irradiations

These tests are covered by the European Fusion Technology Programme and form part of the R & D work towards the NET design and towards future demonstration plants.
Some of the experiments now under preparation also fall into a test matrix set up in August 1981

under the "IEA implementing agreement for a programme of research and development on radiation damage in fusion materials" (Paris, 1980).
The present generation **(Table 14)** mainly concerns creep, fatigue and crack growth in austenitic stainless steel together with research on vanadium alloys, as well as on breeding and structural ceramics and on liquid breeder material.
Fusion material irradiations which represented about 22% of the total reactor utilization during the year 1988, are reviewed by experts' group meetings at regular intervals.
In the following sections all fusion reactor material irradiation experiments are reviewed in the order of **Table 14.**

o Unstressed Austenitic Stainless Steel (incl. AMCR) Irradiations

R139 Series

Objective: ECN participates in the frame of the Commission's cost shared action in the European Fusion Reactor Materials Programme. A number of candidate materials' properties are determined and presented as a comparison between irradiated and non-irradiated specimens with identical heat treatment.
Crack propagation and fracture toughness are obviously the main areas of interest. In order to save irradiation space and limit the temperature gradients in the specimens caused by gamma heating, most specimens are of the compact tension type.

Progress:

R139-63

The irradiation successfully terminated in cycle 88.07 after nearly 5 years of irradiation. The total accumulated dpa is 5, and the irradiation temperature 700 K. The irradiation took place in a REFA-170. A typical statistical analysis of the temperature distribution during a reactor cycle is presented in **Table 15.**

R139-64 AKTINES

Objective: In the framework of the cost sharing action of the Commission in support of the NET fusion reactor materials development, ECN sponsors stainless steel 316 irradiations in the HFR.

The purpose of this irradiation, which is carried out in a SIENA type capsule, is to induce a material damage corresponding to that expected in the first wall material of a fusion reactor.

This neutron induced material damage is a combination of void formation, filled with gas, specially helium, and the displacement of atoms. The damage parameter is defined as the number of produced helium atoms, expressed as atoms in parts per million, and the number of displacements per atom. In accordance with the requirements, a ratio of 13 between the produced helium atoms and the number of displacements per atom must be obtained at the end of the irradiation period.

Progress: The SIENA device /1/ used in this experiment consists of 16 cylindrical and 3 flat tubes bundled together inside a tube of 72 mm internal diameter. Each cylindrical tube contains a sample holder loaded with 3 tensile and 6 fatigue samples. The flat tubes contain sample holders with 13 CT samples each. The AKTINES irradiation started in 86.09 in the reactor position E7. There are three different irradiation temperatures: 500 K, 600 K and 700 K. At the end of cycle 88.03 one sample holder was replaced by a new one. The specimens of the replaced sample holder will be transported to Rockwell International for He analysis. This will give us the possibility of comparing the experimental findings with theoretical predictions. The AKTINES irradiation terminated in cycle 88.11. Dismantling will take place in the beginning of 1989.

R139-65

Objective: ECN Petten participates in the frame of the Commission's cost shared action in the European Fusion Reactor Materials Programme. A number of candidate materials' properties are determined and presented as a comparison between irradiated and non-irradiated specimens with identical heat treatment. Crack propagation and fracture toughness are the main areas of interest. Most specimens are of the compact tension type, most of them being miniaturized to save irradiation space and to limit temperature gradients in the specimens caused by gamma heating.

Progress: This is an irradiation for martensitic steel at three different irradiation temperatures, 500 K, 600 K and 700 K, at different fluence levels. The specimens are designed to be irradiated in TRIO 129 legs. The 600 K and 700 K are planned for 10 dpa and occupy two legs of a TRIO 129 in E3 position, whereas there are three different legs to be irradiated at 500 K: the first one at 0.5 dpa, the second at 2.5 dpa and the third at 7 dpa. Irradiation of the first leg (500 K and

Table 14 Survey of fusion materials irradiations in the HFR Petten

HFR proj.	Project name	Specimen material	Test type	Status end 1988
R139	SINAS	Austenitic stainless steel	Post-irradiation tensile and creep tests. Post-irradiation crack growth experiment	Continuous programme, enlarged towards higher fluences
	AKTINES			Under dismantling
	FRUST 10		Post-irradiation tensile	Finished
E198	FRUST 01-03, 11-13	Austenitic stainless steel, incl. AMCR	Post-irradiation tensile	Finished
	FRUST 04-06			Irradiation finished
	FRUST 07-09			Irradiation finished
	SIENA 14		(high fluence) includes ferritic steel	Under assembly. Irradiation in 1987/91
E167	TRIESTE	Austenitic stainless steel	In-pile creep measurements: intermittent	Irradiation to be continued
E157	CRISP	Austenitic stainless steel	In-pile creep measurements: continuous	Under irradiation
R207	INFANTE		In-pile crack growth	(Dormant)
D202	SUPRA	V_3Si, $PbMo_8S_6$	Fundamental research in radiation damage in superconducting materials	Several irradiations finished. Programme continues
R204	VABONA	V-5Ti	Radiation damage studies	First irradiation series finished. Second series (4, 5, 6) under assembly.
R212	EXOTIC	Ceramic breeder compounds e.g. Li_2O, $LiAlO_2$, Li_2SiO_3, Li_2ZrO_3, Li_8ZrO_6, $Li_6Zr_2O_7$	Irradiation testing with parameter variation and of T-release and property charges, T-recovery with in-pile loop	Fourth irradiation completed. Design fifth irradiation completed. Programme continues.
E224	LIBRETTO	Liquid breeder Pb-17Li	In-pile breeding and permeation testing. Post-irradiation T-recovery	LIBRETTO 1 completed. Design LIBRETTO 2 completed. Programme continues.
D237	ELIMA	Ceramic breeder components	Irradiation of 36 closed capsules under cadmium screen	Design completed. Irradiation started in April 1988 and will finish in January 1989.
D217	CERAM 1	Insulator and first wall ceramics	Radiation damage studies	Under dismantling
	CERAM 2	First wall ceramics	Radiation damage studies	Under assembly.
D225	CEFIR		Radiation damage studies	Under manufacture
E236	LOTOS	HT brazing of first wall cand. st. st.	Post-irradiation tensile and fatigue	Dormant
D241	GRIPS	Fist wall coating graphite	Basic property changes under neutron irradiation	Under preparation

Table 15 R139-63. Typical statistical analysis of a temperature distribution in a reactor cycle (88.05)

CYCLE NO: 88-06 "D A C O S S Y S T E M" DATE: 16:10:46 29-SEP-88

ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 08:48:00 23-JUN-88 TO 09:08:00 18-JUL-88

EXPERIMENT NO.	: R139-63	NOMINAL DEGREES "C":	430.00
NAME	: SINAS	SAMPLE	:
START DATE	: 28-02-85	STRESS MODE	:
REACTOR LOCATION	: E1	DATA LOGGER NUMBER :	2
GAS PANEL USED	: 'F'	RECORD INTERVAL :	10 MINUTES

CHAN NO.	MEASUR'G POINT NAME	ENG'RING UNIT	ANALYSIS OF MEASURING POINT (BY ENGINEERING UNITS) AVERAGE	MINIMUM	MAXIMUM	STANDARD DEVIATION	ERROR	TOTAL RECORD	ANALYSIS OF DATA RECORDS (BY PERCENTAGE) REACTOR < 43.MW	NO DATA	< LOW LIMIT	> HIGH LIMIT	WITHIN LIMITS
256	TC30	DEG. C	437.34	352.61	450.70	7.001	0.128	3603	17.32	0.00	0.64	0.56	81.49
251	TC25	DEG. C	443.68	371.46	450.70	3.746	0.069	3603	17.32	0.00	0.06	0.92	81.71
246	TC20	DEG. C	432.37	369.07	437.10	3.199	0.059	3603	17.32	0.00	0.28	0.00	82.40
241	TC15	DEG. C	432.23	374.86	437.15	2.756	0.050	3603	17.32	0.00	0.06	0.00	82.63
235	TC9	DEG. C	420.90	371.42	424.62	2.297	0.042	3603	17.32	0.00	0.17	0.00	82.51
231	TC5	DEG. C	411.35	362.61	414.87	2.266	0.042	3603	17.32	0.00	22.43	0.00	60.26
227	TC1	DEG. C	442.05	389.01	445.40	2.460	0.045	3603	17.32	0.00	0.03	0.00	82.65

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.

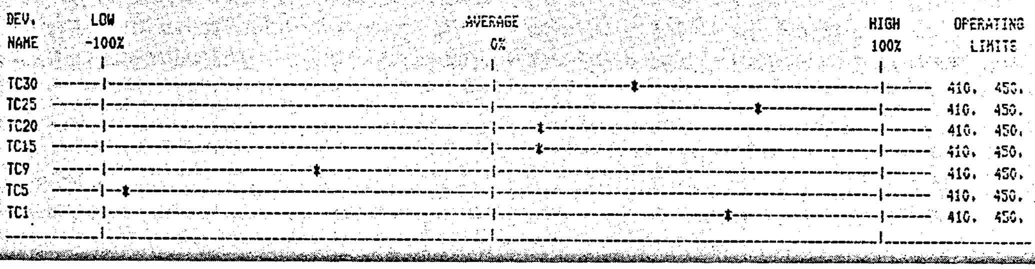


Table 16 R139-65. Typical statistical analysis of a temperature distribution in a reactor cycle (88.07)

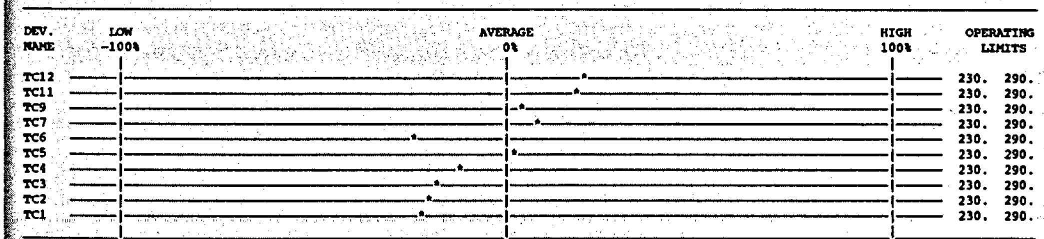
CYCLE NO: 88-07 "D A C O S S Y S T E M" DATE: 11:55:18 4-OCT-88

ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 20:20:00 7-SEP-88 TO 09:40:00 29-SEP-88

EXPERIMENT NO.	: R139-654	NOMINAL DEGREES "C":	270.00
NAME	: SINAS	SAMPLE	:
START DATE	: 23-06-88	STRESS MODE	:
REACTOR LOCATION	: D2	DATA LOGGER NUMBER :	4
GAS PANEL USED	: PSF-4	RECORD INTERVAL :	10 MINUTES

CHAN NO.	MEASUR'G POINT NAME	ENG'RING UNIT	ANALYSIS OF MEASURING POINT (BY ENGINEERING UNITS) AVERAGE	MINIMUM	MAXIMUM	STANDARD DEVIATION	ERROR	TOTAL RECORD	ANALYSIS OF DATA RECORDS (BY PERCENTAGE) REACTOR < 43.MW	NO DATA	< LOW LIMIT	> HIGH LIMIT	WITHIN LIMITS
1601	TC12	DEG. C	266.05	191.09	277.94	16.416	0.299	3105	2.74	0.00	7.15	0.00	90.11
1600	TC11	DEG. C	265.41	189.88	276.99	16.415	0.299	3105	2.74	0.00	7.15	0.00	90.11
1598	TC9	DEG. C	261.29	186.58	272.39	16.934	0.308	3105	2.74	0.00	7.15	0.00	90.11
1596	TC7	DEG. C	262.69	193.91	272.05	16.343	0.297	3105	2.74	0.00	7.15	0.00	90.11
1595	TC6	DEG. C	252.68	184.36	300.52	17.692	0.322	3105	2.74	0.00	7.15	0.03	90.08
1594	TC5	DEG. C	260.61	192.76	313.73	17.550	0.319	3105	2.74	0.00	7.15	0.06	90.05
1593	TC4	DEG. C	256.30	185.16	308.76	19.672	0.358	3105	2.74	0.00	7.18	0.03	90.05
1592	TC3	DEG. C	254.32	181.22	266.86	20.085	0.365	3105	2.74	0.00	7.18	0.00	90.08
1591	TC2	DEG. C	254.27	178.17	265.53	20.947	0.381	3105	2.74	0.00	7.18	0.00	90.08
1590	TC1	DEG. C	253.28	175.80	306.19	21.370	0.389	3105	2.74	0.00	7.18	0.03	90.05

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.



0.5 dpa) started in 88.02 and terminated in 88.03 in E3. Irradiation of the remaining two legs (500 K, 2.5 and 7 dpa) started in 88.06 in D2 position and is still underway. A typical statistical analysis of the temperature distribution during a reactor cycle is presented in **Table 16.**

E198-14 SIENA (35 dpa, 423 K to 1073 K)

Objective: In the years 1985/87, the NET Team in particular stressed the need for a very high dose irradiation of first wall candidate stainless steels. For this purpose, the development of a low temperature irradiation facility was started, which should fulfil the following requirements:

- irradiation temperatures: up to 773 K (500^{0}C) for S.S., 1073 K (800^{0}C) for other materials, and possibly as low as 423 K (150^{0}C)
- neutron fluence: corresponding to 30 or 35 dpa, which means an irradiation duration of about 5 years, in the best HFR position, with the possibility to unload part of the samples, after accumulation of a lesser dose, e.g. after 5 dpa
- Helium/dpa ratio as close as possible to 13 for austenitic steel, which can only be obtained in a special capsule, calculated and designed for this special purpose of "spectrum tailoring".

The design was given the name SIENA, standing for Steel Irradiation in Enhanced Neutron Arrangement. It features zircaloy and aluminium as the main construction materials, and an unusual arrangement of the Zry tubes containing the samples. As in a heat exchanger the tubes are bundled inside a larger outer tube, allowing for large water gaps between them. This leads to a strong enhancement of the thermal neutron flux density and thus, to a He/dpa ratio of ≃ 13.

The parties involved in this irradiation are:

- JRC Ispra : tensile samples of 316 L, AMCR, Cu and Cu-Cr-Zr
- KfK Karlsruhe: Tensile and Sharpy samples of DIN 1.4914
- ECN Petten : tensile and fatigue samples of different vanadium alloys, together with UKAEA Harwell and Tohoku University, Japan

The duration of the irradiation has been calculated to be about 60 cycles in position C5, corresponding to ≃ 30 dpa in the austenitic S.S. samples.
In the meantime the targets of the NET development have been reconsidered and the extremely high doses are of less interest. It was recently decided to conclude the SIENA irradiations at 15 dpa, bearing in mind the continuation of materials irradiations in the SIENA capsule using other, more advanced materials.

Progress: During the reporting period, the irradiation of the SIENA samples continued, as scheduled, in HFR position C5. In the meantime, the irradiation specifications were partially changed: the target dose for the sample holders 19, 20 and 21, originally 3 dpa, was changed to 5 dpa. Thus, the irradiation duration of these sample holders was increased to the end of the cycle 88.06. The irradiation was then interrupted to permit the unloading of the samples. A report concerning this first irradiation step is presently being printed /2/.
The three sample holders were replaced by three new ones with identical specifications. The samples were supplied by KfK Karslruhe. New thermal calculations were performed to improve, as much as possible, the temperature distribution in the sample holders which led to minor modifications with respect to the original design. The irradiation started in cycle 88.10, the obtained temperatures corresponding to the calculated values.

As a result of a request from JRC Ispra, a new sample holder for SIENA was developed, with the following layout:

- samples : 27 tensile samples (9 per channel) of welded AISI 316 L
- temperature : the minimum possible; calculations resulted in temperatures between 373 and 403 K (100 and 130^{0}C)
- neutron fluence: ≃ 1 dpa.

These three sample holders were loaded in channels 3, 8 and 12 which were previously filled with dummies. The irradiation of the sample holders started in cycle 88.10. The temperatures obtained did not correspond to the calculated values. They vary from ≃ 403 to 473 K (≃ 130 to 200^0). An explanation for this discrepancy could not be found.

o Creep Testing of Fusion Materials (Austenitic Stainless Steel)

Objective: Austenitic stainless steels have been considered as candidate structural materials for the First Wall of NET. Manganese containing steels are developed within the scope of the fusion materials programme of the JRC because the helium production rate of these alloys is smaller, the corrosion resistance against lithium is better, and the neutron activation is lower compared to nickel-based austenitic stainless steel alloys. In order to study the effects of neutron irradiation on the creep behaviour of these materials and on nickel-based steels such as 316-CE -reference, US 316 and US PCA steels two irradiation creep facilities were developed for the HFR at Petten.

In the creep facilities TRIESTE a series of tests are carried out on 294 samples. The elongations are measured at intervals of irradiation in hot cells. In a single irradiation rig, 49 specimens can be irradiated simultaneously in uniaxial tension.
In the irradiation device CRISP strain registrations are performed in situ. Three specimens, each with indepedent control of stress and temperature are irradiated simultaneously in uniaxial tension. The results obtained from these experiments will be complementary to those from the TRIESTE series. In both rigs irradiations can be performed in the temperature range between 470 K and 870 K for uniaxial stresses between 25 and 300 MPa.

Progress:

E167 TRIESTE
Intermittent Creep Measurement (MAT-5)

The entire experimental TRIESTE programme comprises six irradiation facilities where each facility is irradiated for eight steps and dimensional measurements on the individual tensile samples are performed in hot cells between the irradiation steps. The irradiation series E167-10, E167-20, E167-30, E167-40, E167-50 and E167-60 are distinguished by the type of sample material, the irradiation temperature and the applied stresses during the irradiation. During the whole irradiation campaign a total of 294 tensile samples and a large number of reference half-shell pairs are tested. Irradiation samples and half-shells pairs are manufactured from nine different materials. The chemical composition of these materials is given in **Table 17.**
Two cold work levels (10 and 20%), three separate aging conditions as well as the non pre-treated condition were employed. The total irradiation time of 17 HFR cycles in reactor positions G3 and G7 corresponds to about 5 dpa in the austenitic stainless steel samples.

The irradiation history of the TRIESTE series is shown in **Table 18.** The end of the total irradiation is scheduled beyond 1990.

The following activities were pursued during the reporting period:

- Irradiations continued in 1988. Experiments E167-17, E167-27 and E167-36, were irradiated for three HFR cycles. In the same period the experiments E167-42 and E167-43 were irradiated for one cycle and the experiments E167-44 and E167-45 for two cycles.

- Load calibration tests and pre-measurements of sample stems of the new E167-50 and E167-60 irradiations facilities were performed and the irradiation campaigns started successfully with the series E167-50 in cycles 88.04 and 88.08 and the series E167-60 in cycles 88.07 and 88.11.

- During the reporting period creep elongations of individual samples of the experiments E167-16, E167-27, E167-36, E167-42, E167-43, E167-44, E167-51 and E167-61 were measured in hot cells using semi-automatic measuring devices. Some results of these measurements have been partly analysed and published /3/. A typical creep curve is shown in **Fig. 33,** where the secondary creep rate for plastically deformed AMCR 0033 steel is plotted versus the applied stress. The stress exponent $n \simeq 1.1$ is obtained from the slope of the straight line.

- Preparation of fabrication of a further 33 tensile samples and the same number of half-shell pairs for the enlargement of the programme for the E167-70 series. A number of AMCR 0034 and AMCR 0035-type samples will be cold-worked prior to machining and others heat-treated after machining.

- Feasibility study of low temperature irradiations of stainless steel samples (about 370 K) has been started. A design modification of the TRIESTE irradiation device is in preparation. The irradiations of the E167-80 series will start at the end of 1989.

- Due to the long irradiation period of the TRIESTE experiments additional information on the neutron fluence has been collected with external fluence detectors placed in the four corners of the filler assembly in which the experiments were

Table 17 Composition of steels (wt%) tested in TRIESTE and CRISP

Designation	C	Mn	Ni	Cr	Si	Mo	Ti	N	S	P
AMCR-0033 Creusot-Loire (France)	0.105	17.50	<0.10	10.12	0.555	<0.06	-	0.19	0.008	0.016
AMCR-0034 Creusot-Loire (France)	0.100	17.69	0.15	10.11	0.64	1.52	-	0.16	0.008	0.025
AMCR-0035 Creusot-Loire (France)	0.029	19.88	0.265	14.09	0.63	<0.06	-	0.048	0.006	0.018
AISI 316 L Creusot-Loire (France)	0.024	1.81	12.32	17.44	0.46	2.5	-	0.06	0.002	0.027
7758 Vakuum Schmelze (Germany)	0.062	28.6	-	10.0	0.87	-	0.87	-	-	-
7761 Vakuum Schmelze (Germany	0.11	29.4	-	10.2	1.01	-	-	-	-	-
7763 Vakuum Schmelze (Germany)	0.10	19.4	-	10.2	0.94	-	0.85	-	-	-
AISI 316 ORNL-stockpile SS 316	0.06	2.0	10-14	16-18	1.0	2.3	-	-	-	-
PCA ORNL-stockpile Path A PCA	0.06	1.5-2.25	15-17	13-15	0.4-0.6	1.8-2.2	0.2-0.4	-	-	-

Table 18 Damage obtained in TRIESTE experiments at the end of 1988

TRIESTE series	Irradiation Start [HFR-cycle]	Damage obtained [dpa]
E 167-10	83.10	3.9
E 167-20	85.03	4.0
E 167-30	85.06	3.0
E 167-40	87.09	2.1
E 167-50	88.04	0.6
E 167-60	88.07	0.6

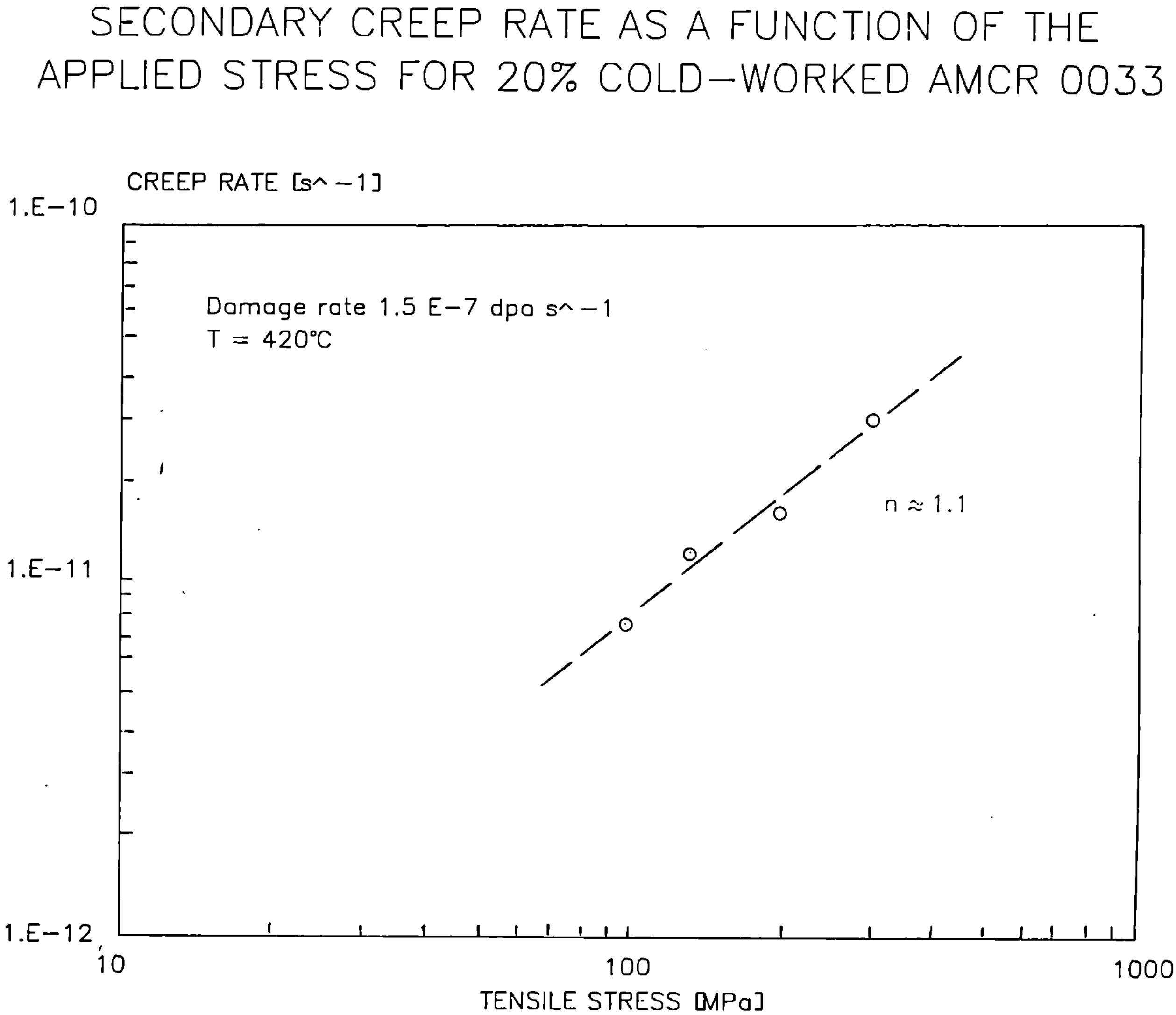


Fig. 33 Secondary creep rate as a function of the applied stress for 20% cold-worked AMCR 0033

irradiated. The external detector sets were present during the irradiation of the experiments E167-11, E167-14, E167-26, E167-33 and E167-43. The neutron metrology of these irradiations (except experiment E167-43) is presented in references /4-7/. The whole operation covered a period of about three years. Fluence rate values averaged over the external detector set positions are presented in **Table 19.**

The fluence rate values are valid for HFR-core position G7 and a reactor power of 45 MW. An average displacement rate of $K = 1.5 \times 10^{-7}$ dpa · s^{-1} has been calculated. The number of displaced atoms in the steel samples is calculated from the relationship:

dpa = DAR x ϕf x <SIGMA d>

A DAR value of 1.5 has been taken from the data set measured in various mock-up assemblies in 1981 /4/.

- Fabrication and assembly of two further special REFA type capsules, two sample carriers, two special REFA heads, and 14 sample stems needed for the new E167-70 and E167-80 series.

E157 CRISP. In-Pile Creep Measurement (MAT-5)

In the irradiation device CRISP the creep elongation of three specimens in three different rigs can be measured simultaneously. All three rigs, combined

Table 19 Results of neutron metrology with external detector

TRIESTE experiment	Irradiation Time [days]	Fast Fluence averaged [10^24 m^-2]	Displacement Rate averaged [dpa . s^-1]
E 167-11	24.8	2.50	
E 167-14	50.4	4.49	1.5 x 10^-7
E 167-26	65.4	6.69	
E 167-33	21.3	2.04	

in one standard TRIO irradiation facility, are independent with respect to the irradiation temperature and the applied stresses which can be varied between 570 K and 870 K, and between 25 and 300 MPa, respectively. The experimental programme comprises three irradiation thimbles with a total of nine individual creep rigs.

In each rig a single cylindrical dumbell-shaped sample, which is submerged in NaK, is stressed in tension by a bellows system. Strain measurements are taken semi-continuously by comparing the sample length with the length of an unstressed reference piece of the same material. Length changes are detected by a displacement transducer remote from the reactor core. The measurement sequence is controlled by a dedicated processor and the whole experiment is supervised by a PDP 11/04 computer. In order to measure thermal creep strains the irradiation temperatures are maintained during reactor shut-down periods by in-built electrical heaters.

Experience from prototype irradiations (E157/01-03) has led to a number of design changes for subsequent irradiations. First results of these measurements are discussed and published together with the results obtained from the TRIESTE irradiations /3/. The assembly of the second set of three sample holders (E157/11-13) was delayed due to a number of minor technical difficulties. After the necessary commissioning tests, including the standard quality checks and the measurement of the sample Young's Modulus by the rig the irradiation is scheduled to start in HFR cycle 89.06. The fabrication of a third set of three sample holders (E157/14-16) is in preparation.

o Irradiation of Materials Used in Super-Conducting Magnets

D202 SUPRA

Objective: In this experiment series materials are being irradiated whose changes under irradiation give data on the behaviour of the coil and structure materials in superconducting magnets of fusion reactors.

Progress: Sponsored by KfK Karlsruhe, two materials have been investigated up to the present time: V_3Si and some screening experiments in $PbMo_8S_6$.

With the recent development of so-called High Temperature Superconductors the emphasis of the sponsor changed completely to this new material. Starting with D202-18 and using always the same reloadable rig carrier, a total of 18 irradiations were performed. Small specimens of the new material ($YBa_2Cu_3O_7$) were irradiated to different fast neutron fluences, all at the same temperature (323 K to 353 K), see also /8/.
All irradiations were performed with a Cd screen surrounding the sample holder, to filter thermal neutrons and thus to minimize activation of the samples. All samples have been dismantled and returned to the sponsor for PIE.
During the reporting period only one experiment was performed : D202-36 was loaded with one sample of another new material, namely $TlCa_3BaCu_3O_9$, which was irradiated to a fast neutron fluence of 1 x 10^{18} cm^{-2} (E > 1 MeV), during cycle 88.11.
More irradiations are planned for the first half of 1989.

o Vanadium Irradiations

R204 VABONA

Objective: ECN Project 1.624 foresees in the "Radiation Damage Investigation of Vanadium for Fusion Reactors" and, more specifically, in the assessment of the viability of boron doping of the vanadium samples, prior to neutron irradiation, as a means of simulating the effects of fusion reactor irradiation.

The irradiation damage of materials in the neutron flux regions of a fusion reactor will be characterized by a high amount of helium, produced simultaneously with a great number of atomic displacements. Whereas in fission and in fusion reactors the dpa rates are of a comparable order of magnitude, the He production rate in a fusion device is much larger.

As the irradiation of materials with 14 MeV neutrons is at present only possible to a very limited scale, simulation of these effects is a necessity. Relevant simulation requires that He and dpa generation, which are considered to be the most damaging, are introduced in the material in a realistic ratio, preferably at the same time. Doping the candidate material with a certain amount of boron, prior to irradiation seems to be a way to approach realistic fusion reactor irradiation damage. The ^{10}B, with its high cross section for thermal neutrons, will provide an increased He generation, bringing the ratio between dpa and He generation close to "realistic" values.

Progress: Three new experiments R204-07/08/09 have been launched in 1987. Due to problems concerning the production of the new vanadium alloys the work was discontinued until December, 1988. With the samples shape and composition defined, the SIENA sample holders could be calculated and designed.

The experiment specifications are:
Three sample holders, each accumulating 10 dpa at 873 K (600°C), 973 K (700°C) and 1073 K (800°C), respectively.
Since the capsule chosen this time is the SIENA, with a channel diameter of only 10.8 mm, there is no possibility to use sodium as the heat transfer medium and, hence, the experiment will be of the "dry" type. To reduce the possibility of contamination of the samples to a minimum, the material of the sample holder will be Zr, being a strong getter at the temperature range in question. In addition, the sample holder will be placed in a closed containment of stainless steel, filled with neon or argon (depending on the irradiation temperature) of the highest available degree of purity, and it will be degassed thoroughly, before being closed for irradiation.

During the reporting period, the thermal calculations and the complete drawing work was performed. The irradiation is scheduled for cycle 89.03.

o Blanket Breeder Material Irradiations

Within the European Fusion Technology Programme on Blanket Breeder Technology three experimental programmes are carried out in the HFR Petten, namely EXOTIC, LIBRETTO and ELIMA. The blanket materials are either ceramic lithium compounds or the eutectic alloy Pb-17Li.

The main objectives ot these irradiation tests are :
- to study in-situ tritium release kinetics
- to study irradiation damage
- to study tritium extraction methods
- to study tritium permeation through reference cladding materials
- to study compatibility between blanket and cladding materials.

The results of these experiments provide the designers of blanket concepts the data needed for the selection of candidate blanket breeder materials for future fusion reactors (e.g. NET).

The HFR activities on the blanket breeder irradiations are summarized in **Table 20.**

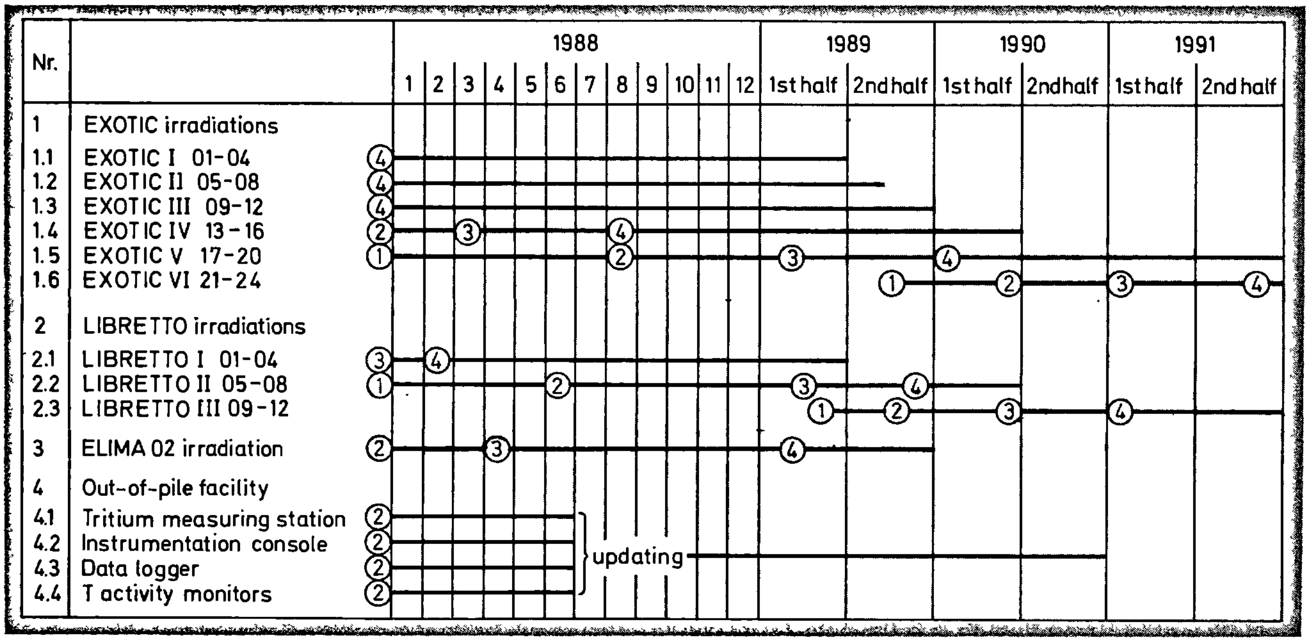
R212 EXOTIC.
Irradiation of Ceramic Lithium Compounds

The EXOTIC programme is being carried out as a joint project by SL Springfields, SCK/CEN Mol and ECN Petten in co-operation with JRC Petten.

The programme consists of manufacture, characterization, irradiation and pre- and post-irradiation examination of the Li-compounds $LiAlO_2$, Li_2SiO_3, Li_2O, Li_2ZrO_3 and Li_8ZrO_6, and $Li_6Zr_2O_5$.

The EXOTIC programme within the 1982-1986 European Fusion Technology Programme consisted of three irradiations, EXOTIC I, II and III (see PPR 1987). The 1988 activities for these experiments concentrated on post-irradiation examinations.

Table 20 Survey of fusion blanket breeder activities



Legend:
1 Design and calculation
2 Manufacture and commissioning
3 Irradiation, cycle reporting
4 Dismantling, evaluation

Circles indicate start of activity

Table 21 R212-17/20. Loading scheme of EXOTIC 5

Capsule no.	**17.1 vented**	**18.1 vented**	**19.1 vented**	**20.1 vented**
Material suplier	SCK/CEN	CEA	ENEA	KfK
Material	Li_2ZrO_3	Li_2ZrO_3	$LiAlO_2$	Li_4SiO_4
Density TD%	80	80	80	66
Li-6 enrichment %	7.50	7.50	7.50	7.50
Temperature, ^0C	300/500	300/500	300/500	300/500

Capsule no.	**17.2 vented**	**18.2 vented**	**19.2 vented**	**20.2 vented**
Material suplier	SCK/CEN	NRL	CEA	JAERI
Material	Li_2ZrO_3	Li_8ZrO_6	$LiAlO_2$	Li_2O
Density TD%	80	80	80	80
Li-6 enrichment %	7.50	7.50	7.50	7.50
Temperature, ^0C	300/500	300/500	300/500	300/500

Table 22 R212-13/16. Irradiation data of EXOTIC 4

Material	Li_2ZrO_3			Li_8ZrO_6	$Li_6Zr_2O_7$
Capsule no.	14.1	14.2	16.1	15.1	15.2
Temperature range (°C)	350/430	480/650	380/680	450/650	470/650
Irradiation time (FPD)	97	97	97	97	97
Burn-up (% Li)	0.13	0.13	0.13	0.14	0.15
Initial tritium release rate					
(µCi/min)	320	300	130	300	200
(µCi/(min g))	5.4	5.1	3.8	11.7	6.7

Table 23 Tritium residence times of Li-zirconates irradiated in EXOTIC-4, during temperature transients

T ** C	Temp.*** step	Time h	T ** C	Temp.*** step C	Time h
Li2ZrO3-SCK/CEN (14.1/2)			Li2ZrO3-NRL (16.1)		
350	- 45	69	369	-111	>>6.4
375	- 45	40	376	- 17	10.7
425	+ 80	>3.3*	390	-180	3.8
470	-180	4.2	392	- 26	3.05
521	-180	1.4	418	- 15	1.12
524	-110	1.2	435	- 83	1.1
560	- 55	0.52	440	-120	0.27*
588	- 82	>0.20*	518	- 55	0.10
620	- 50	0.29	538	-116	<0.15*
627	+106	0.22	570	-110	0.09
640	+116	0.17	652	+156	<0.23*
657	+140	0.10			
670	+30	0.10			
Li8ZrO6-NRL (15.1)			Li6Zr2O7-NRL (15.2)		
560		28	420	-170	0.26
560		40	430	-115	0.36
580		13	430	-100	0.65
625		14	431	- 49	0.75
635		8	431	-177	0.4
			472	- 80	0.2
			480	- 81	0.12
			490	+ 60	<0.2*
			610	+190	<0.2*

* steady state not achieved or temperature not constant after the transient
** at end of temperature transient
*** (-) decrease and (+) increase in temperature

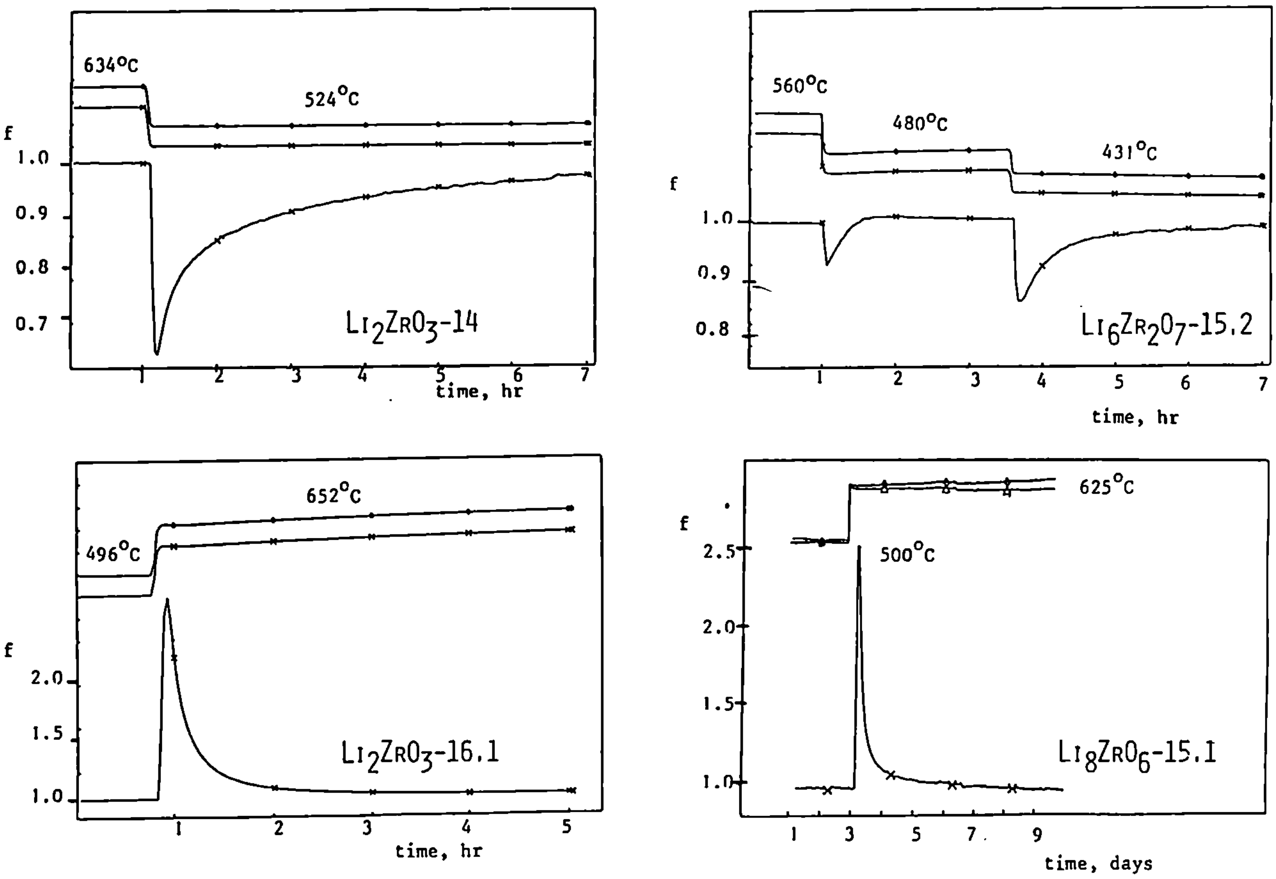


Fig. 34 R212-14/16. Examples of fractional tritium release, f, after temperature transients

Within the 1985-1989 and 1988-1991 European Fusion Technology Programme three more EXOTIC experiments are planned.
The EXOTIC VI experiment (see PPR 1987) was prepared and irradiated in 1988.
The EXOTIC V and VI experiments will be joined by CEA, ENEA and KfK. SCK/CEN Mol and NL will stop their participation after the EXOTIC V experiment. JAERI joins the programme with the EXOTIC V experiment. The EXOTIC V experiment was designed in 1988 /9/ and will be irradiated in 1989. The test matrix is given in **Table 21.** The EXOTIC VI experiment is planned to be performed in 1990/1991.
The EXOTIC IV experiment (see **Table 21,** PPR 1987) was successfully irradiated in 1988 during the cycles 88.03 and 88.06 /10/. Results of this experiment were presented at the 15th SOFT conference in Utrecht, and at the 30th EWGIT working group in Mol, both in September 1988 /11,12/.
EXOTIC IV was irradiated in a peripherical in-core position during 97 full power days. The main objective of this experiment was to obtain data on tritium residence times at higher lithium burn-up and in the temperature range between 623 K and 973 K (350°C and 700°C) for the three zirconates: Li_2ZrO_3, Li_8ZrO_6, $Li_6Zr_2O_7$.
In the first cycle the temperatures have been kept at nominal values, 623 K (400°C) for capsule 14.1 and 973 K (600°C) for the other capsules, in order to achieve steady state conditions. Temperature transients have been carried out in the second, third and fourth cycle. The nuclear conditions remained constant throughout the irradiation. The capsules were purged with dry helium, doped with 0.1 vol % hydrogen at a flow rate of 100 cm/min. The relevant process parameters were scanned every two minutes by a computerized data-logger. The irradiation conditions are given in **Table 22.**

In order to determine tritium release kinetics, temperature transients were performed from different temperatures levels and with various steps, both by increasing and decreasing the temperature. For each temperature step a positive or negative tritium release peak was observed. Examples are given in **Fig. 34.** The temperature ranges and measured initial steady state tritium release rate are given in **Table 23.**
The steady state tritium release rates equal the calculated tritium production rates for all temperatures, except for Li_8ZrO_6 where steady state tritium release was not observed below 823 K (550°C).
The kinetic approach to steady state tritium release after a temperature step was analysed. The resulting characteristic time constants, τ, were determined by the following models:
- intra-granular diffusion with constant internal tritium source and zero surface concentration
- first order desorption with constant internal tritium source.

For both models the relative differential equations for a spherical geometry were analytically solved to predict the tritium release behaviour after an ideal temperature step.

Good data fitting was obtained with the diffusion model at temperatures below 803 K (530°C). At temperatures > 803 K (530°C) both models gave equal residence times. The results are given in **Table 23** and are shown in an Arrhenius-plot in **Fig. 35.**

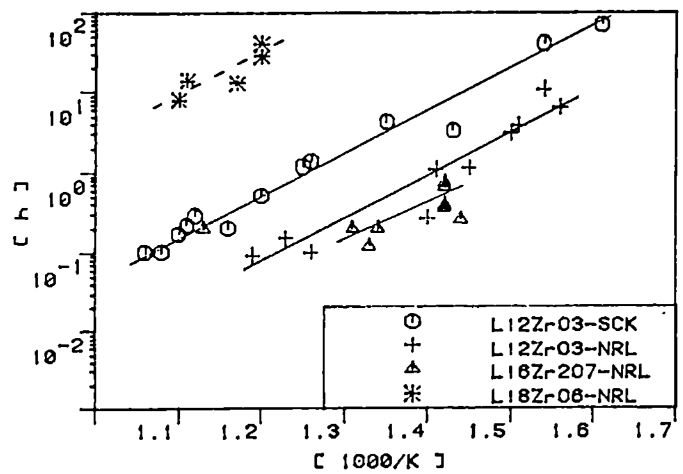


Fig. 35 Arrhenius plot of tritium residence times, t, in minutes

E224 LIBRETTO.
Irradiation of Liquid Breeder Material Pb-17Li

Objective: The purpose of this experiment is the in-pile testing of the eutectic alloy Pb-17Li, a candidate liquid breeder material for NET, in a thermal neutron spectrum to assess tritium release kinetics, tritium extraction methods, material properties, compatibility studies and tritium permeation through reference stainless steel cladding with and without permeation barriers.
The LIBRETTO experiments should provide the designers of the NET thermo-nuclear fusion reactor with liquid blanket breeder relevant data on the above mentioned issues.
The LIBRETTO experiments are being carried out as a joint project by JRC Ispra, JRC Petten and CEA Saclay.
The test programme consists of four irradiations with static alloy in the current programme **(Table 20).**

Progress and Results

E224-01/02/03/04 LIBRETTO 1

The first LIBRETTO experiment was terminated in 1988 with cycle 88.01.
Results were presented at the 15th SOFT conference in Utrecht and at the 30th EWGIT conference in Mol, both in September 1988 /12,13/.
The irradiation of the LIBRETTO 1 experiment was performed in a peripheral in-core position of the HFR Petten during 69 full power days.

The relevant process parameters of each capsule were scanned by a computerized data logger.
The capsule surrounding containments of the closed capsules and the plenum swept capsule were continuously purged by purified helium, doped by 0.1 vol % hydrogen.
The downstream gas was analysed and the tritium activity was quantitatively measured by calibrated ionization chambers.
Temperature transients in the temperature range 600 K-680 K were performed to study tritium release kinetics from closed capsules.
The main irradiation parameters are give in **Table 24.**

The irradiation results for the closed capsules are:
- as expected for each temperature increase or decrease a positive or negative tritium release peak was observed; see **Figs. 36 and 37.**
- characteristic in-pile residence times, τ, were calculated by:
  $\tau = I/G$
  where: I is the tritium inventory in the capsule;
  G is the tritium production rate.

The residence times determined for the different temperatures are given in **Table 25** and plotted in an Arrhenius-plot in **Fig. 38.**

The irradiation results for the plenum swept capsules are:
- the extraction of tritium plenum sweeping took place after alloy melting, and increased up to 47% of the production rate,
- considering the unfavourable geometrical conditions (ratio gas-liquid interface to permeation areas of only 4%) the extraction method is revealed to be relatively efficient,
- rather big spikes in the sweeping tritium release signal were continuously observed; see **Fig. 39.** The reason is most probably due to helium and tritium rising gas bubbles,
- due to alloy sputtering onto the purge gas tube the blockage of the sweeping minitube occurred after 18 days of operation.

The post-irradiation programme was carried out in 1988. The programme consisted of:
- X-ray and neutron-radiography, to visualize the alloy distribution in the capsule plenum
- dosimetry, to confirm the calculated nuclear characteristics
- puncturing, to determine the quantity and the composition of the plenum gas
- scanning electron miscroscopy of alloy and cladding samples
- tritium retention measurements of alloy and cladding samples
- metallography of cladding/alloy samples to examine surface interactions (in progress)
- polonium concentration measurements of alloy samples.

The results are :
- dosimetry and gamma-scanning results were in good agreement with pre-irradiation calculations
- plenum puncturing and plenum gas analysis indicated that ≃ 50% of the produced helium was released. The remaining amount was retained in the alloy. The quantity of tritium in the plenum gas was negligible
- SEM analysis confirmed the retention of helium in the form of up to 1 mm diameter gas bubbles **(Fig. 40)**

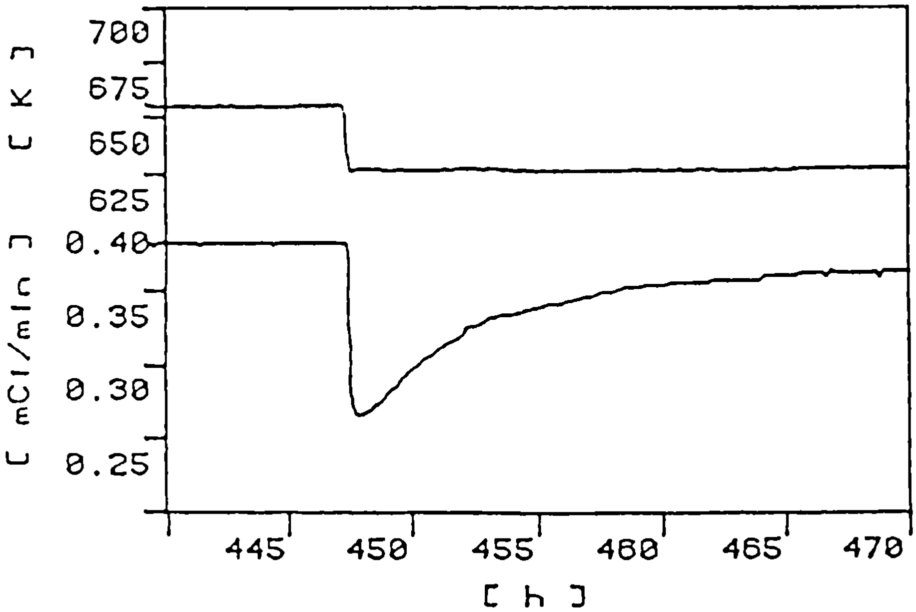


Fig. 36 E224-02. Example of tritium release and temperatures vs. time

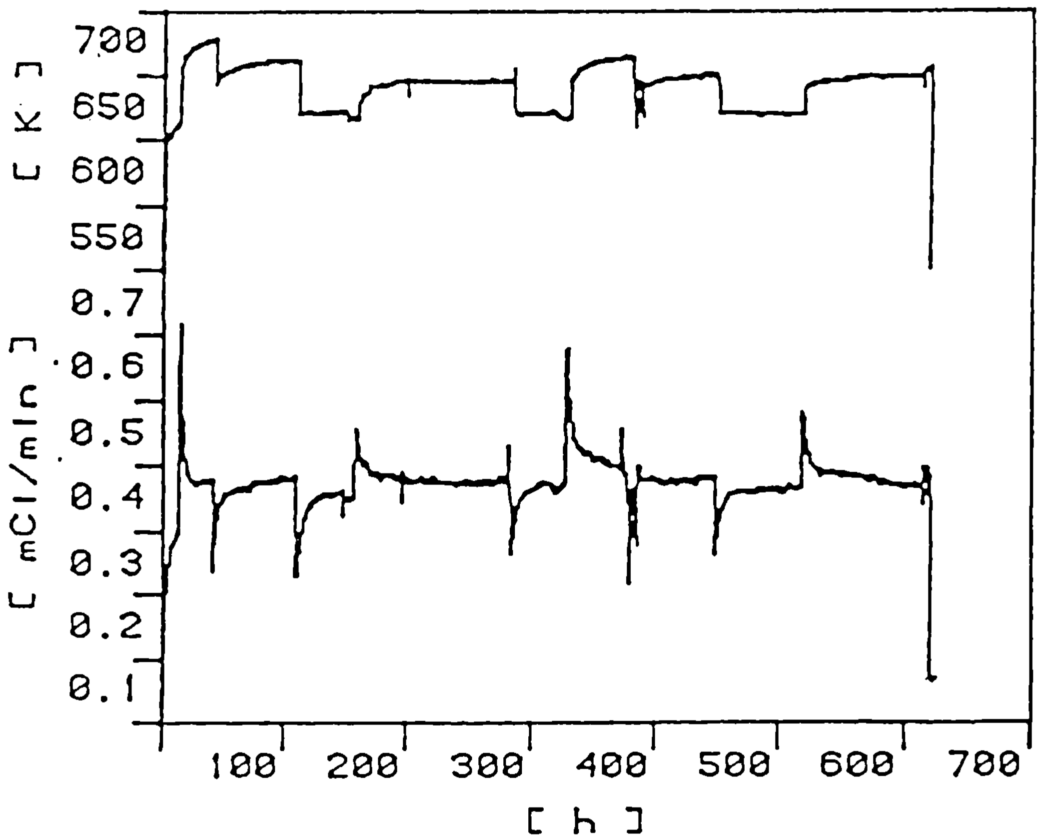


Fig. 37 E224-01/02. Tritium release and temperature vs. time of capsule 2 during the last cycle

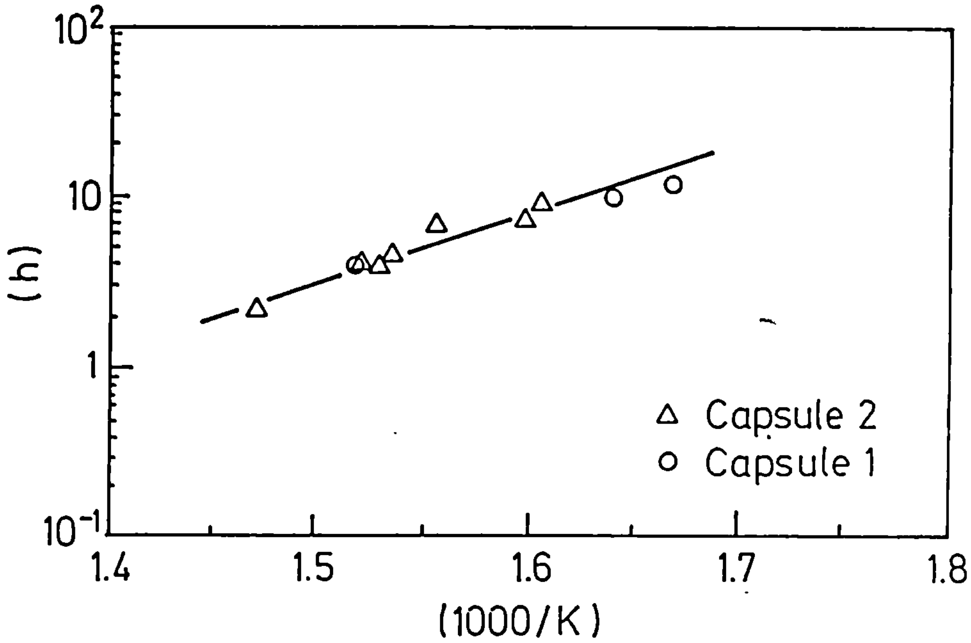


Fig. 38 E 224-01/02. Arrhenius plot of residence times in hours

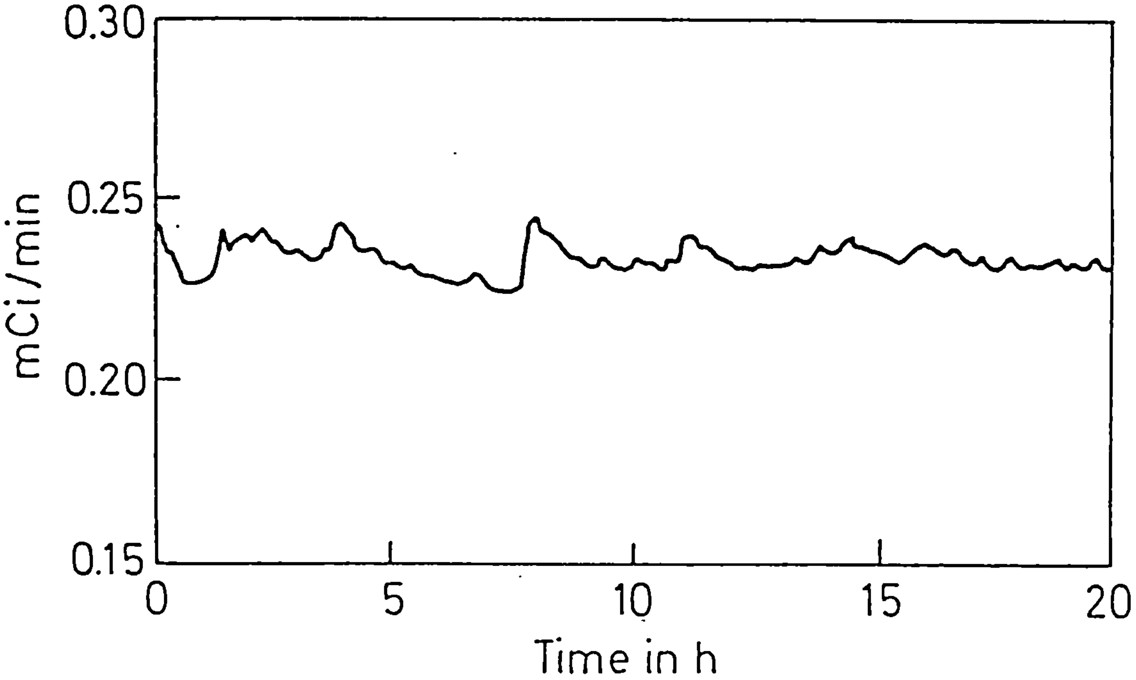


Fig. 39 E224-03. Steady state tritium release of swept capsule 3 showing the effect of rising gas bubbles on tritium release

Table 24 E224-01/03. Irradiation parameters of LIBRETTO 1

Capsule no.	1	2	3
Closed	x	x	
Sweeping			x
Irradiation time (days)	69	69	69
Temperature range (K)	560/680	560/680	560/680
Temperature gradient radial/axial (K)	21/15	21/15	21/15
T-release rate (uCi/(min g))	3.45	3.70	3.58
Burnup (% Li)	1.07	1.14	1.12

Table 25 E224-01/02. Measured tritium residence times

Temperature [K]	Capsule no.	Time [h]
600	1	~12
610	1	~10
623	2	9.0
626	2	7.3
643	2	6.8
652	2	4,6
655	2	3.9
658	2	4.2
659	1	~ 4.0
680	2	2.2

Table 26 E224-05/08. Loading scheme of LIBRETTO 2

Capsule no.	05 closed	06 closed	07 closed	08 closed
Cladding	alpha-Fe	AISI316L	AISI316L	AISI316L
Tritium barrier	no	no	no	no
Material	Pb-17Li	Pb-17Li	Pb-17Li	Pb-17Li
Li-6 enrichment, %	7.5	7.5	7.5	7.5
Specimen volume, cm^3	4	4	4	4
Temperature, ^0C	300/400	300/400	300/400	300/400

- metallography of radial/axial capsule cross sections confirm the gas bubbles formation **(Fig. 41)**
- micro-sonde analysis showed the existence of cladding-alloy local interaction layers of up to 8-12 μm
- tritium retention measurements confirm the low capability of Pb-17Li to confine tritium. The retention was < 0.05% of the produced tritium
- alloy sputtering, observed in the plenum swept capsules, was confirmed by neutron-radiography and X-ray analysis
- the measured ^{210}Po activity of alloy samples was > 30 Bq/g. This result was in agreement with pre-irradiation calculations.

E224-05/06/07/08 LIBRETTO 2

The design and the manufacture of the LIBRETTO 2 experiment started in 1988. Irradiation start is planned for the beginning of 1989. CEA will participate in this experiment with one capsule **(Table 26).**

D237-01 ELIMA.
Irradiation of Ceramic Lithium Compounds Under a Fast Neutron Spectrum

Objective: In the frame of the development of ceramic blanket tritium breeding materials for thermo-nuclear fusion reactors within the European Fusion Technology Programme, KfK has set up comparative irradiations in thermal and fast neutron spectra. This programme should clarify irradiation damage caused by spectrum effects, i.e. fast neutrons and tritium- and alpha-recoil particles.
The thermal spectrum irradiation will be performed in the OSIRIS material testing reactor. The fast spectrum irradiation, originally planned for the KNK-II reactor, will be performed in the HFR Petten. Therefore the specimen materials will be surrounded by a cadmium screen in order to absorb the thermal neutrons.
The test materials, ceramic lithium compounds as Li_2O, $LiAlO_2$, Li_2SiO_3, Li_4SiO_4 and Li_2ZrO_3, originate from different European partners of the NET co-operation programme.

Progress: The assembly of the sample holder was completed in 1988. The irradiation was started as planned in cycle 88.04. The specified irradiation parameters were achieved. The irradiation was terminated as scheduled after seven reactor cycles on 5th January, 1989.
In 1988, the design and safety report /14/ and the

Fig. 40 E224-01. SEM image of alloy and cladding (20x)

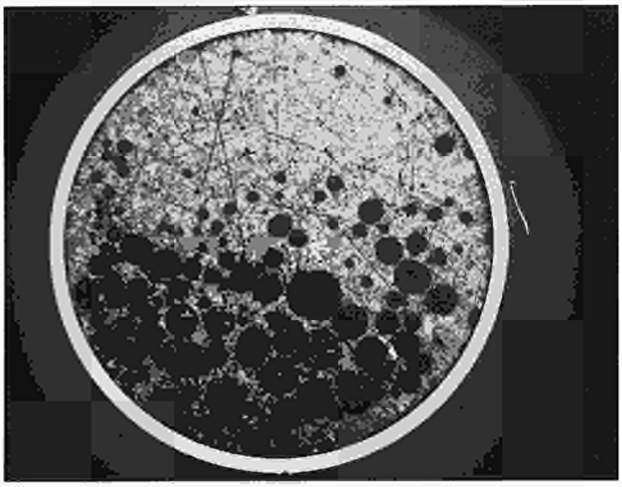


Fig. 41 E224-01. Longitudinal metallography of the lower part of capsule 1

operation manual /15/ were issued. The irradiation results are compiled in **Tables 27 and 28** and in /16/. The post-irradiation examinations at Petten, including neutron-radiography, X-ray analysis, gamma scanning, dosimetry and preparation of sample rods for transport to KfK is planned for the first half of 1989.

o Irradiation of Ceramic First Wall and Insulators Material

D217 CERAM

Legs 11, 12 and 13

Objective: In the frame of the European Fusion Reac-

Table 27 D237-01. Sample rod temperatures per cycle and irradiation period

Cycle	Temperatures in Deg. C			
	Level 1	Level 2	Level 3	Level 4
88.04	452	466	630	663
88.05	453	472	631	670
88.06	445	464	628	683
88.07	472	485	640	692
88.08	462	483	643	692
88.09	474	477	644	698
88.10	452	473	640	695
88.11	452	474	640	696
averaged	458	474	637	686
required	425+-50	425+-50	675+-50	675+-50

Table 28 D237-01. Preliminary neutron fluence data

	Neutron fluence in 10^{25} m^{-2}				
Energy range	Ø1	Ø2	Ø3	Ø4	E > 0.1 MeV
position averaged	0.61	1.37	1.75	0.53	1.92
position max.	0.87	1.72	2.20	0.66	2.42
Level 1 & 4	0.67	1.36	1.70	0.05	1.93
Level 2 & 3	0.80	1.66	2.02	0.06	2.30

Ø1 : > 1.353 MeV
Ø2 : 67.4 keV – 1.353 MeV
Ø3 : 0.683 eV – 67.4 keV
Ø4 : 0 – 0.683 eV

tor Materials Research Programme (MAT 6/MAT 13), different ceramics are investigated as candidate materials for the first wall protection of NET.
The experiment is part of a joint programme including CEA Saclay and KfK Karlsruhe. Two other experiments are performed in OSIRIS (Saclay) and PHENIX (Marcoule).

The damage level required is 10 dpa, which corresponds to a nominal fluence level of 10^{26} m^{-2}, $E > 0.1$ MeV. The nominal fluence is expected at the peak flux position in the experiment with a peak to average ratio of about 1.2 over a height of 400 mm.

The irradiation temperatures are nominally 1473 K and 673 K.

Progress: The experiment consists of three sample holders in a TRIO arrangement in one reactor position. Two 1473 K holders house specimens for MAT 6, and the third one, (673 K) houses specimens, for MAT 13.
The specimens for the low temperature leg consist of Al_2O_3-EK, Al_2O_3, AlN and MgO from AERE Harwell, CEA Saclay, KfK Karlsruhe and CIEMAT Madrid. For the two high temperature legs the samples are SiC-HIP, SiC-CVP and SiC(AlN) from CEA, KFA and KfK (see Figs. 50 and 51 of PPR 1987 – EUR 11645).

The irradiation of the experiment started in July, 1986 and finished in November, 1987. The total accumulated fluence is 1.65 x 10^{26} m^{-2}, ($E > 0.1$ MeV) i.e. within the requested limit. The temperature distribution in the specimens during the whole irradiation period was also within the requirements.

The capsules were dismantled in July, 1988 and the specimens will be transported to KfK Karlsruhe, CEA Saclay, CIEMAT Madrid and AERE Harwell at the beginning of 1989.

Legs 14, 15 and 16

Objective: This experiment is part of a joint CEA Saclay, KfK and KFA programme. The aim of the experiment is to select materials satisfying the phase 1 requirement of NET. The irradiation temperature is 1773 K (1500^{0}C) and the target dose 3 dpa. The materials are different types of SiC and carbonite materials (2 irradiations with woven graphite fibers, 2 irradiations with random graphite fibers).

Progress: The specimens from KfK and CEA Saclay will be irradiated in the TRIO-131 legs whereas due to the large KFA specimen diameter, the irradiation will take place in a REFA-170. Assembly of leg 14 has been finished in November, 1988 and irradiation of this leg has been scheduled for cycle 89.01.

D225 CEFIR

Objective: CEFIR is a contribution of KFA Jülich to the NET fusion programme and concerns an irradiation of several ceramic materials at three temperatures (673 K, 873 K, 1073 K). The experiment has been irradiated in two HFR positions: C7 (5 1/2 cycles) and G5 (7 cycles).

The initially planned dose for this experiment was 10 dpa (graphite) which meant an irradiation of about 18 cycles, from 87.05 to 88.11. However, a decision to stop the irradiation at the end of cycle 88.06, at about 6 dpa was taken. The main reason for this interruption was that it was no longer possible to control the temperature of the experiment, because most of the thermocouples in two of the three rigs (D225-01 and 02) were defective. In addition, the vertical displacement unit of rig D225-03 was blocked. Hence the temperature profile of this rig could not be controlled.

Distmantling of the three sample holders had to be done in the LSO; the samples will be transported to Jülich during the first weeks of 1989.

The irradiation report has been written and is being printed /17/. A possible continuation of CEFIR has not yet been decided.

o First Wall Coating Graphite Irradiations

D241 GRIPS

Objective: The aim of this new experiment (GRIPS stands for GRaphite Irradiation in Pool Side facility) is to investigate the irradiation behaviour, in particular the reduction in thermal conductivity, of several types of nuclear graphite, which are potential candidates for the first wall protection and other applications in NET. This experiment is part of a research programme carried out by KFA Jülich, in support of and in collaboration with the materials experts of the NET Team at Garching.

Progress: When the GRIPS experiment was first proposed /18/, the irradiation specifications were

as follows:
- five irradiations with neutron fluences (E > 0.1 MeV) ranging from 10^{16} to 10^{20} cm^{-2}
- temperature of 1073 K (800°C) for all irradiation steps
- a total of 32 cylindrical samples to be irradiated in each experiment; the dimensions were 6 mm diameter x 32 mm, and 6 mm diameter x 25 mm.

Because the low fluence irradiation steps lead to a very short irradiation duration, well below the duration of a normal HFR cycle, a new falicity had to be developed for the irradiation of GRIPS in the Pool Side Facility of the reactor instead of the core positions, where unloading of an experiment during the cycle is normally not possible.

The short duration of some of the irradiation steps leads to another difficulty : the impossibility of reaching the required sample temperature by absorption of gamma rays only; the heating-up time would, in this case, be too long compared with the irradiation time. It was therefore decided to provide a system of electric heaters, capable of bringing the rig to the specified temperature before the irradiation start.

The design work on the device began in May, 1988 and, by the end of July, the drawings were ready and the Design and Safety Report was written, in draft form. However, before the fabrication could start, the sponsors of the experiment made significant changes to the specifications : instead of 5 fluence steps at one temperature, 1073 K (800°C), the same 5 fluence steps should in addition be performed at 1473 K (1200°C) and at 673 K (400°C).
Thus, the initial design had to be completely reconsidered, both from the point of view of the materials used for the sample holder and of the electric heating system. It was obvious that a sample holder design capable of reaching 1473 K (1200°C) would easily cover the two lower temperatures.

The ongoing work for GRIPS was therefore, stopped, and a market inquiry was launched in order to find an electric heating system corresponding to the requirements of the 1473 K (1200°C) GRIPS. After several months of intense market research, no suitable heater system was found.

The following agreement was made, with the sponsor: the original GRIPS design will be built, and used to irradiate 5 fluence steps at 1073 K (800°C) and 673 K (400°C). At the same time, R & D work will be continued to find a solution, possibly quite different from the above, for the 1473 K (1200°C) rig.

The actual time schedule foresees the irradiation of D241-00 (a dummy prototype) in cycle 89.05, followed by D241-01 to -10 in cycle 89.06 and/or 89.07.

References to paragr. 2.2.3.4.

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AKTINES: Project R139-64. Steel Irradiation in an Enhanced Neutron Arrangement
Design and Safety report HFR/86/2318
/2/ Fraipont, P. and Scheurer, H.
E198-14 SIENA, 5 dpa Irradiation, Final Report
Technical Note P/F1/88/... (being printed)
/3/ Hausen, H., Schüle, W. and Cundy, M.R.
"Neutron Irradiation Creep Experiments on Austenitic Stainless Steel Alloys"
15th Symposium on Fusion Technology (SOFT), Utrecht, September, 1988
/4/ Neutron Metrology in the HFR E167-11 TRIESTE
ECN-Report 86-79
/5/ Neutron Metrology in the HFR E167-14 TRIESTE
ECN-Report 88-31
/6/ Neutron Metrology in the HFR E167-26 TRIESTE
ECN-Report 88-39
/7/ Neutron Metrology in the HFR E167-33 TRIESTE
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/8/ Küpfer, H., Wiech, U., Apfelstedt, I., Flükiger, R., Meier-Hirmer, R., Wolf, T. and Scheurer, H.
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/10/ Conrad, R.
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/11/ Kwast, H., Conrad, R., Debarberis, L., Kennedy, P., Filpot, A.J. and Elen, J.D.
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"Irradiation experiments on solid and liquid tritium breeder materials for thermo-nuclear fusion reactors in the HFR Petten"
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"In-pile tritium release from liquid breeder material Pb-17Li in LIBRETTO I experiment"
15th SOFT, 19-23 September, 1988, Utrecht

/14/ Conrad, R. and Debarberis, L.
"Design and Safety Report ELIMA D237-01"
Technical Note P/F1/88/5, June, 1988

/15/ Conrad, R.
Manual ELIMA 02
Technical Memorandum HFR/88, April, 1988

/16/ Conrad, R. and Debarberis, L.
Interim Progress Report of Irradiation Experiment ELIMA 02
Technical Memorandum HFR/89/2489, January, 1989

/17/ Scheurer, H.
CEFIR D225-01/02/03; Abschlussbericht
Technical Note P/F1/88/17, Petten, October, 1988

/18/ Scheurer, H.
GRIPS : GRaphite Irradiation in Pool Side facility, Project D241
Irradiation Proposal, HFR/88/2431, Petten, April, 1988

2.2.3.5. Radionuclide Production

ER136 In-Core-FIT. Irradiation of Fissile Targets

Objective: The objective of this irradiation is the recovery of Mo-99 from the irradiated fissile targets for the manufacture of Tc-99m generators with high specific activities, and the production of Xe-133 and I-131. Tc-99m ($t_{1/2}$ = 6 hrs) is an important tracer radioisotope because of its multiple applications for the in-vivo tracing of the organism.

Progress : During the reporting period, the irradiation of the fissile targets continued routinely. In total 300 targets (in 1987 : 224) were irradiated and transported in special containers to the reprocessing plant in Belgium. Each target contains 4 g ^{235}U, 93% enriched. The targets are in the form of tubes, which contain a fissile matrix in an aluminium cladding.

ER197 COBI/ER203 CORRI. Irradiation of Cobalt

Objective: Irradiation of cobalt for use in a sterilization plant. Two COBI facilities with 120 cobalt strips each, and two CORRI facilities with 48 cobalt strips each are available for this type of irradiation. Requested specific cobalt activity is normally 1500-3000 GBq (40-80 Ci) per gram. After unloading the activated strips are sent to the customer.

Progress: The production of Co-60 by irradiation of Co-59 in free core and reflector positions was continued. A facility for 120 cobalt strips, ER197 COBI and a facility for 48 strips, ER203 CORRI, reached activities of 89 and 82 kCi/kg respectively, the first after cycle 88.06, the second after cycle 88.03.
The facilities have been unloaded in the DM cell. The 168 cobalt strips contained a total activity of about 100.000 curies.
From cycle 88.07 the irradiation of a COBI-facility, which was already irradiated during a few cyles, was continued and in cycle 88.09 the irradiation of a new facility has been started. In cycle 88.07 the irradiation of a new CORRI-facility has also been started.

o General Radionuclide Production

Various irradiations of different materials have been performed for INZINTA (Isotope Trading Enterprise, Budapest) and the isotopes produced shipped to Budapest. In addition, several irradiations have been carried out for different European universities.

o Activation Analysis Irradiation

The contacts established in the past with British universities have led to successful routine irradiations devoted to the age determination of various kinds of minerals.

A series of irradiations, carried out for the JRC Ispra, were concerned with the examination of human and animal tissues, and other biological materials.

o Change of Properties in Minerals

Short-time irradiations have been performed on a large scale for a private company.

o Standard Radionuclide Production Facilities

In the second cycle a new HF-PIF came into use, which was fabricated because of damage to the previous one. At the end of the year a design was started for a facility, in which all the standard capsules can be irradiated. The capsules will be stacked in a holder, which can be placed easily in a thimble. Forced cooling is planned. When the facility is ready, it will replace the RIF facility. There is also a plan for a similar facility in the East side PSF.
The RIF ER90 has been irradiated for short periods during 6 cycles.

2.2.3.6. Nuclear Physics

o Renewal of Shielding for Beam Tubes HB11/12

New neutron and gamma shielding has been installed together with a new shutter for HB11, and modifications on existing shutters have been executed. The present set up is shown in **Fig 42.**

o Neutron Capture Therapy

Within the frame of a feasibility study for a "European filtered beam facility" the nuclear physics group contributed their experience of many decades in neutron beam research, in a study of the following subjects:

- neutron spectrum and the gamma background at filtered beams
- measurement of flux densities of epithermal neutrons
- investigation of the possibility to install other filters
- a survey of charged particles suitable for therapy
- selection of filters for therapy.

o Nuclear Physics Activities at the HFR

Exchange of mesons between the neutrons and protons holds the nuclei together. Contributions of the electrical currents of these mesons to the magnetic field and therefore to the electromagnetic radiation from the nucleus are not averaged out to zero. A set of measurements on the reaction D(n, γ) showed that the mesonic exchange currents almost triple the cross section for radiative capture in the lowest of the two spin channels. For this purpose use was made of cryogenically polarized deuterium nuclei and of polarized neutron beams (HB2 and HB7).

Emission of photons from capture of neutrons in ^{3}He is relevant to the solar neutrino problem as well as to the meson exchange current, and the cross section for this reaction has been measured using the new beam tubes HB11/12. In contrast with most other reactions, ^{3}He(n,γ) seems to run for a large fraction (about 30%) through the double photon emission process, which makes this reaction very suitable to study double photon emission in general and the states of ^{4}He in particular.

2.2.3.7. Solid State Physics

The Solid State Physics group of ECN utilizes at the HFR, 5 neutron spectrometers for carrying out both fundamental and applied research in Solid State Physics and Materials Science. The techniques used are: neutron diffraction for the determination of the crystallographic and magnetic structure of both powdered and mono-crystallographic specimens; diffuse scattering for the determination of chemical short range order and magnetic correlations; inelastic scattering for investigation of phonons, magnons and crystal-field excitations; and, very recently, small-angle neutron scattering for research into a large variety of disperse systems (pores, precipitates, gas bubbles, voids, colloids, polymers, etc, embedded in a homogeneous matrix material).

In the period under review, much effort has been put into studies on high-Tc superconductors (role of oxygen atoms), on heavy fermion systems, which show peculiar behaviour with respect to specific heat, magnetic correlations and superconductivity at low temperatures and on structure determination of compound forming liquid alloys. In addition, considerable effort has been made to develop new equipment.

It is ECN policy to direct the application of neutron beams more towards materials characterization. In view of this, a conventional powder diffractometer has been modified for use in the investigation of residual stresses in different kinds of construction materials. With this neutron scattering technique, ECN has become a partner in a BRITE-contract to study micro-structural properties with different non-destructive testing methods. The completion of a new facility for small-angle neutron scattering (SANS) at HB3 is another important achievement. For this purpose, beam hole HB3 had to be modified in order to extract a twin-beam, to serve two spectrometers. **Fig. 43** gives a schematic drawing of the SANS-facility. It employs 2 coupled sets of 6 monochromator crystals for producing a monochromatic beam. A two-dimensional area sensitive detector at a maximum distance of 4 m from the sample, detects the scattered radiation. The subsequent data is stored and analysed by means of a multi-channel analyser and a micro-Vax computer.

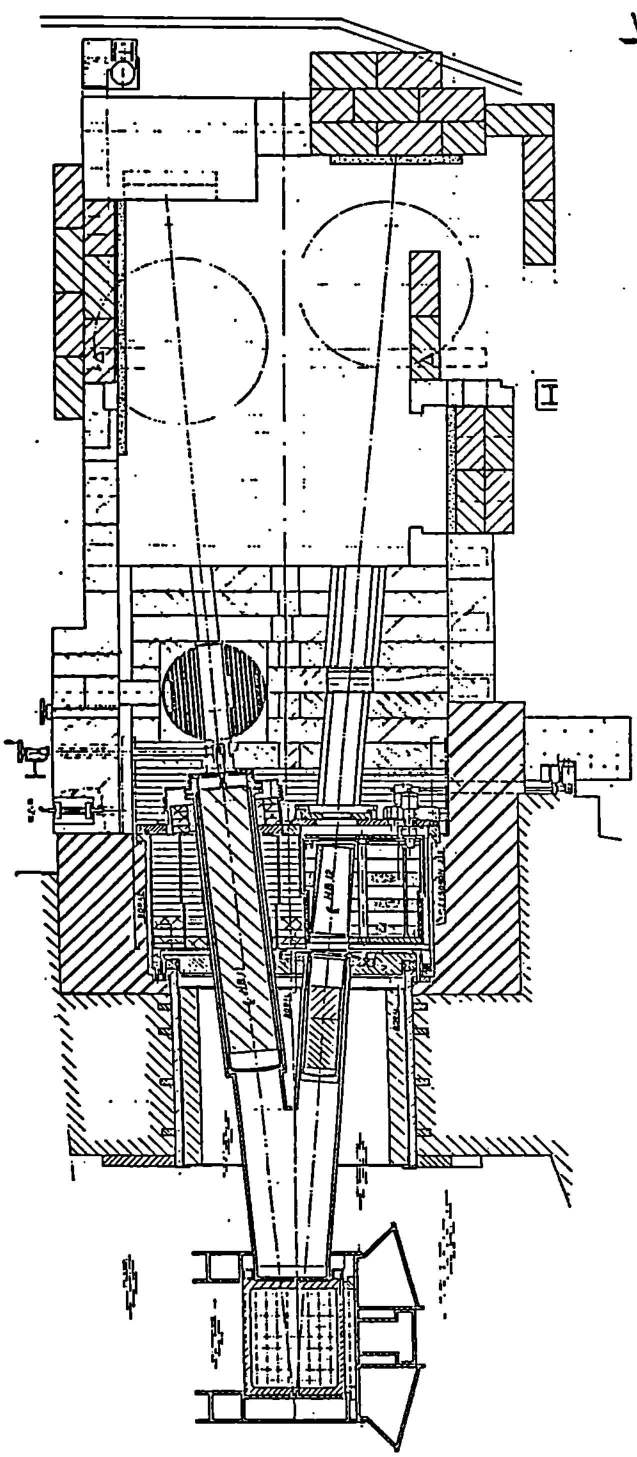

Fig. 42 Renewed shielding for the beam tubes HB 11/12

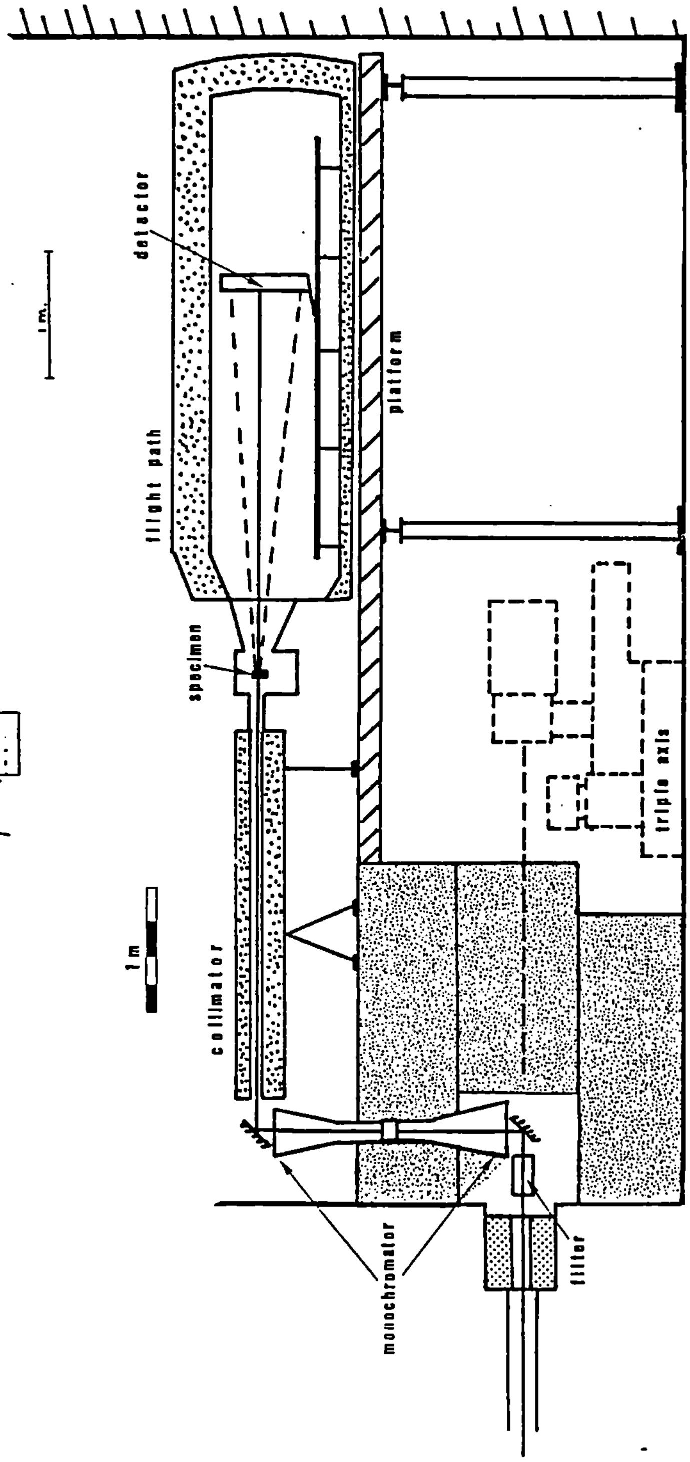

Fig. 43 HB 3. Schematic drawing of SANS facility

2.2.3.8. Miscellaneous

ER220 SIP (Project 0008.22).
Irradiation Facility for Silicon Characterization

Objective: the SIP Facility has been designed for the activation and subsequent analysis of industrial silicon samples with regard to impurities. The facility allows the irradiation of 5 to 30 stacked silicium-discs (4″ or 6″ diameter, 0.5 mm thick) packed into a quartz glass container. This container is placed in a reloadable irradiation canister which rotates during irradiation in order to provide maximum neutron fluence rate flattening. The irradiation is carried out in PSF position 2.

Progress: On March 31, 1988 a new irradiation rack was put into use. From this date until the end of the year, 24 containers (14 of 4″ and 10 of 6″ diameter) filled with silicon discs have been irradiated. The total irradiation time amounts 1716 hours. Since the start of the irradiation for this project (May 1985), 91 irradiations have been carried out with a total irradiation time of 6453 hours.

R229 BISAR BF_3 Irradiation.(Project 0625)

Objective: Investigation of radiolysis in boron trifluoride gas in a strong gamma radiation field at high pressure and temperature (request from CEA, Saclay).
An irradiation device has been developed and fabricated by ECN. If radiolysis in BF_3-gas occurs, the pressure inside the sample holder will increase and solid B will deposit on the gas containment, according to the reaction mechanism:
$2\,BF_3 + E\gamma \rightarrow 2\,B\downarrow + 3\,F_2$

Three sample holders have been simultaneously irradiated in the High Flux Reactor. Initial BF_3 pressure in the containments was 0.5, 2.0 and 4.0 MPa respectively. Central gas temperature in all sample holders was 573 K (300^{0}C). To observe the changes in BF_3-pressure during irradiation, each sample holder has been supplied with a pressure transducer which gives a continuous pressure registration.
To avoid a high thermal neutron fluence rate in combination with a high gamma radiation field, the irradiation has been performed in a cadmium shielded TRIO-capsule (TRIOX-Sp03). TRIOX is a trefoil thimble arrangement with three separate shielded channels, each with a diameter of 24 mm.

The final report on the results of the BF_3 irradiation has been prepared /1/.
From the pressure histories it can be concluded that no pressure increase due to radiolysis of the BF_3-gas has been observed.
In conclusion, the R229 irradiation has been successful and operational requirements were met in the three sample holders.

R233 SIDO (Project 3266)

Objective: Development, design, manufacture and characterization of a prototype facility for the "doping" of industrial silicon crystals. The facility consists of a driving unit with a sample holder rotating inside an insert tube. The crystal, mounted in an open holder, will be placed in the insert-tube by means of a chain which is connected to the removable part of the driving gear. The dimensions of the crystals to be irradiated are limited to a diameter of 103 mm and a length of 500 mm. The vertical fluence rate distribution will be flattened by a neutron absorber screen positioned outside the insert tube. To enable fluence monitoring three collectrons (self-powered neutron detectors) are fitted. The facility will be positioned in the south-west PROF hole.

Progress: The prototype has been manufactured. A trial mounting into the dummy reactor vessel has taken place followed by a test period.
Some necessary modifications are in progress. The instruction manual has been written. Te facility will be mounted into the reactor in January 1989 for characterization. The first irradiation will be a mock-up with several fluence rate detectors. This irradiation is planned for cycle 89.01

D239 IDA (former name : ROSI).
Irradiation Facility for Silicon Characterization.

Activation analysis will be applied as a QA tool in the field of silicon semiconductor materials. For detection of some impurities (e.g. metal) an irradiation device providing a higher fast neutron fluence rate than available in the SIP (ER220) is required.

Therefore, a study has been made for a rig for fast neutron activation analysis of rectangular Si-discs from the semiconductor industry. The Irradiation Device for fast neutron Activation (IDA) can be accomodated in every PSF position. It is designed to be used in front of other PSF experiments (e.g. CH 240).

A decision on the utilization of the new facility by the MEGA-chip project was still pending at the end of 1988.

CH240. Minerals Irradiations

Objective: The purpose of the irradiation is to induce physical property changes in the material without activation.

Progress: A series of small scale test irradiations have been performed on naturally occuring minerals with a view to establishing base parameters. Eleven irradiations have been completed with encouraging results.

R244 HEISA. Irradiation of Rock Salt.

Objective: As part of the investigation into the storage of nuclear waste in salt domes, the influence of gamma radiation on salt has to be examined. Gamma radiation causes the desintegration of sodium and chlorine elements from the salt NaCl with a release of some energy. The irradiation of salt samples under high pressures (200 bar) will be performed between spent fuel elements in the storage basin, GIF.

Progress: A special holder for 4 or 8 pressurized samples will be designed. In the meantime irradiations of salt samples without pressure are performed in a modified GIF container.

An electrical heater is wound round the sample and the temperature is measured with a thermocouple. The irradiation temperature is 373 K (100°C). During the first days of the irradiation between fresh spent fuel elements, the temperature reached a value of 301 K (128°C), caused by gamma heating. In the final design this relatively high heating has to be taken in account.

Project 0308. Source Term Research KEMA

Objective: Irradiation of single special UO_2 fuel spheres for the experimental determination of fission products release characteristics, carried out by KEMA. The irradiations take place in a small uninstrumented capsule (type Saclay) containing two fuelled sub-capsules, each loaded with one fuel particle.

Progress: Several capsules have been irradiated in the reloadable isotope facilities (RIF and HF-PIF). After the irradiation of two spheres (diameter 1 mm, enrichment 8%) with zircaloy cladding, the irradiations for this project will be finished.
In the framework of the research project, KEMA has the intention to start a new project called the Sourcier programme. For this programme small fuel rods have to be developed, fabricated and irradiated under PWR conditions. A feasibility study has started.

Reference to paragr. 2.2.3.8.

/1/ Visser, J.F.J. and Wijtsma, F.J.
"Project 0625. Irradiation of BF_3 in a cadmium shielding, using a TRIOX facility. In-pile performance of R229".
Report ECN-88-077 (ECN, Petten, April 1988)

2.3. GENERAL ACTIVITIES

2.3.1. Objectives

The chapter "General Activities" concerns either services supporting a number of projects or investments and work intended to keep equipment and competence at the required level. The general activities within the HFR project include:
- operation and maintenance of ancillary services and laboratories (e.g. workshops, hot laboratories, general purposes control equipment, computing facilities)
- design studies and development of new irradiation devices
- irradiation technology and other research
- programme management

i.e. support work not directly linked to a specific irra diation experiment. About 8% of the annual HFR budget and 35% of the scientific and technical JRC staff capacity are normally allocated to general activities.

2.3.2. Methods

A total of 15 to 20 general activities are defined for each year, and man-power and budget are allocated. In the current year the following activities were undertaken:

a) Operation and maintenance
  - testing and commissioning
  - in-pile experiment operation
  - data acquisition and computing facilities
  - neutron radiography
  - post-irradiation examinations, hot cells
  - assembly, workshops.

b) Design studies and developments
  - standard irradiation devices
  - in-pile instrumentation, feasibility studies
  - fusion material test facility development
  - LWR irradiation facilities
  - out-of-pile systems.

c) Irradiation technology and other research
  - reactor upgrading, in particular: primary heat exchanger upgrading and studies on possible reactor power increase to 60 MW
  - new control room equipment
  - reduced enrichment fuel studies.

d) Programme management
  - documentation and editing
  - CPM planning of irradiation experiments
  - reactor utilization management
  - working groups, conferences
  - ACPM meetings.

2.3.3. Results

2.3.3.1. Assembly Laboratories

Assembly work on irradiation devices was carried out as usual. The completion of the new assembly room has been further delayed.

2.3.3.2. Standard Irradiation Devices

The production of standard in-core capsules and heads is mainly done by an external supplier. The current situation is as follows:

delivered:	3 x TRIO 129	Nos. 40-42
	3 x QUATTRO 129	Nos. 4-9
	3 x TRIO-head	
	3 x QUATTRO-head	
new order:	3 x TRIESTE rig incl. carrier	Nos. 10-12
	2 x TRIESTE-head	Nos. 6-7
	1 x REFA 170-head	
	1 x REFA rig	No. 28

2.3.3.3. Quality Control

- o During the reporting period acceptance tests of the following have been performed **(Fig. 44)**:
  - 35 sample holders
  - 9 in-core capsules
  - 11 instrumentation heads
  - 3 PSF-supports
  - 12 BWFC capsules
  - 5 BWFC supports
- o The ECN sodium-filling station will be transferred to the HFR-division. The QC department will then operate both the sodium and NaK filling installations.
- o A new more powerful X-ray installation is now operational. The source is a metal-ceramic tube MCN 225 from Philips **(Fig. 45)**. It is an end grounded, double focus X-ray tube with a maximum capability of 225 KV/10 mA providing a penetration power of up to 55 mm in stainless

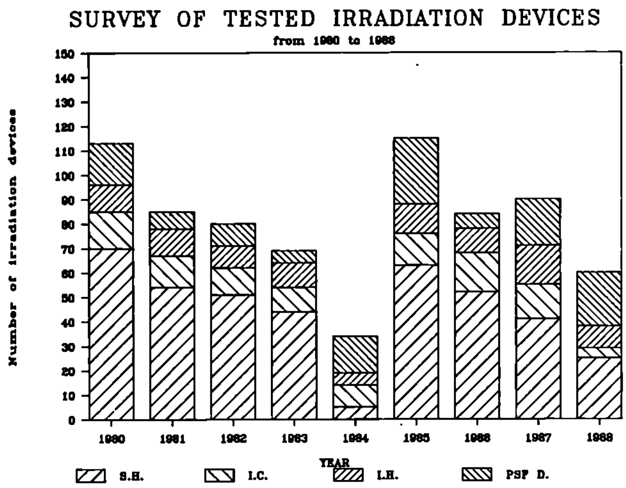

Fig. 44 Quality control. Survey of tested devices from 1980 to 1988

steel. The microprocessor-control unit guarantees a safe operation and enables storage of 100 preselected programmes concerning all exposure data e.g. KV, mA, time of exposure and focal spot.

2.3.3.4. Experiment Operation and Control Installations

A new data logger system for 2048 channels and a new control unit for 48 vertical displacement units became operational.

2.3.3.5. Hot Cells and Post-Irradiation Work

o Dismantling cell (DM cell)

In addition to normal maintenance and renewals, the cell team provided the following services:
- dismantling and reloading of 82 sample holders
- loading and transport of 13 waste drums (diameter 26 cm, length x 70 cm) on site
- 1 external fuel transport
- visual control of 33 Be-reflector elements and 27 Be-plugs
- general inspection of the "underwater saw"
- handling and transport of 66 fuel element end pieces to waste
- handling and transport of 18 control rod components.

o G5/G6 cells (LSO)

- renewal of 3 manipulators **(Fig. 46)**
- D85-50/54/57
  Loading of the TRIO sample holders with irradiated graphite samples from KFA Jülich.
- D138-04 BEST
  Design and construction of a measuring device for irradiated spherical HTR fuel elements (G6 cell). Packing and transport of the samples to KFA Jülich.
- D156-50/51/51A
  Distmantling and measuring of tensile sample sets after irradiation. Re-encapsulation and transport to the HFR for continuation of irradiation
- D206 ISOLDE
  Laboratory tests with the hot cell assembly device for fuel rod re-instrumentation were performed and the assembly device finalized for hot cell installation.
  Welding tests performed on dummy PWR and BWR fuel rods for the determination of optimized welding parameters for the hot cell procedure.
  Transition plug for the hot cell wall for passage of the control and command lines completed.
  Training of the hot cell re-instrumentation procedure started on a dummy hot cell arrangement.
- E167-42/50/43/16/27/51/60 TRIESTE
  Dimensional measurements of irradiated steel samples.

o EUROS. Remote Cell Encapsulation System

Plans to modify the EUROS cell to include dimensional measurements on irradiated steel samples were postponed due to discussion on new projects concerning pre-irradiated FBR fuel pins.

2.3.3.6. Neutron Radiography

o During the reporting period 62 neutron radiographs have been made of irradiated fuel pins and material samples with their associated irradiation capsules.

o Beam Tube Facility at HB8 (ER169)

The extension of the HB8-facility towards sub-thermal neutron radiography has been finished and the facility has been operational since April 1988.
A further extension of the HB8-facility into a dedicated neutron radiography laboratory outside the HFR containment building is under consideration.

o A market survey regarding the industrial applica-

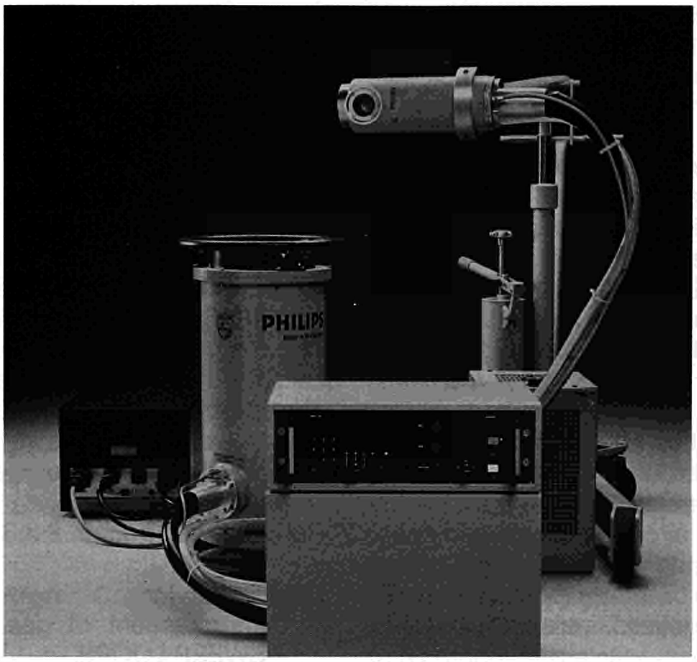

Fig. 45 Quality control. New x-ray installation

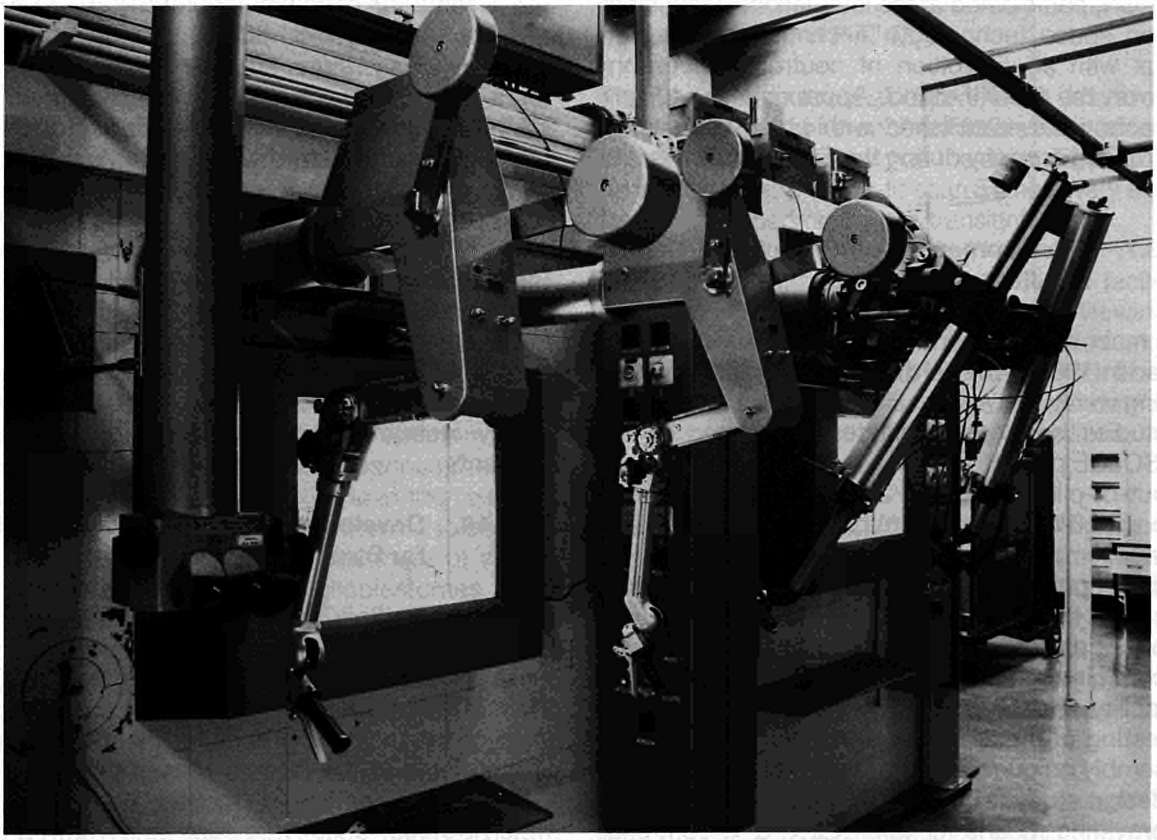

Fig. 46 Hot cells G5/G6 cells with two new manipulators (in front)

tion of thermal and sub-thermal neutron radiography was conducted and completed during 1988. Industrial and research institutes primarily in the Netherlands and Germany were contacted. The findings of the market survey are:

- there is a limited market for neutron radiography in the Netherlands and Germany
- further investigation into the aero-space industry, and the chemical and petro-chemical industry needs to be pursued
- further development of neutron radiography methodology should be pursued in support of industry and research.

o In a promotional action several potential industrial clients were invited to provide test samples for proof testing. Positive reactions came from the turbine blade industry (for aircraft engines) and space craft technology. The images taken for both groups were appreciated by the clients as a very high quality performance. Further negotiations are being pursued.

o At the beginning of December 1988 the Petten Neutron Radiography Service, a partnership of JRC and ECN, participated at the international technology fair on space technology "Technospace" at Bordeaux with an exhibition of neutron radiography work on the DG XII stand. Approximately 40 new contacts were established with potential users of neutron radiography during the Technospace exhibition.

2.3.3.7. Development of LWR Fuel Rod Testing Facilities

The main development activities pursued or continued in 1988 in the field of LWR fuel and materials testing were:

- studies and out-of-pile testing related to the ISOLDE project
- out-of-pile testing and 2DT modelling of the low power BWFC capsule (typical LWR fuel rod surface temperature, 150 W/cm upwards)
- development of the 2DT-BOIL code, an extension of the 2DT code with water, steam and two-phase data and related heat transfer modes
- commissioning of the fuel rod re-instrumentation facility and associated devices, out-of-hot cell testing of the facility and training of hot cell assembly on dummy rods
- design study for a BWFC-type irradiation device providing means for application of a controlled axial load to the test fuel rod during irradiation.

Some of the earlier mentioned development activities could not be pursued due to shortage of manpower (e.g. commissioning of the in-pile profilometry rig and the parallel displacement of PSF experiments).

2.3.3.8. Development of a Control System for Swept HTR Fuel Experiments

The up-grading of the gamma spectrometer and the gas chromatograph for the D214 experiment and the future D138 reference tests continued. All measuring sensors /1/, including the Ge(Li)detectors were calibrated as part of the quality control programme. The up-stream purge gas lines were equipped with a set of new filters, in order to decrease the impurity level of water, nitrogen, oxygen, etc. to < 0.5 ppm /2/.

References to paragr. 2.3.3.8.

/1/ Timke, Th.
Improvement of gas supply quality for the SWEEP LOOPS
HFR/88/2455, December 1988

/2/ Otterdijk, K.H.
Calibration of flowmeters for SWEEP LOOPS
Memorandum MH-88/25

2.3.3.9. Development of Irradiation Facilities for Fusion Blanket Materials

The up-grading of the existing Tritium Measuring Station (TMS) continued in 1988.
The up-grading included:

- installation of new tritium filters
- re-arrangement of the data transfer system
- re-arrangement of the pool wall penetration box
- new instrumentation for the D237-01 experiment
- new instrumentation for the R212-13/16 experiments.

2.3.3.10. Development of Irradiation Facilities for Structural Fusion Materials

Problem definition: The first wall of a fusion reactor is subjected to neutron irradiation, thermal and mechanical loads, surface erosion processes, and thermal fatigue load due to the cyclic mode of operation of the machine. Moreover the manufacturing process and/or the plasma disruptions will initiate surface cracks which will propagate in a material which is creep-fatigue damaged, and whose properties change as result of neutron irradiation. Environmental conditions will also play an important role in the crack propagation.

Objectives and description of the project: The major objective of the FAFNIR project is the measurement and the modelling of crack propagation in cyclic thermal gradient fields in a multi-axial stress state with and without simultaneous irradiation damage. The project output will extend the data base necessary for the design of the NET first wall to more realistic conditions, and in terms of materials science it will be helpful in improving the understanding of crack growth mechanisms under irradiation.

Progress: Little progress has been made with the project due to lack of manpower. Work has recently started (in the Materials Division of JRC Petten) on setting up the out-of-pile test.

2.3.3.11. Boron Neutron Capture Therapy (BNCT)

The topic and theory behind BNCT was briefly presented in the last PPR. BNCT is an alternative method to conventional radiotherapy and is currently arousing interest worldwide. An essential basic tool is a high flux epithermal beam, which can only be successfully delivered by a high flux materials testing reactor - hence the involvement of the HFR. The technique involves the injection of a boron-loaded compound into the blood system which is then deposited into the tumour. Exposure of the boron to slow (thermal) neutrons produces highly energetic fission products by neutron capture, particularly alpha particles, which because of their short range destroy the tumour cells and not the surrounding tissues.
During 1988, HFR staff participated at conferences in Bremen (Federal Republic of Germany) and Brookhaven (USA), and attended various meetings within Europe with relevant experts in the field. It is apparent that BNCT has a huge potential to become a very successful method for treatment of certain types of cancer, particularly, glioblastomas (brain tumours) and melanomas (skin cancer). The epithermal beam obviates the need for surgery, e.g. craniotomy, and has a greater penetration and better homogeneity in the tumour volume, i.e. irradiates the whole tumour. In addition, epithermal beams give relatively lower doses to the skin and brain than the thermal beams previously used. Through the initiative of HFR staff, and in co-operation with NCT experts from AERE Harwell and the University of Bremen on behalf of the European NCT community, a Concerted Action, has been started. This is a means of gaining substantial financial support from Brussels in order to fund meetings of European specialists for the exchanges of information on a medical project. In addition, a Petten BNCT group has been set up between JRC and ECN Petten, and the Nederlands Kanker Instituut in Amsterdam. This group has proposed a programme of work to realise a BNCT facility which will be the focus of the European activities. The first tasks, i.e. confirmation by metrology of the nuclear characteristics of the candidate beam tube (HB11) were completed at the end of the year.

2.3.3.12. DACOS. The General Data Acquisition and Processing System for HFR Experiments

During 1988, the general data acquisition system was substantially up-dated and installed to become fully operational in September 1988. The new system comprises mainly 4 fast scanning data-loggers, 512 channels each , manufactured by NEFF, a local area network ETHERNET, and a front-end system of 2 x PDP 11/73 mini-computers. A lay-out of the new system is shown in **Fig. 47.**

The new system scans all experimental data every 10 seconds, instead of every 2 minutes as in the previous system. The system now has the capability, which will be implemented in 1989, to scan 5 times every second for special experiments, e.g. transients.

The software has also been extended to facilitate, amongst other things, dynamic on-line viewing for monitoring the changes in pre-specified signals (data), plotting routines to produce plots from 24 hours to a few reactor cycles, plus the standard plots for reactor power, control rod positions, thermocouple temperatures, etc.

The philosophy of the JRC/HFR DACOS group is to continually improve and develop the system, as awareness of the latest techniques and equipment is considered to lend greater reliability to a system, and ultimately, to be economically advantageous.

2.3.3.13. In-pile Biaxial Creep Experiments (Project)

In the framework of "Preparatory Research" programme, the possible irradiation of austenitic stainless steel for in-pile creep experiments under biaxial

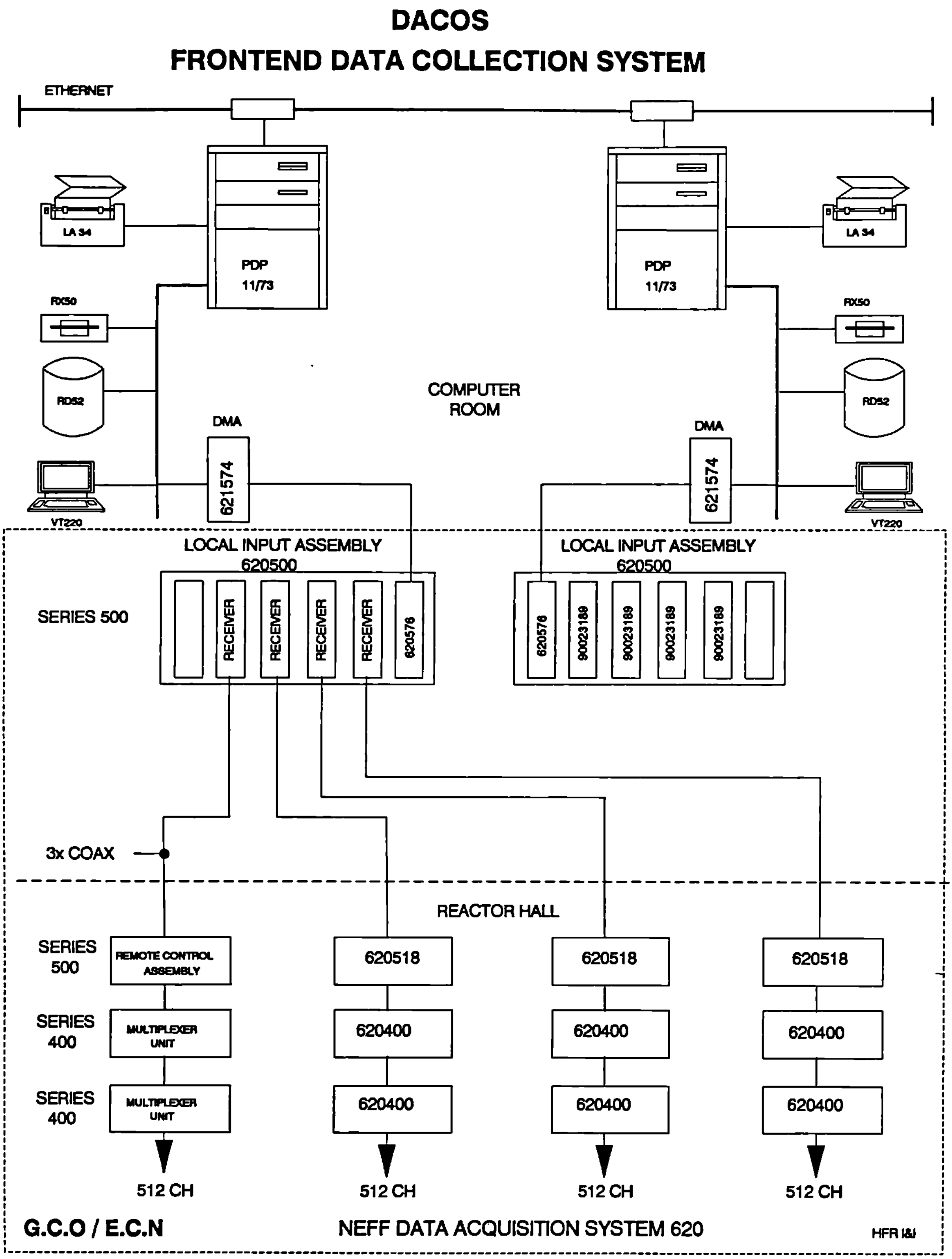

Fig. 47 DACOS. Lay-out of the new system

loading was discussed in April 1988. The goal of the research is the development of a methodology which could be used in the future for any high temperature reactor application.
The Applied Mechanics Division of the JRC Ispra, intends to sponsor a programme for the irradiation of specimens of stainless steel 316 H. The shape of the samples is such that a combined shear stress can be applied by tensile and torsional loads. After irradiation the specimens will be tested in a special biaxial testing device to ascertain residual strength and ductility up to impact strain rate. In parallel out-of-pile experiments are planned at JRC Ispra on the same specimen configuration. Comparison of the two series of results will allow the determination of the irradiation effects.
The results of the feasibility study performed at Petten show that the specimens could be irradiated in TRIO capsules, arranged in columns each about 400 mm long and consisting of 20 specimens. The load will be applied to the specimen by the combined action of two motors.
The first irradiation campaign requires the following parameters:

- temperature : 823 K (550°C)
- radiation damage: up to 2 dpa
- load (tension) : 500 kg
- load (torsion) : 3500 kg mm.

The surrounding medium will be helium. In future irradiations, the samples will be subjected to various temperatures and load histories and continued in-pile measurements are planned.

2.3.3.14. Spent Fuel Manipulations for CIEMAT

JRC Petten is preparing a contract with Transnuclear SA, Madrid, for assistance in the decommissioning of the CIEMAT reactor, Madrid. The work consists of cutting off the end pieces of 40 spent high enriched MTR-type fuel elements and preparing them for shipment to the USA.

2.3.3.15. Programme Management and Miscellaneous

- Planning
  The HFR Planning Meeting was held five times and five editions of the loading chart were issued (from no. HFRII/18 to no. HFRII/22).

- EWGIT (European Working Group on Irradiation Technology)
  The 30th Plenary Meeting was held at CEN/SCK Mol, 28/30 September 1988 and 25 papers were presented orally to about 60 participants.

- EWGRD (Euratom Working Group on Reactor Dosimetry)
  The 53rd Meeting was held on April 27, 1988 at JRC Ispra. During the meeting there was a report and a discussion on possible "Normalization and Standardization Activities" of the working group. To initiate this work several actions were defined. The technical topic of the meeting was "Quality Assurance in Reactor Dosimetry" and seven contributions from the various centres were presented.
  The subgroups on "Radiation Damage" and on "Monitor Materials" met on April 26, 1988 at JRC Ispra. With regard to the "Monitor Materials" programme, it was said that it needs more publicity and marketing actions.
  The EWGRD Programme Committee for the preparation of the 7th ASTM-EURATOM Symposium also met on April 26, 1988 at JRC Ispra to discuss with the ASTM programme committee chairman the organization for the symposium scheduled for 27/31 August, 1990 in Strasbourg ("Palais de l'Europe"), France.

- NRWG (Neutron Radiography Working Group)
  The 10th Plenary NRWG Meeting and subgroup meetings on "Nitrocellulose Film" and "Measurements" took place at KfK Karlsruhe, May 17/18, 1988.
  The NRWG Test Programme is finished and the results were presented to the participants. An EUR-report on this subject is being prepared.
  Editing work on the publication on "Nitrocellulose Film" is in progress. Publication is now scheduled for early 1989. Some contributions for the "Handbook on Practical Neutron Radiography" are still missing and the final editing will be further delayed.

- ACPM
  The Advisory Committee on Programme Management met in Petten on June 15 and December 8, 1988. It reviewed the status and progress of the HFR Programme on the basis of documents prepared by JRC Petten.

- HFR Users' Meeting
  A colloquium on "Prospects and Future Utiliza-

tion of the HFR" will be arranged and held on 20/21 April, 1989 at Petten. The colloquium will provide a forum for more detailed presentation of the main irradiation programmes of the present users of the HFR.

- SEMINARS organized by the HFR Division in 1988

  Dr. Kirch, N. - KFA/HBK Jülich
  "High Temperature Reactor Development in the FRG"
  29th February 1988

  Dr. Moss, R.L. - JRC Petten
  "Boron Neutron Capture Therapy"
  16th June 1988

  Prof. Dr. Dühmke, E. - Georg-August Universität Göttingen
  "Neutron Radiography with Fast Neutrons on Biological Objects"
  12th September 1988

  Burnette, R.D. - Visiting Scientist JRC Petten
  "Hydrolysis of HTGR Fuel"
  6th October 1988

  Dr. Ahlf, J. - JRC Petten
  "Embrittlement of Reactor Pressure Vessel Steel"
  21st October 1988

  Dr. Tartaglia, G. - JRC Petten
  "Radiation Damage on Insulation Materials"
  10th November 1988

  Dr. Tsotridis, G. - JRC Petten
  "Noise Analysis"
  24th November 1988

3. SUMMARY

3.1. HFR Operation, Maintenance and Development

In 1988 the HFR was operated routinely without any unforeseen event. The total availability of the reactor was 99% of its scheduled operating time, i.e. 252 out of 255 days. However the operating time per cycle had to be reduced from the summer onwards due to potential problems with fuel element supply.

3.2. Reactor Utilization

The average occupation of the HFR by experimental devices was reasonably high again in 1988, namely 80% of the practical limit. Breakdown of the utilization pattern in terms of the different programme objectives is shown in **Figs. 48 and 49.** Programmes related to nuclear energy deployment had again the largest share, the contribution of fission reactor related research being somewhat smaller than that related to fusion research. Nuclear and solid state physics at the beam tubes retained their relatively high share. The same holds for radioisotope production and related activities.

3.3. General Activities

Work in support of the irradiation programmes, such as assembly of rigs, quality control, experiment operation and PIE and hot cell work, continued as normal.

The following development activities took place:
- upgrading of the LWR irradiation facilities
- improvement of the sweep loops for fission product and tritium analysis
- design of multi-axial creep facilities
- further development in the direction of industrial neutron radiography
- preparatory work for neutron capture therapy.

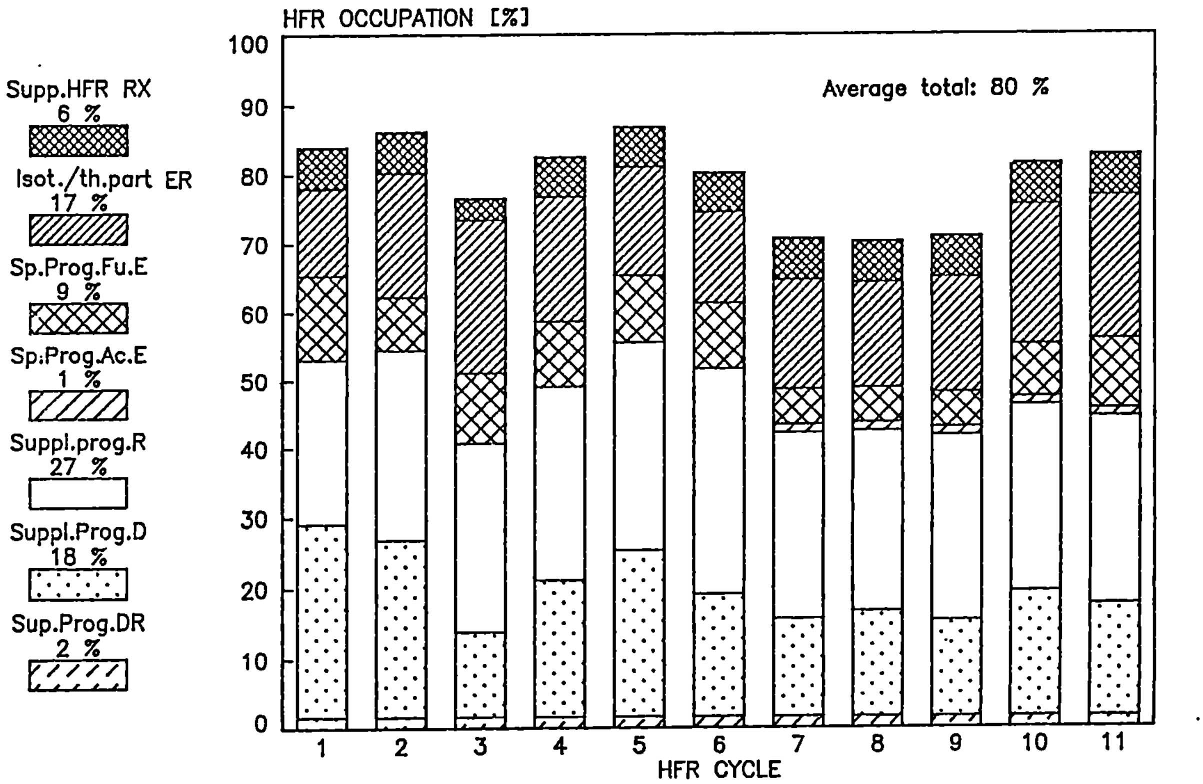

Fig. 48 HFR occupation per cycle subdivided into the various programmes during 1988

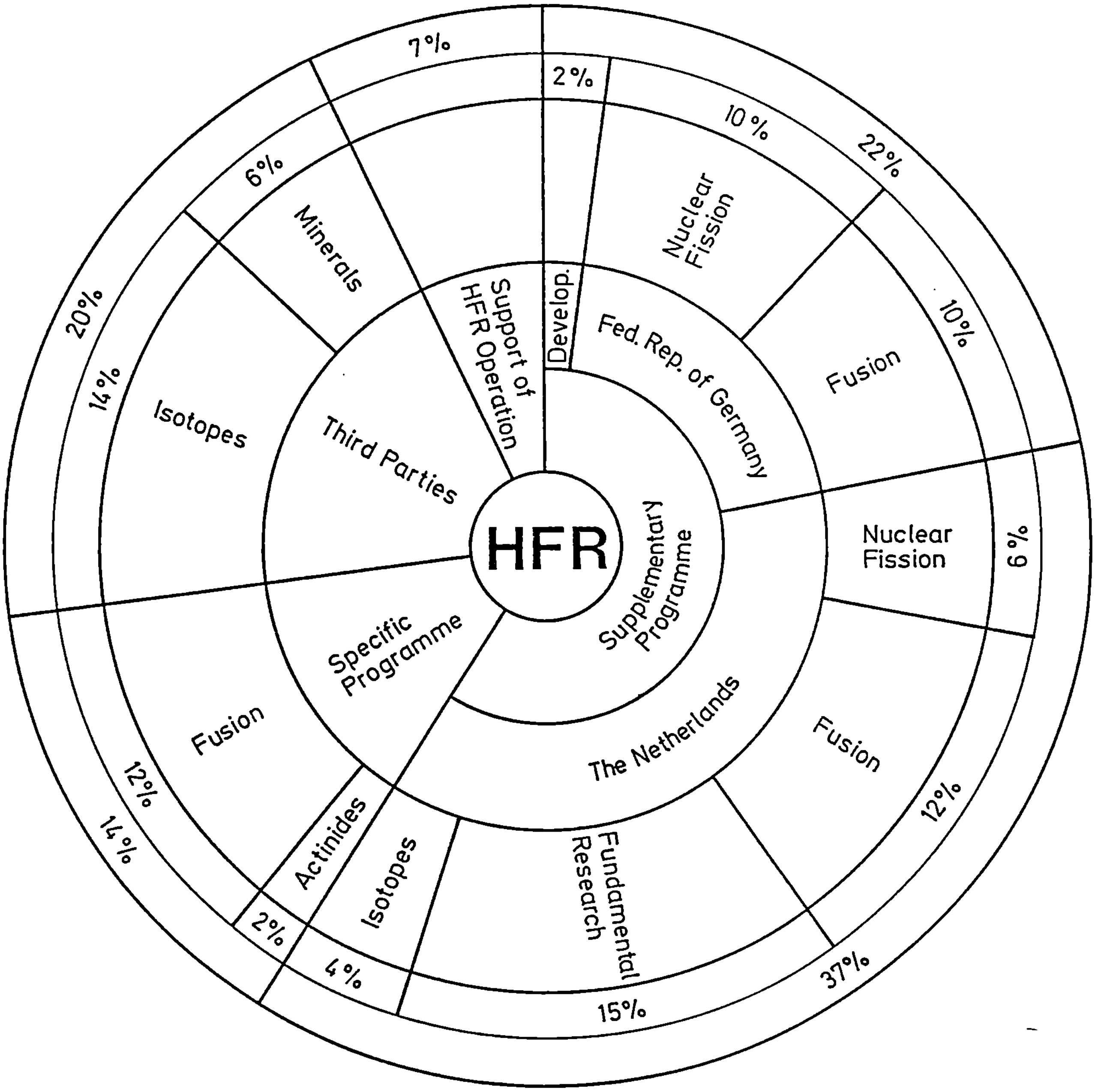

Fig. 49 HFR occupation for 1988 in % of used capacity based on tariff.
Average occupation 80%

4. HFR PUBLICATIONS, JANUARY-DECEMBER 1988

o Topical Reports

H. Röttger (ed.)
Programme Progress Report "Operation of the High Flux Reactor"
January-December 1987
EUR 11645 (1988)

o Contributions to Conferences

J.A. Collis-Smith, M.R. Cundy, R.J. Swanenburg-de Veye
The Dismantling of Active Plant at the Petten High Flux Reactor
International Conference on Decommissioning of Major Radioactive Facilities, London, October 1988

R.J. Swanenburg-de Veye, M.R. Cundy
The European Communities High Flux Materials Testing Reactor (HFR) at Petten as a model for a successful exploitation of a Large Research Facility
United Nations Conferences for the Promotion of International Co-operation in the Peaceful uses of Nuclear Energy, Geneva, March/April 1987

H. Hausen, W. Schüle, M.R. Cundy
Neutron Irradiation Creep Experiments on Austenitic Stainless Steel Alloys
15th Symposium on Fusion Technology (SOFT), Utrecht, 19-23 September 1988

C.R. Kennedy, M.R. Cundy, G. Kleist
The Irradiation Creep Characteristics
Carbon' 88, Newcastle-upon-Tyne, UK, September 1988

Kwast, H., Conrad, R., Debarberis, L., Kennedy, P., Filpot, A.J., Elen, J.D.
"In-situ tritium release from various lithium zirconates"
15th SOFT, 19-23 September 1988, Utrecht

Conrad, R. and Debarberis, L.
"In-pile tritium release from liquid breeder material Pb-17Li in LIBRETTO I experiment"
15th SOFT, 19-23 September, 1988, Utrecht

Conrad, R., Debarberis, L., Timke, Th. and Doré, J.
"Irradiation experiments on solid and liquid tritium breeder materials for thermo-nuclear fusion reactors in the HFR Petten"
30th EWGIT, 28-30 September, 1988, Mol

Kennedy, D., Markgraf, J., McAllister, S. and Ruyter, I.
"Thermohydraulic Studies related to the development of an LWR fuel rod testing capsule"
30th EWGIT Plenary Meeting, Mol, September 28-30, 1988

Fischer, B., Kwast, J., Markgraf, J. and Perry, D.
"An LWR fuel rod irradiation device for the investigation of axial load effects on the fuel rod behaviour"
(ibid)

Ruyter, I., Reichardt, K., Thöne, L. and Markgraf, J.
"LWR Safety Experiments in the HFR Petten
(ibid)

Moss, R.L., Beers, M., Korko, A.R. and Tsotridis, G.
"Fast Breeder reactor fuel pin experiments in the High Flux Reactor at Petten : specialist design and instrumentation, and ancillary activities"
30th EWGIT, Mol, September, 1988.

Moss, R.L. and Scharroo, W.
"The latest upgrade of the data acquisition system DACOS in the High Flux Reactor at Petten"
30th EWGIT, Mol, September, 1988.

o Scientific or Technical Articles

Fischer, G., Sontheimer, F., Ruyter, I. and Markgraf, J.
"Experiments on the load following behaviour of PWR fuel rods"
Nuclear Engineering & Design 108 (1988), 429-432

Tsotridis, G., Moss R.L.
Irradiation of Fusion Reactor Ceramic Materials
Journ. Nuclear Materials, 155-157 (1988), 295-297

5. RELATIONS TO EXTERNAL ORGANIZATIONS

Major contacts established by the HFR Programme are summarized in the following table.

Table 29 HFR Programme. Relations to external organizations

Organization	Place	Type of relations or topics	Remarks
CEN/SCK	Mol, Belgium	Reactor operation Irradiation technology Reactor dosimetry Neutron radiography Fusion reactor materials	
Belgonucléaire	Brussels, Belgium	LMFBR fuel transient irradiation testing	Through SNR "Arbeitskreis"
I.R.E.	Fleurus, Belgium	Radioisotope production	Commercial contract
Nuclear Services	Braaschaat, Belgium	Decontamination of heat exchangers	Service contract
Risø National Lab.	Roskilde, Denmark	Reactor operation Irradiation technology Neutron radiography	
GKSS	Geesthacht, Germany	Irradiation technology Neutron radiography	
Hahn-Meitner-Institut	Berlin, Germany	Reactor operation	
HOBEG	Hanau, Germany	HTR fuel technology	Through KFA Jülich
INTERATOM	Bergisch Gladbach, Germany	LMFBR fuel transient irradiation testing Research reactor technology	Through SNR "Arbeitskreis" Collaboration contract
IKE	Stuttgart, Germany	Neutron Capture Therapy Neutron Radiography	
KFA (+HBK)	Jülich, Germany	Fuel and materials irradiation testing Irradiation technology Reactor dosimetry	Outline contract
KfK	Karlsruhe, Germany	Fuel and materials irradiation testing Reactor dosimetry Reactor technology Neutron radiography Radioniclide production	Outline contract
NCS	Hanau, Germany	HFR fuel cycle services Radioactive sample and isotope transports	Service contract Ad-hoc orders
NET-Team	Garching, Germany	Fusion reactor irradiations	
NUKEM	Alzenau, Germany	HFR fuel cycles services	Supply contract
NTG	Gelnhausen, Germany	Standard irradiation devices	Supply contract
PTB	Braunschweig, Germany	Reactor dosimetry	
SIEMENS, UB KWU	Erlangen, Germany	LWR fuel testing	
University of Berlin	Berlin, Germany	Materials irradiations	Contract

CERCA	Romans-sur-Isère, France	Standard HFR fuel elements supply Reduced enrichment fuel development	Supply contract Collaboration contract
CEA, CEN de Cadarache	St. Paul-lez-Durance, France	Reactor dosimetry Neutron radiography	
CEA, CEN de Grenoble	Grenoble, France	Irradiation technology Development and supply of irradiation devices Neutron radiography Reactor Dosimetry	Several study and supply contracts
ILL	Grenoble, France	Reactor operation	
CEA, CEN de Saclay (Fontenay-aux-Roses)	Gif-sur-Yvette, France	Irradiation technology Reactor dosimetry Neutron radiography Cobalt 60 production	Several study and supply contracts Commercial contract
KODAK-PATHE	Paris, France	Neutron radiography	
SODERN	Suresnes, France	In-pile instrumentation (mainly thermocouples)	Supply contract
E.N.E.A./C.S.N. Casaccia	Roma, Italy	Irradiation technology Reactor dosimetry	
CESNEF-Politecnico di Milano	Milano, Italy	Reactor dosimetry	
ENEL	Milano, Italy	Reactor dosimetry	
Politecnico di Torino	Turin, Italy	Irradiation technology	
AGIP S.P.A.	Milano, Italy	LWR fuel testing	
ECN	Petten and The Hague, Netherlands	HFR operation and general site services Reactor dosimetry Neutron radiography	Permanent service contract
		Materials irradiation testing Beam tube utilization	Outline irradiation contract
ESA	Noordwijk, Netherlands	Neutron radiography	
IRI	Delft, Netherlands	Research reactor engineering	
NEDERLANDS KANKER INSTITUUT	Amsterdam, Netherlands	Neutron capture therapy	
KEMA	Arnhem, Netherlands	Ancillary studies	Service contract
KEMA/GKN	Arnhem, Netherlands	LWR fuel testing	Service contract
University College	Dublin, Eire	Nuclear engineering	
UKAEA/AERE	Harwell, Oxfordshire, UK	Irradiation technology Neutron radiography Reactor dosimetry Fusion reactor materials	
UKAEA SL	Springfields, UK	Fusion breeder materials	

University of Birmingham	Birmingham, UK	Neutron radiography	
HC+D	Highworth, Wilts, UK	Calculation and design	Service contract
UKAEA	Winfrith, Dorch. Dorset, UK	Reactor dosimetry	
UKAEA	Risley, Warrington, Lancashire, UK	Irradiation technology	
CEGB	Berkeley, GL, UK	Filtered beam facility	Study contract
Inspectorate International	Swansea, UK	Reactor vessel in-service inspection	Service contract
Rutherford Appleton Labororatory	Chilton, Didcot, UK	Radionuclide production	Commercial contract
University of Leeds	Leeds, UK	Radionuclide production	Commercial contract
University of Liverpool	Liverpool, UK	Radionuclide production	Commercial contract
IAEA	Vienna, Austria	International Working Group on Fuel Performance and Technology (IWGFPT) Reactor dosimetry Research reactor operation	
NFI	Tokai-mura, Japan	LWR fuel testing	
University of Kyoto	Kyoto, Japan	Research reactor engineering	
JAERI	Tokai-mura, Japan	Fusion reactor materials and graphite irradiation	Irradiation contract
Nissho Iwai	Tokyo, Japan	Marketing of HFR irradiation services	Marketing contract
Halden Project	Halden, Norway	Irradiation technology	
Paul SCHERRER Institute	Würenlingen, Switzerland	Research reactor engineering Reactor dosimetry Neutron radiography Fusion material testing	
AB Studsvik	Nyköping, Sweden	Research reactor engineering Neutron radiography Fusion reactor materials	
ANL	Argonne, Ill., USA	Reduced enrichment fuel development	Collaboration contract (through ECN)
ORNL	Oak Ridge, Tenn., USA	Fast reactor fuel in-pile testing Research reactor management Irradiation technology Fusion material testing	

HEDL	Hanford, Wash., USA	Reactor dosimetry	
ASTM	Philadelphia, Penn., USA	Reactor dosimetry Neutron Radiography	
EPRI	Palo Alto, Calif., USA	LWR fuel testing	
Battelle, Pacific Northwest Labs.	Richland, Wash., USA	High burn-up effects and gadolinea programs	
ANF	Richland, Wash., USA	LWR fuel testing	
General Electric Co.	San José, Calif., USA Vallecitos, Calif., USA	Irradiation testing Research reactor engineering	
I.N.E.L.	Idaho Falls, Idaho, USA	MTR fuel reprocessing	Service contract
University of Missouri	Columbia, Missouri, USA	Research reactor management	
M.I.T.	Cambridge, Massachusetts, USA	Research reactor management	
CE	Windsor, CT, USA	LWR fuel testing	
Hungarian Academy of Sciences	Budapest, Hungary	Radionuclide production	Commercial contract
Inzinta. Isotope	Budapest, Hungary	Radionuclide production	Commercial contract

GLOSSARY

ACPM	Advisory Committee on Programme Management
AERE	Atomic Energy Research Establishment
AKTINES	AKTI (irradiation) NE (neutrons) S (steel)
AMCR	Acier Mangan Chrome (Low activation material)
ASTM	American Society for Testing and Materials
AUGIAS	Automatic Gas Supply System for Irradiation Devices
BEST	Brenn Element SegmenT
BNCT	Boron Neutron Capture Therapy
BOL	Beginning Of Life
BU or bu	Burn-up
BUMMEL	Fission gas BUbble Mobility Measurement Level
BWFC	Boiling Water Fuel-element Capsule
BWR	Boiling Water Reactor
CEA	Commissariat à l'Energie Atomique
CEN	Centre d'Etudes Nucléaires
CEFIR	Ceramic Fusion Irradiation
CERAM	net CERAMics
CERCA	Compagnie pour l'Etude et la réalisation de Combustibles Atomiques
CFC	Carbon Fibre Compound
CIEMAT	Ciemat-Elements Manipulations for Transport
COBI	Cobalt Isotope Production
CORRI	Cobalt Isotope production
CPM	Critical Path Method
CRISP	Creep in Steel Specimens
CT	Compact Tension (specimen)
DACOS	Data Acquisition and Control On-line System
DAR	Damage to Activation Ratio
DIN	Deutsche Industrie Norm
DISCREET	Disposable CREEP in TRIO
DM	Dismantling Cell
ECN	Energieonderzoek Centrum Nederland
EDN	Equivalent DIDO Nickel fast neutron fluence
EFR	European Fast Reactor
ELIMA	Exp. for Li-materials
ENEA	Ente Nazionale Energie Alternative
EOL	End Of Life
ETHERNET	Computer connection system
EUROS	European Remote encapsulation Operating System
EWGIT	European Working Group on Irradiation Technology
EWGRD	Euratom Working Group on Reactor Dosimetry
EXOTIC	Extraction of Tritium in Ceramics
FAFNIR	Fatigue in First Wall Nuclear Irradiation Rig
FANTASIA	Fracture Toughness Irradiation (Austenitic Stainless Steel)
FBR	Fast Breeder Reactor
FIT	Fissile Isotope Target
FPD (or f.p.d.)	Full Power Day
GA Technologies	General Atomics
GIF	Gamma Irradiation Facility
GRIPS	Graphite Irradiation in Pool Side Facility
HBK-Projekt	Hochtemperatur reaktor-BrennstoffKreislauf
HEISA	HEated and Instrumented SAlt-irradiation
HEU	Highly Enriched Uranium

HFR	High Flux Reactor
HP-PIF	High Flux Poolside Isotope Facility
HRB	Hochtemperatur ReaktorBau GmbH
HTR (HTGR)	High Temperature Reactor
IAEA	International Atomic Energy Agency
IDA	Irradiation Device for fast neutron Activation (formerly ROS)
IDEAS	Irradiation Damage Evaluation of Austenitic Steel
IEA	International Energy Agency
INSAR	Integrated Safety Assessment of Research Reactors
INZINTA	Isotope Trading Enterprise, Budapest
ISOLDE	Iodine Solubility and Degassing Experiment with pre-irradiated PWR fuel Rods
JAERI	Japanese Atomic Energy Research Institute
KAKADU	Kamin Kasel-Duo (Twin capsules for fuel pin irradiation)
KFA	Kernforschungsanlage Jülich
KFD	Kernfysische Dienst
KfK	Kernforschungszentrum Karlsruhe
KNK	Kompakte Natriumgekuhlte Kernreaktoranlage
KWU	Siemens AG, UB KWU
LEU	Low-enriched Uranium
LIBRETTO	Liquid BReeder Experiment with Tritium Transport Option
LMFBR	Liquid Metal Fast Breeder Reactor
LOCA	Loss of Cooling Accident
LOF	Loss-Of-Flow
LSO	Laboratorium voor Sterk radioactieve Objekten
LTI	Low Temperature Isotropic
LWR	Light Water Reactor
MD	Materials Division
MEDINA	FBR fuel, power cycling experiment (POCY)
MOX	Mixed Oxide
MTR	Materials Testing Reactor
NAST	Na-steel irradiation
NCT	Neutron Capture Therapy
NET	Next European Torus
NILOC	Nitride fuel, Low in Oxygen and Carbon
NRWG	Neutron Radiography Working Group
OPEQU	Over-Power EQuilibrium
OPOST	Overpower steady/state irradiation
ORNL	Oak Ridge National Laboratory
PCI	Pellet-Cladding Interaction
PDP	Trademark for "Digital Equipment Corporation" computers
PHWR	Pressurized Heavy Water Reactor
PIE	Post-irradiation Examinations
PIF	Pool side Isotope Facility
POCY	Power Cycling Experiment
POMPEI	Pellets Oxyde Mixte, PEtten Irradiation
POTOM	Power to melt irradiation
PPR	Programme Progress Report
PROF	Pool side Rotating Facility
PSF	Pool Side Facility
PWR	Pressurized Water Reactor
QA or Q/A	Quality Assurance
QC	Quality Control

QUATTRO	Four channel reloadable rig (29 mm)
RASA	Radiation metrology and Applied Systems Analysis
R & D	Research and Development
REFA	Reloadable Facility
RELIEF	FBR fuel/cladding, axial displacement measurement experiment
RIF	Reloadable Isotope Facility
SANS	Small Angle Neutron Scattering
SCK	StudieCentrum voor Kernenergie (Mol, B)
SIDO	Silicon Doping Facility
SIENA	Steel Irradiation in Enhanced Neutron Arrangement
SIMONE	Test Irradiation for low enriched Silicide fuel elements
SINAS	Simplified NAST (irradiation capsule)
SIP	Silicium Investigation Philips
SISSI	Safety Investigation by Stainless Steel Irradiation
SNR	Schneller Natriumgekühlter Reaktor (Kalkar)
SOFT	Symposium on Fusion Technology
SUPRA	Irradiation of Superconducting Alloys
TEDDI	Computer programme to evaluate reactor neutron spectrum
THTR	Thorium High Temperature Reactor
TMI	Three Mile Island
TMS	Tritium Measuring Station
TOP	Transient Overpower
TRAGA	Transient Gap conductance measurement
TRAMP	Travelling Measuring Probe (STICK) Gamma calorimeter
TRIESTE	TRIO Irradiation with Experiment of Steel-Samples under Tension
TRIO	Irradiation Device with three thimbles
TRISO	Coated HTR fuel particle types
UKAEA	United Kingdom Atomic Energy Authority
VABONA	Vanadium Irradiation with Boron doping in Natrium-bonding
VOLEX	Mixed oxyde fuel, VOLume Expansion experiment

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