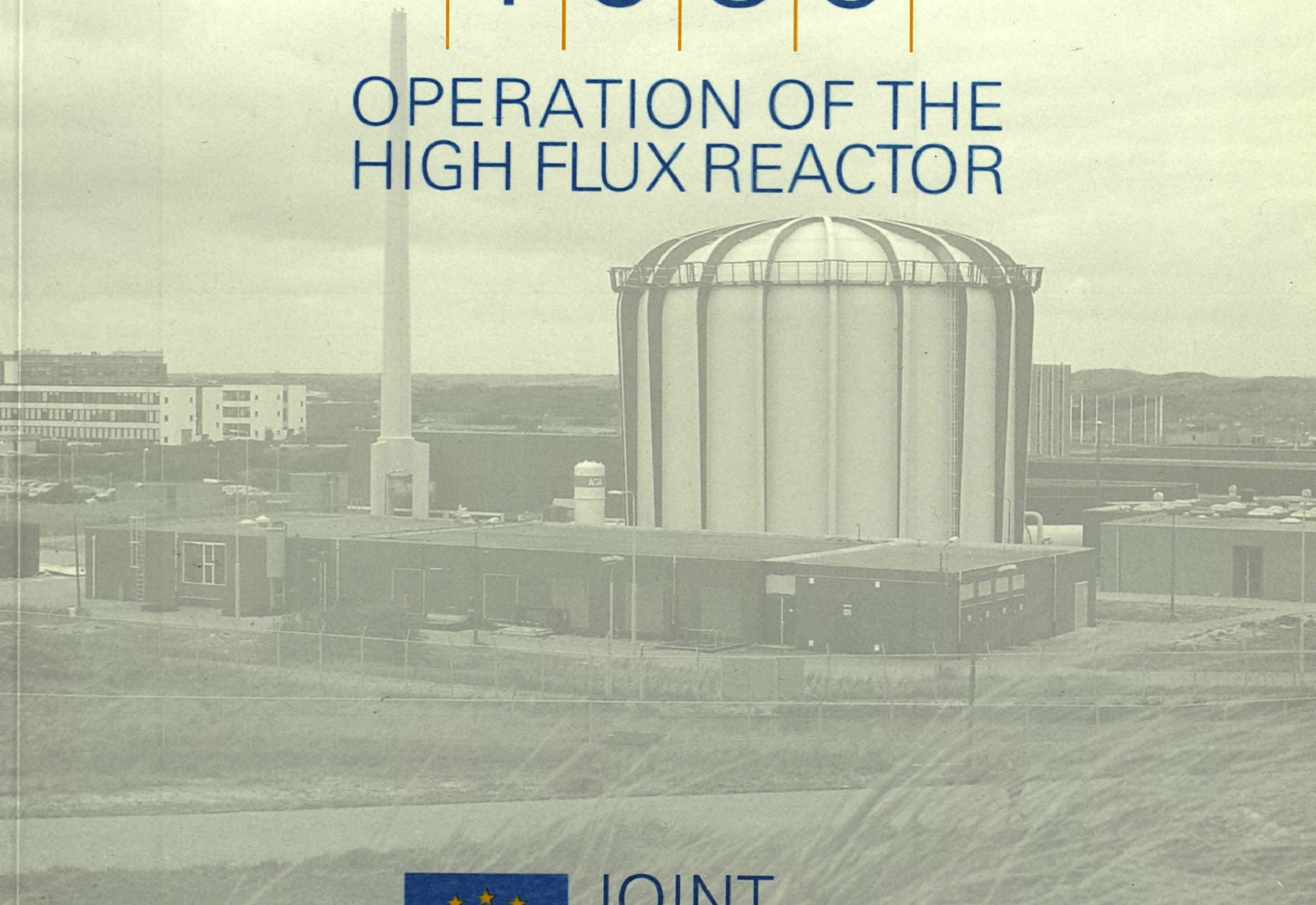
ANNUAL REPORT 1989

OPERATION OF THE HIGH FLUX REACTOR



JOINT RESEARCH CENTRE

COMMISSION OF THE EUROPEAN COMMUNITIES

ANNUAL REPORT 1989

OPERATION OF THE HIGH FLUX REACTOR

J. AHLF, A. GEVERS,
editors

Commission of the European Communities
JOINT RESEARCH CENTRE
Institute for Advanced Materials
Petten Site

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The HFR Petten.

1. INTRODUCTION

The High Flux Reactor Petten belongs to the Institute for Advanced Materials of the Joint Research Centre of the European Communities.
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 fields of nuclear and solid state physics and materials science, large scale radioisotope production for medical, agricultural and industrial applications, neutron activation analysis, development and application of neutron radiography and application of neutrons for cancer therapy. Safe operation of the reactor is in itself an expressed programme objective.

Since the first criticality of the HFR in 1961 it has been the 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 are continuously adapted and kept versatile by responding to changing requirements from the experimental programmes.

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 stoppages due to component failure. This policy resulted in a high plant availability 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.

DATE 1989	TIME OF ACTION hour	RESTART OR POWER INCREASE hour	NOMINAL/ ORIGINAL POWER hour	ELAPSED TIME TO RESTART OR POWER INCREASE h.min	ELAPSED TIME TO NOMINAL/ ORIGINAL POWER h.min	DISTURBANCE CODE 1	MW	2	3	REACTOR SYSTEM OR EXPERIMENT CODE	COMMENTS
12 Feb.	09.21	09.28	10.08	00.07	00.47	MP	15	E	S	D227-01	Installation of experiment
12 Feb.	14.29					AS		R	I	Interlock	Unidentified disturbance
14 Feb.		13.00	14.35	45.21	46.56						on a safety channel
01 Mar.	00.12					AS		E	H	ER136	During handling of rig,
02 Mar.		20.15	21.37	44.03	45.25						trip of safety channel.
03 Apr.	17.45					AP	1	R	I	Pool cooling	Flow measurement failure
	20.00					MS		R	R	Pool cooling	Necessary for in-pool reparations
04 Apr.		02.00	02.38	08.15	08.53						
04 Apr.	03.08	03.13	03.14	00.05	00.06	AP	23	R	H	Reactor cooling	Set point inlet temperature exceeded
	06.00					AP	29	R	I	Pool cooling	Flow measurement failure
	06.10					MS		R	R	Pool cooling	Necessary for in-pool reparations
05 Apr.		08.30	09.55	26.30	27.55						
06 Apr.	08.33	08.35	08.40	00.02	00.07	AP	33	R	I	Pool cooling	Flow measuring defect
10 Apr.	16.32	16.38	16.40	00.06	00.08	MP	35	E	S	ER136	Isotope handling
12 Apr.	14.12	14.16	14.19	00.04	00.07	MP	35	E	S	ER136	Isotope handling
17 Apr.	00.14	00.45	00.47	00.31	00.33	MP	35	E	S	ER136	Isotope handling
	01.10	01.17	01.19	00.07	00.09	MP	39	E	S	ER136	Isotope handling
19 Apr.	00.10	00.17	00.20	00.07	00.10	MP	35	E	S	ER136	Isotope handling
30 Apr.	11.18	11.22	11.23	00.04	00.05	MP	35	E	S	ER136	Isotope handling
	11.53	11.57	12.02	00.04	00.09	MP	35	E	S	ER136	Isotope handling
03 May	19.08	19.15	19.19	00.07	00.11	MP	20	E	S	D183	Poolside experiment removal
08 May	00.21	00.26	00.30	00.05	00.09	MP	35	E	S	ER136	Isotope handling
	00.32	00.41	00.45	00.09	00.12	MP	35	E	S	ER136	Isotope handling
15 May	00.12	00.24	00.35	00.12	00.13	MP	35	E	S	ER136	Isotope handling
29 May	13.25	14.25	14.25	01.00	01.00	MP	35	E	S	ER136	Isotope handling
05 June	00.10	01.05	01.10	00.55	01.00	MP	35	E	S	ER136	Isotope handling
06 June	11.26	11.40	12.05	00.14	00.39	MP	20	E	S	D227	Capsule reloading and power adaption to 44 MW
18 June	04.00	04.03	04.05	00.03	00.05	AP	23	E	I	D227-01	Pressure setpoint exceeded
	09.43	09.49	09.50	00.06	00.07	MP	35	E	R	ER136	Isotope handling
20 June	17.29	17.52	18.25	00.13	00.56	MP	20	E	S	D227-01	Fuel pin loading, max. power limited at 41 MW
26 June	00.14	00.22	00.27	00.08	00.13	MP	35	E	R	ER136	Isotope handling
	01.48	01.58	02.00	00.10	00.12	MP	35	E	R	ER136	Isotope handling
	14.00	14.04	14.08	00.04	00.08	MP	35	E	R	ER136	Isotope handling
03 July	00.11	00.25	00.31	00.14	00.20	MP	35	E	R	ER136	Isotope handling
07 July	16.40	17.45	19.10	01.05	02.30	MP	20	E	R	D227-01	Fuel pin unloaded, reactor power adjusted to 45 MW
27 Aug.	12.15	12.26	12.46	00.11	00.31	MP-20		E	S	D227-2	Loading of experiment.
30 Aug.	00.12	00.16	00.20	00.04	00.08	MP-35		E	S	ER136	Isotope handling
14 Sep.	17.27	17.35	17.40	00.08	00.13	MP-10		E	S	D227-2	Unloading of experiment.
27 Sep.	11.34	11.35	11.37	00.01	00.03	AP	40	E	H	BWFC-A	Recorder repair
27 Sep.	15.03	15.09	15.14	00.06	00.11	MP	35	E	R	ER 136	Facility handling
27 Sep.	16.22	16.31	16.39	00.09	00.17	MP	20	E	R	D227-2	Experiment handling
04 Oct.	00.13	00.19	00.22	00.06	00.09	MP	35	E	R	ER 136	Facility handling
04 Oct.	01.13	01.21	01.24	00.08	00.11	MP	35	E	R	ER 136	Facility handling
04 Oct.	09.32	09.40	10.00	00.08	00.28	AP	2	R	I	Pool	Flow instrumentation power supply unit
09 Oct.	05.53					MS	0	R	M	Primary	Pump bearing replacement
10 Oct.		21.58	23.15	40.05	41.22						Indication: increased noise level
16 Oct	17.19	17.31	17.36	00.12	00.17	MP	20	R	R	D227-2	Experiment handling
20 Oct.	17.45	17.50	18.08	00.05	00.23	AS	0	E	M	D215-12	Cooling water disturbance
20 Oct.	19.43	19.55	20.00	00.12	00.17	MP	25	E	R	D215-12	Experiment handling
21 Oct.	13.22	13.34	13.46	00.12	00.24	MP	20	E	R	D227-2	Loading/unloading of experiment
25 Oct.	13.10	13.23	13.30	00.13	00.20	MP	35	E	R	ER136	Facility handling
25 Oct.	14.00	14.07	14.15	00.07	00.15	MP	35	E	R	ER136	Facility handling
26 Oct.	09.57	10.18	10.30	00.21	00.33	MP	25	E	R	D215-12	Experiment handling
01 Nov.	00.20	00.30	00.36	00.10	00.16	MP	35	E	R	ER136	Facility handling
10 Nov.	17.00	17.05	17.08	00.05	00.08	MP	20	E	R	D227-2	Experiment handling
10 Nov.	20.00	20.02	20.06	00.02	00.06	AP	29	E	I	BWFC-A	Activity failure instrumentation
18 Nov.	21.55					MS	0	E	R	E198-14	Experiment removed in order with too high temperature
22 Nov.	11.32	11.38	11.47	00.06	00.15	MP	20	E	R	D227-2	Experiment handlings
24 Nov.	13.17	13.38	13.40	00.21	00.23	MP	35	E	R	ER136	Handling facility
29 Nov.	00.05	00.11	00.27	00.06	00.22	MP	35	E	R	ER136	Handling facility
29 Nov.	00.48	00.50	01.04	00.02	00.16	MP	35	E	R	ER136	Handling facility
05 Dec.	09.05	09.30	09.40	00.25	00.35	MP	20	E	R	D183-27	Experiment handling
11 Dec.	17.55	18.02	18.10	00.07	00.15	MP	20	E	R	D227-2	Experiment handling
Dec 15	08.55	11.06	12.08	02.11	03.03	0	MS	E	M	E167.47	Leakage experiment
Dec 15	12.20	12.24	12.34	00.04	00.14	0	AS	I	H	Safety	Testing setpoint
Dec 18	10.55	11.09	11.20	00.14	00.25	20	MP	E	S	D227-02	Experiment handling
Dec 18	12.06	12.13	12.21	00.07	00.15	35	MP	E	S	ER136	Facility handling
Dec 25	08.00	08.04	08.06	00.04	00.06	35	MP	E	S	ER136	Facility handling
Dec 25	09.00	09.05	09.06	00.05	00.06	35	MP	E	S	ER136	Facility handling
Jan 1	08.12	08.23	08.26	00.11	00.14	35	MP	E	S	ER136	Facility handling
Jan 8	09.00	09.07	09.12	00.07	00.12	20	MP	E	S	D227-02	Experiment handling

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 I
- mechanical M
- electrical E

2. HFR OPERATION, MAINTENANCE, DEVELOPMENT AND SUPPORT

2.1. OPERATION

2.1.1. Operation Survey

The "short" cycle pattern which was started in 1988 because of unsecured fuel element supply, has been maintained throughout 1989 with a scheduled number of 232 operation days.
Actually the HFR has been operated during 246 days, which corresponds to an overall availability of 67%. Nominal operation power has been 45 MW. Total energy production has been approximately 9900 MWD, corresponding to a fuel consumption of approximately 12,5 kg U-235.

2.1.2. Operational Characteristics

The main operating characteristics for 1989 are given in **Table 1.**

Table 1.
Reactor operation characteristics during 1989

HFR cycle	Beginning of cycle	End of cycle	Time at power h.min.	Energy production MWd	Unscheduled operation interruptions
88.11		05.01.89			
89.01	06.01.89	06.02.89	514.3	880	–
89.02	07.02.89	04.03.89	449.42	846	2
Shut-down	05.03.89	31.03.89			
89.03	01.04.89	24.04.89	472.23	889	2
89.04	25.04.89	20.05.89	542.44	1024	–
89.05	21.05.89	14.06.89	508.53	951	
89.06	15.06.89	10.07.89	548.36	972	–
Shut-down	11.07.89	21.08.89			
89.07	22.08.89	14.09.89	513.45	968	
89.08	15.09.89	16.10.89	475.56	850	1
89.09	17.10.89	10.11.89	536.02	895	1
89.10	11.11.89	11.12.89	548.22	1040	1
89.11	12.12.89				

At the begin of the reporting period, the HFR was in operation for the completion of cycle 88.11 up to January 5. Since then the HFR was operated for 10 complete cycles at a nominal power of 45 MW. At the end of the year cycle 89.11 was still in progress, scheduled for completion at January 8, 1990. To compensate for lost operating time, cycle 89.04 was extended by two days. During part of cycle 89.06 the reactor power level has been reduced to 41 MW in order not to exceed the maximum permissible power for an experimental fuel pin irradiation.

Special operation runs, mostly at low power, were carried out for neutron spectra measurements in preparation for the boron neutron capture therapy facility and for two irradiation projects. Regular reactivity measurements were made in the context of the testing of HFR-LEU fuel elements. Core loadings, power pattern and control rod position for the eleven fully completed reactor cycles is given in **Figs. 1 to 11.** Detailed information on the various irradiation experiments is given under chapter 3.

2.1.3. Operational Disturbances

Deviations from nominal power level occurred 66 times during 1989, 49 of these were scheduled, mostly for intermediate handling or adjustment of irradiation facilities. The remaining 17 were related to technical failures or other safety-related events. Detailed characteristics of all power disturbances are given in **Table 2.**

◁ **Table 2**
Full power interruptions.

Fig. 1
HFR cycle 89.01. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.

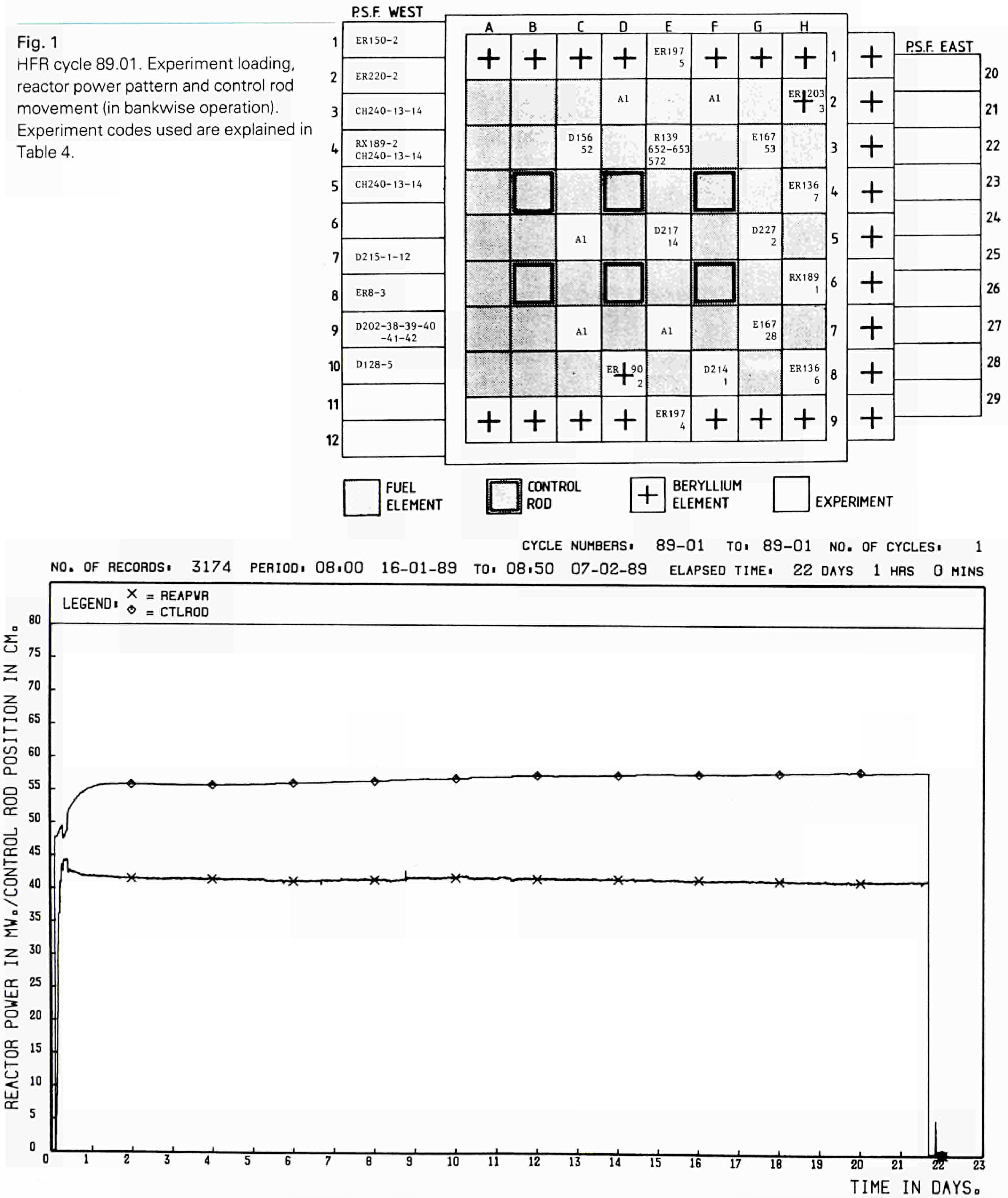
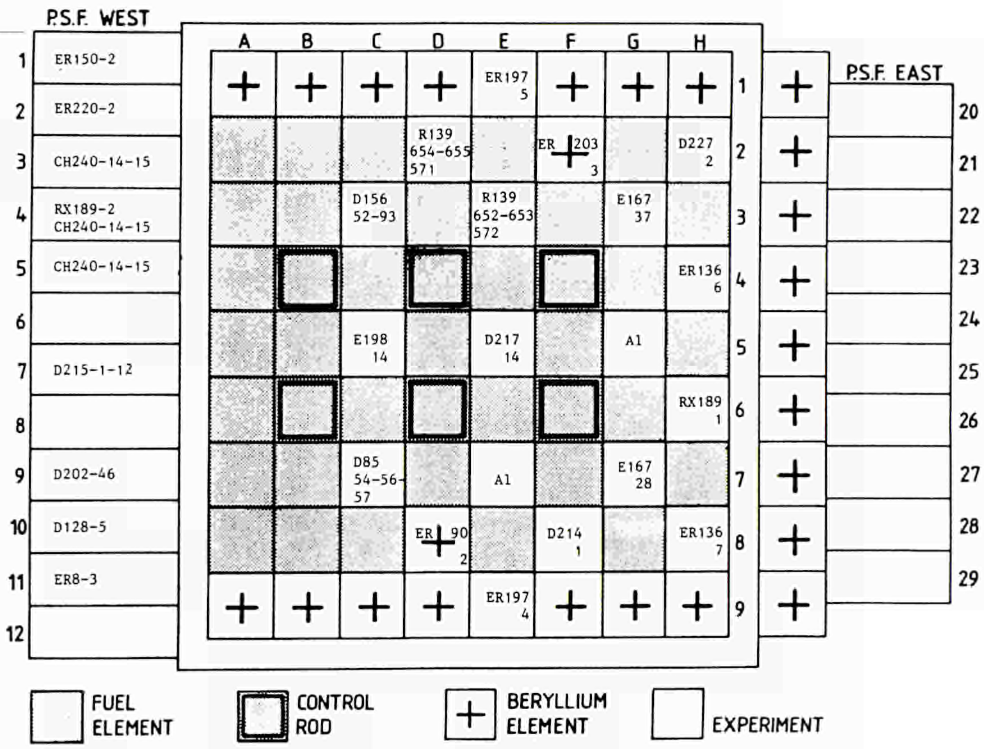


Fig. 2
HFR cycle 89.02. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



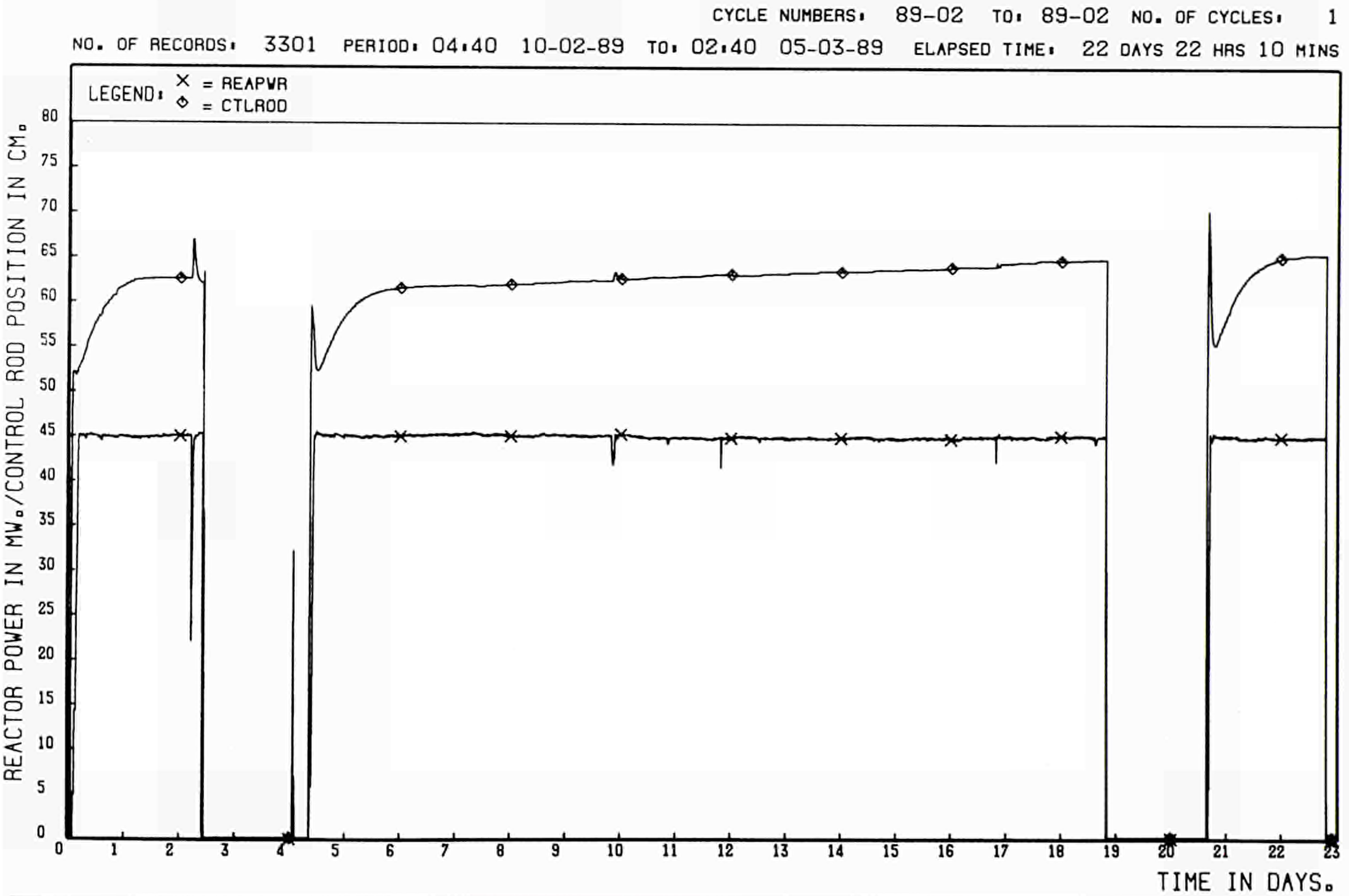
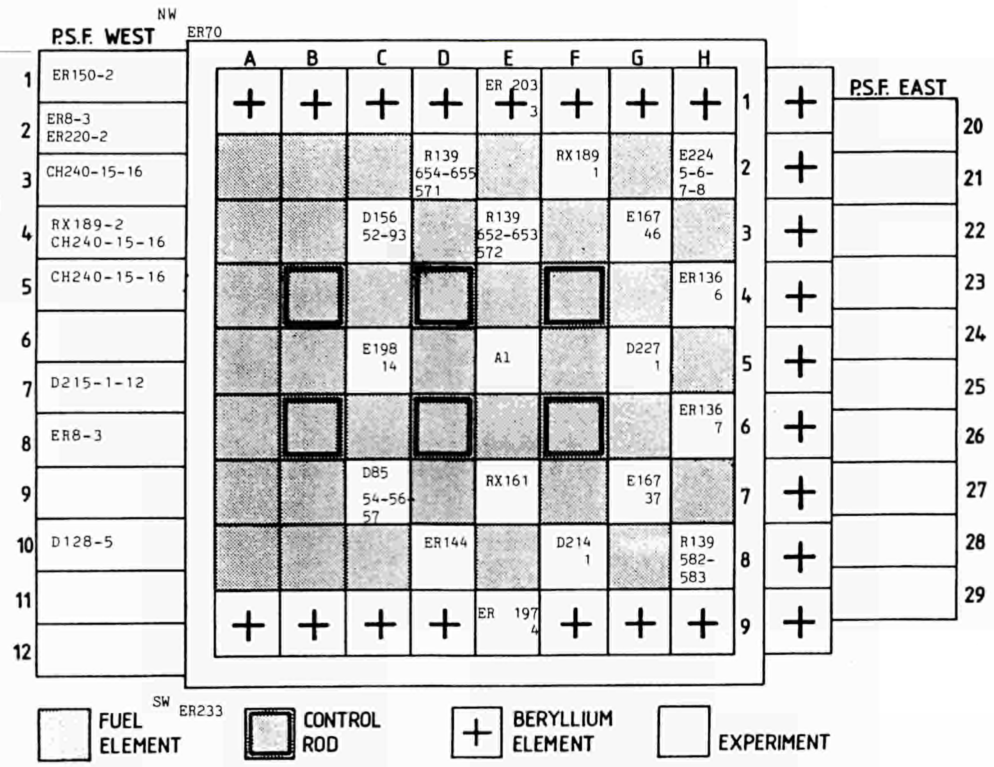


Fig. 3
HFR cycle 89.03. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



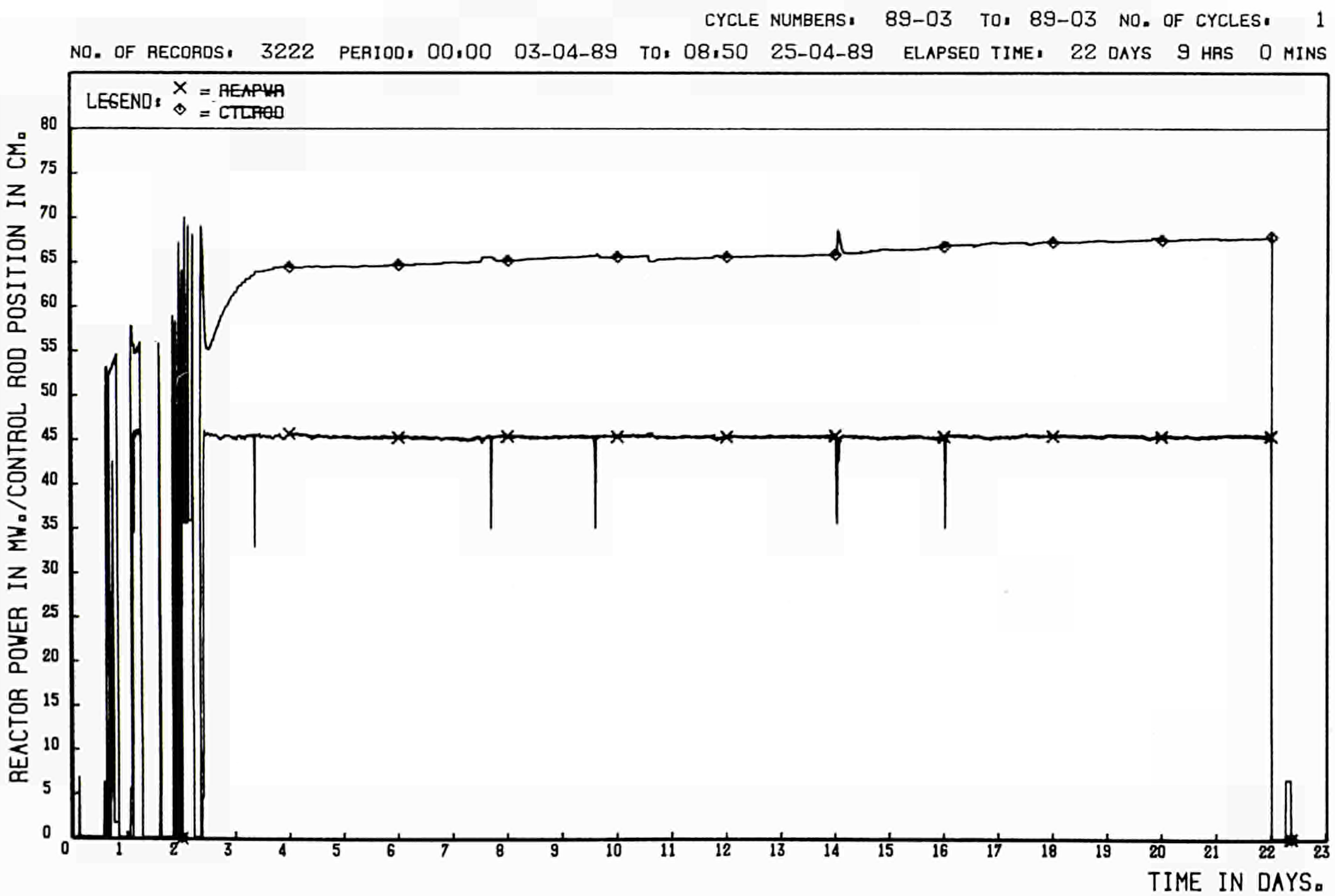
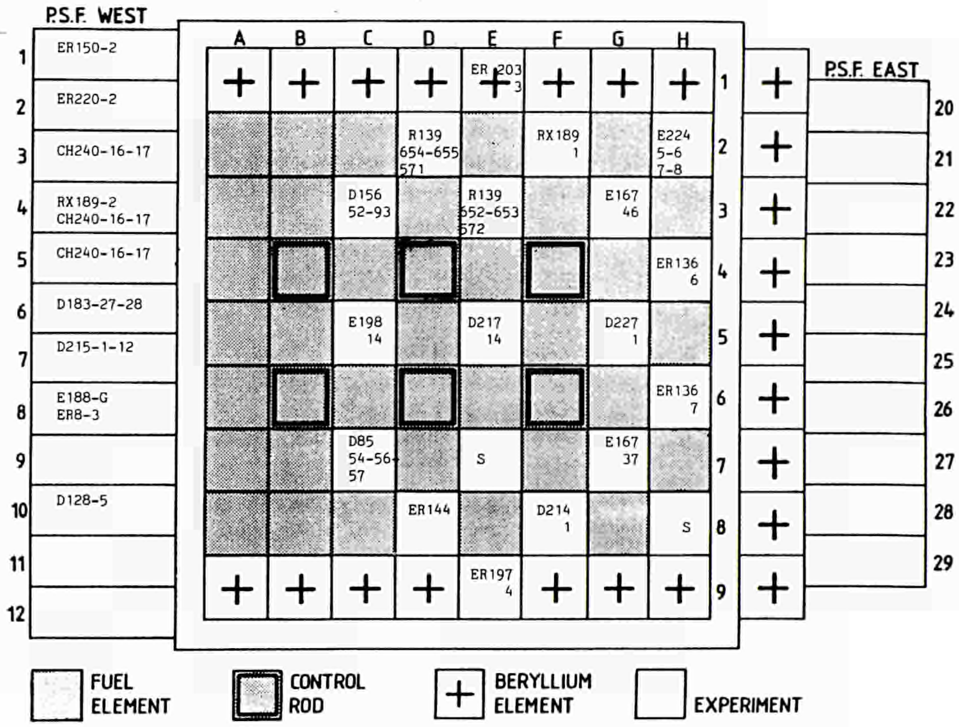


Fig. 4
HFR cycle 89.04. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



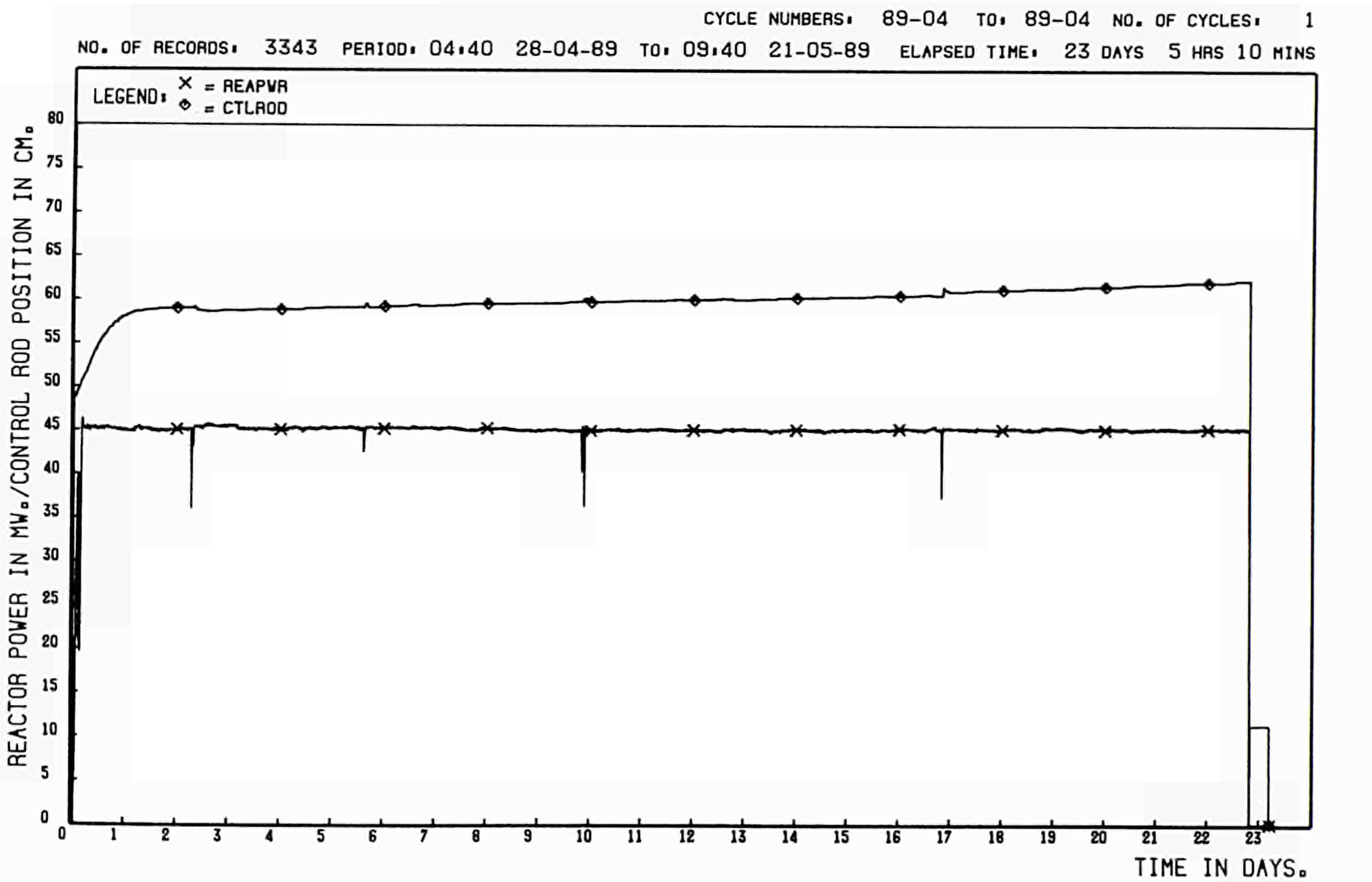
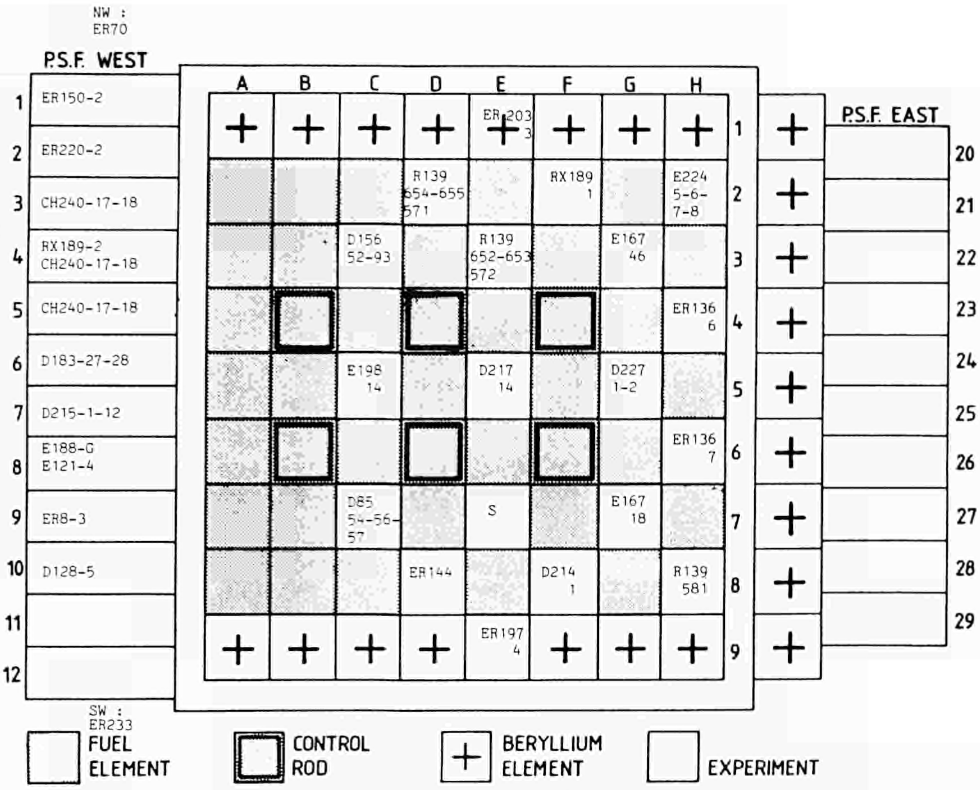


Fig. 5
HFR cycle 89.05. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



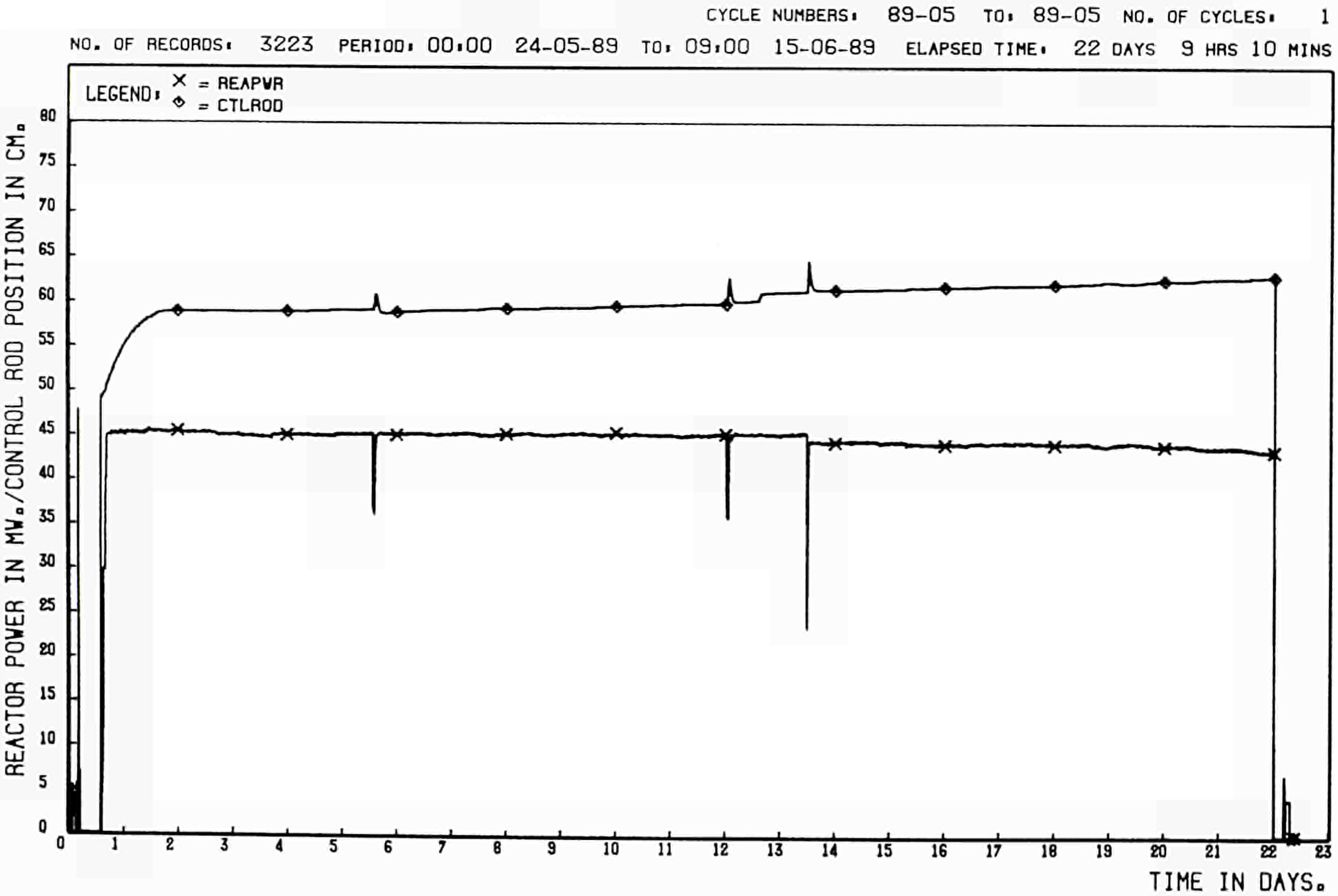
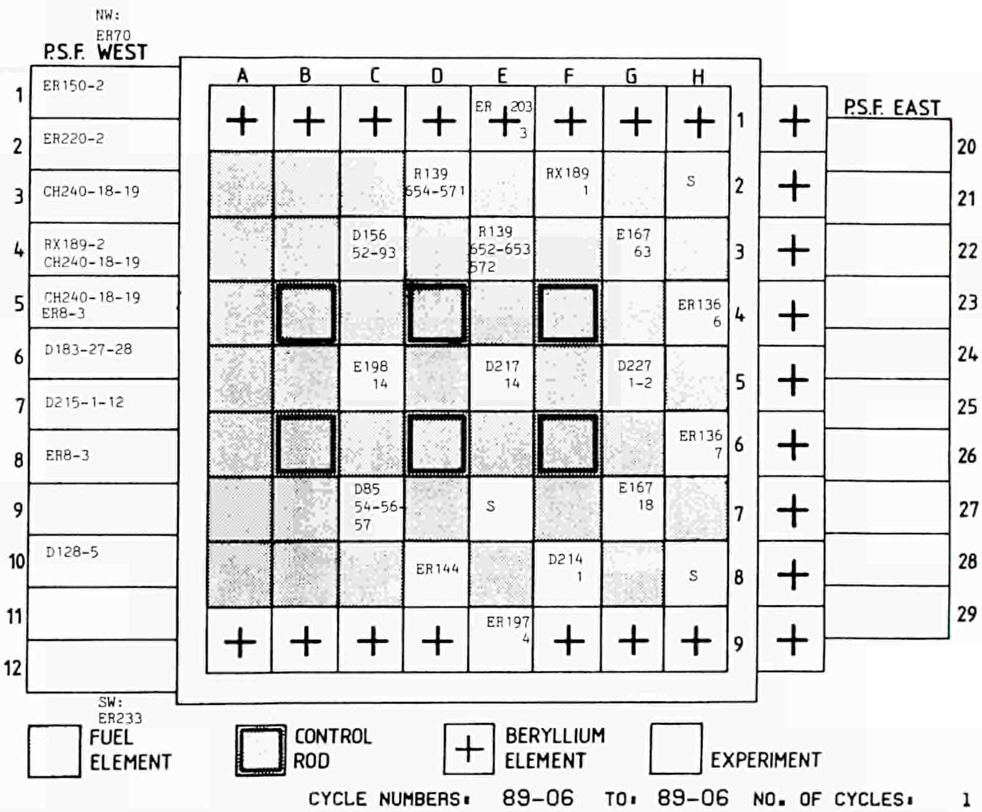


Fig. 6
HFR cycle 89.06. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



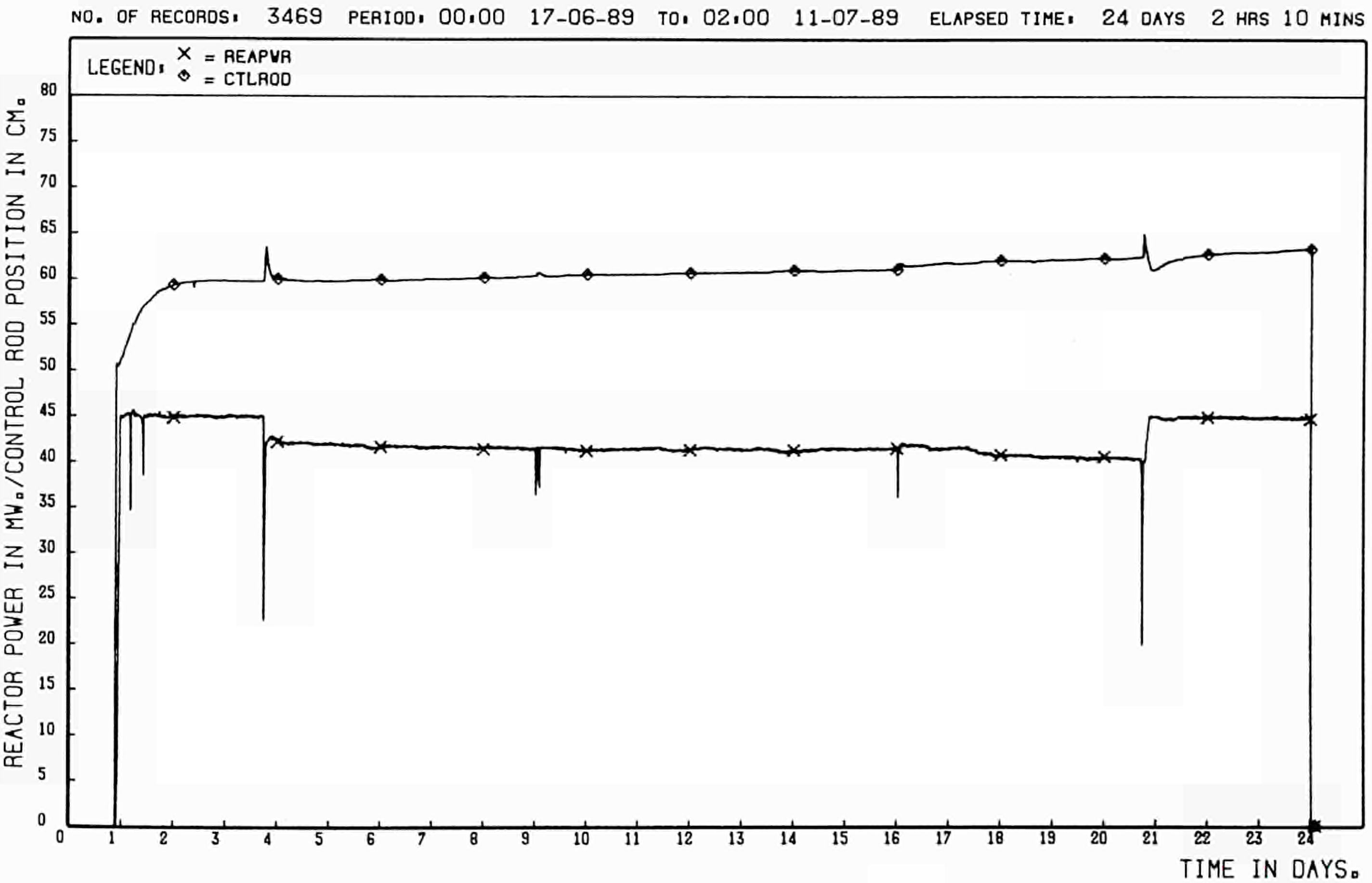
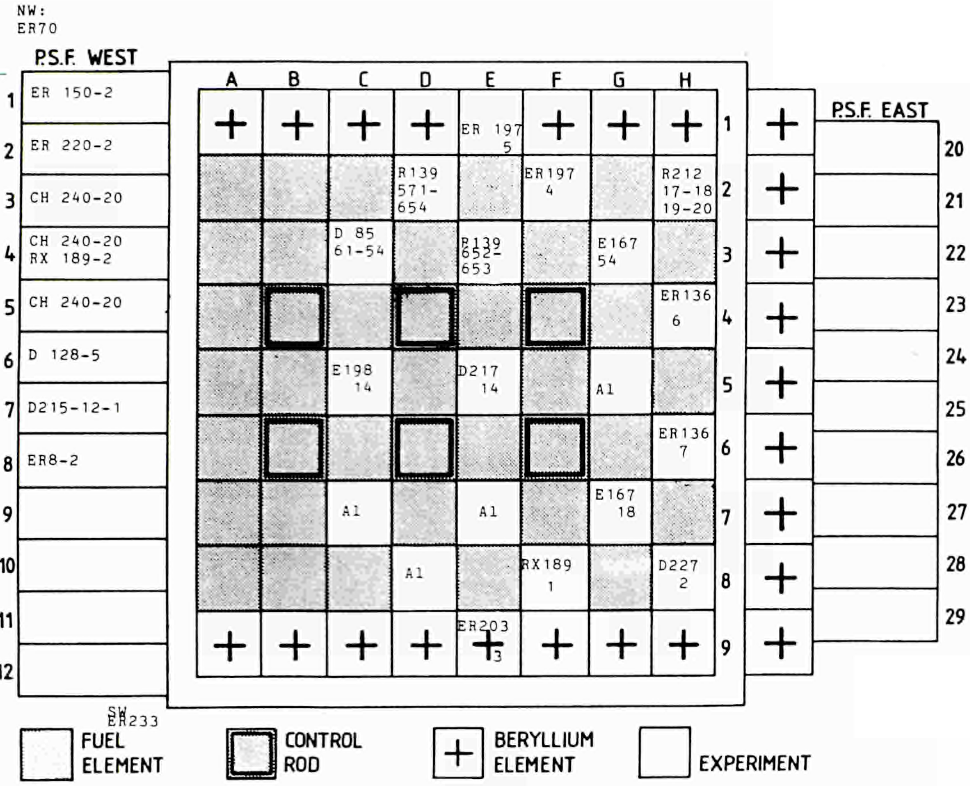


Fig. 7
HFR cycle 89.07. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



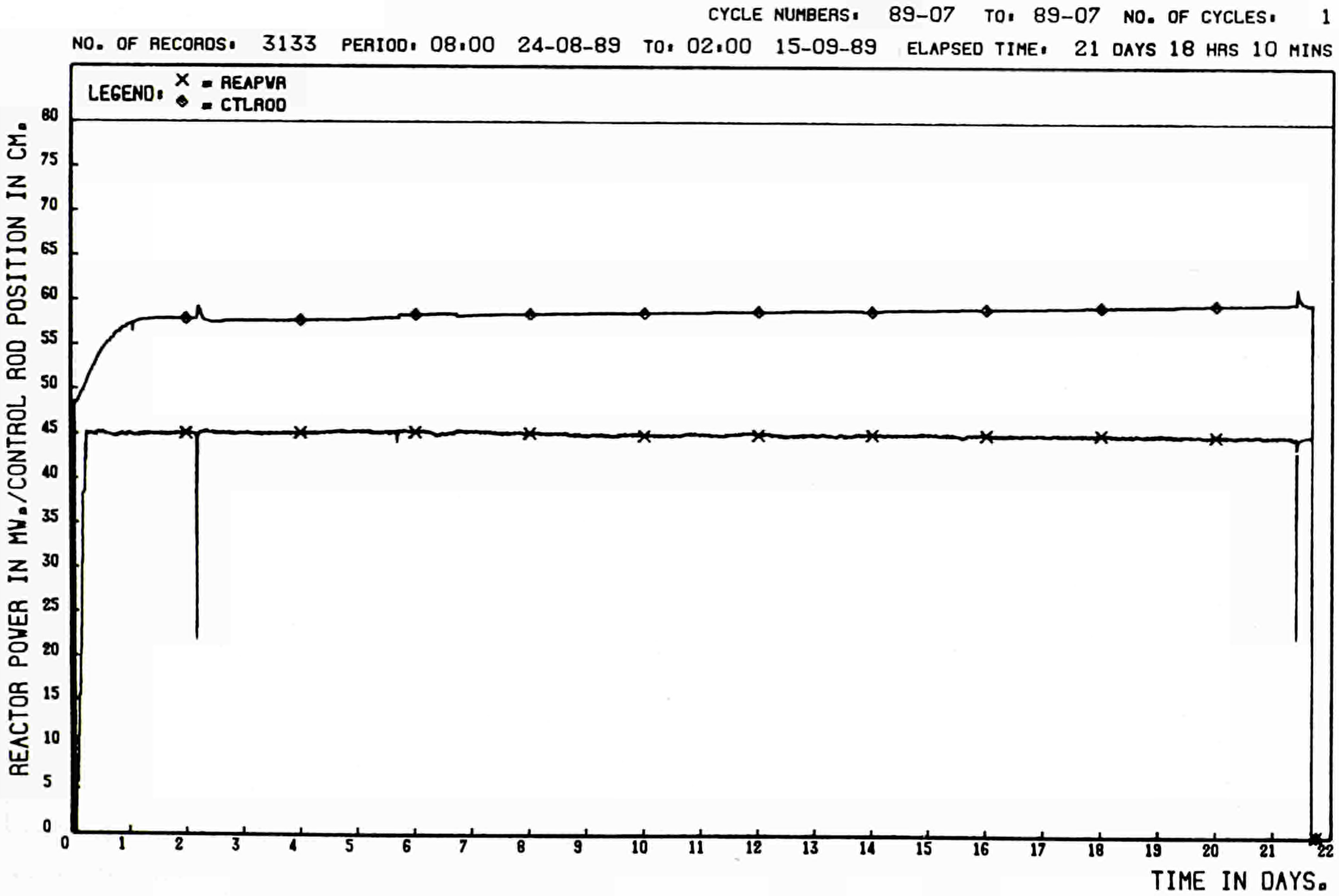
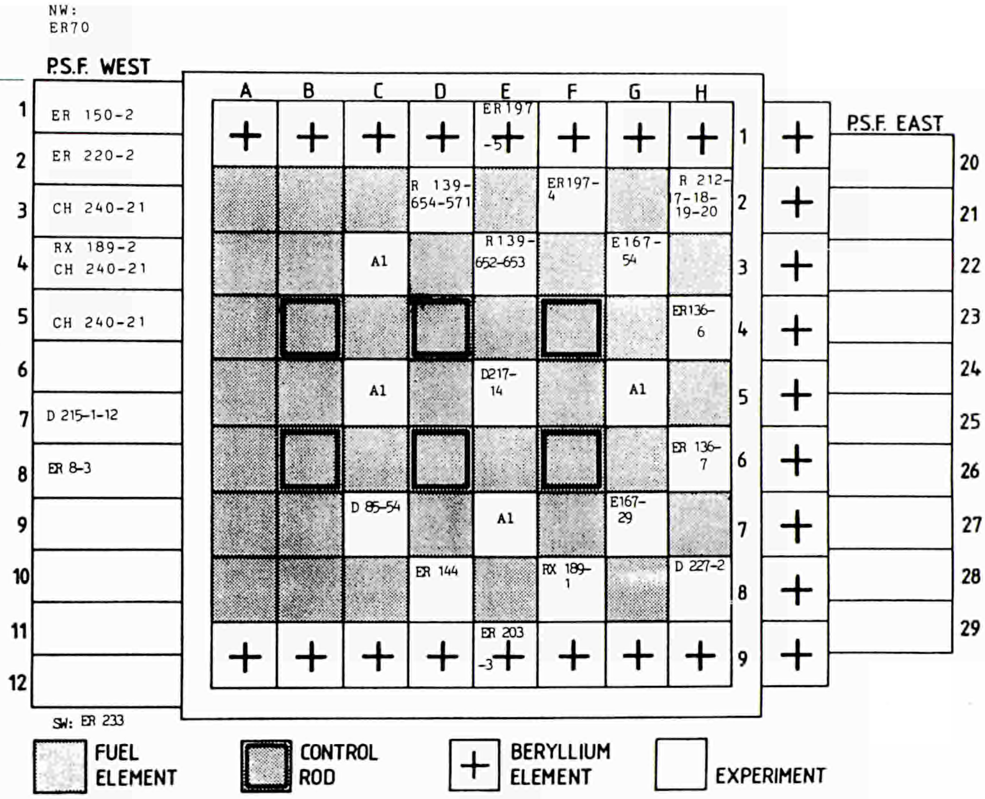


Fig. 8
HFR cycle 89.08. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



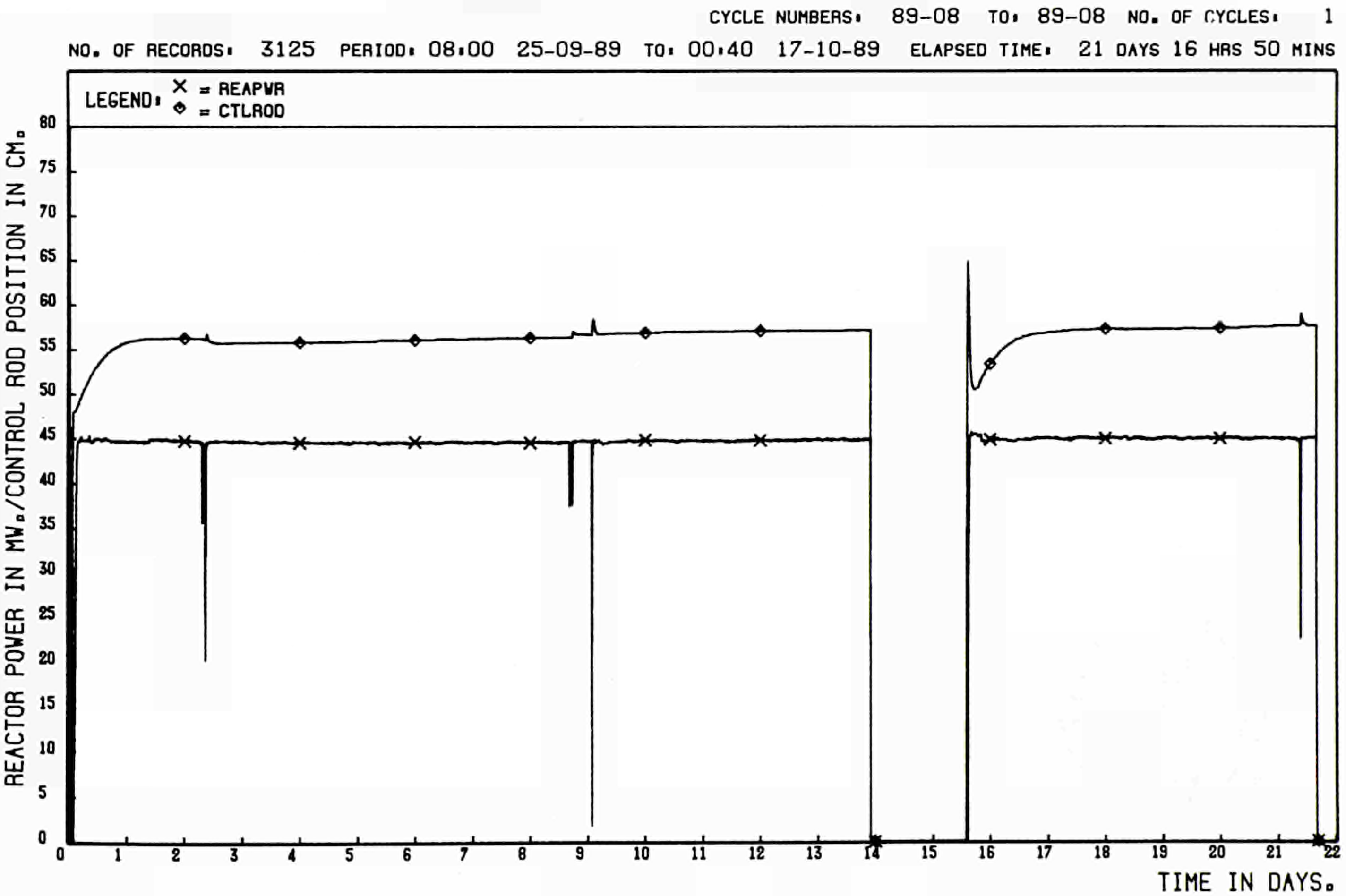
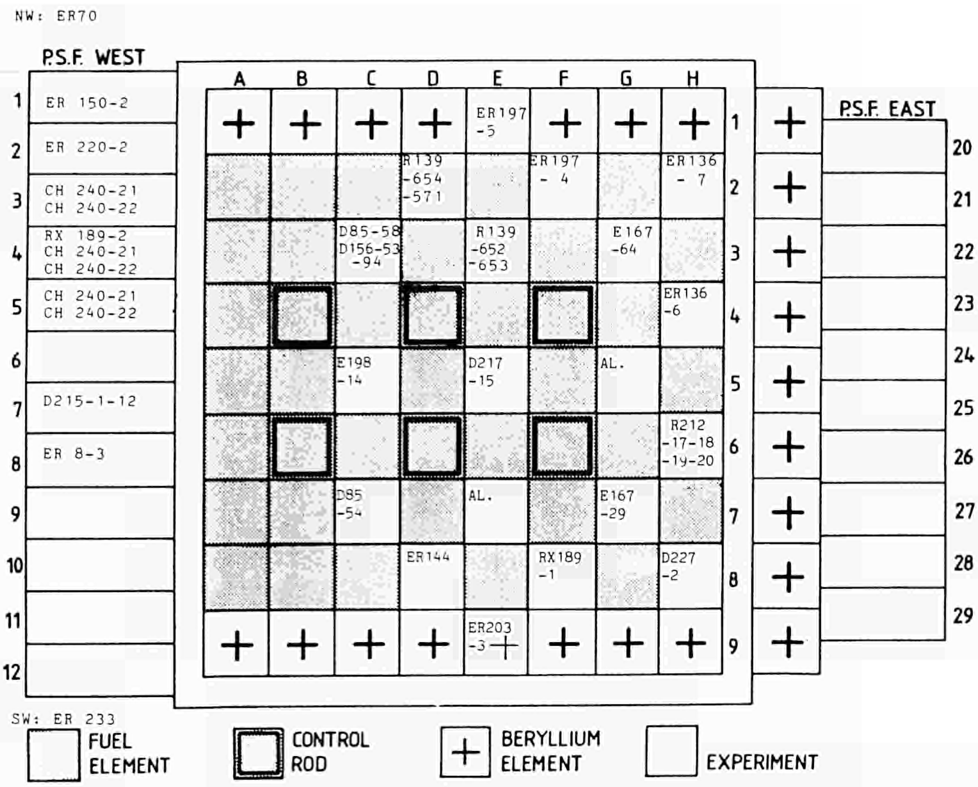


Fig. 9
HFR cycle 89.09. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.



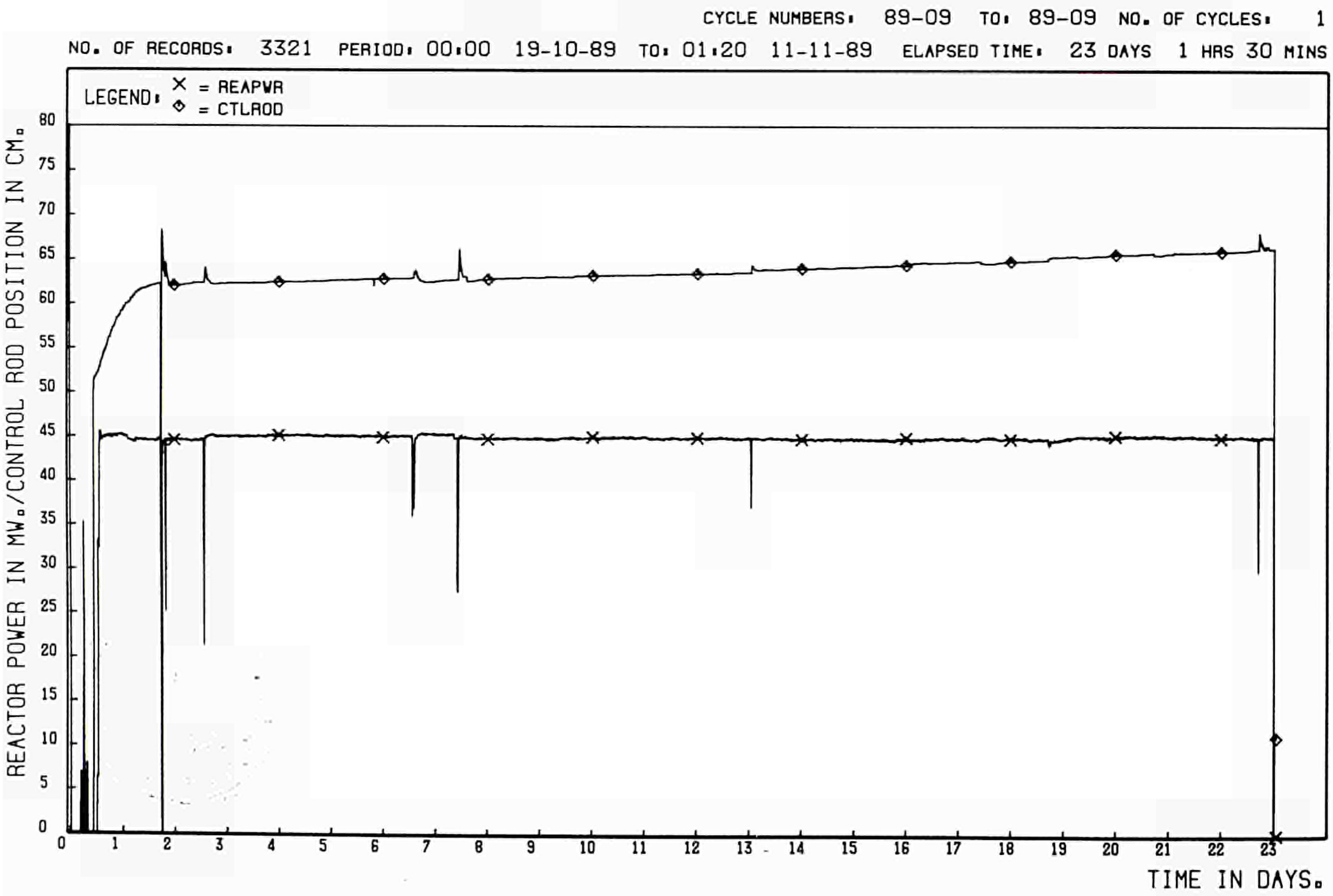
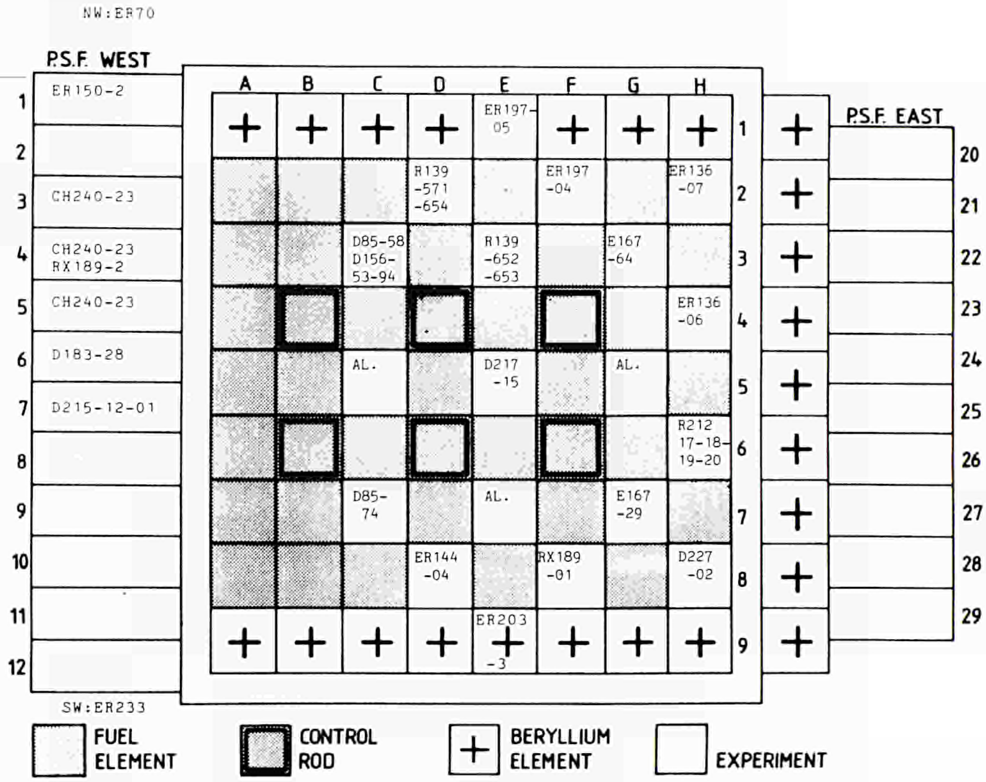
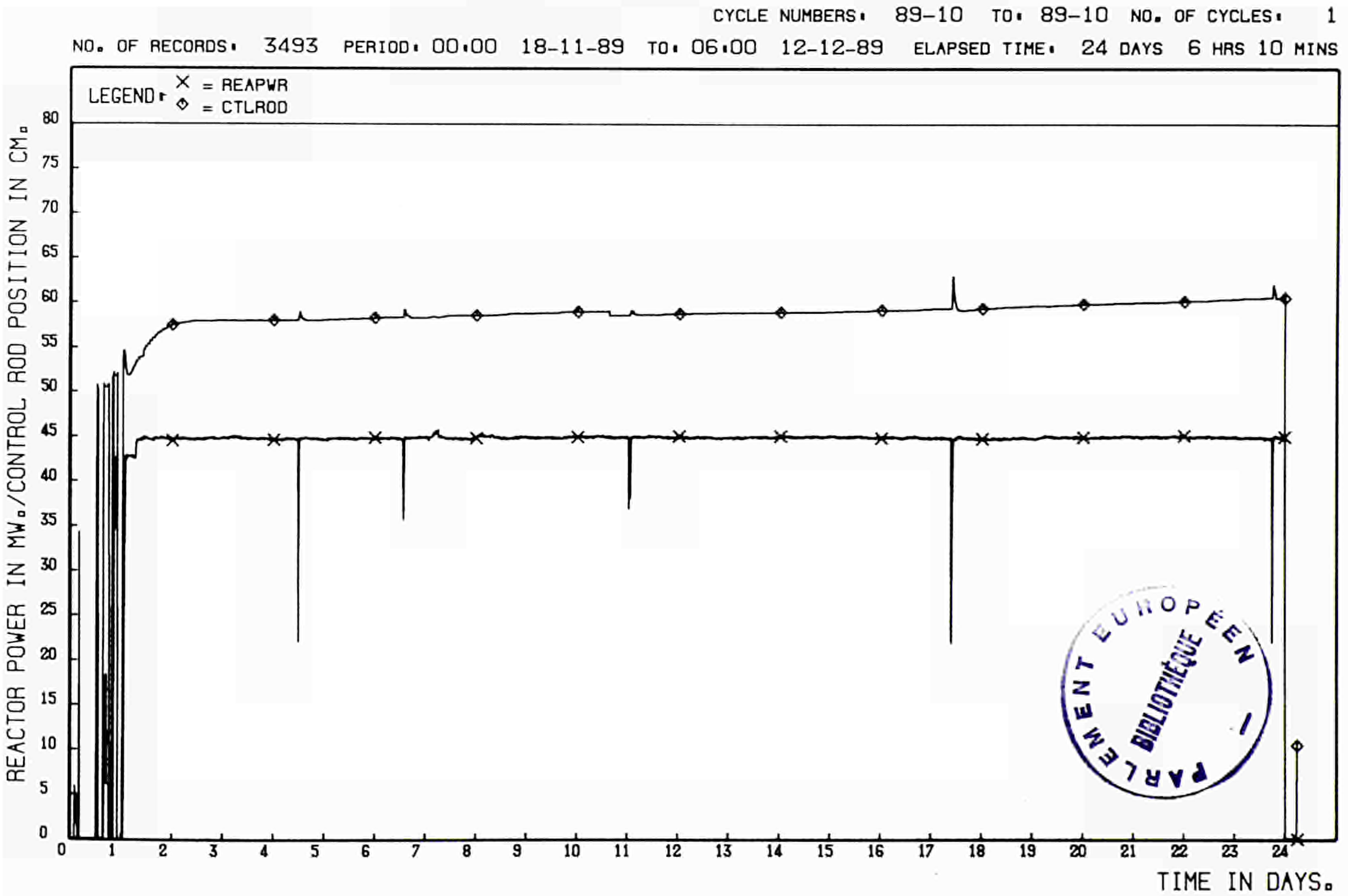


Fig. 10
HFR cycle 89.10. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.





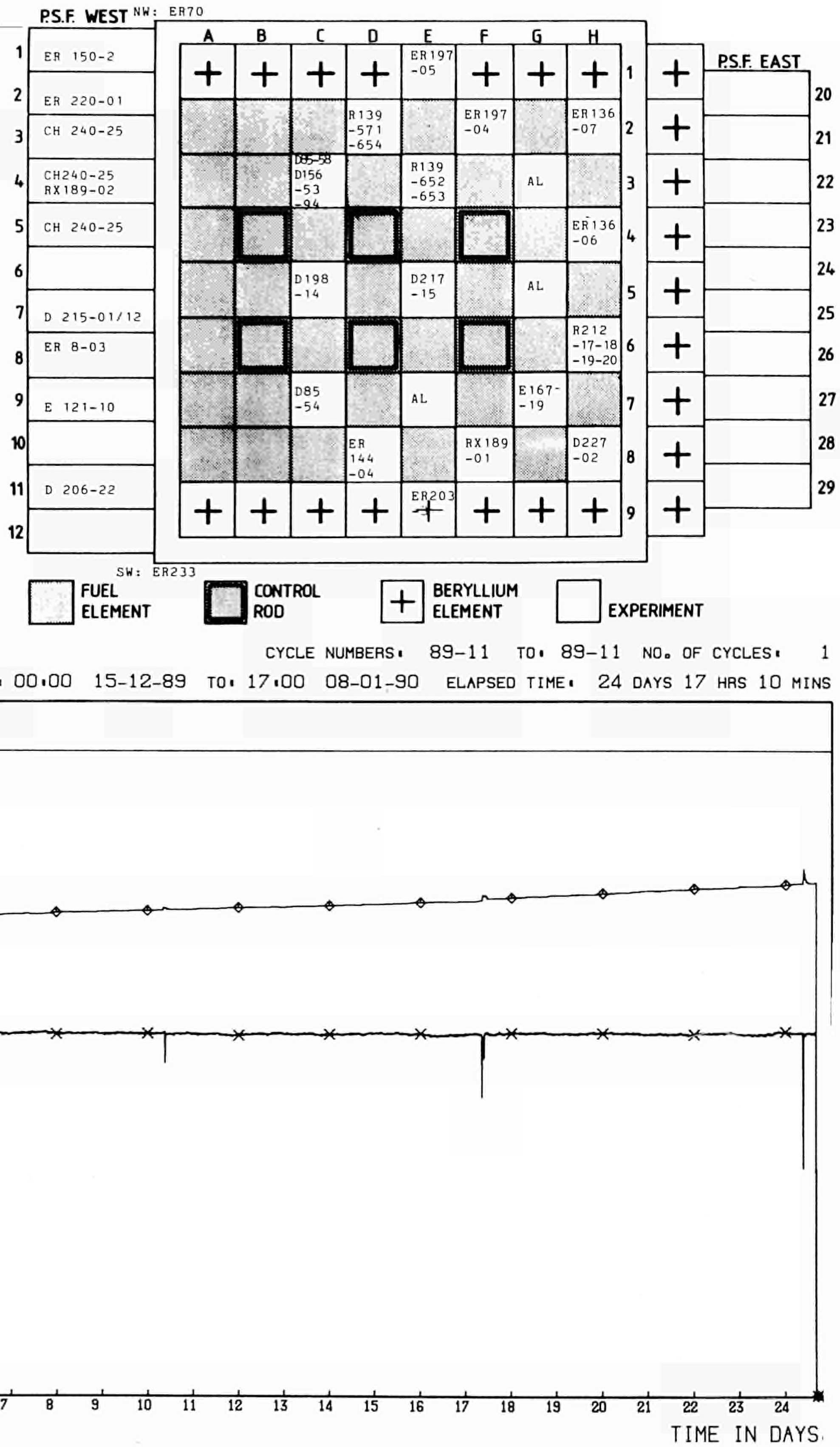


Fig. 11
HFR cycle 89.11. Experiment loading, reactor power pattern and control rod movement (in bankwise operation). Experiment codes used are explained in Table 4.

2.2. FUEL CYCLE

2.2.1. Fuel Supply

The USA authorities granted an export license for 38 kg of HEU which was delivered in October 1989. This supply, together with existing stock will assure HFR operation until autumn 1991. Negotiations have started for the purchase of a further 38 kg of HEU for delivery in 1990.

2.2.2. Fuel Management

During 1989 70 new fuel elements were delivered by the manufacturer (CERCA). Transfer of depleted HFR fuel elements to the reprocessing facility at Savannah River (USA) has been delayed pending the outcome of an environmental impact review.

At the end of the year one transport vessel containing 42 spent fuel sections was waiting shipment. Provisions for extension of the storage capacity for depleted HFR fuel are being prepared. Details on fuel delivery, consumption and fuel disposal are given in **Table 3.**

Table 3
Status of HFR fuel elements in 1989.

Delivery of new fuel elements	70
Delivery of new control rods	13
New fuel elements available for use at the end of the year	37
New control rods available for use at the end of the year	3
New fuel elements charged to the core	55
New control rods charged to the core	11
Fuel elements depleted	75
Control rods depleted	13
Depleted fuel elements in pool at the end of the year	117
Depleted control rods in pool at the end of the year	23
Depleted fuel elements prepared for shipment	35
Average burn-up of these fuel elements	50,9%
Depleted control rods prepared for shipment	7
Average burn-up of these control rods	50,2%

2.2.3. Testing of LEU Fuel Elements

In-core testing of four test elements (provided by two different suppliers) containing high density, low-enriched (20% U-235) uranium silicide fuel has been continued throughout 1989. The testing programme, which will continue up to fuel burn-up levels of 75%, comprises of neutron flux measurements, cooling gap thickness measurements and reactivity measurements during or in-between reactor cycles.

At the end of the year burn-up levels ranging from 25 to 43% had been reached for three of the elements. One test element was damaged during handling and has been removed from the reactor in order to evaluate whether further irradiation can be justified from a safety viewpoint. The test programme will be completed during 1990 after which the elements will be subjected to post-irradiation examination.

2.3. SAFETY AND QUALITY MANAGEMENT

2.3.1. Operational Safety Audit

The report of the Dutch Licensing Authority (KFD) on their 1988 audit on HFR operation was received early 1989.
The report concluded with various recommendations, related to, amongst others, reactor management and administration, quality assurance, and

training and education of reactor personnel. A working plan has been set up for the evaluation and eventual implementation of these recommendations.

2.3.2. Renewal of Technical Safety Documentation

In the context of a future renewal of the HFR Operating License, all technical safety documents, such as reactor description, detailed safety analyses and technical safety specifications are currently being updated. On the basis of these technical documents a new "public" design and safety report will be submitted to the Dutch Licensing Authorities. During 1989 the drafts for most of the internal documents have been completed and internal review of the documents has been started.

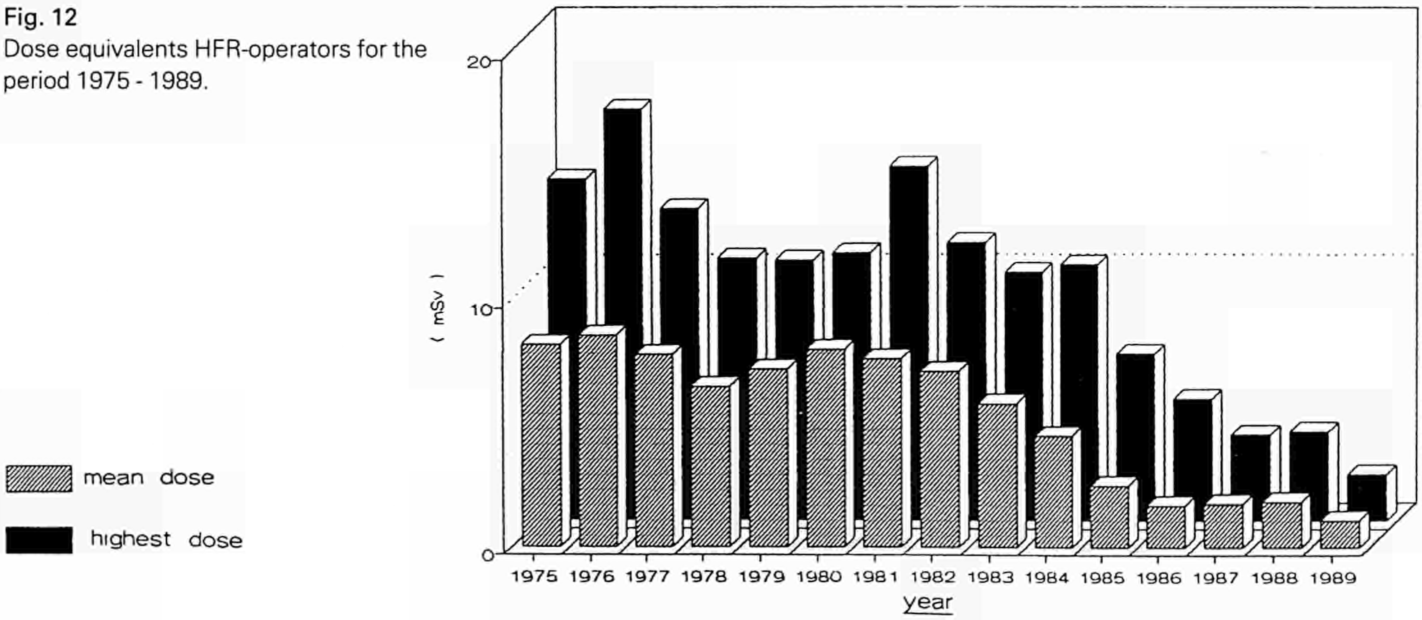
2.3.3. Quality Assurance

On the basis of an evaluation, by an external firm, of the existing Q/A procedures and provisions at the HFR a "Quality Handbook" for HFR operation has been submitted and approved by the relevant managements. Implementation of the more stringent requirements related to Q/A has led to a considerable effort in drafting new procedures and instructions.

2.3.4. Personnel Exposure

A survey of the registerd annual radiation doses of HFR operating personnel is given in **Fig. 12.** The downward trend in irradiation exposure, which commenced after the HFR vessel replacement in 1984 and which also reflects the more stringent ALARA principle followed in HFR working practices, has clearly been continued.

Fig. 12
Dose equivalents HFR-operators for the period 1975 - 1989.



2.4. TECHNICAL MAINTENANCE

Inspection, overhaul, repair and replacement of technical systems and components has been carried out according to the scheduled reactor maintenance programme. Two extended reactor shutdown periods (one in March, another in July/August 1989) have been specially devoted to major inspec- tion and maintenance activities. Some special items are described below.

Fig. 13
Control room of the data acquisition and processing system DACOS.

2.4.1. Mechanical Installations

- The balcony platform around the pools was replaced and modernized.
- A new safety cable system along the north and south sides of the reactor pool and the storage pool has been installed, in order to improve working safety during in-pool inspection and manipulations.
- Decontamination and derusting of the ion-exchanger drain tanks revealed that a complete renovation of the drain tank system was necessary. Preparations for this renovation have been started.
- In view of technical problems with the grid-bar locking system preparations for introduction of an improved system have been started.

2.4.2. Instrumentation Systems and Informatics

- The installation of a data communication network with glass fibre cables between the HFR complex and other JRC buildings has been started. This will lead to a quick data-exchange between the JRC data system and the DACOS system of the HFR.
- The transient data registration system, newly installed in DACOS, has been tested and became operational. The smallest transient interval is 0.2 s (frequency 5 Hz).
- At the horizontal beam tube facilities new area radiation monitors have been installed.

2.4.3. Electrical Installations

- An improved intercommunication system for the HFR complex has been installed.
- Several new cabinets for electrical power distribution have been manufactured and installed.
- Provisions for connecting the HFR to the renovated emergency power station at the ECN site have been installed. During the replacement of the emergency diesel generators a standby diesel unit has been installed and operated at the HFR site.

2.4.4. Buildings and Site

- Technical specifications have been drafted for the renovation of the secondary pump building and the main transfer building adjacent to the HFR containment.

— Plans for a future extension of the HFR building (for storage and transfer purposes) have been further developed.

2.4.5. General Irradiation Provisions

— The DACOS-system for the acquisition, registration and evaluation of irradiation data has been further extended and improved (see also 2.4.2.).

— Functional specifications have been elaborated for the development and design of an automated gas-mixing system for the temperature control of irradiation devices.

— The BF_3-system, by which BF_3-gas can be supplied for dynamic flux and power control of fuel irradiation devices and which had originally been developed for an earlier ECN experiment (POTRA), has been converted into a general service system. In June the MOKA-irradiation device (exp. D227) has been connected to the BF_3-system for operation at pressures up to 50 bar.

2.4.6. Standard Irradiation Devices

— The HIFI isotope irradiation facility has been adapted for easier in-pool and in-reactor manipulation. In April the facility has been re- commissioned by the (successful) test irradiation of two iridium samples.

2.5. TECHNICAL AND EXPERIMENTAL SUPPORT

2.5.1. Containment Building Leakage Test

In March 1989 the four-yearly extended leak-tightness test of the HFR containment building has been carried out. The internal overpressure during the test was 0.5 bar. Prior to the test all procedures and provisions related to the execution of the test had been updated and stringently documented, in accordance with the new quality assurance system which was introduced in 1989. The test was carried out in the presence of representatives of the Dutch nuclear inspectorate. The test lasted for 24 hours. An effective leakage rate of 0.052 vol % per day (with a standard deviation of 0.005% was measured). This value satisfies the licensing requirement for the HFR containment building, which is that the leakage rate at 0.5 bar overpressure should not exceed 0.1 vol % per day.

2.5.2. Reactor Vessel Material Surveillance ("SURP"-project)

In order to study the irradiation induced changes in the material of the HFR reactor vessel various aluminium samples are being irradiated in the reactor core (pos. H6 and F2) and in the poolside irradiation facility (pos. 4). At the end of 1989 (calculated) fluence values have been reached of 1.64×10^{26} n/m^2 (fast, i.e. ϕ (>0.1MeV)) and 1.03×10^{26} n/m^2 (thermal, i.e. ϕ (>0.414 eV)).
These values can be compared to the neutron fluence values to which the walls of the core section of the reactor vessel were subjected since the vessel was put into operation in 1985. Typical neutron fluence values for the vessel wall sections are:

North 0.28×10^{26} n/m^2 fast and 0.72×10^{26} n/m^2 thermal
East 0.83×10^{26} n/m^2 fast and 0.94×10^{26} n/m^2 thermal
South 1.27×10^{26} n/m^2 fast and 0.99×10^{26} n/m^2 thermal
West 1.64×10^{26} n/m^2 fast and 1.03×10^{26} n/m^2 thermal

Several neutron fluence monitors have been removed and replaced from the SURP irradiation devices during 1989 but the analysis of these and earlier withdrawn monitors has not yet taken place.

2.5.3. In-Service Inspection

The final report on the in-service inspection of the reactor vessel, carried out in 1988, has been completed and submitted to the relevant review bodies. The next in-service inspection is foreseen for 1992.

2.6. UPGRADING AND MODIFICATION PROJECTS

2.6.1. Replacement of Pool Heat Exchanger

Objective:
To increase the heat removal capacity of the pool cooling system in order to maintain an acceptable (> 38°C) pool temperature during summer conditions in case of a future HFR power increase.

Progress:
The new pool heat exchanger was installed in March 1989. An extensive testing program for measuring pressure drops and heat removal capacity was carried out with positive results. All associated technical documentation has been completed.

2.6.2. Replacement of Beryllium Elements

Objective:
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:
All new in-core elements have been delivered at the end of 1988. A Design and Safety Report has been written and reviewed by the Reactor Safety Committee. At the end of 1989 introduction of the elements in the reactor core started.

2.6.3. Introduction of a Second Reactor Power Safety Protection System

Objective:
To provide redundancy and diversification for the present 3-channel flux protection system.

Progress:
The manufacture of the new system was completed in 1988. In 1989 the system was installed and tested without being incorporated in the safety interlock system. Pending approval by the various safety bodies this incorporation will take place in early 1990.

2.6.4. HFR Control Room Upgrading

Objective:
Reconfiguration and upgrading of HFR control room functions and equipment in order to replace outdated components and to introduce modern ergonomic principles with regard to information access and display.

Progress:
As part of the design study a report has been submitted, adapting earlier specifications to the required modular renewal which is to be realized in several phases.
The next step in the preparation phase comprises the compilation of all required functional and technical specifications.

2.7. NUCLEAR SUPPORT

2.7.1. HFR Core Characteristics

Nuclear Heating Measurements (TRAMP-project, RX 161)
A comprehensive series of measurements on the nuclear heating in several irradiation positions was carried out in 1986 and 1987. The data have been reported in ECN 88-104 and ECN 88-105. Detailed information on the heating values in graphite, stainless steel and aluminium became available. Additional measurements have been performed during cycle 89.04 (position E7). During the handling afterwards the measuring device became de-

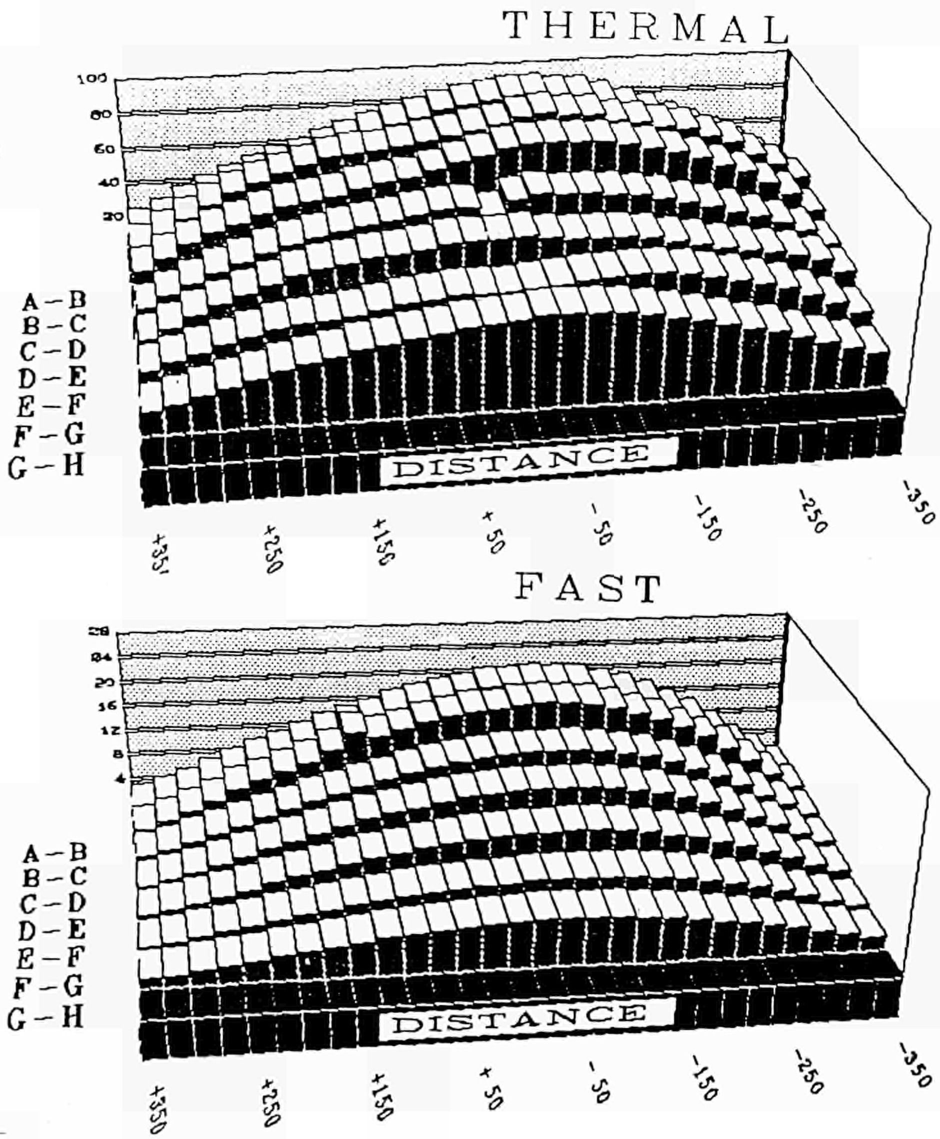


Fig. 14
Vertical relative thermal and fast fluence rate distributions at the north side of the reactor (measured between the beryllium reflector and the core box wall).

fective. A new calorimeter type device is being designed which also fits in the new (72 mm bore) filler elements.

2.7.2. Fuel Storage Analysis

A study was made to improve the facilities for storage of fuel elements and control rods. Many reactor physics calculations were performed to analyse the criticality aspects of various geometries under different conditions with old and new computer code packages.
Reports for submission to the Reactor Safety Committee have been prepared and the required actions were taken.

2.7.3. User Support

Neutron Flux Characterization for the BNCT-Facility
In connection with plans for the design and construction of a BNCT (Boron Neutron Capture Therapy) facility at HB11 of the HFR, thermal and fast neutron fluence rate measurements and neutron spectrum adjustments have been performed for the entrance of HB11, as part of a feasibility study.

Figure 14 shows some vertical fluence distributions. The activation monitor holders were always positioned in the wedge-shape channel between two beryllium assemblies and the core box wall. Since HB11 is not yet available for an optimalisation study on filtered beam parameters, the smaller beam HB7 was used. Several neutron spectrum measurements have been performed in the period July-September, to validate neutron spectrum data calculated by AERE Harwell.

Three different core configurations have been envisaged with various occupations of the core positions F9, G9 and H9: Be/Be/Be, Al/Al/Al and Al/F/Al in which Be, Al and F stand for a beryllium reflector assembly, an aluminium filler assembly and a fuel assembly respectively. **Figure 15** shows the neutron spectrum at the entrance of HB7 for configuration Al/Al/Al.

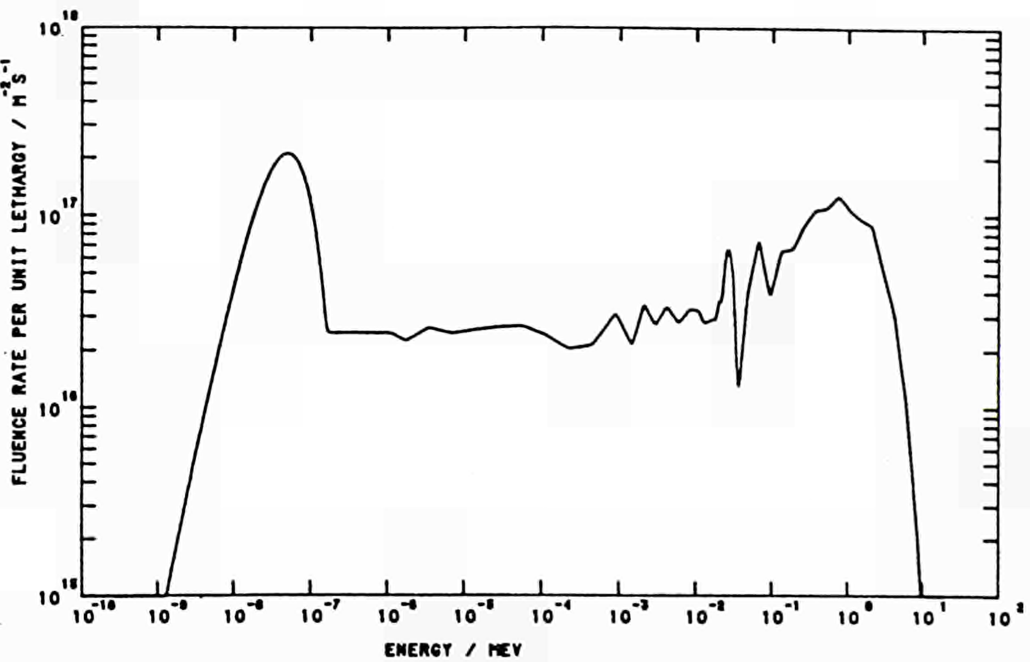


Fig. 15
Adjusted neutron spectrum valid for the entrance of HB7.
Core configuration Al/Al/Al.

2.7.4. Methods Development

Neutron Fluence Monitor Development
In order to limit the radiation from activated fluence monitors even after very long irradiation periods, a choice was made for a far-reaching miniaturisation of monitors and if needed the application of diluted materials. So the preparation of a standard monitor set (figure 16) led to handling, weighting and encapsulation of very small pieces of material, i.e. nickel-cobalt monitors with diameter of 0.1 mm, a length of 1 mm and a mass of 0.07 mg.

As a result from the collaboration in the Subgroup Monitor Materials of the Euratom Working Group on Reactor Dosimetry (EWGRD) between JRC Geel (Central Bureau for Nuclear Measurements) and ECN, the development has started on a new vanadium alloy monitor containing 1.5% titanium, 1% iron, 0.1% nickel and 0.0005% cobalt. JRC Geel has just finished the preparation of a wire (diameter 1 mm) of the new materials.
Irradiations in the HFPIF are planned to measure the homogeneity of the alloy. In case of succes, 4 monitors, under which the very small nickel-cobalt monitor, are replaced by one monitor with a length of 5 mm.

Revision of Nuclear Data
A complete revised version of the Nuclear Data Guide has been presented at the 54th meeting of the EWGRD at Petten. The report has been published as a EUR report.

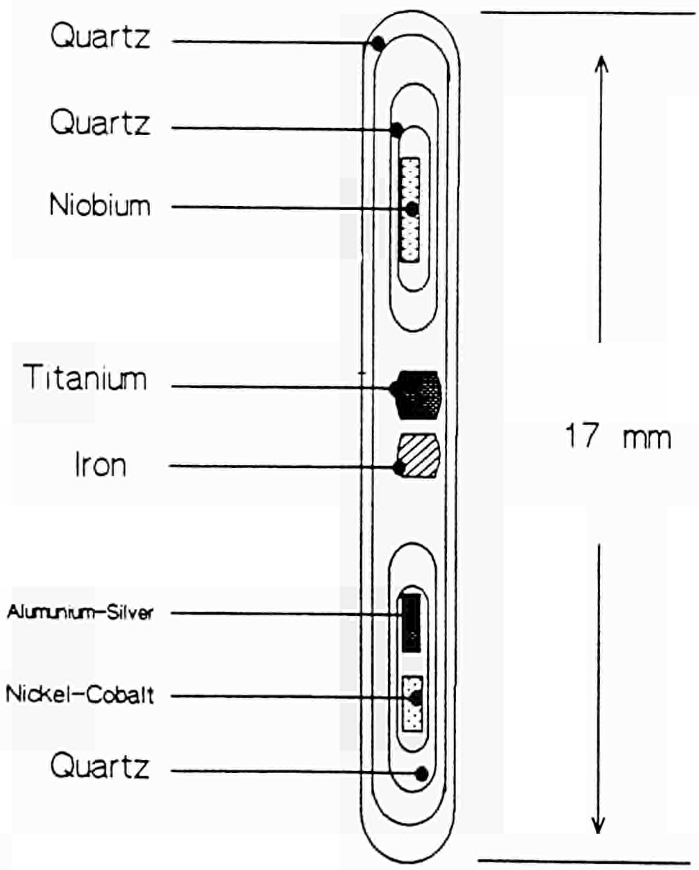


Fig. 16
Monitor set.

3. HFR UTILIZATION

In 1989 the average occupation of the HFR by experimental devices was 72% of the practical occupation limit.
A list of irradiation projects is given in **Table 4.** Results are discussed below for each of the programme sectors.

3.1. LIGHT WATER REACTOR (LWR). FUEL AND STRUCTURAL MATERIAL IRRADIATIONS

The LWR irradiation programmes in the HFR address primarily fuel irradiation experiments with pre-irradiated fuel rod segments (rodlets) emanating from commercial power reactors (BWR and PWR).
Since 1976 more than 250 pre-irradiated LWR fuel rods have been tested in the HFR in various programmes. 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 latest test series addressed the dynamics of transient effects. As these tests required more and better instrumentation, as well as more refined techniques for operation in the HFR and for the pre- and post-irradiation examination, the number of test per year has been gradually reduced from approx. 30 tests to a number around 10 tests.

The major topics of the 1989 LWR fuel irradiation programmes are:
— fuel rod behaviour at extended burn-up
— transient fission gas release
— restructuring of fuel at constant temperature operation
— irradiation behaviour of PHWR fuel
— iodine release under simulated in-pile LOCA conditions.

Most of the above irradiation programmes required new test devices, therefore, most of the 1989 activities were related to development work on the new irradiation devices. It is anticipated that most of the new test devices will become operational during the first part of the next reference period and contribute to an increase of the HFR utilization.

Together with a member of the CEC Delegation in Tokyo and the HFR Division agent in Japan for HFR irradiation services (Nissho Iwai) approx. 12 Japanese institutes and industry were visited and informed about the HFR capabilities related to LWR fuel testing.

D125, D176, D178, D201. Power Ramp Tests of Pre-irradiated LWR Fuel Rods *1., 2., 3.*

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.

During 1989 the development and preparation of the "low power" BWFC capsule and the re-instrumentation technique for pre-irradiated fuel rods were continued.

Fig. 18 provides an overview of the in-cell assembly device for the re-instrumentation of pre-irradiated LWR fuel rods.
The post-irradiation examinations on 24 fuel rods were finalized at the Petten hot cells. All fuel rods were then transported to the SIEMENS UB KWU hot cells.

LIST OF ACTUAL IRRADIATION PROJECTS

Exp. Code	Fill. elem.	Irrad. Position	Description	Inst.	Person in charge	Irradiation 89	90	91	ECN/JRC proj. nr.	Remarks
ER 8	—	P	HF-PIF	ECN	Nolten	X	X	X	—	
R 9,11	—	HB1,3	Triple axis spectrometer	ECN	van Dijk	X	X	X	3260	
R 10,14	—	HB2,7	N-G-research	ECN	Abrahams	X	X	X	3261	
R 12 13	—	HB4,5	Neutron diffraction	ECN	van Dijk	X	X	X	3260	
ER 70	—	spec.	PROF	ECN	Nolten	X	X	X	—	
D 85	72/74/76	C	Intermed. + high temp. graph.	JRC	Tartaglia	X	X	X	7307AAP2	more nrs.
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	3260	
RX 117	—	P/C	Reactor noise studies	ECN	Turkcan	1)	1)	1)	1417	
DR 121	—	P	Development LWR irrad. dev.	JRC	Markgraf	X	X	X	—	
D 125	—	P	Power ramp experiments	JRC	Markgraf	X	X	X	7307APP2	more nrs.
D 128	—	P	Fuel stack displacement	JRC	Markgraf	X	X	X	7307BAP2	more nrs.
R 130	—	HB11	Mirror-system	ECN	Abrahams	X	X	X	3261	
ER 136	74	C/P	FIT	JRC	Konrad	X	X	X	73829321	
D 138	74	C	BEST	JRC	Conrad	X	X	X	7307BIP2	more nrs.
R 139	72	C	SINAS	JRC	Tsotridis	X	X	X	7307IAP2	more nrs.
ER 144	72	A	HIFI	JRC	Konrad	X	X	X	73829321	
ER 150	—	(P)	Neutrografie kamera	ECN	Leeflang	X	X	X	—	
D 156	72	C	DISCREET	JRC	Cundy	X	X	X	7307BQP2	more nrs.
E 157	72	C	CRISP	JRC	Cundy	X	X	X	730814P2	
RX 161	52/72	C	TRAMP	ECN	Nolten	X	X	X	—	
E 167	72	C	TRIESTE	JRC	Cundy	X	X	X	730813P2	
FR 169	—	HB8	ILONCA	ECN	Leeflang	X	X	X	—	
D 176	—	P	Power ramp experiments	JRC	Markgraf	X	X	X	—	(see also D125)
D 178	—	P	Power ramp experiments	JRC	Markgraf	X	X	X	—	(see also D125)
D 183	—	P	KAKADU	JRC	Moss	X	X	X	7307FAP2	
ER 185	—	C	AUGIAS	ECN	Nolten	X	X	X	—	
DR 188	—	P	BWFC without fuel	JRC	Markgraf	X	X	X	—	
RX 189	72	C/P	SURP	ECN	Nolten	X	X	X	—	
D 192	72	C	OPOST	JRC	Moss	X			7307FGP2	more nrs.
D 195	—	P	Power Ramp BWR-Fuel	JRC	Markgraf	X	X	X	—	(see also D125)
ER 197	—	A	COBI	ECN	Nolten	X	X	X	—	
E 198	74/76	C	FRUST	JRC	Tartaglia	X	X	X	730815P2	
D 201	—	P	Power PWR-fuel	JRC	Markgraf	X	X	X	—	
D 202	—	P	SUPRA	JRC	Tartaglia	X			7307FQP2	more nrs.
ER 203	72	A	CORRI	ECN	Nolten	X	X	X	—	
D 206	—	P	ISOLDE	JRC	Markgraf	X	X	X	7307CAP2	more nrs.
ER 209	—	-	GIF	ECN	Nolten	X	X	X	—	
ER 210	—	-	PR	ECN	Nolten	X	X	X	—	
E 211	72	C	NILOC	JRC	Moss	X			730346P2	
R 212	74	C	EXOTIC	JRC	Conrad	X	X		7307ISP2	more nrs.
D 214	72	C	"GA-rods"	JRC	Conrad	X			7307OGP2	
D 215	72	P	RELIEF	JRC	Moss	X	X	X	7307GAP2	
D 217	—	C	CERAM	JRC	Tsotridis	X	X		7307FWP2	more nrs.
ER 220	—	P	SIP	ECN	J.F.J. Visser	X	X	X	—	
R 221	—	HB12	filtered beam facility	ECN	Abrahams	X	X	X	3261	
E 224	74	C	LIBRETTO	JRC	Conrad	X	X	X	730812P2	
E 226	—	P	POMPEI	JRC	Moss	X			730346P2	
D 227	72	C/P	MOKA	JRC	Markgraf	X	X		7307GGP2	more nrs.
E 228	72	C	BUMMEL	JRC	Moss	X			730346P2	
E 230	72	C	PROFI	JRC	Conrad			X	—	
ER 231	—	fuel elem.	SIMONE	ECN	Pruimboom	X	X		0357	
ER 233	—	spec.	SIDO	ECN	J.F.J. Visser	X			—	
D 235	—	P	TRAGA	JRC	Moss		X	X	—	
D 237	52	C	ELIMA-2	JRC	Conrad	X			73076MP2	
D 239	—	P	ROSI	JRC	Markgraf	X			—	
CH 240	—	3(5) x P	IRMA	JRC	Cundy	X	X	X	—	
D 241	—	P	GRIPS	JRC	Tartaglia	X	X		7307CPP2	
S 242	—	-	CIEMAT	JRC	Husmann		X		Spanish	MTR fuel handling
ER 243	72	C	LIMO	JRC	Konrad	X			73829321	
R 244	—	GIF	HEISA	ECN	Nolten	X			—	in ER209
D 245	72	C	NEMESIS	JRC	Tartaglia		X	X	—	

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
BEST = Brenn-Element SegmenT
BUMMEL = fiss-gas BUbbles (M) Mobility study (EL)
BWFC = Boiling Water Fuel Capsule
CERAM = net CERAMics
CIEMAT = CIemat-Elements MAnipulations for Transport
COBI = COBalt Isotope production
CORRI = COBalt 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
HEISA = HEated and Instrumented SAlt Irradiation
HF-PIF = High Flux Poolside Isotope Facitily
HIFI = HIgh Flux facility for Isotopes
ILONCA = Installation of a Long Object Neutron CAmera
IRMA = IRradiation of MinerAls
ISOLDE = Iodine SOLubility and Degassing Exp.
KAKADU = KAmin KApsel-DUo
LIBRETTO = LIquid BReeder Experiment with Tritium Transport Option
LIMO = Lamella Irradiation of MOlybdenum
MOKA = Misch OXyd-brennstäbe
NAST = NAtrium STaal bestraling
NEMESIS = NEt MEtalS IrradiationS
NILOC = NItride fueL irradiation in (O) Cd-screen
OPOST = Over POwer Steady state exp.
POMPEI = Pellets Oxyde Mixte, PEtten Irradiation
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
SUPRA = irradiation of SUPRA-conducting materials
SURP = SURveillance Program
TRAGA = TRAnsient GAp conductance measur.
TRAMP = TRAvelling Measuring Probe
TRIESTE = TRio Irrad. Exp. of Steel sampl. under TEnsion

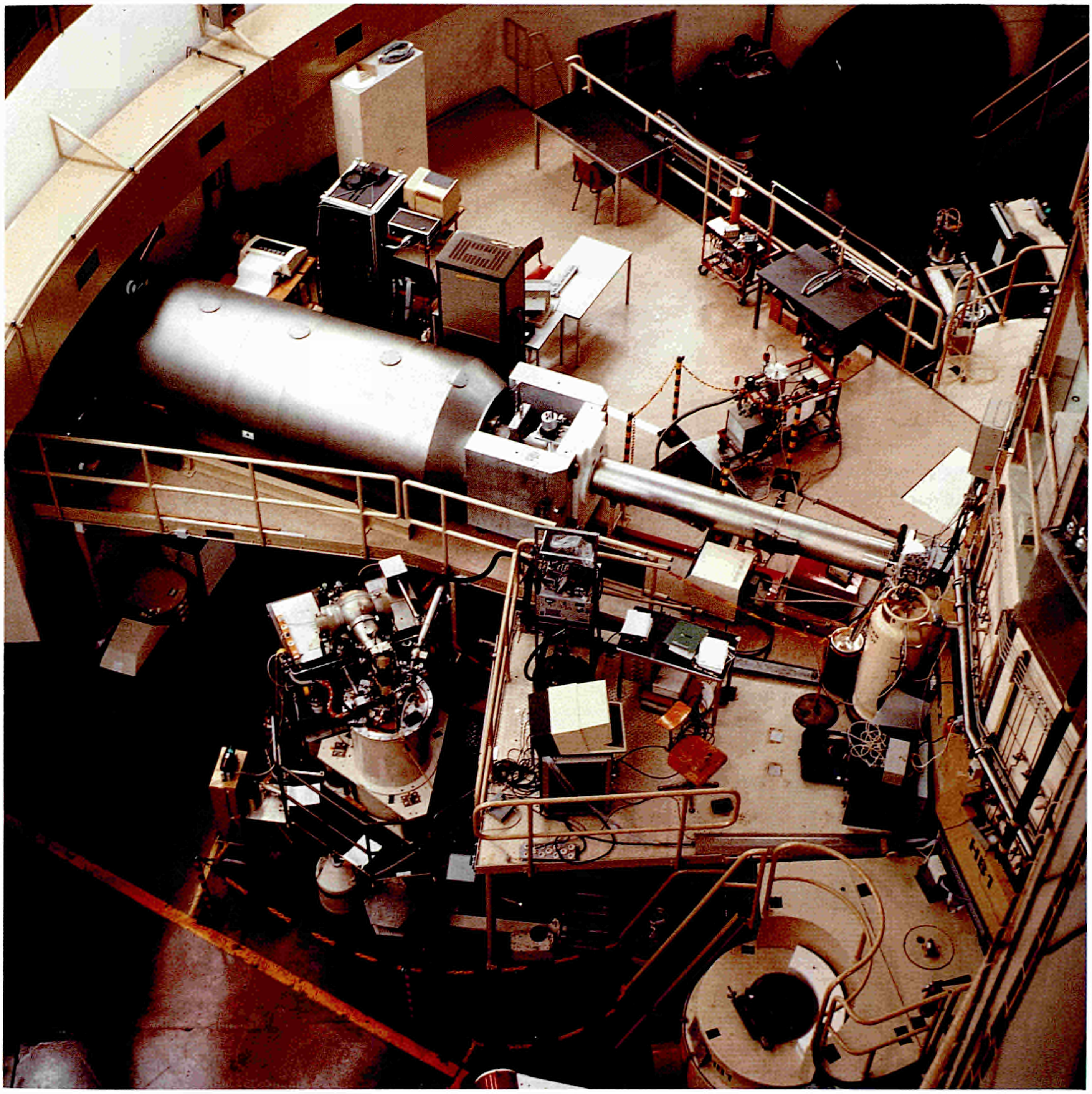


Fig. 17
Experimental equipment around the horizontal beam tubes.

◁ **Table 4**
List of actual irradiation projects.

5 pre-irradiated fuel rods were received from SIEMENS UB KWU for power cycling or power ramp testing using the "low power" BWFC capsule. The preparative works at these fuel rods prior to HFR testing were started.

"Fachausschuss KFA/KWU Rampentest" meetings were held in June and November in order to review the current programmes and to decide on the future programme. Approx. 10 tests are anticipated for the next

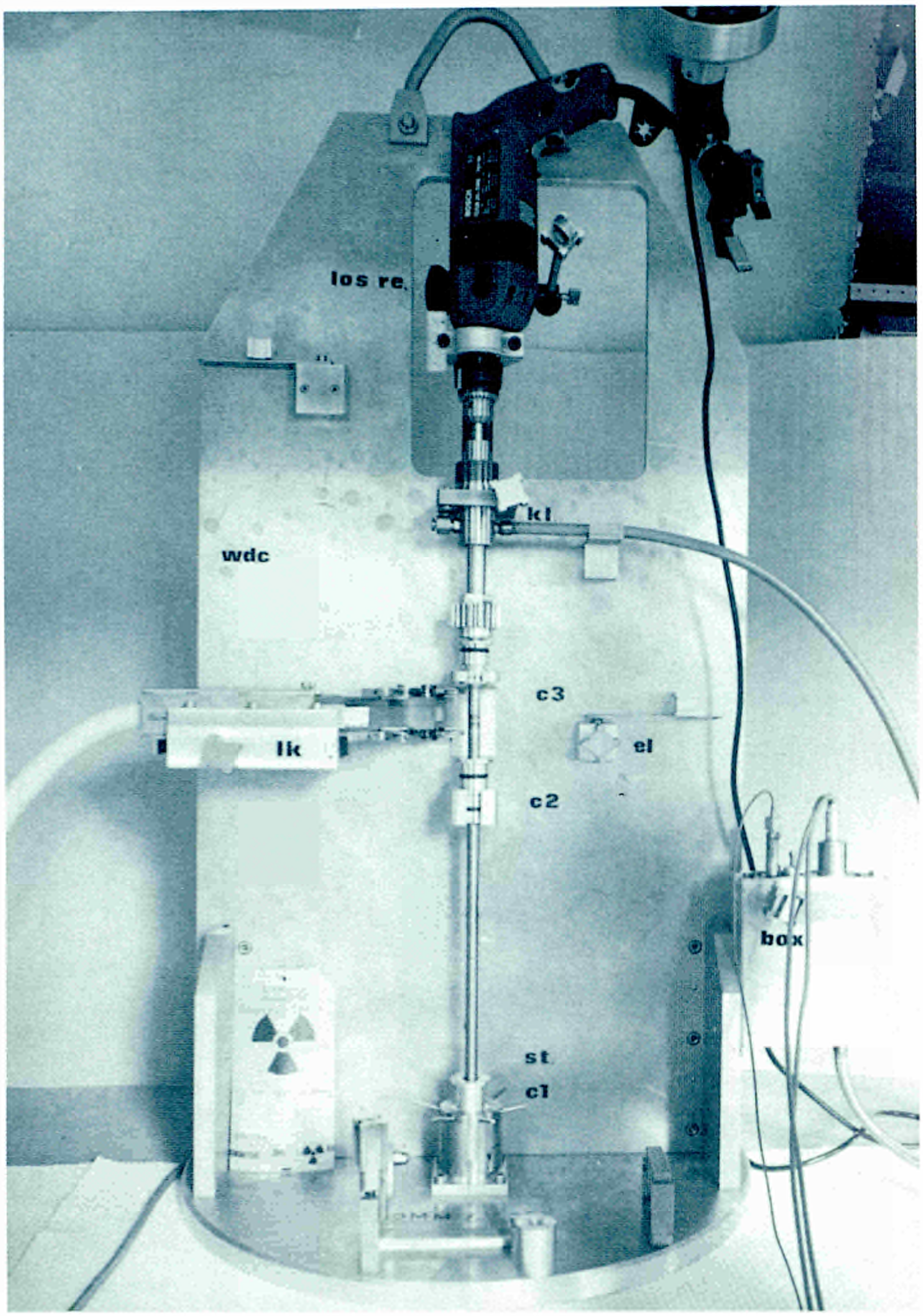


Fig. 18
Hot cell assembly device for re-instrumentation of LWR fuel rods.

reference period and are mainly depending on the availability of newly developed irradiation devices.

D128. In-pile Measurements in LWR Fuel

Three D128 experiments have been performed between 1983 and 1989. Each test used a pressurized BWR fuel rod which was instrumented with a central thermocouple and two pressure transducers for fuel rod pressure monitoring.

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. During 1988 all non-destructive PIE was completed. In 1989 all destructive PIE including puncturing, fission gas analysis, segmentation, metallographic and ceramographic investigations was performed. Herewith all anticipated activities at Petten on the D128-03 experiment are terminated.

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) from 1985 until February 1988 (burn-up of 18 GWd/t(U)).

During 1988 most of the non-destructive PIE has been performed and been completed in 1989. The destructive PIE will be performed by KFA Jülich. The fuel rod is temporarily stored at the Petten hot cells until transport to the KFA hot cells (together with the D128-05 fuel rod).

D128-05

The objective of the D128-05 test is comparable to the D128-04 test. However, the central temperature is kept constant at 1348 K (1075 °C), see **Fig. 19.** At the end of the test, at approx. 16 GWd/t(U) burn-up, a transient test to a final temperature of 1973 K (1700 °C) was performed. Approx. 2 minutes after the final transient a fuel rod failure was detected and the experiment terminated (**Fig. 20**). **Fig. 21** shows the onset of fission gas release above approx. 1300 °C during the final transient test.

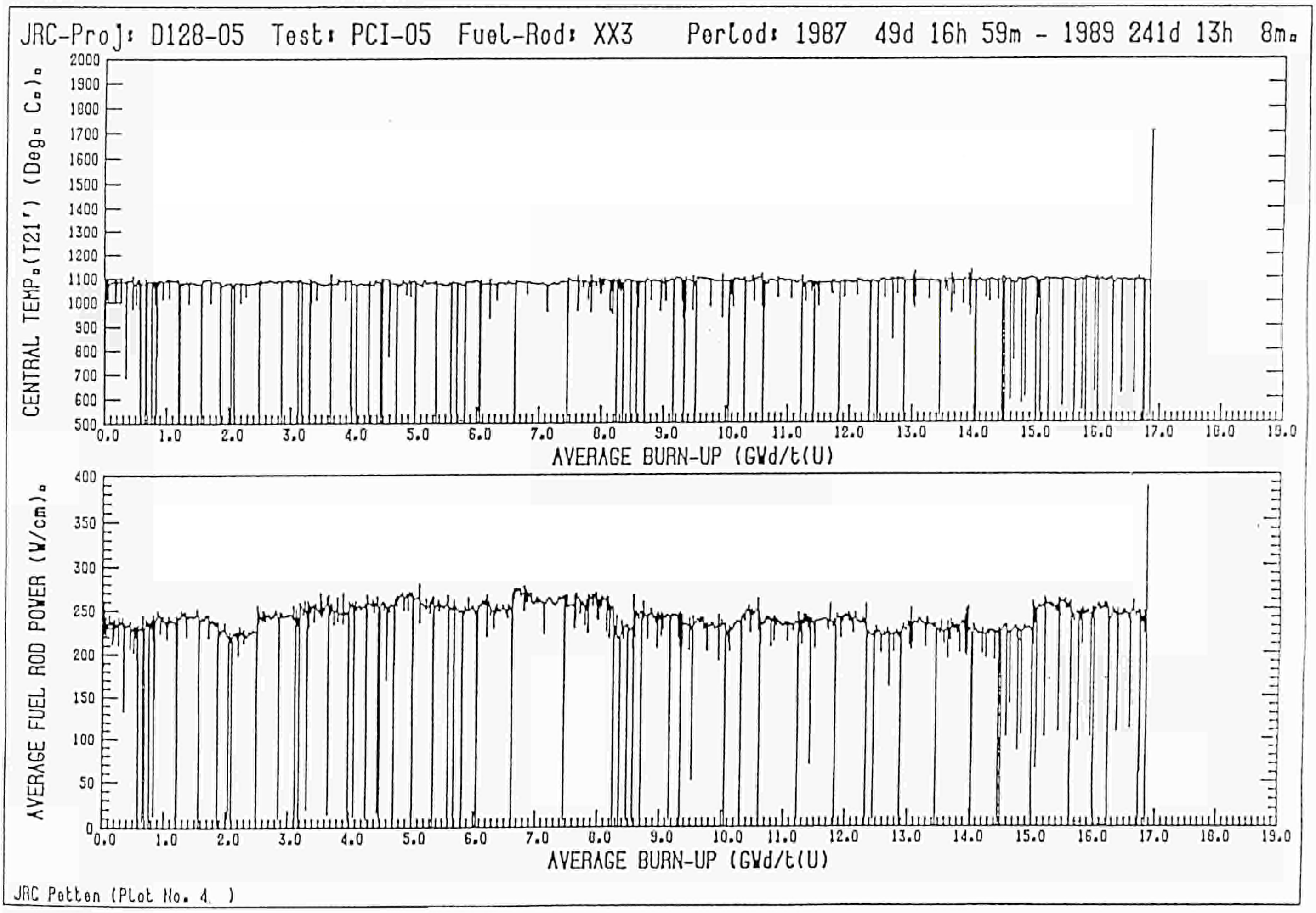


Fig. 19
Power and temperature histogram of the D 128-05 experiment.

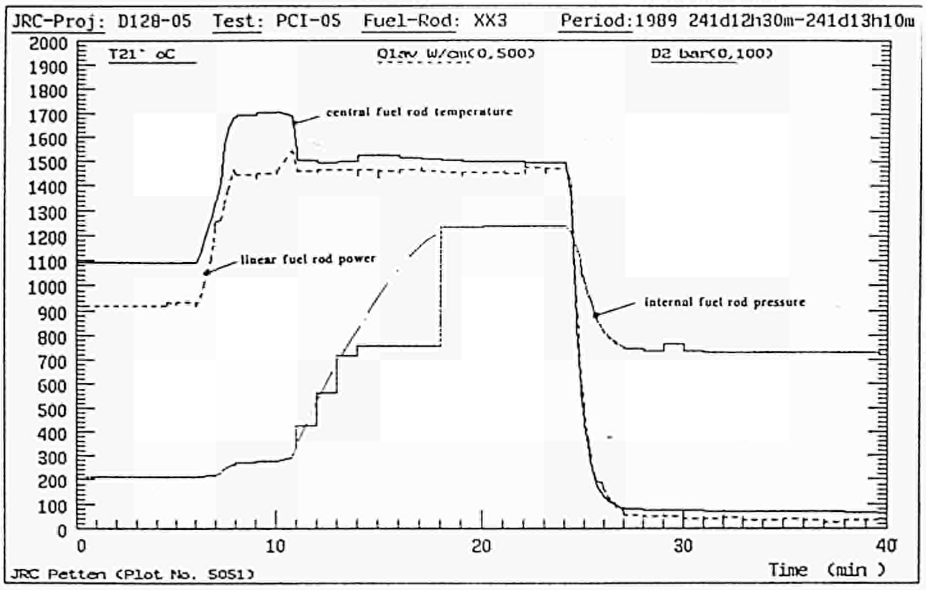


Fig. 20
Final power ramp test of the instrumented D 128-05 experiment.

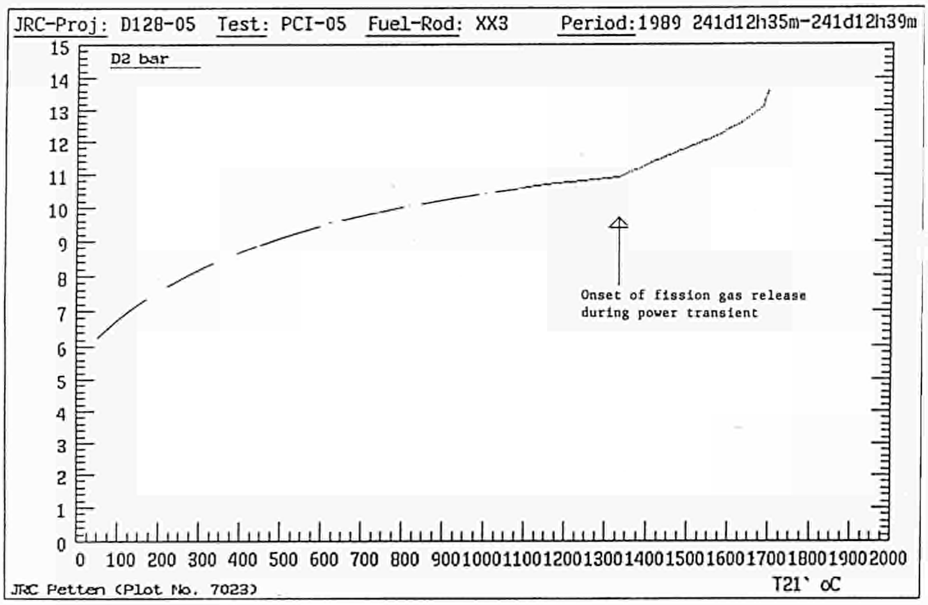


Fig. 21
Fuel rod pressure and temperature behaviour during final transient of the D 128-05 experiment.

The recovery of the instrumented fuel rod and the non-destructive PIE are scheduled for the beginning of the next reference period.

The D128-05 fuel rod will later be shipped together with the D128-04 fuel rod to the KFA Jülich hot cells for the destructive PIE.
An extension of the D128 programme beyond D128-05 is not anticipated.

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.

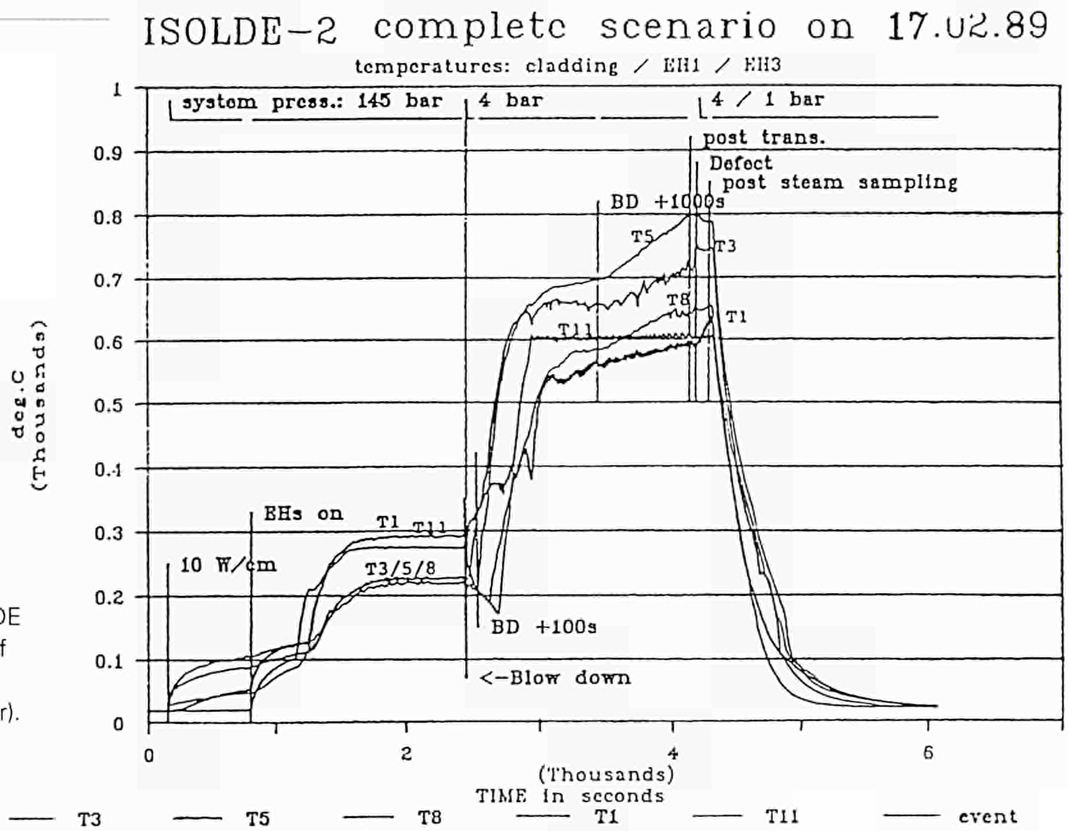


Fig. 22
Temperature history of an ISOLDE out-of-pile test (simulation test of the anticipated first in-pile test using a fuel rod simulation heater).

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 using twenty PWR fuel rods which have been re-irradiated in the HFR and tested at the KFA hot cells.
The preparations for the in-pile tests with five PWR fuel rods were continued with commissioning, out-of-pile testing of the entire ISOLDE experimental equipment and preparations for the first ISOLDE test at the HFR. Three ISOLDE irradiation devices have been qualified for in-pile testing by extensive simulation testing using a fuel rod simulation heater instead of a fuel rod. **Fig. 22** gives an overview about the temperature history of a simulation test representing the first ISOLDE in-pile test.

Installation of the ISOLDE test facility at the HFR was performed during December 1989.
The pre-conditioning irradiation at the HFR of the first ISOLDE test has been started during cycle 89.10. The first ISOLDE test will be performed during cycle 90.02. Two more ISOLDE irradiation devices are in the assembly phase. The lay-out of the ISOLDE device is shown schematically in **Fig. 23.**
Two to three ISOLDE tests will be performed during 1990 and the remaining tests during 1991.
Fig. 24 shows the in-pile part of the ISOLDE capsule. **Fig. 25** provides an overview of the ISOLDE out-of-pile systems.

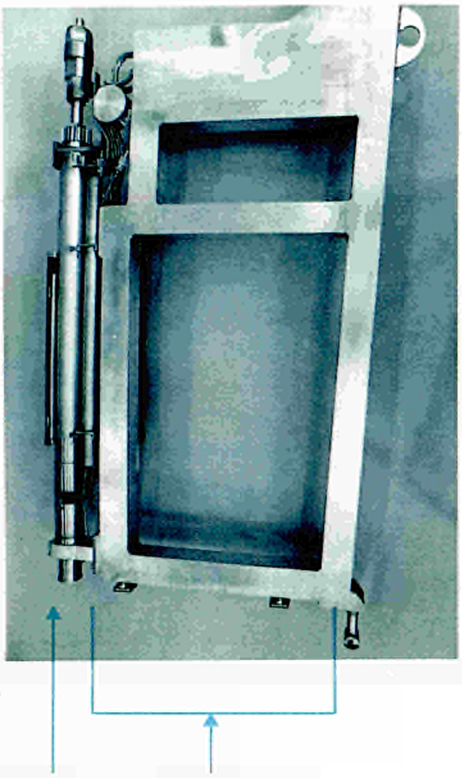


Fig. 24
In-pile section of the ISOLDE irradiation device.

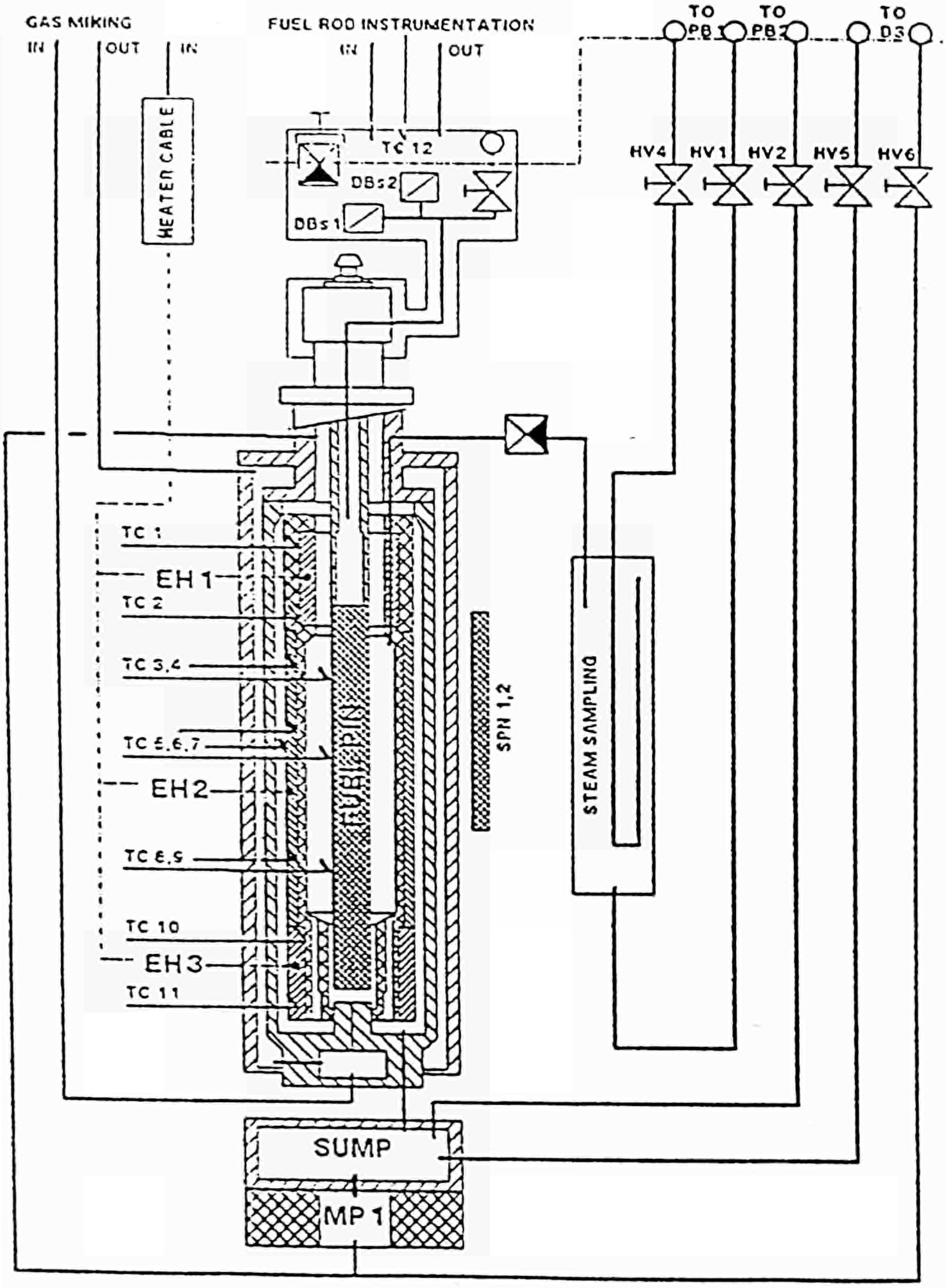


Fig. 23
ISOLDE. Lay-out of in-pile test rig.

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 and been sent to KfK for further PIE.

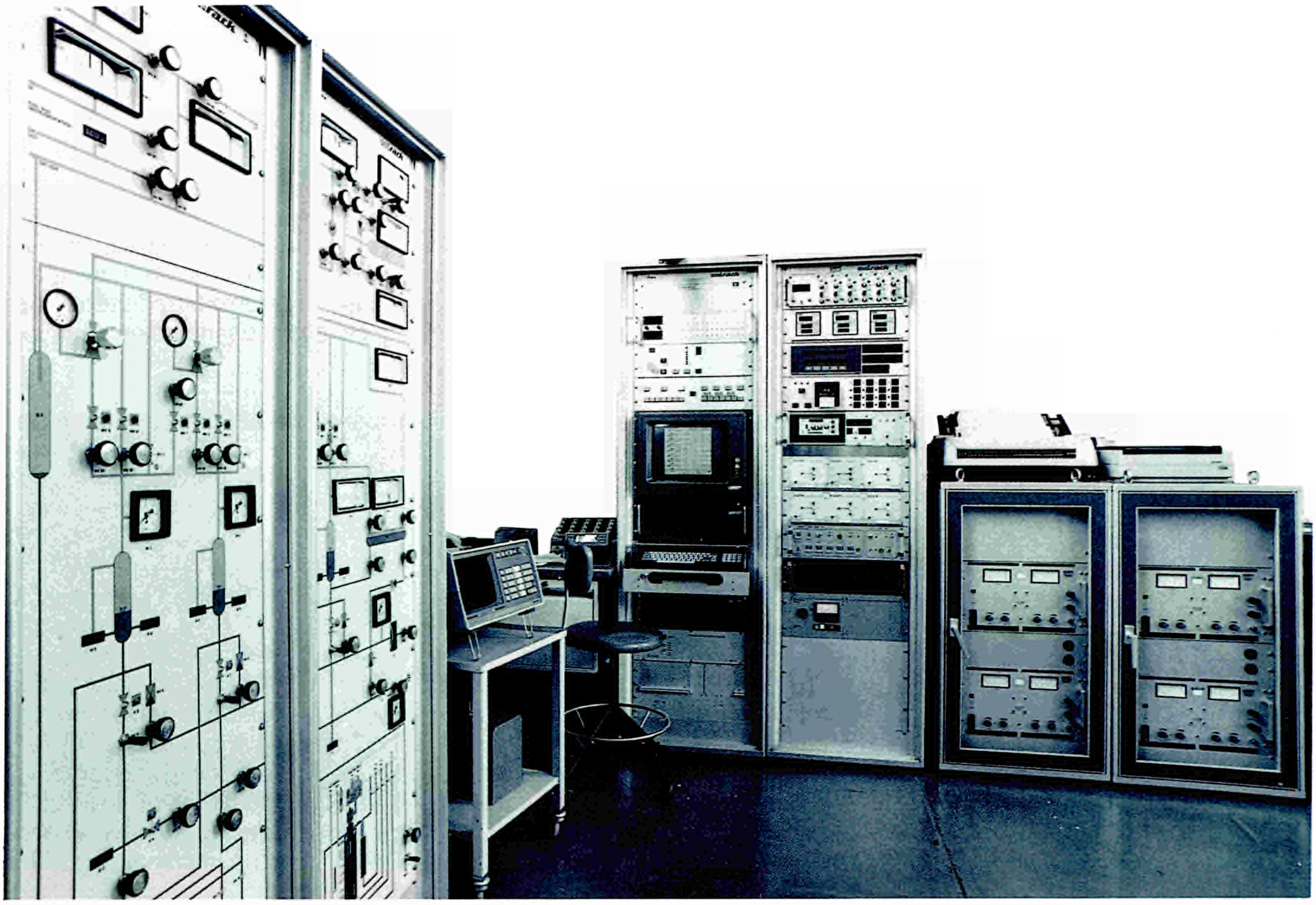


Fig. 25
Out-of-pile installation of the ISOLDE irradiation device.

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 fuel rod irradiation of the BU15 test was started at the beginning of the reference period and will be continued for approx. 20 cycles to approx. the middle of 1991. The burn-up at the end of 1989 is approx. 5 GWd/t(U). The irradiation was started in position G5 and later continued in H2 or H8. The irradiation in G5 was performed for two cycles at reduced HFR power level due to too high power in the D227 experiment.

From the middle of 1990 onwards the pre-irradiation of the D227 experiment will be performed in the PSF.

References

1. G. Fischer, W. Goll, J. Markgraf, I. Ruyter
Transient Behaviour of PWR U/Pu-mixed Oxyde Fuel Rods
Jahrestagung Kerntechnik 1989, Kerntechnische Gesellschaft e.V. & Deutsches Atomforum e.V., D sseldorf, May 9-11, 1989
2. B. Fischer, K.W. de Haan, J. Markgraf, D.J. Perry, P. Puschek
Re-instrumentation Technique of Irradiated LWR Fuel Rods for Pressure Monitoring during Irradiation Testing at the HFR Petten
Annual Meeting of the EC Working Group on Hot Cells, Karlsruhe, September 27 and 28, 1989
3. B. Fischer, G. Fischer, J. Markgraf, S. McAllister, D. Perry, I. Ruyter
Power Ramp Testing of LWR Fuel Rods at the HFR
Colloquium on the HFR Petten, prospects and future utilization, Petten, April 20-21, 1989, proceedings EUR 12522, page 343 (poster).

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 under 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

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. The features investigated include start-up behaviour, power cycling and ramping, fuel melting, transient overpower (TOP) and simulated loss-of-flow (LOF) behaviour. Recently, however, running experiments and new experiments are being performed with a view to utilizing the information for the design aims of the European Fast Reactor (EFR).

— *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 experiments is part of the JRC Specific Programme on Nuclear Fuels and Actinide Research.

A review of the FBR experiments and their facilities are presented in refs *1.* and *2.*

Progress:
Transient Tests

During the reporting period two transient experiments were irradiated over a total of 15 reactor cycles. The status of the programme of transient experiments is as follows :

D183 KAKADU

The KAKADU experiment 27/28, also referred to as OPEQU i.e. Over-Power EQUlibrium had a further 4 cycles of irradiation. The experiment was stopped after achieving 5.2 at.% burn-up and 0.2 at.% burn-up in fuel pins 27 and 28 respectively. The irradiation of the latter was continued for just one extra day irradiation at 720 W/cm and then stopped.

D183 SUPERKAKADU

Preparations are underway for the construction of 3 new capsules for the irradiation of 3 pre-irradiated fuel pins. The 3 pins were irradiated in the PHENIX reactor in France and will be transported at the beginning of 1990 to Petten.

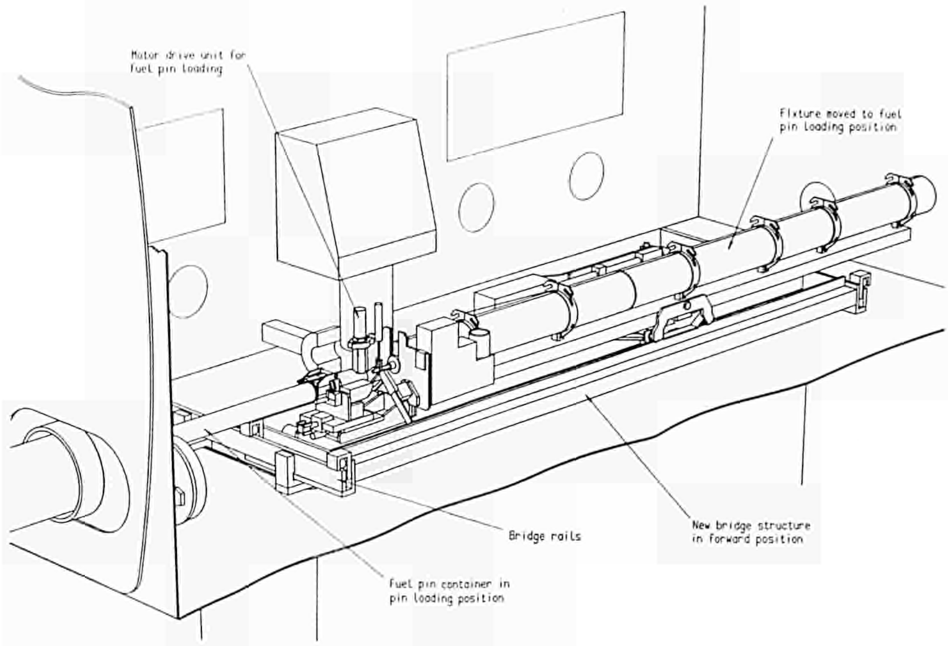


Fig. 26
New situation. Pictorial view, fuel pin loading in EUROS cell.

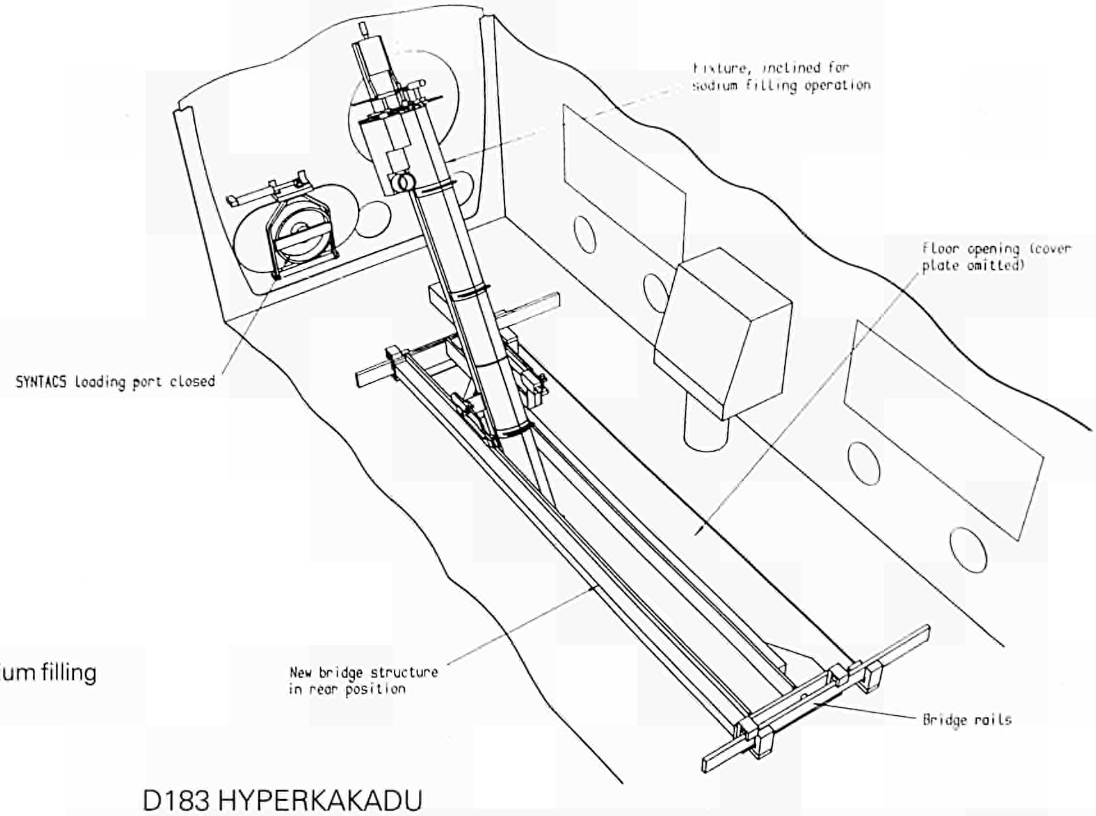


Fig. 27
New situation. Pictorial view, sodium filling in EUROS cell.

D183 HYPERKAKADU

The new KAKADU series of experiments consisting of up to 10 pre-irradiated (in PHENIX) fuel pins is under consideration and currently being discussed within the EFR design group. The extra long pins (>2m), have necessitated a re-design of the special α-tight EUROS cell, ref. *3.* A recent technical investigation, see ref. *4.*, has shown that it is possible to execute the loading and sodium filling of these longer fuel capsules in a modified EUROS cell without too much rebuilding and expenditure. The modifications have been designed and tested on the CAD system of the JRC Drawing Office. Fine examples of this type of design are shown in **figs. 26 and 27.** The series of irradiations are planned to start during 1991.

D184/D192 POTOM/OPOST

No further irradiations in this series have been carried out. Evaluation of the previous irradiations continues.
To assess in this evaluation exercise, two dummy irradiations were performed in July 1989. These consisted of 2 irradiations of a few hours each at different reactor power levels in reactor positions C5 and G5. The new analysis, based on the dummy tests, has given further information on the previous 5 POTOM tests, where 16 fuel pins have been irradiated. The analysis now gives reliable predictions of power-to-melt values for the linear fissile power.
The next experiment in this series, OPOST 1, is planned for early 1990.
A following POTOM experiment, no. 4, is planned for 1991.

D215 RELIEF

The experiment aims to study, by means of in-pile measurement, the differential and absolute fuel and cladding axial displacements during operational transients. The present RELIEF experiment, no. 12 began irradiation in cycle 88.11. The experiment has now completed almost 12 cycles of irradiation at a steady power of 480 W/cm. The attained burn-up is approximately 3.4 at.%.
A transient programme with various power increases up to 130 % nominal power will be executed after approximately 5.0 at.% burn-up has been attained, i.e. in May/April 1990. Preparations are also well underway for the start of the next RELIEF experiment, i.e. no. 13, in the beginning of 1990.

D235 TRAGA

The development of the TRAGA experiment, which aims to determine by means of noise analysis, the change in the fuel cladding gap heat conductance during simulated transients, is still under consideration.

Advanced Fuel Irradiations

E211 NILOC

Preparations have begun for the third and fourth NILOC experiments, which will take place in 1990. The experiments will irradiate 3 mixed nitride fuel pins simultaneously. The fuel pins are currently being manufactured by the Institute for Transuranium Elements at Karlsruhe, and are expected to arrive at Petten at the beginning of 1990.

E226 POMPEI

Due to a delay in the complex process for manufacturing the special pellets of mixed nitride fuel, the POMPEI experiment will not commence irradiation until mid-1990.

E228-01/02 BUMMEL

The first stage (01) of the BUMMEL irradiation ended in December 1988 following 105 days irradiation in reactor position D2. The 2 fuel pins con-

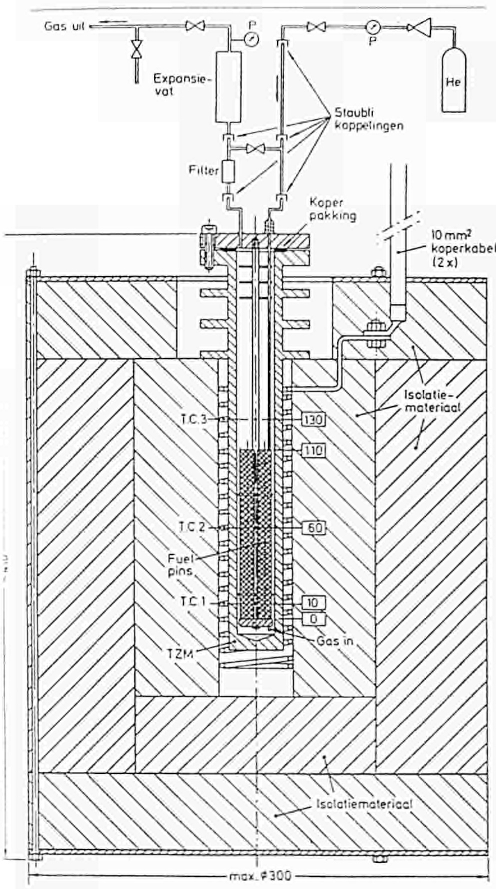


Fig. 28
Hot-cell oven used in the heat-treatment of the 2 fuel pins in project E 228 BUMMEL.

sisting of 10 UO_2 discs each were irradiated to 0.4 at.% burn-up during 5 reactor cycles. Thereafter, both fuel pins were withdrawn and transferred to the HFR hot cells, where in July 1989, a specially-equipped oven heated the 2 fuel pins, over an axial range of 1100-1328 °C each for 3 hours. A sketch of the special oven is shown in **Fig. 28,** with a temperature history of the 3 thermocouples during the heating test given in **Fig. 29.** The heat treatment serves to ensure complete precipitation of the fission gases. The required and difficult heating conditions are seen to have been readily achieved.

Following the heat-treatment, one of the fuel pins was irradiated further in a specially designed capsule to achieve an axial temperature distribution of 1273 to 2073 K (1000 to 1800 °C) along the fuel pin length.
This part of the experiment, stage 3, was completed successfully in July 1989. The achieved temperatures of each fuel disc were within ± 3% of the requested conditions.

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.

R 139-57

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, SS316 and 304.

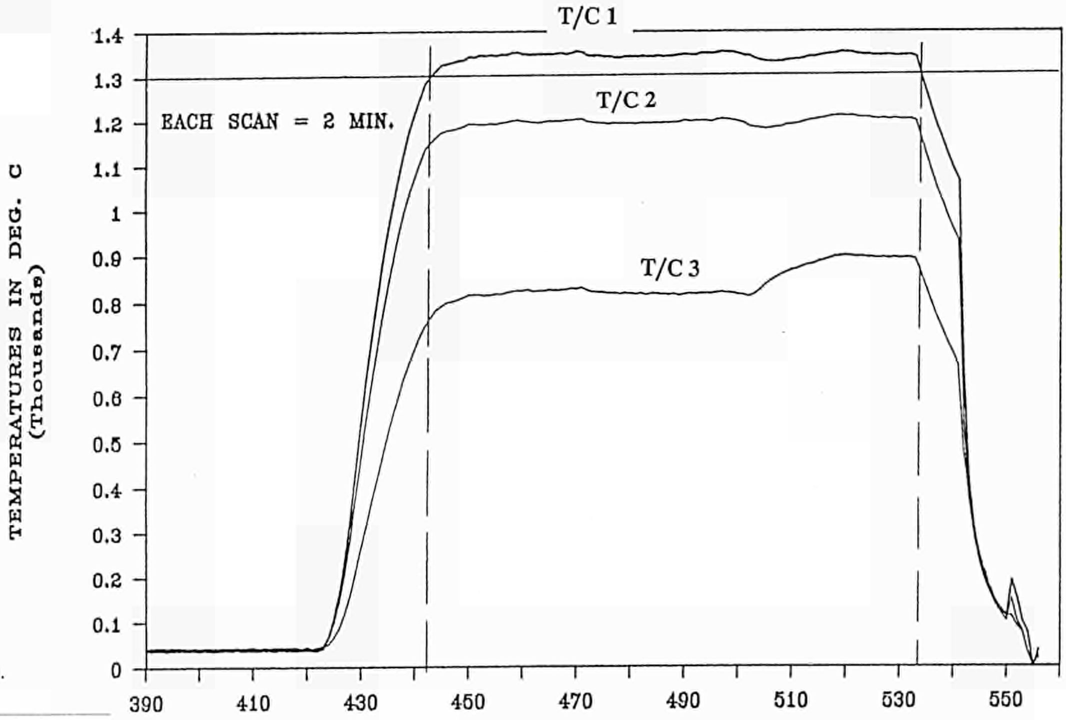


Fig. 29
Temperature history of
E 228 BUMMEL during short,
3 hours, second stage irradiation.

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 5.**

Irradiation of leg R139-572, terminated in cycle 89.05, and of leg R139-571 in cycle 90.11.

R 139-58

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

Table 5

R 139-572. Typical statistical analysis of a temperature distribution in a reactor cycle (89.06).

CYCLE NO: 89-06 "D A C O S S Y S T E M" DATE: 15:14:19 10-OCT-89

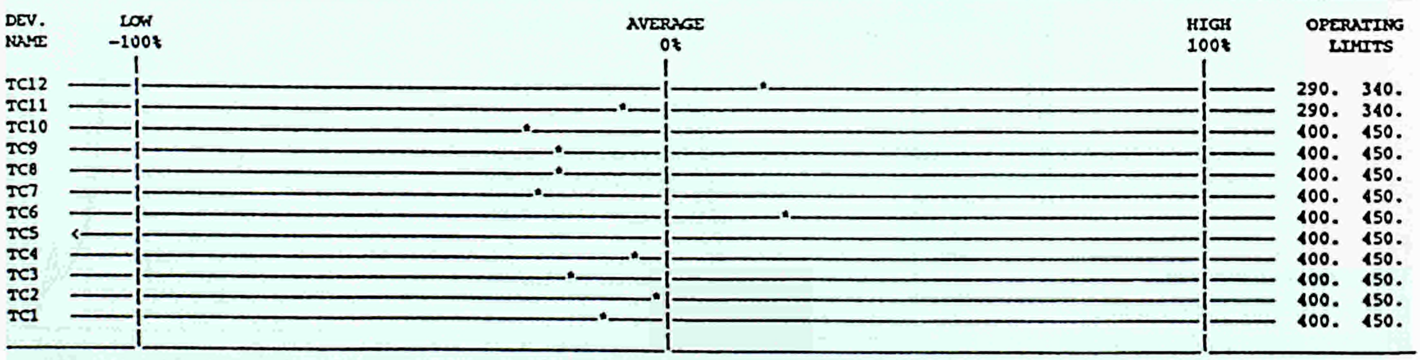
ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 21:00:00 17-JUN-89 TO 03:10:00 11-JUL-89

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 : 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 < 40.MW	NO DATA	< LOW LIMIT	> HIGH LIMIT	WITHIN LIMITS
228	TC12	Deg. C	319.60	254.41	339.57	7.673	0.134	3350	1.52	0.00	0.75	0.00	97.73
227	TC11	Deg. C	312.85	248.90	332.86	7.662	0.133	3350	1.52	0.00	0.99	0.00	97.49
226	TC10	Deg. C	418.65	341.00	442.36	8.619	0.150	3350	1.52	0.00	1.43	0.00	97.04
225	TC9	Deg. C	420.17	341.58	444.17	8.805	0.153	3350	1.52	0.00	1.31	0.00	97.16
224	TC8	Deg. C	420.02	359.25	440.09	6.169	0.107	3350	1.52	0.00	0.66	0.00	97.82
223	TC7	Deg. C	418.89	358.12	439.11	6.293	0.110	3350	1.52	0.00	0.81	0.00	97.67
222	TC6	Deg. C	430.64	389.48	448.87	5.097	0.089	3350	1.52	0.00	0.03	0.00	98.45
221	TC5	Deg. C	352.21	289.02	370.11	6.603	0.115	3350	1.52	0.00	98.48	0.00	0.00
220	TC4	Deg. C	423.58	399.30	441.80	5.591	0.097	3350	1.52	0.00	0.03	0.00	98.45
219	TC3	Deg. C	420.45	396.34	438.46	5.496	0.096	3350	1.52	0.00	0.03	0.00	98.45
218	TC2	Deg. C	424.39	404.77	444.09	6.234	0.109	3350	1.52	0.00	0.00	0.00	98.48
217	TC1	Deg. C	421.97	218.73	443.63	19.767	0.344	3350	1.52	0.00	1.73	0.00	96.75

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.



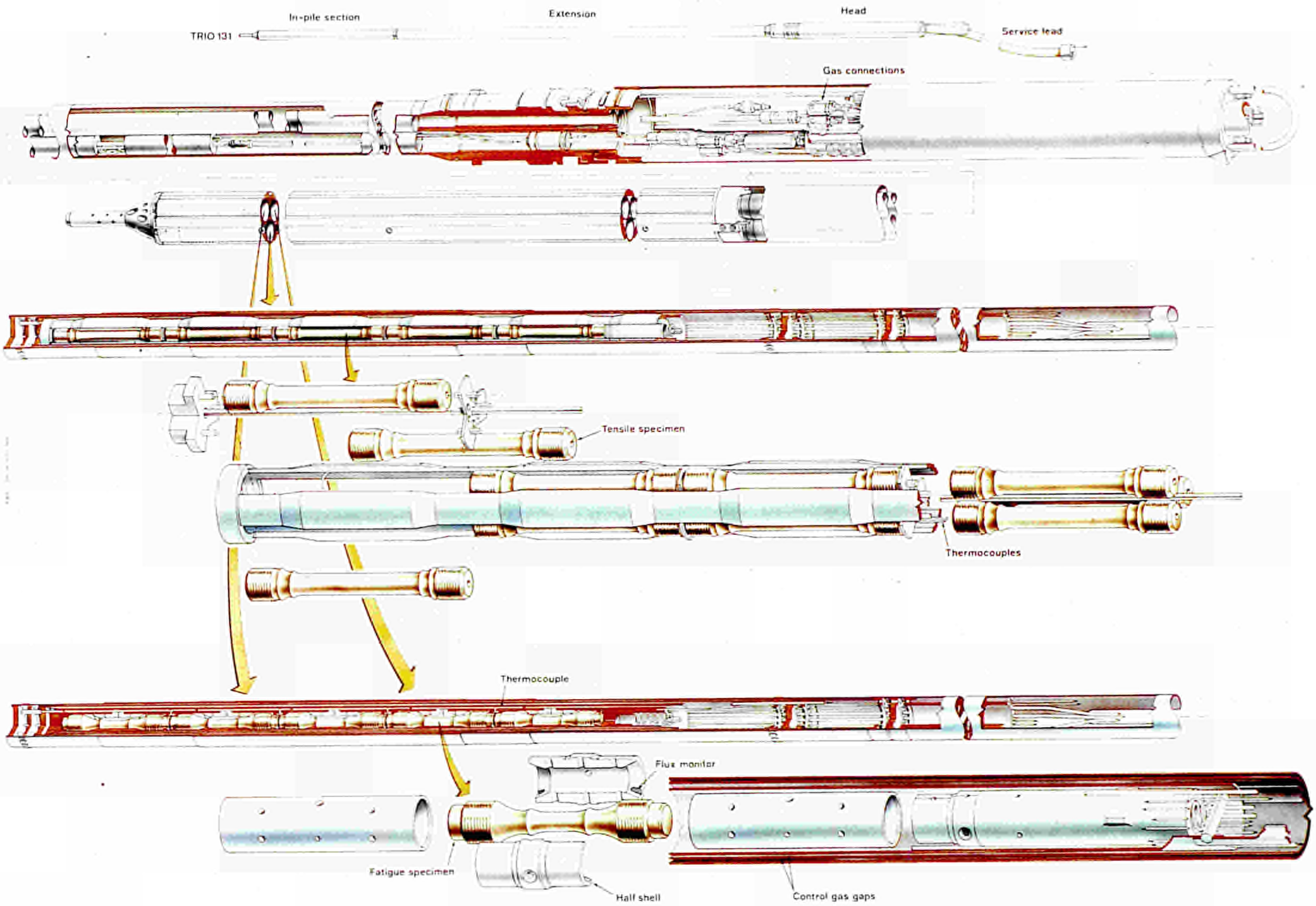


Fig. 30
TRIO-131 containing fatigue and tensile specimens in a double containment.

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, shown in **Fig. 30.**

Irradiation of the two fatigue sample holders took place in cycle 89.03 and of the tensile-creep sample holder in cycle 89.05. The performance of this experiment is shown in **Tables 6 and 7.** Further 12 sample holders will start irradiation in the first half of 1990.

R 139-416

The experiment is a continuation of the 400-series using a REFA type capsule for the irradiation of large or half-size CT specimens at evaluated temperatures. Design and assembly of the experiment is finished and irradiation will start at cycle 90.03.

CYCLE NO: 89-03 "D A C O S S Y S T E M" DATE: 17:05:59 17-MAY-89

ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 10:00:00 3-APR-89 TO 00:50:00 25-APR-89

EXPERIMENT NO. : R139-582
NAME : SINAS
START DATE : 04-04-89
REACTOR LOCATION: H8
GAS PANEL USED : TRIO-6

NOMINAL DEGREES "C": 550.00
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
142	TC16	Deg. C	512.21	181.86	557.73	63.529	1.193	3114	8.96	0.00	66.63	0.00	24.41
141	TC15	Deg. C	530.86	11.46	549.60	76.216	3.314	3114	8.96	74.05	0.87	0.00	16.12
140	TC14	Deg. C	544.58	199.29	590.72	66.272	1.245	3114	8.96	0.00	4.53	1.19	85.32
139	TC13	Deg. C	547.00	206.81	597.12	65.575	1.232	3114	8.96	0.00	4.53	2.86	83.65
138	TC12	Deg. C	542.48	215.49	596.29	63.006	1.183	3114	8.96	0.00	4.56	0.96	85.52
137	TC11	Deg. C	542.46	215.54	596.34	63.092	1.185	3114	8.96	0.00	4.56	0.93	85.55
136	TC10	Deg. C	535.63	188.55	591.83	60.673	1.140	3114	8.96	0.00	4.66	0.90	85.48
135	TC9	Deg. C	540.91	233.98	597.71	58.804	1.104	3114	8.96	0.00	4.62	0.93	85.48
134	TC8	Deg. C	541.26	234.39	598.17	58.829	1.105	3114	8.96	0.00	4.62	0.96	85.45
133	TC7	Deg. C	536.62	237.90	594.17	57.262	1.075	3114	8.96	0.00	4.66	0.90	85.48
132	TC6	Deg. C	541.52	249.00	598.90	55.660	1.045	3114	8.96	0.00	4.62	1.09	85.32
131	TC5	Deg. C	543.85	250.75	601.72	55.655	1.045	3114	8.96	0.00	4.62	2.60	83.82
130	TC4	Deg. C	538.98	252.95	595.96	54.225	1.018	3114	8.96	0.00	4.66	0.87	85.52
129	TC3	Deg. C	543.42	22.41	600.77	66.724	1.253	3114	8.96	0.00	4.56	2.89	83.59
128	TC2	Deg. C	545.33	21.03	602.41	66.895	1.256	3114	8.96	0.00	4.56	4.75	81.73
127	TC1	Deg. C	540.90	22.27	595.77	65.075	1.222	3114	8.96	0.00	4.59	0.90	85.55

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.

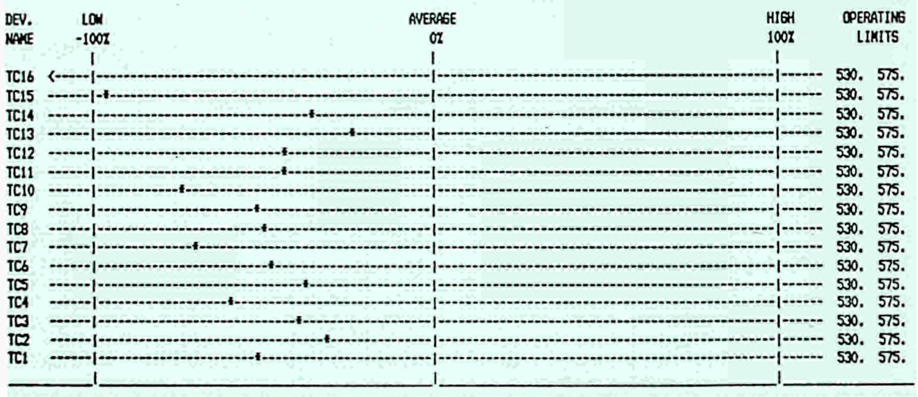


Table 6
R 139-582. Typical statistical analysis of a temperature distribution in a reactor cycle (89.03).

E 177 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 E177 – FANTASIA has been designed.

Progress:
A total of 144, 3PB samples and the same number of tensile samples have been irradiated in a sodium environment at 623 K and 823 K (350 °C and 550 °C). The irradiations have been carried out in the HFR Petten in the time between 1980 and 1987 and the samples were transported to Ispra for PIE.

CYCLE NO: 89-03 "D A C O S S Y S T E M" DATE: 09:05:27 18-MAY-89

ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 10:00:00 3-APR-89 TO 00:50:00 25-APR-89

EXPERIMENT NO.	: R139-583	NOMINAL DEGREES "C":	550.00
NAME	: SINAS	SAMPLE	:
START DATE	: 04-04-89	STRESS MODE	:
REACTOR LOCATION:	H8	DATA LOGGER NUMBER :	1
GAS PANEL USED	: TRIO-6	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
160	TC16	Deg. C	506.96	22.61	561.19	59.689	1.121	3114	8.96	0.00	81.86	0.00	9.18
159	TC15	Deg. C	544.75	272.56	596.20	46.097	0.866	3114	8.96	0.00	5.20	1.51	84.33
158	TC14	Deg. C	541.17	268.19	587.53	46.484	0.873	3114	8.96	0.00	5.20	0.64	85.20
157	TC13	Deg. C	549.11	282.09	596.29	45.239	0.850	3114	8.96	0.00	5.20	2.67	83.17
156	TC12	Deg. C	545.67	294.28	593.55	42.252	0.794	3114	8.96	0.00	5.56	0.03	85.45
155	TC11	Deg. C	546.63	296.85	594.70	41.981	0.788	3114	8.96	0.00	5.56	1.96	83.53
154	TC10	Deg. C	542.02	305.66	589.40	39.186	0.736	3114	8.96	0.00	5.62	0.03	85.39
153	TC9	Deg. C	548.12	321.03	594.33	37.093	0.697	3114	8.96	0.00	5.59	1.54	83.91
152	TC8	Deg. C	545.31	21.68	590.15	57.432	1.079	3114	8.96	0.00	5.59	0.06	85.39
151	TC7	Deg. C	542.39	324.56	586.84	35.298	0.663	3114	8.96	0.00	5.65	0.03	85.36
150	TC6	Deg. C	549.38	373.52	594.68	30.440	0.574	3114	8.96	0.71	4.85	0.03	85.45
149	TC5	Deg. C	547.15	369.72	588.77	30.895	0.583	3114	8.96	0.71	4.88	0.03	85.42
148	TC4	Deg. C	541.22	21.46	592.06	54.023	1.015	3114	8.96	0.00	5.59	0.03	85.42
147	TC3	Deg. C	547.10	22.89	598.73	53.743	1.009	3114	8.96	0.00	5.52	1.57	83.94
146	TC2	Deg. C	549.06	387.09	595.36	27.878	0.526	3114	8.96	0.71	4.82	1.54	83.98
145	TC1	Deg. C	540.52	25.18	594.44	52.542	0.987	3114	8.96	0.00	5.59	1.57	83.88

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.

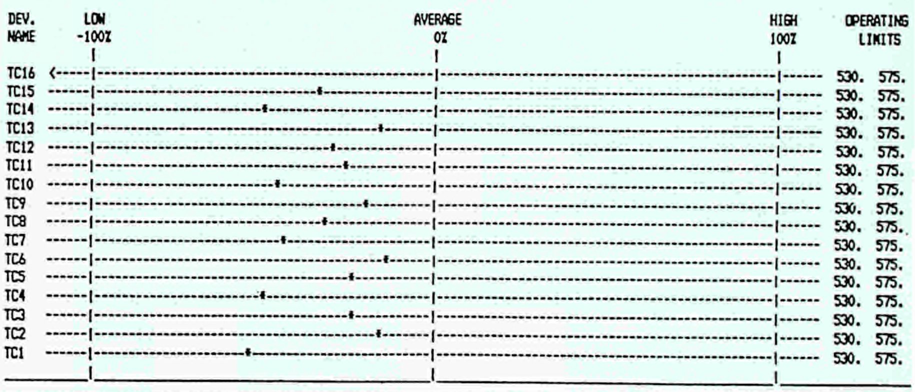


Table 7

R 139-583. Typical statistical analysis of a temperature distribution in a reactor cycle (89.03).

Irradiation temperature history and neutron metrology results of irradiation E177/34-36 are summarized in irradiation report *5*.

E 208 SISSI.

Sponsored by the JRC Ispra Reactor Safety Programme, SISSI is an experiment series to investigate the behaviour of austenitic stainless steel of the 316 L type under irradiation. In 1983, a first experiment was performed at 823K (550 °C) and to a damage of 1 dpa.

Four irradiations were performed, according to the following table:

E208-02 2.5dpa 623K 350 °C
E208-03 2.5dpa 823K 550 °C
E208-04 1 dpa 623K 350 °C
E208-05 1 dpa 823K 550 °C

After dismantling, the PIE work (tensile tests) has been performed at ECN-Petten on 96 samples (over a total number of 144 irradiated samples). Evaluation of the collected PIE results is in progress at HFR *6.*

References

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 Reactors and Related International Co-operation, Grenoble, October 1987.
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   "Fast Breeder Reactor Fuel Pin Experiments in the High Flux Reactor Petten: Specialist Design and Instrumentation, and Ancillary Activities"
   EWGIT, Mol, September 1988.
3. Konrad, J. and Pithan, D. "EUROS European Remote Encapsulation Operating System".
   Atomkernenergie-Kerntechniek, nr. 2, 1984.
4. Hale, R.G. "Technical Investigation into Possible Modifications of the Existing EUROS cell", HFR/89/2968, Petten.
5. FANTASIA E177/34-36 Irradiation Report
   Technical Note P/F1/89/3.
6. Tartaglia, G.P., Piatti, G., Scheurer, H. and Van Witzenburg, W.
   "Irradiation Effects on AISI 316 welded joints"
   Submitted to 16th SOFT.

3.3. HIGH TEMPERATURE REACTOR (HTR). FUEL AND GRAPHITE IRRADIATIONS

The High Temperature Reactor technology is being developed in the Federal Republic of Germany for different applications with three designs:
— the HTR-500 for electrical power generation,
— the HTR-Module for the combination of power generation and process heat and direct cycle application and
— the gas-cooled heating reactor for district heating.

In this frame, test irradiations are being performed in the HFR on two materials which are typical for the HTR *1., 2.*:
— spherical fuel elements with coated particles and
— graphite as a predominant core structural and fuel element matrix material.

Irradiation testing of fuel elements and graphite materials for the US HTGR is performed in the HFR under the Umbrella Agreement between FRG and USA.

a) Fuel Element 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-$Th0_2$ 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 wide range (10^{-9} > R/B > 10^{-1}) are performed, as well as on-line gas chromatographical analysis of the downstream carrier

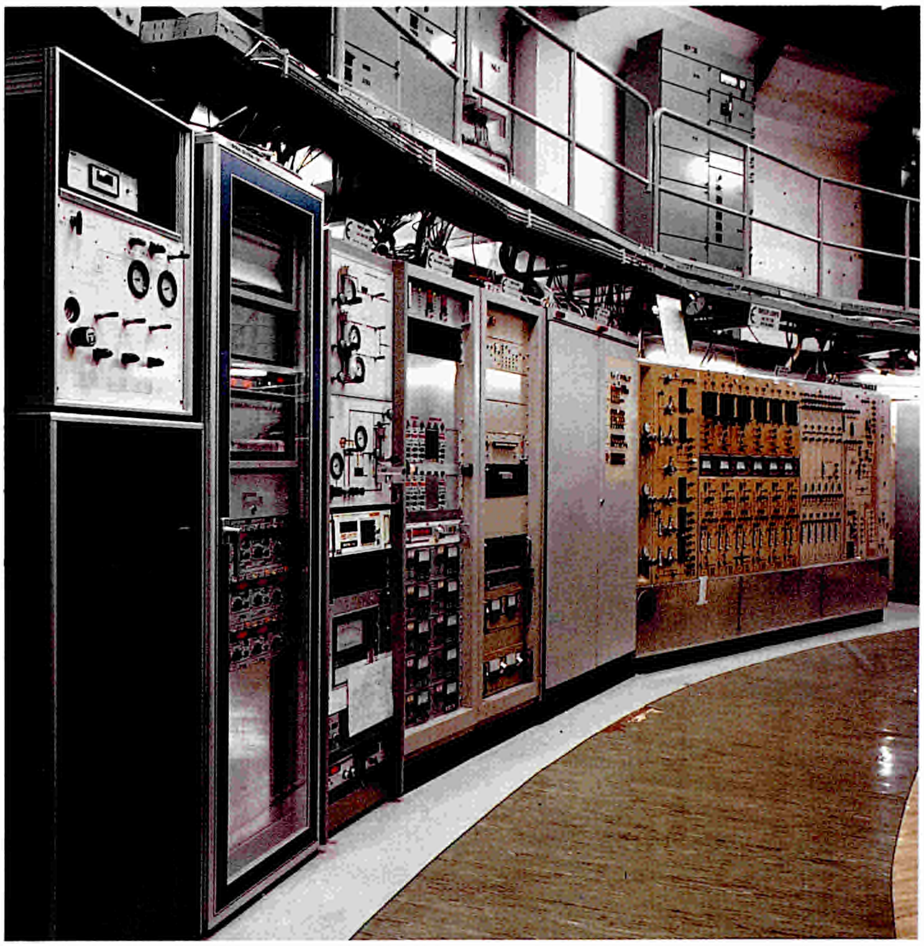

Fig. 31
Sweep loops. Instrumentation and command panel in the HFR basement.

gas with the specially designed Sweep Loop installation **(Fig. 31).** A survey of these activities is given in **Table 8.**

Spherical Fuel Elements for the German HTR Programme

D 138-04. Temperature Control Test of Spherical Fuel Elements

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 LEU fuel elements for future High Temperature Reactors, and also for previous LEU fuel element irradiations. The test samples were equipped with thermocouples located in the centre and on different radii to measure the temperature field under irradiation. This experiment, the first of its kind, provided 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 final irradiation data have been published in *3.*

D 138-05/08. Reference Test for the HTR-MODULE

Objective:
These reference tests should confirm the design fission product release

After dismantling, the PIE work (tensile tests) has been performed at ECN-Petten on 96 samples (over a total number of 144 irradiated samples). Evaluation of the collected PIE results is in progress at HFR *6.*

References

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 Reactors and Related International Co-operation, Grenoble, October 1987.

2. Moss, R.L., Beers, M., Korko, A.R. and Tsotridis, G.
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EWGIT, Mol, September 1988.

3. Konrad, J. and Pithan, D. "EUROS European Remote Encapsulation Operating System".
Atomkernenergie-Kerntechniek, nr. 2, 1984.

4. Hale, R.G. "Technical Investigation into Possible Modifications of the Existing EUROS cell", HFR/89/2968, Petten.

5. FANTASIA E177/34-36 Irradiation Report
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6. Tartaglia, G.P., Piatti, G., Scheurer, H. and Van Witzenburg, W.
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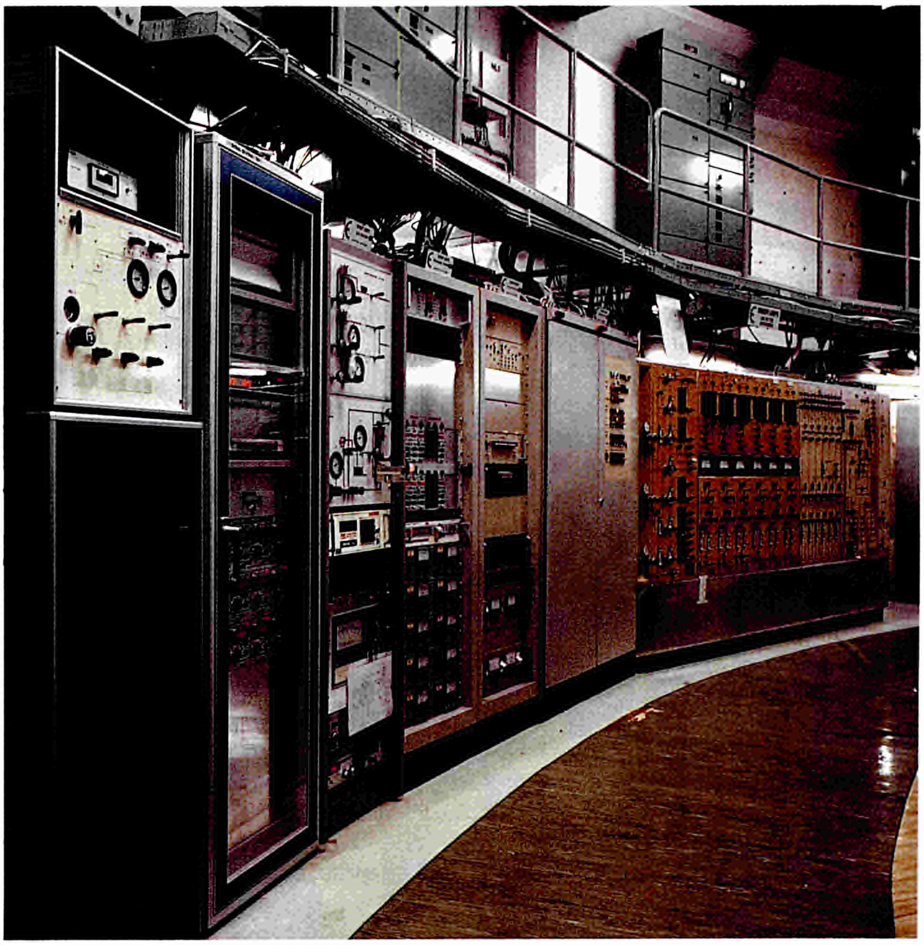

Fig. 31
Sweep loops. Instrumentation and command panel in the HFR basement.

gas with the specially designed Sweep Loop installation **(Fig. 31).** A survey of these activities is given in **Table 8.**

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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 LEU fuel elements for future High Temperature Reactors, and also for previous LEU fuel element irradiations. The test samples were equipped with thermocouples located in the centre and on different radii to measure the temperature field under irradiation. This experiment, the first of its kind, provided 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 final irradiation data have been published in *3.*

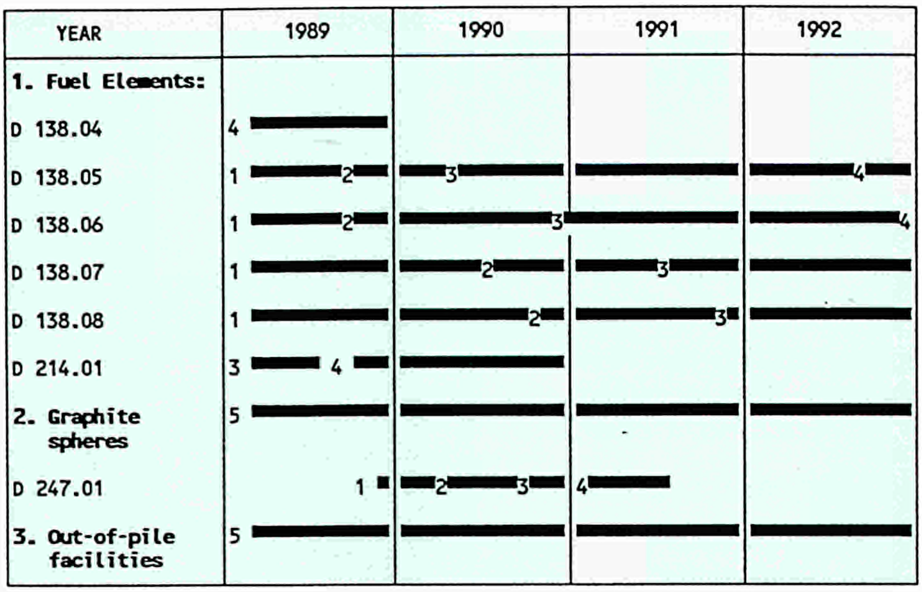
D 138-05/08. Reference Test for the HTR-MODULE

Objective:
These reference tests should confirm the design fission product release

Table 8
HTR fuel irradiation experiments. Survey of present and future activities.

Legend:

1 Design & calculation
2 Manufacture and commissioning
3 Irradiation
4 Dismantling & PIE
5 Upgrading



data set of the HTR-Module production fuel elements under irradiation conditions, which simulate the realistic power reactor operating and fuelling conditions *1., 4.*

Progress:
The final design of these experiments was terminated in 1989. The test fuel elements and the structual graphite parts were shipped by KFA to Petten in September, 1989. Assembly of the first rig started during the last quarter of 1989. Irradiation start-up of the first experiment (D 138.05) is planned for the first half of 1990.

D 138-06/07. Reference Tests for the HTR-500

Objective:
These reference tests should confirm the design fission product release data set of the HTR-500 production fuel elements under irradiation conditions, which simulate the realistic power reactor operating and fuelling conditions *1., 4.*

Progress:
The final design of these experiments was terminated in 1989. The test fuel elements and the structural graphite parts were shipped by KFA to Petten in September, 1989. Assembly of the first rig is planned to start during the first half of 1990. Irradiation start-up of the first experiment is planned for the end of 1990.

D 247.01. Irradiation of SiC Coated Graphite Spheres

Objective:
SiC coating on the surface of spherical fuel elements has been proposed by KFA for a corrosion resistant spherical HTR fuel element. The irradiation behaviour of SiC coated spheres of 60 mm diameter will be investigated on unfuelled samples.

The required temperature range is 873 - 1273 K. The max. neutron fluence is 2.6 x $10^{25}m^{-2}$.

Progress:
An irradiation proposal has been issued *5*. The irradiation is planned for the last quarter 1990 during three reactor cycles.

Irradiation of Fuelled Block Segments for the US HTGR

D 214-01. Irradiation of GA Fuel Rods

Objective:
This experiment is a joint effort involving GA Technologies (USA), KFA-HBK project and JRC Petten under the auspices of the US/FRG Umbrella Agreement for co-operation in High Temperature Gas-Cooled Reactor developments. The overall objective of this experiment with three independent capsules 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 graphite and the effects of temperature cycling and fuel hydrolysis on fission gas release. The fuel samples contained ~10% 'designed to failed' coated particles.

Progress:
The irradiation of the D 214 experiment with three independent capsules was completed as planned after cycle 89.06. A total of 445.35 full power days were accumulated during 20 cycles operation. The obtained irradiation parameters are compiled in **Table 9** and are published in *6*.
Capsule 1 was operated at a constant fuel temperature. The fission gas release rates remained constant. Capsule 2 fuel temperatures were varied mostly cycle-wise between 880 and 1230 °C, in order to obtain data on fission gas release dependence from temperature. The fractional fission gas release for Krypton isotopes is given in **Fig. 32.**
The water vapour injections with variation of duration and quantity were continued in capsule 3. Additionally, temperature transients were performed during the last irradiation cycle. The main data of water vapour injections are given in **Table 10.** The final irradiation report is currently being compiled. The rig was dismantled at the ECN Hot Cells and the three capsules were recovered and prepared for transport to KFA for fine-dismantling and further PIE.

Table 9
D 214.01. Final irradiation parameters.

Irradiation Parameters	CAPSULE no. 1	2	3
Duration in fpd	445.35	445.35	445.35
Fast neutron fluence in m^{-2} (E > 0.1 MeV)	6.0 10^{25}	6.6 10^{25}	5.1 10^{25}
Burnup in % FIMA	18.3	18.4	16.7
DPA (graphite)	5.2	5.7	4.4
Fuel temperature in °C	950 °C ± 50 °C	880 - 1230 °C	820 - 1040 °C
Fractional fission gas release (R/B) for ^{85m}Kr	4.6 10^{-4}	2.5 10^{-3}	2.9 10^{-3}

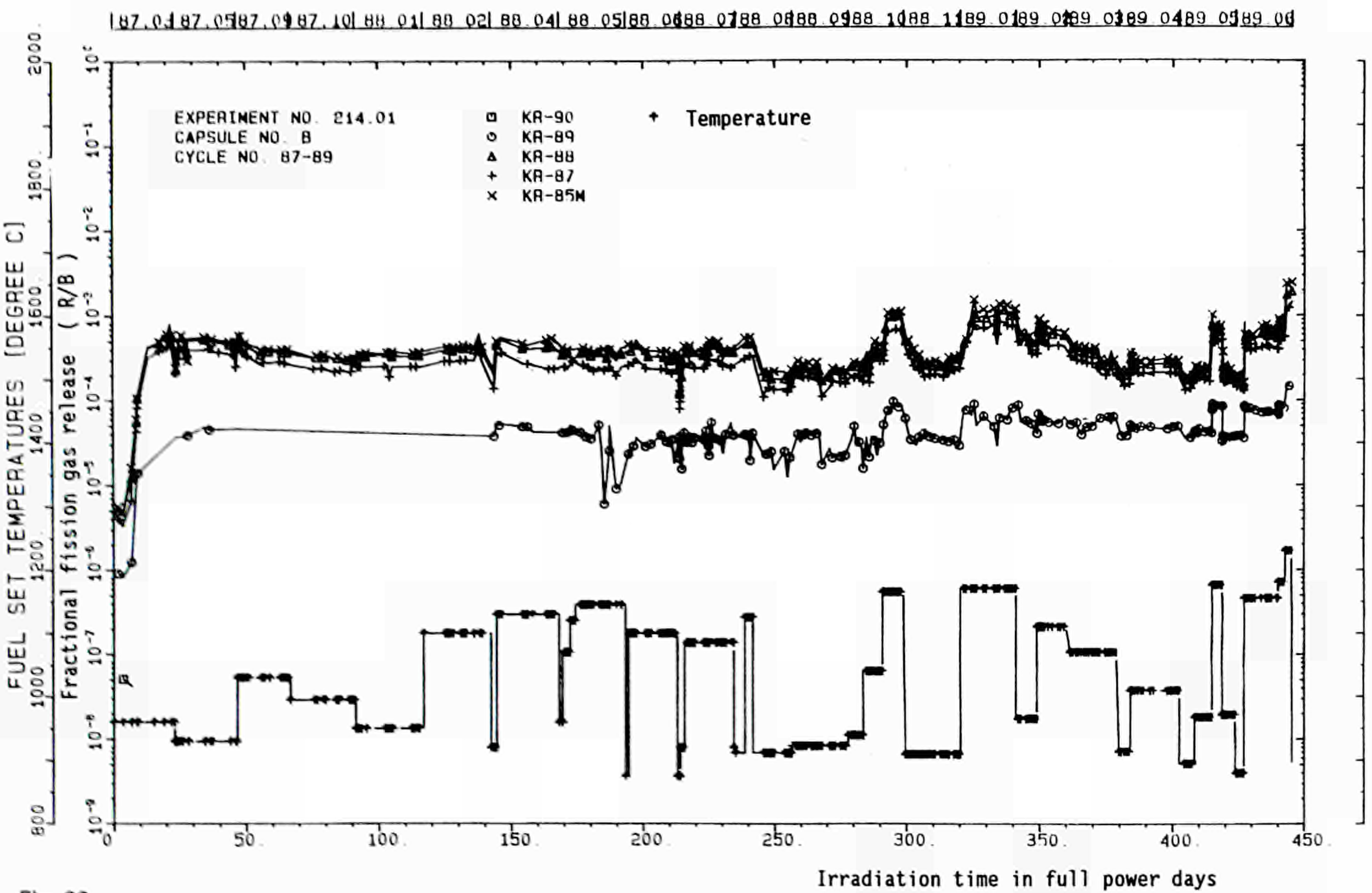


Fig. 32
D 214.01. Fractional fission gas release of Krypton isotopes and fuel temperature vs. irradiation time.

b) *Graphite Irradiations*

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

Unstressed Graphite Experiments

Fundamental Properties Graphite Programme (see **Table 11**).

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

* traditional graphite exposure unit (Equivalent DIDO Nickel)

Run	Cycle no	Duration in hours	Water vapour concentration in μatm	Fuel temperature in °C	Fract. fission gas release for $^{85m}Kr \times 10^3$ pre water vapour injections	during	post
12	89.01	192	1120	887	0.82	1.7	1.1
13	89.02	96	2500	915	1.1	1.75	1.25
14	89.04	96	5500	840	0.74	2.95	1.82
15	89.06	170.5	10600	820/870	1.1	2.5/2.6	2.3
16	89.06	15	2500	893	2.6	2.9	

Table 10
D 214.01. Water vapour injections in capsule 3 during 1989.

(EDN), at higher temperature, ranging from 773 to 1473K (500 to 1200 °C).

Progress:
D85-48, 673K (400 °C) ended in cycle 88.10. The irradiation history has been reported in *7*. Dismantling and recovery of samples and dosimeters took place at the beginning of 1989. Presently P.I.E. is on going at KFA - Jülich.

D85-54/56/57 and 56 II. These are the follow-up irradiations of reflector experiments. They were planned for the same temperatures (573, 773 and 873K; 300, 500 and 600 °C) and with the following neutron fluence steps:
8×10^{21} n cm^{-2} for the 573K (300 °C)
10×10^{21} n cm^{-2} for the 773K (500 °C)
6×10^{21} n cm^{-2} for the 873K (600 °C).

D85-54, 573K (300 °C), the follow-up experiment of D85-47, started irradiation in cycle 88.07. The irradiation end is foreseen in cycle 90.04 (total of 19 cycles in C7). The irradiation runs smoothly: temperatures lie in the specified range.

D85-56, 773K (500 °C) follow up of D85-50 started in cycle 89.02. The irradiation ran without problems until cycle 89.05. Then, because of the impossibility to move the vertical displacement unit (the sample holder was blocked in the channel of the capsule) and, consequently to control the axial temperature distribution, the sample holder was unloaded *8*. Samples were sent to KFA Jülich for P.I.E., presently on-going. Details about irradiation history are given in *8*. A new experiment, D85-56 II will replace the D85-56. The sample holder has already been manufactured. Samples must be provided by KFA Jülich. Irradiation start is foreseen in cycle 90.03 in position C7; it will last 25 cycles. The irradiation temperature will be 723K (450 °C).

D85-57, 873K (500 °C) started irradiation in cycle 88.05. It was irradiated until cycle 89.05 for a total of 11 cycles instead of the 14 cycles foreseen because the sample holder was blocked in one of the channels of the capsule. The samples have been sent to KFA Jülich for P.I.E. examinations. Irradiation history is described in *9*.

D85-55 experiment. This experiment will be a follow-up of the D85-57 experiment. It will be loaded with samples of the previous experiment. It will be irradiated at the same temperature (873K - 500 °C) and the irradiation will last for 7 cycles in position C7. The sample holder is ready for irradiation. Irradiation start is foreseen in cycle 90.03.

D85-58 experiment, 1023 K (750 °C) is using the sample holder previously designed for D85-53, type 31. The irradiation started in cycle 89.09, for a total duration of 11 cycles. Temperatures are in the foreseen range.

D85-61, 673 K (400 °C). In this experiment samples of new type and geometry have been irradiated. The samples had a rectangular cross-section; dimension: 3.2 x 8 x 90 mm. The material was CFC graphite (Carbon Fiber Compound). The irradiation lasted 1 cycle (89.07) in position C3. Details can be found in *10.*

Table 11
Graphite Fundamental Properties Programme. Survey 1988/1994.

Exp.number	Irradiation period	Irradiation temp. K	Present state
48/2	May 87-Dec. 88	673	irradiation ended, P.I.E. on going
54	Aug. 88-June 90	573	under irradiation
55	Mar. 90-Oct. 90	873	S.H. ready, waiting for samples
56	Feb. 89-June 89	773	irradiation ended, P.I.E. on going
56 II	Mar. 90-Mar. 92	723	ready for irradiation
57	June 88-June 89	873	P.I.E. on going
58	Oct. 89-Sept. 90	1023	irradiation started
59	Nov. 90-July 91	1173	under preparation
60	Nov. 90-June 91	1323	planned
61	Aug./Sept. 89	673	P.I.E. on going
62	Sept. 91-Mar. 92	1323	planned
63	Jan. 91-Mar. 92	873	planned
64	Jan. 91-July 92	573	planned
66	Oct. 92-June 94	723	planned
67	Sept. 91-May 92	1023	planned
68	Dec. 91-June 92	1173	planned
69	92/93	723	planned
70	Sept. 91-Dec. 93	873	planned
71	Dec. 92-July 93	1023	planned
72	Jan. 93-Aug. 93	1173	planned
73	April 93-Aug. 94	573	planned

General
During 1989, the design of the sample holder has been reviewed. Particularly, the top and the bottom of the sample holder have been changed. The new design will allow easier and cheaper manufacture, quicker assembly and, above all will simplify the unloading operations after irradiation. The use of the new sample holders will start around cycle 90.05. Details can be found in *11.*

A summary of all planned and current D85 irradiations is presented in **Table 11.**

Graphite Creep Experiments D 156 DISCREET.

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 570K to 1170K (300 °C to 900 °C). Creep measurements are taken out-of-pile at intervals of irradiation.

Progress:
During the reporting period the following activities have taken place.

D156-90 Series ASR-1RS, 770K, 5MPa tensile stress. Sample holder 156-93 restarted irradiation in cycle 89.02 and continued uneventfully until the scheduled end of irradiation in cycle 89.06. Following discussions with ORNL and KFA Jülich on the temperature change experiment (a test designed to confirm an empirical creep model) it was decided to use the 156-90 experiment for this test. The samples have been re-encapsulated in a new sample holder (156-94) and their irradiation at 1170 K, started in cycle 89.09, will finish in cycle 90.02. A further new sample holder D156-95 has been ordered for a second irradiation step at 1170 K. Irradiation start is foreseen in cycle 90.06.

D156-50 Series ASR-1RG, 770K, 5MPa tensile stress. Sample holder 156-52 continued irradiation until the end of cycle 89.06. After dismantling and dimensional measurement the samples were re-encapsulated in a new sample holder, 156-53. Irradiation started in cycle 89.09, will finish in cycle 90.08.

D156-70 Series 770K, 5MPa tensile stress. This is a stress mode change experiment in which samples are first irradiated under compression in the HFIR reactor and then under tension in the HFR. This pattern is representative of service conditions. Due to problems at the HFIR the experiment in the HFR has been delayed until the end of 1991.

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Technical Note P/F1/90/7.
11. P. Fraipont, G.P. Tartaglia
D85 sample holders: new design.
Technical Note in preparation.

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 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.

Unstressed Austenitic Stainless Steel (incl. AMCR) Irradiations

R 139 Series.

Objective:
ECN paricipates 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:

R 139-65.

This is an irradiation for martensitic steel at three different irradiation temperatures, 500K, 600K and 700K, at different fluence levels. The

CYCLE NO: 89-06 "D A C O S S Y S T E M" DATE: 14:16:45 10-OCT-89

ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 21:00:00 17-JUN-89 TO 03:10:00 11-JUL-89

EXPERIMENT NO.	: R139-654	NOMINAL DEGREES "C":	270.00
NAME	: SINAS	SAMPLE	:
START DATE	: 09-02-89	STRESS MODE	:
REACTOR LOCATION:	D2	DATA LOGGER NUMBER :	2
GAS PANEL USED	: TRIO-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 < 40.MW	NO DATA	< LOW LIMIT	> HIGH LIMIT	WITHIN LIMITS
634	TC12	Deg. C	259.87	165.61	279.68	12.280	0.214	3350	1.52	0.00	2.21	0.00	96.27
633	TC11	Deg. C	259.38	164.10	278.87	12.345	0.215	3350	1.52	0.00	2.21	0.00	96.27
632	TC10	Deg. C	255.10	170.03	271.67	10.986	0.191	3350	1.52	0.00	2.21	0.00	96.27
631	TC9	Deg. C	255.84	170.56	272.45	10.931	0.190	3350	1.52	0.00	2.21	0.00	96.27
630	TC8	Deg. C	254.37	177.99	268.88	9.912	0.173	3350	1.52	0.00	2.18	0.00	96.30
629	TC7	Deg. C	253.86	178.20	267.69	9.719	0.169	3350	1.52	0.00	2.18	0.00	96.30
628	TC6	Deg. C	252.93	187.23	264.72	8.710	0.152	3350	1.52	0.00	2.18	0.00	96.30
627	TC5	Deg. C	264.63	197.58	277.48	9.005	0.157	3350	1.52	0.00	2.18	0.00	96.30
626	TC4	Deg. C	262.90	203.32	277.09	8.616	0.150	3350	1.52	0.00	2.18	0.00	96.30
625	TC3	Deg. C	260.01	200.62	274.31	8.604	0.150	3350	1.52	0.00	2.18	0.00	96.30
624	TC2	Deg. C	259.83	202.89	275.34	8.815	0.153	3350	1.52	0.00	2.18	0.00	96.30
623	TC1	Deg. C	253.66	197.44	269.09	8.898	0.155	3350	1.52	0.00	2.18	0.00	96.30

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.

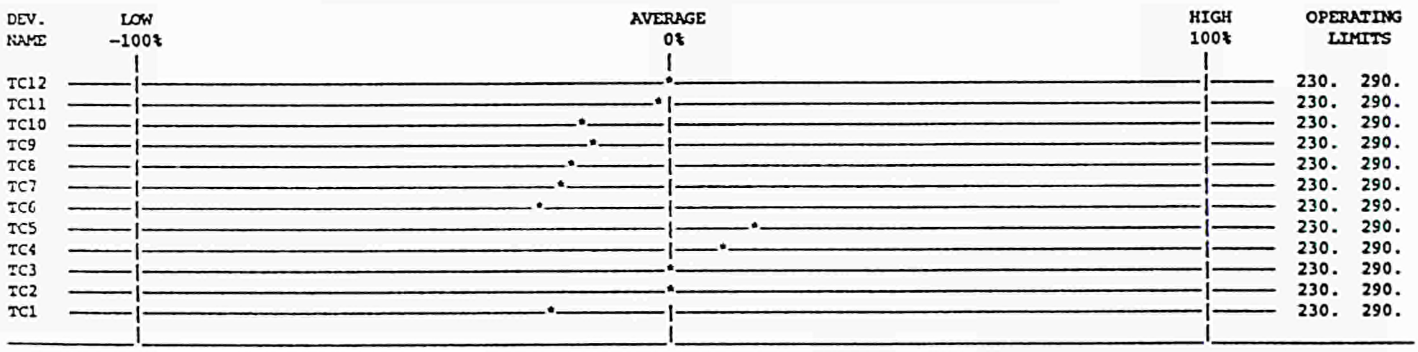

Table 12
R 139-654. Typical statistical analysis of a temperature distribution in a reactor cycle (89.06).

specimens are designed to be irradiated in TRIO 129 legs. The 600K and 700K 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 500K: the first one at 0.5 dpa, the second at 2.5 dpa and the third at 7 dpa. Irradiation of the first leg (500K and 0.5 dpa) started in 88.02 and terminated in 88.03 in E3. Irradiation of the remaining two legs (500K, 2.5 and 7 dpa) started in 88.06 in D2 position and is still underway. A typical statistical analysis of the temperature distibution during a reactor cycle is presented in **Table 12.**

R 139-66

This irradiation will accommodate NET construction material. 40 CT specimens, 10 tensile and 20 fatigue will be irradiated in core position E7 at reactor-ambient temperature (about 350K). The damage required is about 5 dpa. The specimens will be in contact with the reactor coolant in a REFA 170. Design and calculations are in progress. Irradiation will start in the first half of 1990.

R 139-67

Similar irradiation conditions with those of the R 139-66 are applied. 40 CT specimens, 10 tensile and 20 fatigue will be irradiated in position E1 for a damage requirement of about 0.3 dpa. Irradiation will take place in a REFA 170 and the specimens will be in contact with the water of the reactor coolant system. Design of the rig is in progress and irradiation will take place in the first quarter of 1991, due to specimen manufacturing problems.

R 139-69

This experiment consists of 6 sample holders with 10 CT specimens in each holder. Three sample holders are planned for 0.3 dpa at 525K and three for 5 dpa at 525K. Design and thermal analysis are in progress. Irradiation is planned to start in the first half of 1990.

E 198-14 SIENA

Objective:
In the years 1985/87, the NET Team stressed the need for a very high dose irradiation of first wall candidate materials. For this purpose a special irradiation facility was developed, fulfilling the following requirements:
— Irradiation temperatures: up to 773K (500 °C) for S.S., 1073K (800 °C) for other materials, and possibly as low as 423K (150 °C).
— 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.
The parties involved in this irradiation are:
— JRC-IAM Ispra : tensile samples of 316 L, AMCR, Cu and Cu-Cr-Zr
— KfK Karlsruhe : Tensile and Charpy samples of DIN 1.4914
— ECN Petten : tensile and fatigue samples of different vanadium alloys, together with UKAEA Harwell and Tohoku University, Japan. Recently also irradiation of stainless steel has started.

The duration of the irradiation was fixed up to 30/35 dpa in stainless steel samples at the beginning.

In the meantime the targets of the NET development have been reconsidered: the extremely high doses are of less interest. It was decided to conclude the SIENA irradiations at 15 dpa, continuing the 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.
P.I.E. is on going on sample holders 19, 20, 21 unloaded in cycle 88.06 (sponsor: KfK).
Tensile tests have been performed on the samples contained in the sample holders 3, 8, 12 (material: AISI 316L, irradiated up to 1 dpa, sponsor JRC-IAM Ispra).

Unloading of sample holders 15, 16, 6, 17, 22 has taken place at the end of cycle 89.07, having reached the fixed damage of 10 dpa. The samples (AMCR, Cu and Cu-Cr-Zr) will be shipped to Ispra for P.I.E. work at the end of February 1990 *1*.

The sample holder 18 (KfK-containing DIN 1.4914 material) has also reached 10 dpa at the end of cycle 89.07 and consequently been unloaded. It will be shipped to KFA in February 1990 for P.I.E. work *1*.

New sample holders, have replaced in cycle 89.09 the previous ones. The new irradiation series is called E 198-15. The sample holders 15, 16, 17, 22 (JRC-IAM Ispra) contain low activation materials (IFA, IFC, IFE alloys). They are being irradiated at two temperatures (523, 723K - 250, 450 °C) and at two damage values (10, 25 dpa).

Composition of the material is given in **Table 13.** The two other alloys (IFB, IFD) will be irradiated in cycle 90.06. Irradiation conditions are exactly the same as the previous ones. Manufacture of new sample holders is on going.

Table 13
Chemical composition of optimized Cr-Mn stainless steels.

	IF-A	IF-B	IF-C	IF-D	IF-E
			(wt%)		
Cr	13.57	12.37	13.14	10.24	17.86
Mn	11.34	10.62	18.00	16.92	11.00
Ni	2.04	0.23	2.14	0.13	2.08
Mo	0.031	0.023	0.037	0.026	0.041
C	0.10	0.31	0.10	0.26	0.08
N	0.047	0.036	0.042	0.080	0.054
Si	0.20	0.17	0.20	0.50	0.30
V	0.63	0.64	0.021	0.032	0.74
W	1.42	1.38	1.92	2.04	2.02
			(ppm)		
S	70	70	50	30	70
P	130	140	130	80	140
Cu	370	290	360	240	370
Al	30	30	30	45	40
Nb	50	50	50	50	50
Ta	50	50	50	50	50
Pb	2	1	2	1	1.5
Co	220	200	210	200	220
B	3	3	3	3	3
Bi	1	1	1	0.5	1
Ag	1	1	1	1	1
Ti	10	10	10	20	10

The channel 18 (KfK-Karlsrühe) contains an identical sample as the previous one and is irradiated at the same temperature (573K, 300 °C). The damage value is fixed at 5 dpa.

The irradiation of the vanadium alloys (VABONA R204-7/8/9-ECN) has still

Chan. No.	Irr. Temp.	dpa	Client	Sample Mater.	Sample Type	Sample Holder	Irrad. Start	Schedul. Irr. End
01	300	15	CCR/KfK	A + B	1 + 2	Al	87.11	90.05
02	350	15	CCR/KfK	A + B	1 + 2	Al	87.11	90.05
03/3	250	~0.6	ECN[1]	A + B	1	Al	89.09	89.09
04	400	15	CCR/KfK	A + B	1 + 2	Al	87.11	90.05
05	450	15	CCR/KfK	A + B	1 + 2	Al	87.11	90.05
06	250	15	CCR	A	1	Al	87.11	90.05
07	300	15	CCR	A	1	Al	87.11	90.05
08/3	250	~0.6	ECN[1]	A + B	1	Al	89.09	89.09
09	350	15	CCR	A	1	Al	87.11	90.05
10	400	15	CCR	A	1	Al	87.11	90.05
11	475	15	KfK	A	1 + 2	Al	87.11	90.05
12/3	250	~0.6	ECN[1]	B + A	1	Al	89.09	89.09
13	450	15	CCR	A	1	Al	87.11	90.05
14	250	15	CCR/KfK	B	1 + 2	Al	87.11	90.05
15/2	250	10	CCR	C	1	Al	89.09	91.03
16/2	250	25	CCR	C	1	Al	89.09	93.03
17/2	450	10	CCR	C	1	Cu	89.09	91.03
18/2	300	5	KfK	B	1 + 2	Al	89.09	90.08
19/2	300	10	KfK	B	1 + 2	Al	88.10	90.07
20/2	400	10	KfK	B	1 + 2	Al	88.10	90.07
21/2	475	10	KfK	B	1 + 2	Cu	88.10	90.07
22/2	450	25	CCR	C	1	Cu	89.09	93.03

Table 14
Present situation (October 1989) – Occupation of the SIENA capsule – reactor position C5.

Legend:
Sample Type: 1 = Tensile Samples; 2 = Charpy samples
Sample Material: A = AISI 316L; B = 1.4914 St. Steel; C = AMCR; D = Copper; E = Cu/Zr alloy

1. SINAS - R 139-68
Starting (probably) from cycle 90.06 the channels 03, 08 and 12 will be loaded with the three VABONA sample holders, R 204-07/08/09 ECN.

been delayed because the customer has problems in the characterisation/manufacture of the samples. Irradiation start is foreseen in cycle 90.06.

Meanwhile, the three dummies in channels 3, 8, 12 have been replaced with three sample holders of the SINAS experiment (R 139-68), sponsored by ECN.
They contained tensile samples of AISI 316L and martensitic steels and have been irradiated for 1 cycle (up to ~ 0.5/0.6 dpa) in cycle 89.09. P.I.E is on going *2*.

An overview of the present occupation of the SIENA capsule is given in **Table 14.**

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 (AMCR) 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 (namely 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	<06.06	–	0.19	0.008	0.016
AMCR-0034 Creusot-Loire (France)	0.001	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 15
Composition of steels (wt%) creep tested in TRIESTE and CRISP.

Progress:

E 167 TRIESTE
Intermittent Creep Measurement (MAT-5)

The entire experimental TRIESTE programme comprises seven irradiation facilities where each facility is irradiated for eight steps or more and dimensional measurements on the individual tensile samples are performed in hot-cells between the irradiation steps.

The irradiation series E 167-10, E 167-20, E 167-30, E 167-40, E 167-50, E 167-60, E 167-70 and E 167-80 are distinguished by the type of sample material, the irradiation temperature (between 200 and 400 °C) and the applied stresses (between 25 and 300 MPa) during the irradiation. Irradiation samples and half-shell pairs are manufactured from nine different materials. The chemical composition of these materials is given in **Table 15.**

It is aimed to reach about 5.7 dpa. The irradiation history of the TRIESTE series is shown in **Table 16.** The end of the total irradiation is scheduled beyond 1991.

The following activities were pursued during the reporting period:
— Irradiations continued in 1989. Experiments E 167-18, E 167-29, E 167-37 and E 167-46 were irradiated for three HFR cycles.
  In the same period the experiments E 167-28, E 167-54 and E 167-64 were irradiated for two cycles and the experiments E 167-53 and E 167-63 for one cycle.

Table 16
Damage obtained in TRIESTE experiments at the end of 1989.

TRIESTE series	Irradiation Start [HFR-cycle]	Damage obtained [dpa]
E 167-10	83.10	5.1
E 167-20	85.03	5.7
E 167-30	85.06	3.9
E 167-40	87.09	3.0
E 167-50	88.04	1.5
E 167-60	88.07	1.5

— During the reporting period creep elongations of individual samples of the experiments E 167-17, E 167-18, E 167-28, E 167-37, E 167-43, E 167-44, E 167-45, E 167-52, E 167-53, E 167-54, E 167-62 and E 167-63 were measured in hot cells using semi-automatic measuring devices.
— Irradiation creep rates were determined for annealed and cold-worked AMCR- and 316-type steel alloys, for various irradiation temperatures, stresses and for neutron doses up to 4 dpa *3.*
A typical creep curve is shown in **Fig. 33,** where the secondary creep rate for annealed AMCR 0033 steel is plotted versus the applied stress. The stress exponent n ~ 1.85 is obtained from the slope of the straight line.
— The irradiation of the series E 167-30 has been stopped after cycle 89.04 due to difficulties of loading and unloading of the sample stems. Series E 167-30 will be replaced by the E 167-70 series. Assembly and load calibration tests of the sample stems of this new irradiation series

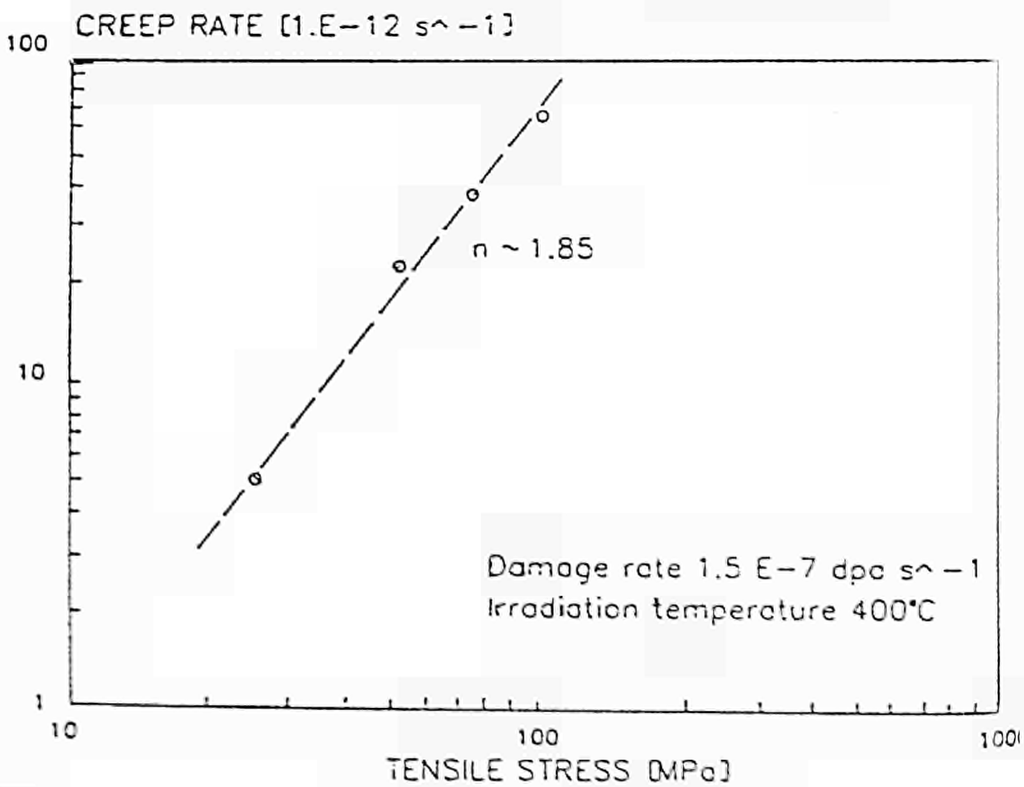

Fig. 33
Log-log plot of the secondary creep rate as a function of the applied stress for AMCR 0033 annealed at 400C before the irradiation.

is presently being carried out. The start of the irradiation is planned in HFR-cycle 90.03.

- Assembly of the new TRIESTE irradiation device for low temperature irradiations of stainless steel samples at about 373 K (100 °C) has been started. Machining of the samples and reference half-shells to be irradiated in this rig is presently being prepared. The start of the irradiation series E 167-80 is planned in HFR-cycle 90.06.
- Assembly work of two special REFA-type capsules, two sample carriers, two special REFA heads and 14 sample stems is needed for the new E 167-70 and E 167-80 series.

E 157 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 in one standard TRIO irradiation facility, are independent with respect to the irradiation temperature and the applied stresses which can be varied between 573 K and 873 K (300 °C and 600 °C) 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 dumbbell-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 lenght with the lenght of an unstressed reference piece of the same material.

Experience from prototype irradiations (E 157/01-03) 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 *4*. The assembly of the second set of three sample holders (E 157/11-13) was delayed due to a large number of minor technical difficulties.

The irradiation is scheduled to start in HFR cycle 90.05. The fabrication of a third set of three sample holders (E 157/14-16) is presently being carried out. The start of the irradiation of this series is planned in cycle 91.02.

Irradiation of Materials Used in Super-Conducting Magnets

D 202 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, various materials like V_3Si, $PbMo_8S_6$ and $TlCa_3BaCu_3O_9$ have been investigated in the past.
Specimens of $YBa_2Cu_3O_7$ have been irradiated up to 10^{17}n cm^{-2} at 323 K (50 °C).
All irradiations are performed with a Cd screen surrounding the sample

holder, to filter thermal neutrons and thus to minimize activation of the samples. All samples, once dismantled, are returned to the sponsor for P.I.E.

Vanadium Irradiations

R 204 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.

Progress:
Three new experiments R 204-07/08/09 have been launched in 1987. Due to problems concerning the production of the new vanadium alloys the work was discontinued until December 1988. The various pieces of the three sample holders are ready since the beginning of 1989. The irradiation has not yet started because the client has not yet provided the samples. They will be delivered in June 1990. The irradiation start is foreseen in cycle 90.07.

Blanket Breeder Materials 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 of these irradiation tests are:
- study of tritium release kinetics by in-situ tritium measurement **(Fig. 34)**,
- irradiation damage studies,
- compatibility studies up to high ^6Li burnup,
- tritium permeation studies through reference cladding materials,
- study of tritium extraction methods,
- study of tritium permeation barriers.

The results of these experiments are relevant for the selection of candidate blanket breeder materials and for the design of blanket concepts for future fusion reactors (e.g. NET, ITER).

The HFR Petten activities on blanket breeder irradiations are summarized in **Table 17.**

R 212 EXOTIC Irradiaton of Ceramic Lithium Compounds

The experimental programme EXOTIC is being carried out since 1984 as a joint project by ECN Petten, NRL Springfields, SCK/CEN Mol in co-operation with the JRC Institute for Advanced Materials at Petten. In 1988, CEA Saclay, KfK Karlsruhe and ENEA Casaccia joined the EXOTIC project. The programme comprises manufacture, characterization, irradiation and pre- and post-irradiation examination of the Li-compounds $LiAlO_2$, Li_2SiO_3,

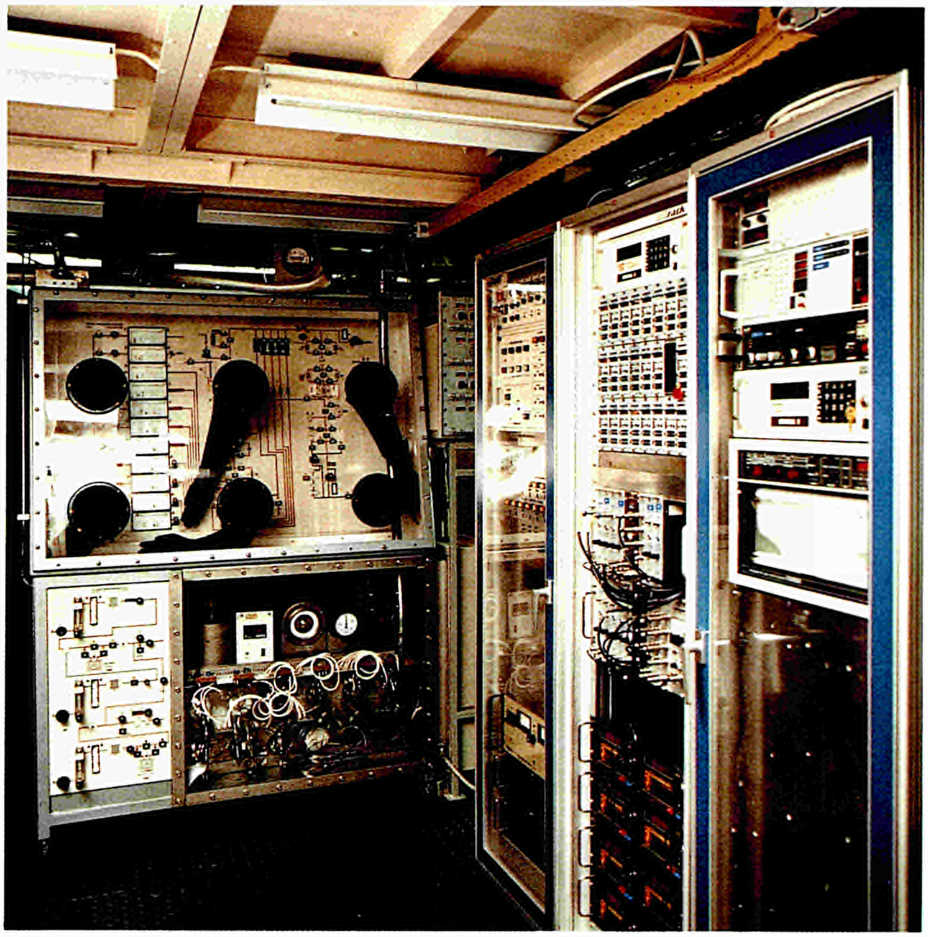

Fig. 34
Fusion blanket breeder material testing.
Tritium measuring and control equipment.

Table 17
Fusion blanket breeder experiments.
Survey of present and future activities.

Legend:
1 Design & calculation
2 Manufacture and commissioning
3 Irradiation
4 Dismantling and PIE
5 Upgrading

YEAR	1989	1990	1991	1992
1. EXOTIC experiments:				
R 212.13-16	4 ▬			
R 212.17-20	2 ▬ 3 ▬	▬ 4 ▬		
R 212.21-24	1 ▬	▬ 2 ▬	3 ▬ 4 ▬	▬
2. LIBRETTO experiments:				
E 224.01-04	4 ▬	▬		
E 224.05-08	2 ▬ 3 ▬ 4 ▬	▬		
E 224.09-12	1 ▬	▬ 2 ▬ 3 ▬	▬ 4 ▬	▬
E 224.13-16		1 ▬ 2	▬ 3 ▬	▬ 4 ▬
3. ELIMA experiment:				
D 237.01	4 ▬	▬		
4. Out-of-pile facilities	5 ▬	▬	▬	▬

Li_4SiO_4, Li_2O, Li_2ZrO_3, $Li_6Zr_2O_7$ and Li_8ZrO_6. The present EXOTIC programme consists of six irradiation experiments. The first four experiments were performed before 1989 in the HFR Petten *5., 6.* P.I.E. is presently going on at the participating laboratories.

EXOTIC-5 R 212.17-20

The JRC Petten activities in 1989 were concentrated on the preparation and irradiation of the EXOTIC-5 experiment *7.* In-pile operation with eight independently purged capsules started as planned with cycle 89.07 in core position H2. The required irradiation conditions were achieved. Five irradiation cycles were completed in 1989. An additional sixth cycle in 1990 was requested by the project partners. Approx. 500 temperature transients between 300 and 650 °C at different ^{6}Li burnup stages were performed to obtain data on tritium release kinetics. The irradiation data were compiled in *8., 9., 10.* The results of the EXOTIC-5 experiment will be published at the 16th SOFT in 1990.

EXOTIC-6 R 212.21-24

An irradiation proposal for the EXOTIC-6 experiment was submitted to ECN Petten *11.* Design work started during the reporting period. The EXOTIC-6 irradiation is planned to start by the end of 1990.

D 237 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 was performed in the OSIRIS material testing reactor. The fast spectrum irradiation, originally planned for the KNK-II reactor, was performed in the HFR Petten. Therefore the specimen materials were surrounded by a cadmium screen in order to cut off 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 cooperation programme.

Progress:
The irradiation was completed as planned with cycle 88.11 on 5th January, 1989. The preliminary irradiation results were compiled in *12.* The post-irradiation examinations at Petten, including X-ray analysis of the 36 rods and gamma scanning of the special detectors was completed in 1989. The samples were shipped for further PIE to KfK Karlsruhe. The dosimetry work at ECN Petten started in 1989.
The final irradiation report will be issued in 1990.

E 224 LIBRETTO Irradiation of the Liquid Breeder Material Pb-17Li

Objective:
The experimental programme LIBRETTO is being carried out as a joint programme between JRC Institute for Safety Technology Ispra and CEA Saclay in co-operation with JRC Institute for Advanced Materials Petten. The programme consists of four irradiation experiments **(Table 17).**
The objectives of the LIBRETTO experiments are the in-pile testing of the eutectic alloy Pb-17Li in a thermal neutron spectrum to assess tritium release kinetics, tritium extraction methods, compatibility studies and tritium permeation through reference stainless steel cladding with and without permeation barriers.

Capsule no.	5	6	7	8
Plenum volume (cm^3)	1.5	4	0.5	8
Alloy volume (cm^3)	8	8	8	8
Ratio sample diameter/length	0.1	0.1	0.1	0.1
Wall material	alpha-iron	316L	316L	316L + permeation barrier
Irrad.time (days)	63.64	63.64	63.64	63.64
Temp.range (K)	560/750	568/760	573/723	550/710
T-release rate (μ Ci/(min g))	3.70	3.80	3.83	3.71
Burnup (%Li)	1.11	1.14	1.16	1.13
Neutron fluence $10^{25}m^{-2}$ (E > 0.1 MeV)	0.4	0.49	0.43	0.35

Capsule no.	09	10	11	12
Test material	Pb-17Li	Pb-17Li	Pb-17Li	Pb-17Li
Material supplier	JRC Ispra	JRC Ispra	JRC Ispra	CEA Saclay
Purged by	plenum sweeping	bubbling	bubbling	bubbling
Cladding material	AISI 316L	AISI 316L	AISI 316L	AISI 316L
Permeation layer	no	no	yes	yes
^{6}Li enrichment	7.5%	7.5%	7.5%	7.5%
Specimen volume cm^3	0.5	3.5	3.5	3.5
Ratio sample diameter/length	1	0.1	0.1	0.1

Table 18
Design and irradiation parameters LIBRETTO 2.

Table 19
Loading scheme of LIBRETTO 3. Project E 224.09-12.

Progress:

LIBRETTO 1 E 224.01-04

Post-irradiation examinations (PIE) continued in 1989 for the LIBRETTO 1 experiment. Results were presented at the 1989 HFR Colloquium *13.* and published in *6., 14.* The final dosimetry results have been published in *15.* A final irradiation report will be published in 1990.

LIBRETTO 2 E 224.05-08

The manufacture and assembly of the LIBRETTO 2 experiments was completed in 1989. A design and safety report was issued *16.* The irradiation of the four sample holders started as planned with cycle 89.03 for an irradiation period of three cycles. The irradiation parameters are compiled in **Table 18.** The irradiation results were published in *17.*

The PIE is currently being performed at Petten. After a neutron-radiograph was taken, dismantling of the sample holders and recovery of the capsules and fluence detector sets were performed.

LIBRETTO 3 E 224.09-12

The objective of the third LIBRETTO experiment is the investigation of tritium extraction methods (plenum sweeping and bubbling) from static alloy samples. At the same time, the efficiency of tritium permeation barriers are investigated. The test matrix is given in **Table 19.** An irradiation

proposal was issued in December 1989 *18*. The irradiation is planned to start at the end of 1990.
The irradiation facilities for testing blanket breeder materials at the HFR Petten were described in *19*.

Irradiation of Ceramic First Wall and Insulators Material

D 217 CERAM

Legs 11, 12 and 13

Objective:
In the frame of the European Fusion Reactor Materials Research Programme (MAT6/MAT13), 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 1473K and 673K.

Progress:
The experiment consists of three sample holders in a TRIO arrangement in one reactor position. Two 1473K holders house specimens for MAT6, and the third one, (673K) houses specimens, for MAT13.

The specimens for the low temperature leg consist of Al_20_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.

The capsules were dismantled in July, 1988 and the specimens were transported to KfK Karlsruhe, CEA Saclay, CIEMAT Madrid and AERE Harwell in June 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 1773K (1500 °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:
Irradiation of sample holder 14 started in cycle 89.07 and finished in cycle 89.08. Irradiation of sample holder 15 started in 89.09 and is expected to

continue in the first quarter of 1990. Assembly of leg 16 is expected to start at the beginning of 1990.

D 225 CEFIR

Objective:
CEFIR is a contribution of KFA J lich to the NET fusion programme and concerns an irradiation of several ceramic materials at three temperatures (673K, 873K, 1073K). The experiment has been irra- diated in two HFR positions: C7 (5½ cycles) and G5 (7 cycles).

Progress:
The experiment was irradiated until cycle 88.06. The samples were transported to Jülich in January 1989.
The dosimetry report has been issued *20.*

First Wall Coating Graphite Irradiations

D 241 GRIPS

Objective:
The aim of this new experiment (GRIPS stands for GRaphite Irradiation in Pool Side facility) is to invesigate 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 *21.*, 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 1073K (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.

The design changed several times, because the sponsors of the experiment made significant changes to the specifications: instead of 5 fluence steps at one temperature, 1073K (800 °C), the same 5 fluence steps should be performed at 673K (400 °C) and at 873K (600 °C) *22.*

The PSF support and the main parts of the facility have already been manufactured and assembled. The time schedule has been changed because of delay in the delivery of the heaters by Thermocoax company.

The irradiation start is foreseen in cycle 90.05. A dummy rig (D 241-00) will be used to check the equipment and the achievement of the operating specifications. The two irradiation series (D 241-01/05 and D 241-06/10) will take place in cycles 90.04 and 90.05.

Divertor Materials Irradiations

KFA Jülich is investigating the irradiation behaviour of Molybdenum and Molybdenum alloys, candidates for the divertor component of the NET.

The experiment called NEMESIS (NEt MEtalS IrradiationS) consists of two irradiations series (0.2 dpa, 1 dpa) of the materials listed in **Table 20** at three temperatures (~ 80 °C, 400 °C, 700 °C).

Characteristics of the specimens are the following *23*.

Specimen type	Dimensions	Number of specimens (per material)
3-points load	$2 \times 2 \times 50\ mm^3$	25
Charpy	$6 \times 6 \times 44\ mm^3$	16

In each irradiation 100 three-points specimens (25 per material) and 64 Charpy samples (16 per material) will be subjected to neutron damage.

Progress:
The contract has been received in december 1989.
During the reporting period, all the thermal and nuclear calculations have been performed. The design is ready *24*.

Table 20
Composition of the 4 divertor materials to be irradiated.

Material	Mo	Ti	Zr	Re	C	Cr
Mo	100	–	–	–	–	–
TZM	99.39	0.5	0.09	–	0.02	–
MoRe20	75.24	–	–	24.76	–	–
Z6	>99	–	0.2	–	–	24ppm

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3.5. RADIONUCLIDE PRODUCTION

Radioisotopes for Medical / Industrial use

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 fissile targets continued routinely. As usually the targets irradiated have been sent 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.
A new design for the In-Core FIT facility is under preparation.

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 is continuing.
During the reporting period the activity has reached the value of 80.000 Ci (February 1990).

The present irradiation series will end in July 1990. Starting from the next irradiation campaign, cobalt will be irradiated in the form of needles. The target activity is unchanged: 100.000 Ci.

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. During 1989, a total of thirty capsules have been irradiated.

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

Irradiation tests

Irradiation of Pd seeds has been performed in cycle 89.03. The total activity reached will be checked by the customer and, if it fits in their needs, a routine production of Pd^{103} will start.

Irradiation tests are on-going to check the possibility to achieve an activity of 300 Ci/g in Ir-pellets. In case of satisfactory results, routine production of Ir^{192} is envisaged.

Irradiation tests are also envisaged for British companies.
Objective: Production of Ir^{192} in the form of pellets.
During the reporting period negotiations were on going to irradiate Y.

Standard Radionuclide Production Facilities

ER8, ER90, ER144

For the production of radionuclides the facility HF-PIF has been operated on a regular schedule. The use of the facility RIF was reduced to a few cycles. A design of a new facility has been made, in which samples, having current dimensions, can be irradiated. The design is based on forced cooling and the irradiation will be performed in one of the PSF-positions. Close attention is given to an easy way of handling of the sample holder. The HIFI facility has been modified for easier handling and has been made operational in cycle 89.03. HIFI is an irradiation facility for the production of radionuclides at very high levels of neutron fluence rates.

The facility has succesfully been used for the production of irridium. The irradiated irridium meets the requirements for medical and technical applications.

ER70 PROF

Objective:
Irradiation of a large number of samples for neutron activation analysis. The Poolside Rotating Facility (PROF) consists of a driving gear and an irradiation rig and is installed near the reactor core in the vertical irradiation position NW. For flattening of the radial neutron fluence rate the rig is rotating around the vertical axis at a speed of one revolution per minute. The rig can be placed or removed at any moment during the reactor operation period.
The irradiation tube has an internal diameter of 60 mm and a lenght of 900 mm. Irradiations will be placed in sample holders fitted into a polyethene container with an outer diameter of 55 mm. A total of 21 sample holders (volume 1 cm^3) can be loaded.

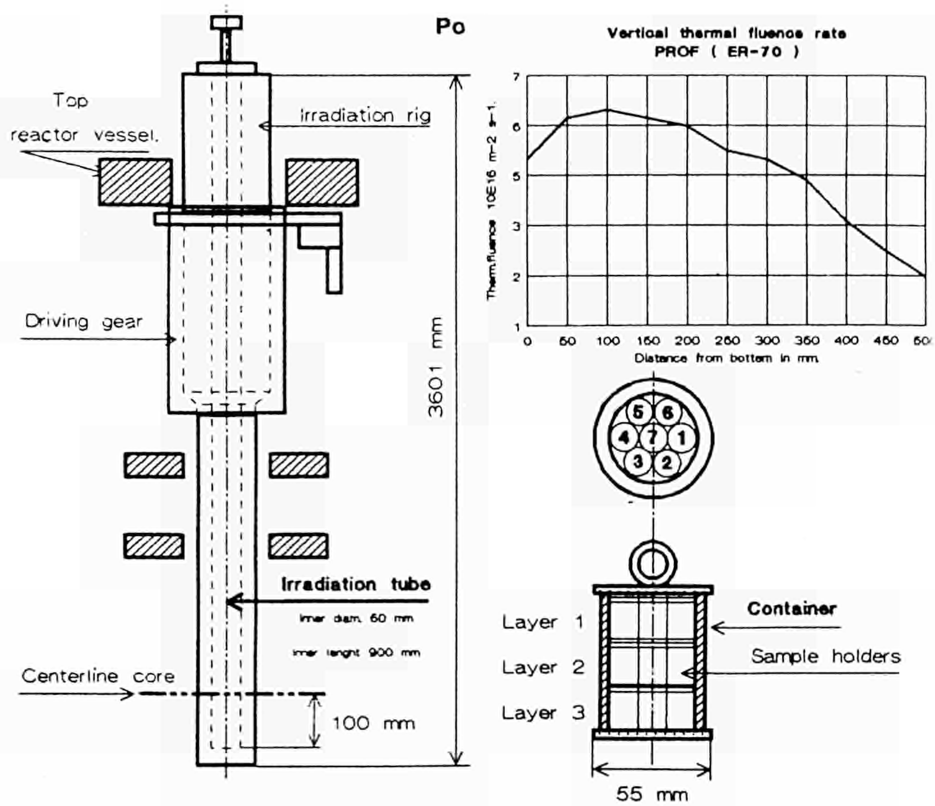

Fig. 35
Pool side rotating facility (ER 70, PROF).

More than one container can be stacked in the irradiation tube. A schematic impression of the facility and a contaner are shown in **Fig. 35.**

Progress:
To know exactly the thermal fluence rate distribution over a lenght of 500 mm above the bottom of the irradiation tube a fluence measurement has been carried out; the results are presented in **Fig. 35.** In February the rotation of the rig stopped due to a mechanical failure of the electromotor. The motor has been replaced by a spare one.

3.6. NUCLEAR PHYSICS

Due to the neutron as well as the gamma quant being electrically neutral, radiative capture reactions are well suited to study minute electrical currents in atomic nuclei. A study of the exchange of sub-nucleonic particles in atomic nuclei has been completed at the two polarized neutron beams (HB2 and HB7) of the HFR.
It was shown that for the simplest nuclear reaction, the capture of a neutron by a proton, the exchange of quarks might play a role even at the energy of the neutrons from the HFR beams. For a slightly more complicated reaction, the capture of a neutron by a deuteron, it could be shown that exchange of mesons plays an important role.
For the much more complicated case of radiative capture of a neutron in a ^{3}He nucleus, such conclusions were much harder to reach, due to computational difficulties. The latter reaction, nevertheless, is very interesting, as it gives a hint of how many high energy neutrino's are emitted by the sun in a reaction between protons and ^{3}He. In competition with Grenoble (ILL) and Argonne (ANL) groups, an attempt was made to reach a far more accurate value for the radiative capture cross section. The first two groups succeeded with a rapid publication, but the Petten nuclear physics group expects to reach an accuracy, two times higher.

3.7. SOLID STATE PHYSICS AND MATERIALS SCIENCE

The Solid State Physics group of the Service Unit Materials of ECN utilises 5 neutron spectrometers for carrying out both fundamental and applied research in Solid State Physics, Chemistry and in Materials Science. It considers the determination of crystallographic and magnetic structures of both powdered (polycrystalline) and mono-crystalline specimens, the study of atomic and magnetic short-range correlations, dynamic studies using inelastic neutron scattering for observing phonons, magnons and crystal-field excitations. Small-angle neutron scattering (SANS) is applied for research of a large variety of disperse systems.

Basic research was carried out on specific systems like 1-dimensional magnetic systems (chains) (static and dynamic properties), heavy-fermion systems and diluted magnetic semi-conductors.
Structure characterization of a large variety of high T_c-superconducting

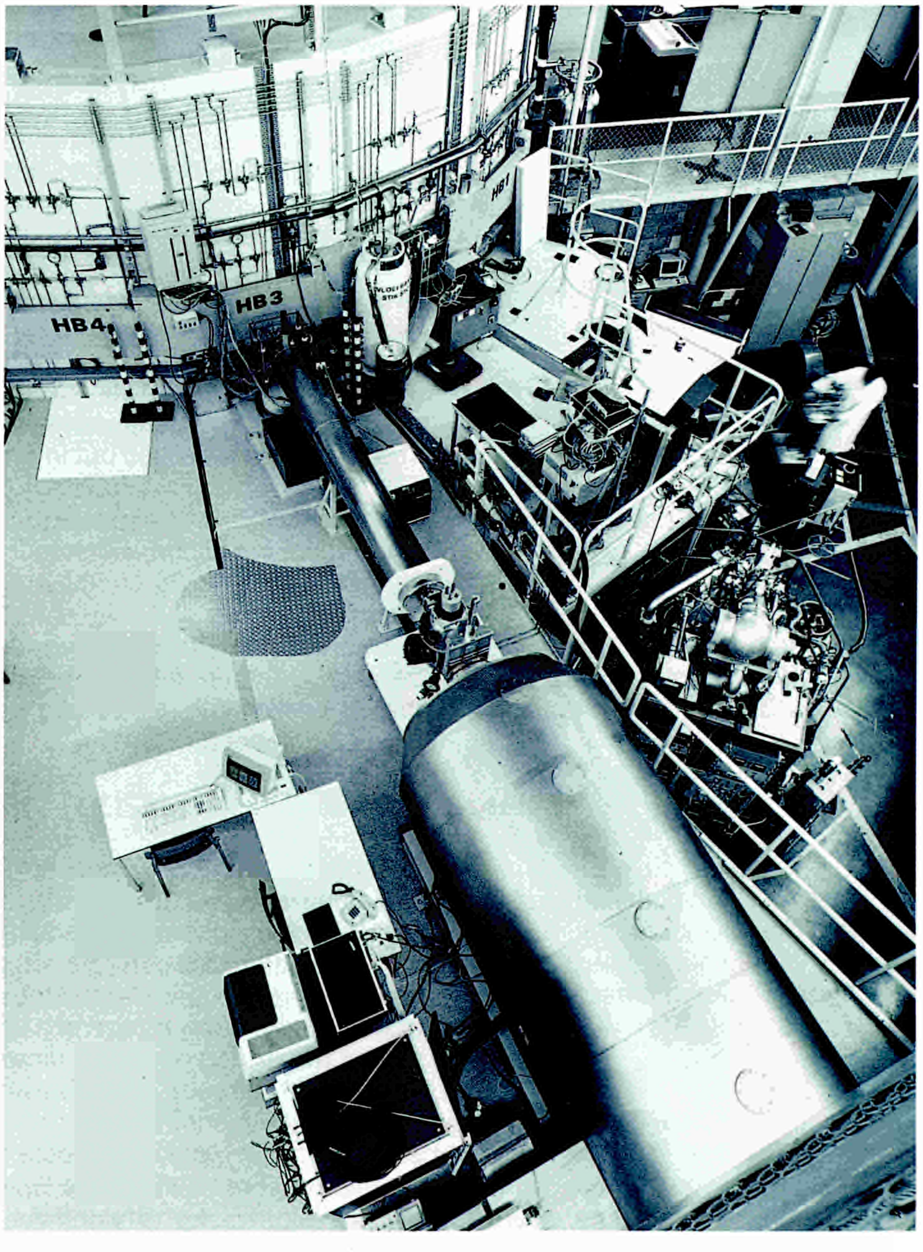

Fig. 36
SANS-facility at beam tube HB 3.

compounds by means of neutron diffraction was carried out.
Determination of residual stresses in different types of steel, which had undergone different working conditions, took place, both in the framework of a Ph.D. study as well as contribution to a BRITE-contract to study micro-structural properties with different non-destructive testing methods. Due to the growing interest in this type of research with neutrons, a new spectrometer, solely dedicated to stress measurements, is under construction. It is expected to be operational by the middle of 1990.
Since there is a mutual influence of residual stress and texture, a start has been made to exploit the advantage of neutrons (as compared to X-rays) for the study of bulk properties, by developing a method for texture determination. The facility for small-angle neutron scattering (SANS) was officially inaugurated in the early spring of 1989 by means of a SANS-colloquium. The facility has been used for the study of several subjects, such as precipitates in steel, porosity in different types of ceramics, silica colloids, biological membranes and "viscosity-index improvers". **Fig. 36** shows a photograph of this new SANS-facility at beam tube HB3 of the HFR.

3.8. MISCELLANEOUS

ER220 SIP
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 silicon 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 the PSF.

Progress:
Irradiations for silicon characterization have been carried out on a regular schedule. In total 28 containers were irradiated in 1989 without major technical problems.
The canister had to be replaced by a spare one. A new spare canister had been manufactured. Since the start of the irradiations for this project 120 irradiations have been carried out with a total irradiation time of 8497 hours.

R233 SIDO

Objective:
Development, design, manufacture and characterization of a prototype facility for the "doping" of industrial silicon crystals.
The facility **(Fig. 37)** consists of a driving unit with a sample holder rotating inside an insert tube. The crystal, mounted in an open holder, wil 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 crystal to be irradiated are limited to a diameter of 103 mm and a lenght 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.

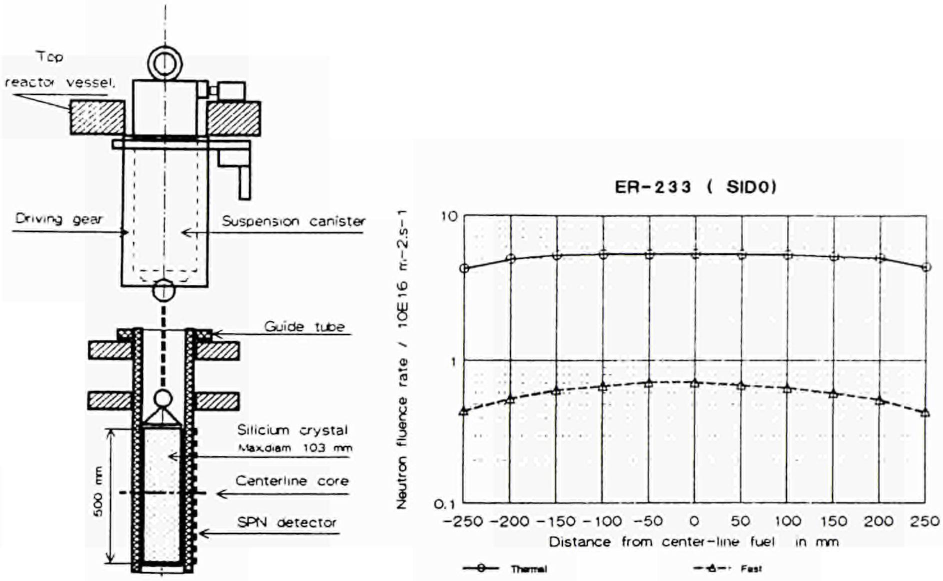

Fig. 37
Facility for neutron transmutation doping of silicium (ER 233, SIDO).

Progress:
Early 1989 several test runs have been performed with a prototype SIDO facility in the PROF position. Some shortcomings were detected, and some modifications were necessary. New test runs were succesfull. Neutron fluence measurements at the sample position were performed. The thermal neutron fluence rate was homogeneous within 5 percent over a lenght of 420 mm. The ratio of thermal and fast neutron fluence rates was approximately 8. The present facility is now ready for irradiation of silicon crystals.

CH240 Minerals Irradiations

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

Progress:
Irradiation parameters have been established to the extent that specified results can be achieved. Contract agreement has been reached on full scale production and design work on the larger rig is well advanced. Irradiation is expected to start in cycle 90.08.

R244 HEISA Heated Instrumented Salt Irradiation

Objective:
The study of the behaviour of salt in a gamma radiation field, as part of the project on the storage of nuclear waste in salt domes. Gamma radiation causes a desintegration of NaCl which produces Cl_2 and H_2 gas with the release of some energy. Salt samples are irradiated under high pressure (~ 200 bar) in the gamma irradiation facility (GIF) in the storage pool.

Progress:
Five irradiations have been performed in the past year. Each time eight spent fuel elements have applied as source in the facility. Because of some difficulties a modified test assembly is being constructed. In this assembly 16 salt samples can be irradiated simultaneously.

4. GENERAL ACTIVITIES

This chapter 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 programme include
— operation and maintenance of ancillary services and laboratories
— design studies and development of new irradiation devices
— technical support to the running irradiation programme.

4.1. ASSEMBLY LABORATORY

45 irradiation experiments were assembled and also carried out under contract to external suppliers.
To maintain equipment at the required level, some measuring instruments have been ordered.
A new ultrasonic two chamber installation is now available with a useful space of 800 mm high for cleaning a complete sample column.
A gas test panel equipped with pressure control transducers and the possibility to operation under vacuum is in construction.
The completion of the new assembly room has been further delayed.

4.2. STANDARD IRRADIATION DEVICES

The following standard in-core capsules and heads ordered with an external supplier are in production.
3 x TRIESTE-rig incl. carrier
1 x REFA 170-head
1 x REFA 170-rig
2 x TRIO-head
New order:
1 x PSF capsule holder
1 x LIBRETTO head

4.3. QUALITY CONTROL

— During the reporting period the Quality Control and Assurance group has sent off 35 reports with the following items:
  – 30 sample holders
  – 10 in-core capsules
  – 2 instrumentation-heads
  – 2 P.S.F.-carriers
  – 5 B.W.F.C.-capsules e.o.
— A lead-shield in the ceiling of the X-ray lab. has reduced the dose-tempo, coursed by the new 225 KV X-ray tube, from 2000 μSc/h until 5 μSv/h. The Radiation Protection Service has fully approved of all the safety precautions.
— The former E.C.N. Sodium Filling Station has been technically updated to recent regulations and will come into operation at the beginning of 1990. In order to follow these regulations a new Sodium Filling Station shall be integrated together with the NaK Filling Station into the concrete cellar.
— The dummy reactor vessel had received a top-lid with five positions for the fitting-simulation of in-core capsules. Also a copy of the restrain-structure will be inplanted.

4.4 EXPERIMENT OPERATION

Despite of increasing technical complexity of the experiments the team provided on schedule their services to a succesful operation of the irradiations.

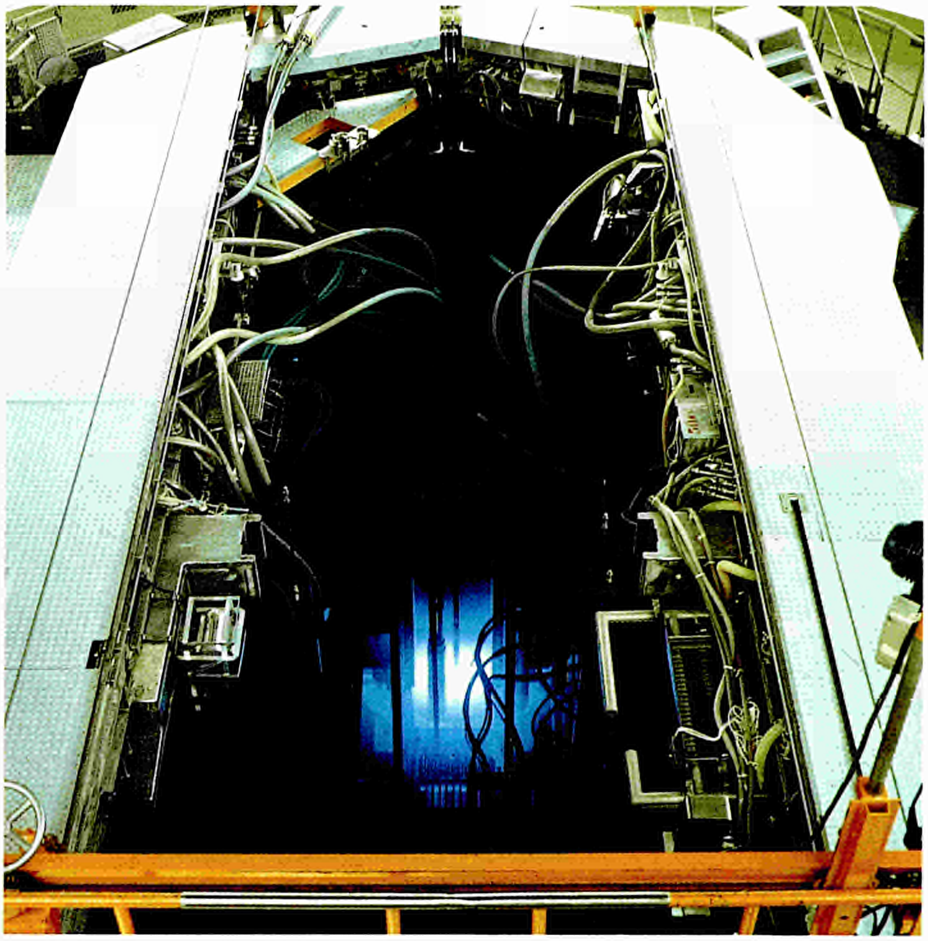

Fig. 38
View into reactor pool.

4.5. HOT CELLS AND POST-IRRADIATION WORK

Dismantling cell

The cell team provided the following services:
- dismantling or reloading of 19 sample holders
- 17 internal transports of irradiated samples, 11 waste transports and preparing two external transports
- repairwork on waste containers, manipulators and posting machine.

A major oil-leak of the window of the dismantling-cell made it necessary for personnel to enter the cell in order to perform a provisional repair.

At the same time an order for a new cell window (ca 6000 kg glass) was placed at SOVIS (F).
The delivery and assembly in the cell wall will take place during early 1990.

G5/G6 cells (LSO)

D 85-56; -48/2
Visual inspection and reloading in sample holder.

E 167
Inspection, dimensional checks and reloading in sample holder of a number of sample carriers.

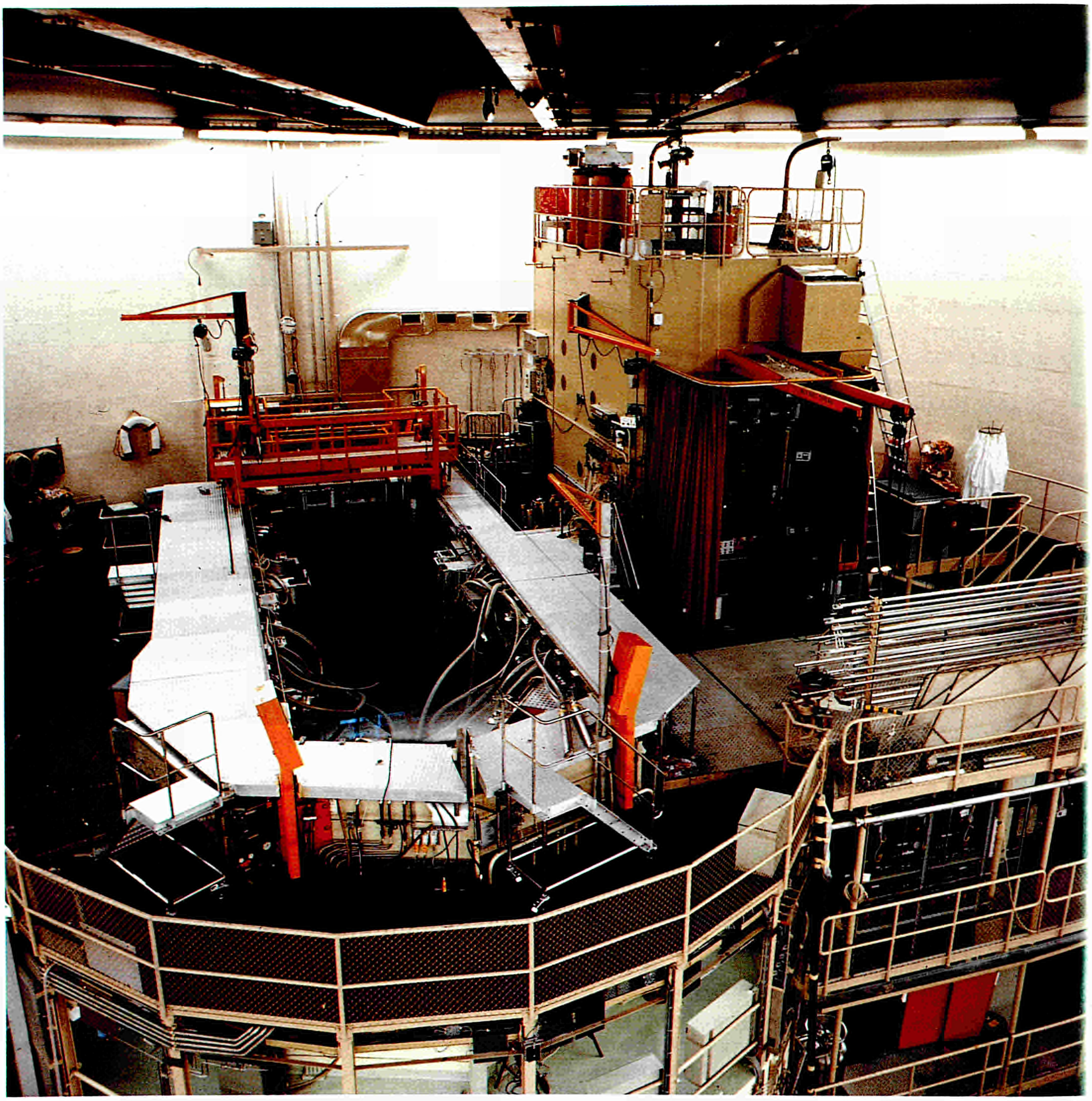

Fig. 39
Reactor pool and dismantling cell.

A second measurement equipment became operational in case of use in the DM-cell.

D 156-52;-93
Dismantling, dimensional checks of samples reassembly and reloading of sample holder.
Development of new equipment for new series -70, -7.1 and -72.

EUROS Remote Encapsulation Cell

During the reporting period the EUROS-cell was up-graded and a first "cold" FBR-fuel pin encapsulated. This "cold" encapsulation was necessary to check all the components before the hot re-encapsulation. The re-encapsulation of the three pre-irradiated FBR-fuel pins, is planned in the first quarter of 1990.

4.6. JOINING TECHNIQUES

The Electron Beam Welding (EBW) and High Temperature Brazing group provided the following services:
- routine weldings for sample holder assembly
- welding of 45 tensile samples for materials department
- specific weldings for irradiation devices fabricated at outside delivery firms
- heat treatment of minerals.

4.7. NEUTRON RADIOGRAPHY

- HFR underwater camera:
  During the reporting period 25 neutron radiography images have been taken of irradiated fuel pins and other irradiated material.

- Beam Tube Facility at HB8 (ER169):
  - Fluence rate measurements with different filter combinations were performed for beam evaluation purposes.
    The exposure station is being modified to further reduce the gamma radiation level.
  - A feasibility study is being performed to upgrade the HB8 facility to a commercial facility. A decision on design and construction will depend on the investment costs and the result of a market study.
  - An image analysis system became available for dimensional analysis of radiographed fuel pins on a routine basis. Quantification of defects and dimensional analysis of radiographed ceramic objects on X-ray film and radiographed objects on track-etch film are under development.
  - In promotional actions several potential clients were invited to provide test samples for proof testing. Negotiations with a number of clients continue.
  - A proposal for a study on the application of neutron radiography to space components technology was submitted to ESA, the European Space Research and Technology Centre. Negotiations for a research contract in this area were successfully completed.
  - Subthermal neutron radiography and investigation of the images by image analysis has been performed on pyrotechnique devices for space crafts.

- A neutron radiography course was developed by the Petten Neutron Radiography Services for educational purposes at Technological High Schools.

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4.8. DEVELOPMENT OF LWR FUEL ROD TESTING FACILITIES

The main development activities pursued or continued in 1989 in the field of LWR fuel and materials testing were:

- Studies and out-of-pile testing related to the ISOLDE project.
  A European Patent *1.* was granted on a pump with electronically controllable stroke volume which was developed for application under neutron and gamma irradiation at the ISOLDE capsule.
- Out-of-pile and in-pile testing of the "low power" BWFC capsule (typi-

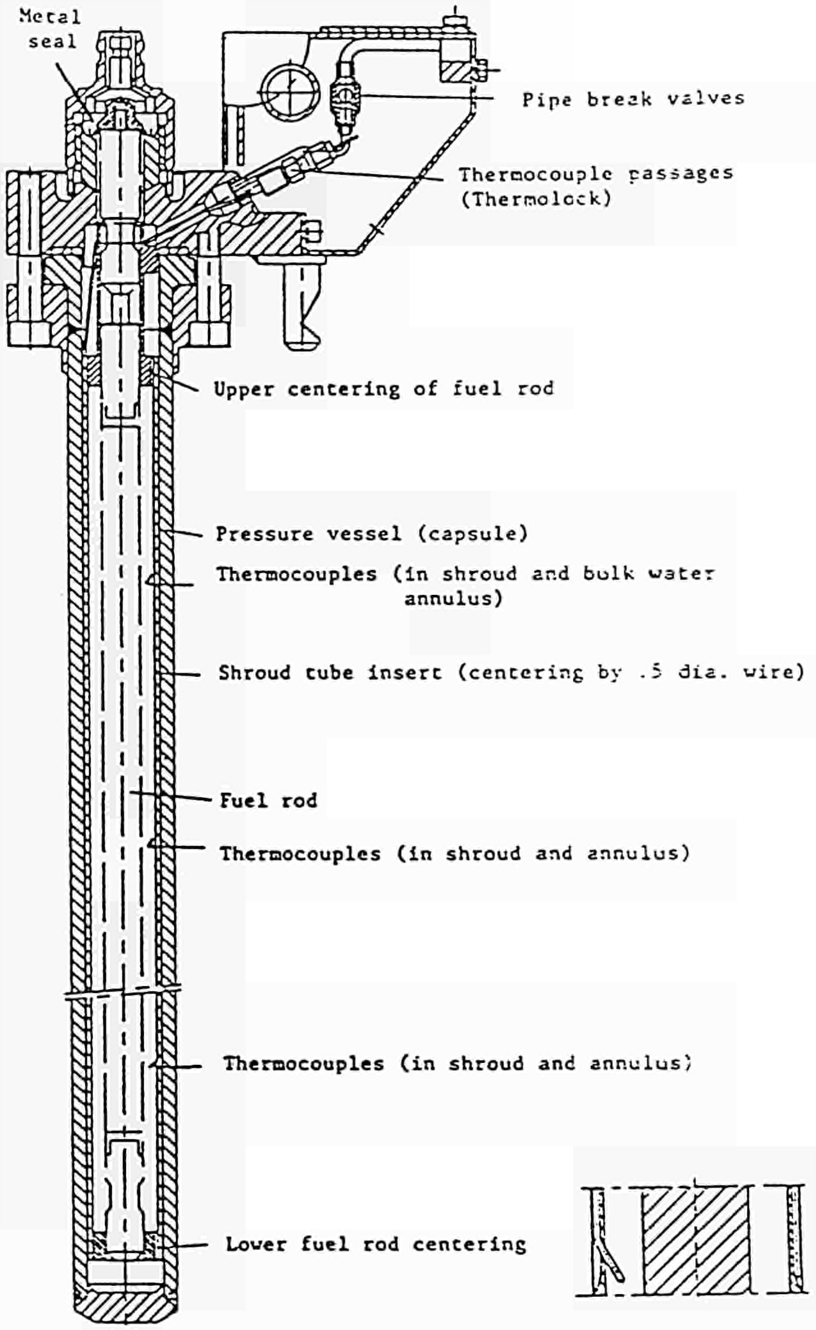

Fig. 40
Lay-out of the low power capsule for LWR fuel rod testing at HFR Petten.

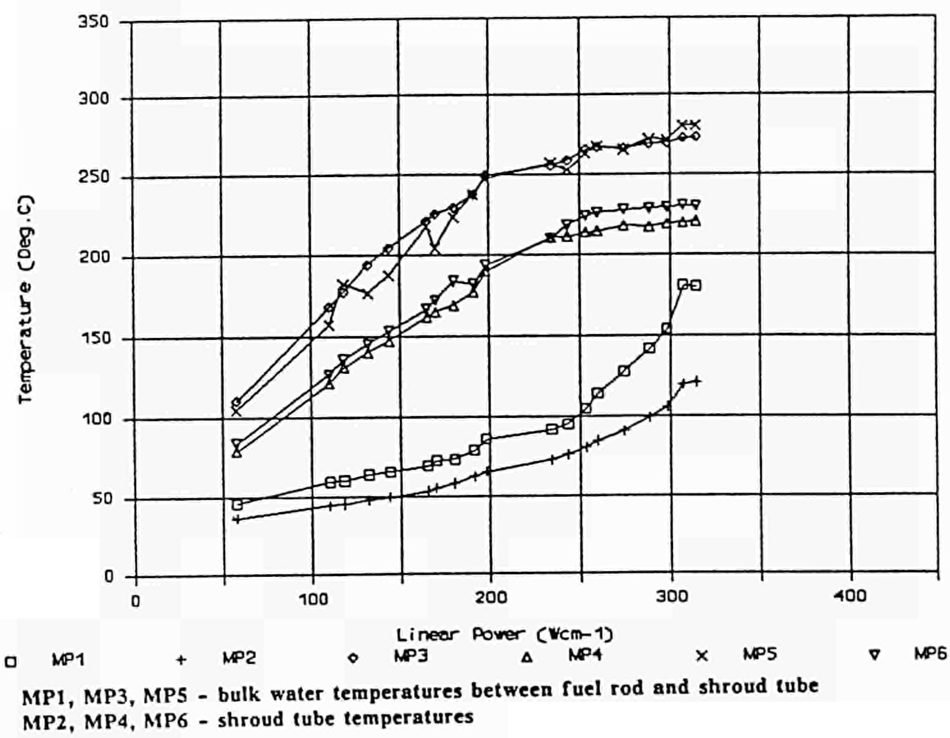

Fig. 41
In-pile performance test of the "low-power" BWFC-type capsule with the E 121-04 BWR fuel rod.

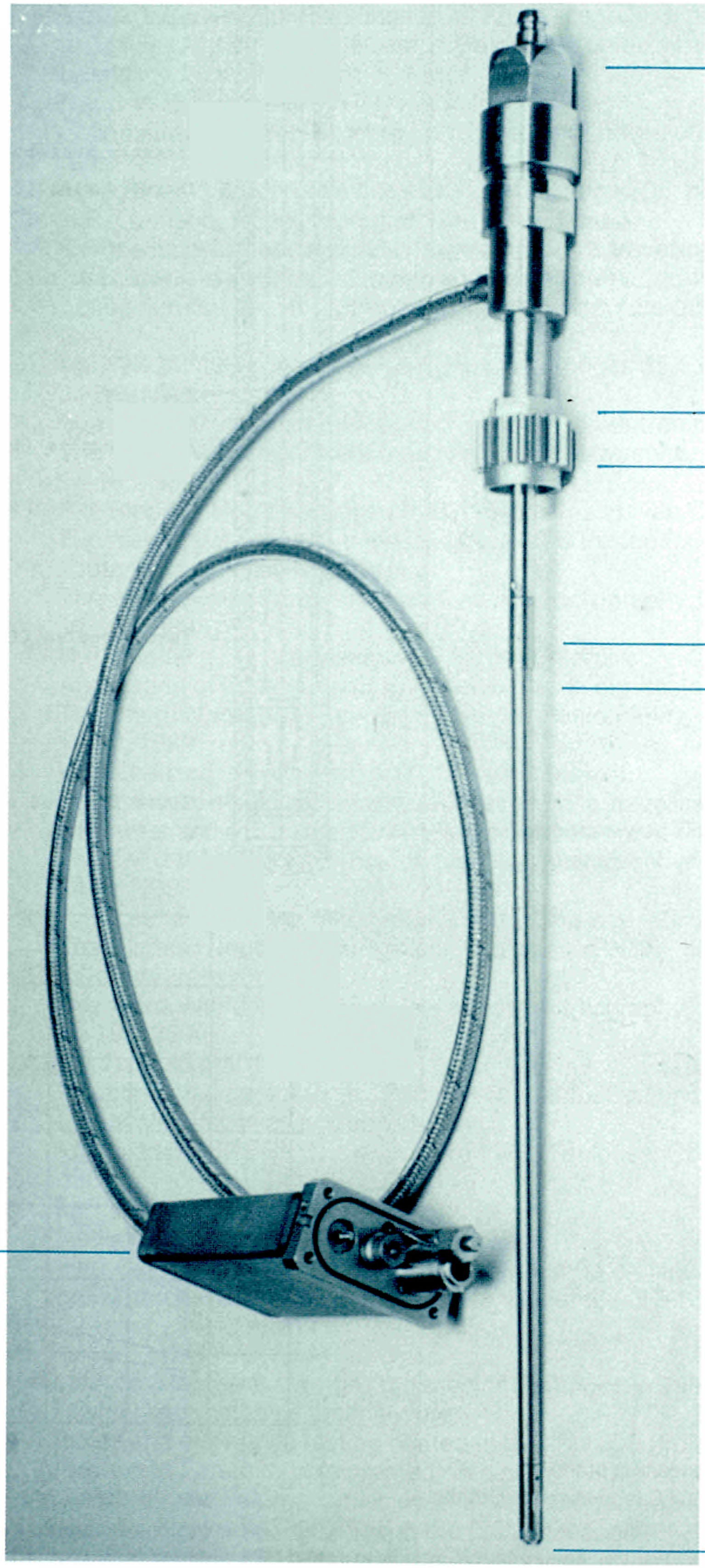

Fig. 42
Re-instrumented LWR fuel rod.

cal fuel rod surface temperature from approximately 150 W/cm onwards), **Fig. 40.** The temperature behaviour during in-pile testing of the BWR device is shown in **Fig. 41.**

A publication on the 2DT-BOIL code development was prepared and offered to the British Nuclear Energy Society for publication *2.* in Nuclear Energy.

- Commissioning of the fuel rod re-instrumentation facility and associated devices, out-of-hot cell testing of the facility, training of hot cell assembly on dummy rods, and re-instrumen-tation of a fresh BWR fuel rod under simulated hot cell conditions. **Fig. 42** shows the fuel rod and re-instrumentation head prior to welding. The irradiation testing of the re-instrumented fuel rod E121-10 during cycle 89.11 was successfully started.
- Preparation of the manufacturing of a prototype version of the BWFC-type irradiation device providing means for application of a controlled axial load to the test fuel rod during irradiation was commenced at the end of the reference period.

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A pump with an electronically controllable stroke volume European Patent granted under nb. EP 0 202 714 B1, 1989.

2. T.D.A. Kennedy, J. Mc.Allister, J. Markgraf, I. Ruyter.
Development of a two-dimensional computer code for the prediction of two-phase heat transfer in an experimental LWR irradiation capsule. Proposed to BNES Journal, Nuclear Energy, for publication. DGXIII reference: ART 29 142.

4.9. DEVELOPMENT OF A CONTROL SYSTEM FOR SWEPT HTR FUEL EXPERIMENTS

The upgrading of the Sweep Loop facilities for the future D 138 reference tests continued with respect to the gamma-spectrometer and the gas chromatograph. Calibration of all measuring sensors *1.*, including the Ge(Li) detectors was performed in the frame of quality control.

Reference:

1. K.H. Otterdijk
Calibration of flowmeters for SWEEP LOOPS
HFR-G090100 (1989)

4.10. DEVELOPMENT OF IRRADIATION FACILITIES FOR FUSION BLANKET MATERIALS

The upgrading of the existing Tritium Measuring Station (TMS) continued in 1989.

The upgrading consisted of:

- installation of new tritium filters
- re-arrangement of the data transfer system
- re-arrangement of the pool wall penetration box
- new instrumentation for the E 224.05/08 experiments
- new instrumentation for the R 212.17-20 experiments.

References:

1. R. Conrad, Th. Timke
Manual for LIBRETTO 2 experiment
Technical Memorandum HFR/89/2900 (1989)

2. R. Conrad, Th, Timke
Manual for EXOTIC 5 experiment
Technical Memorandum HFR/89/2919 (1989)

4.11. DEVELOPMENT OF IRRADIATION FACILITIES FOR STRUCTURAL FUSION MATERIALS

New effort was directed towards the development of a thermal fatigue rig for the interdivisional materials project "FAFNIR" (Fatigue in First Wall Nuclear Irradiation Rig).
The major objective of the project is the measurement and the modelling of crack propagation in cyclic thermal gradient fields in a multiaxial 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 to understand the crack growth mechanism under irradiation.

Various calculations for the characterization of the specimens have been performed during 1989 *1., 2., 3.*

A design study for irradiation of materials under biaxial loading was performed at the end of 1988 – beginning of 1989 *3.* The project is presently sleeping because of lack of funds.

Other work has been performed to improve the capabilities of the IAM Data Bank *4.* This activity has been stopped, because of lack of personnel.

References:

1. G.P. Tartaglia
Thermomechanical Analysis of specimens used in the first wall fatigue experiment (Fafnir)
Technical Note P/F1/89/6
2. G.P. Tartaglia
Temperature and stress distributions in cylindrical samples (Fafnir project – out-of-pile rig)
Technical Note P/F1/89/12
3. G.P. Tartaglia
Irradiation Facilities for Thermal Fatigue and Biaxial Creep Experiments
Paper presented at the International Conference on Fusion Reactor Materials (ICFRM-4) - Kyoto, Japan, 4-8 December 1989
4. G.P. Tartaglia, H. Over, H. Kröckel
Integration of a FEM code with a material properties data bank
Paper presented at the International Conference on Fusion Reactor Materials (ICFRM-4) - Kyoto, Japan, 4-8 December 1989

4.12. BORON NEUTRON CAPTURE THERAPY (BNCT)

Succinctly, the method of BNCT utilises the energy produced by the instantaneous nuclear fission of the boron-10 nucleus into an alpha particle and a lithium ion, after the capture of a slow (thermal) neutron, ie $^{10}B(n,\alpha)^{7}Li$.

The therapeutic efficacy of BNCT depends on, amongst other things, a high flux of epithermal neutrons, which due to the excellent nuclear characteristics of the HFR, can be easily achieved at the HB11 beam tube.

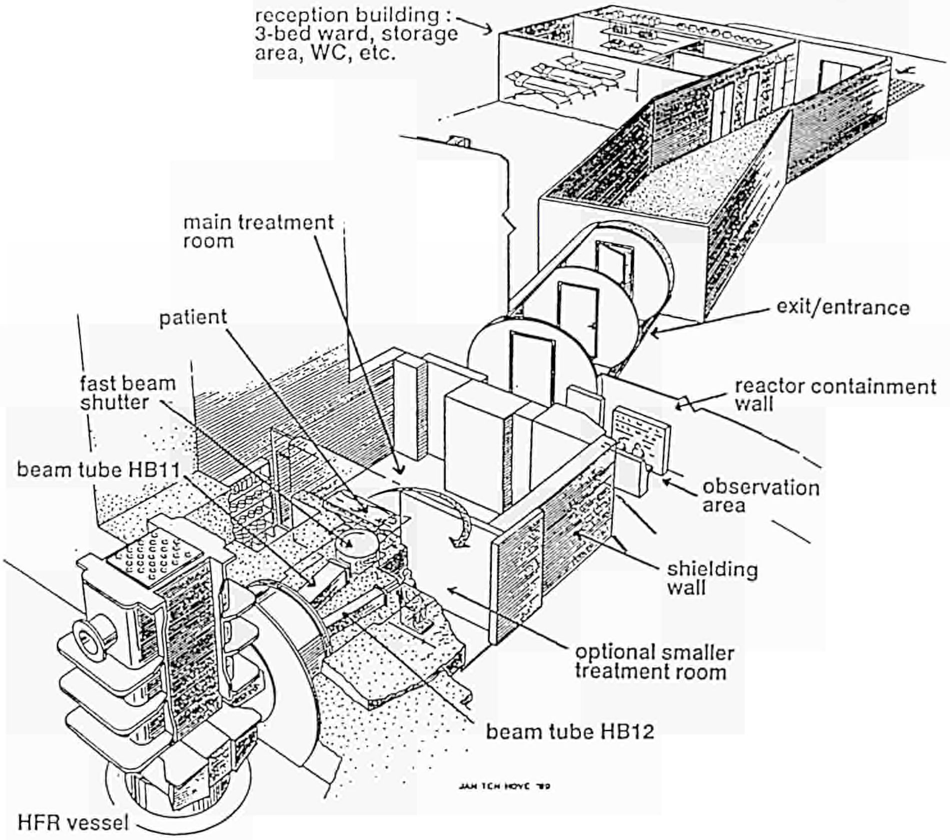


Fig. 43
The envisaged Petten BNCT facility, indicating treatment room and outer reception facilities.

Plans to develop the beam tube, progressed smoothly, as planned. Due to the considerable amount of re-building involved, this can only be achieved during the summer stop of 1990. Consequently, to gain experience in the designing of a facility before mid 1990, a design exercise, plus a series of confirmation measurements, were performed during the summer of 1989, on an available, but smaller beam tube, ie HB7.

The modelling of the HB7 facility was carried out using the Monte Carlo computer programme, MCNP. Numerous filter configurations were modelled in order to achieve an optimum set-up. A typical model used filter combinations based on Aluminium, Sulphur, liquid Argon, Cadmium and Titanium. During July and August, a team from UKAEA Harwell, with the help of JRC and ECN staff, performed a series of measurements on HB7 to determine the neutron fluence rate, energy spectrum and gamma content of typical beam set-ups used in the design calculations.

Comparison of results, to give confidence in the design calculations, were in agreement to within 10-60%, depending on the configuration considered.
The better results have fortunately been obtained for the most likely configuration that will be exploited. The design work has recently entered the initial stages of calculations for the HB11 facility. First indications confirm that as expected, an adequate facility can be readily built.
To execute the BNCT activities at Petten, the local Petten BNCT group met 5 times throughout the year. The group, consisting of staff from JRC, ECN and the Netherlands Cancer Institute in Amsterdam, coordinate the design, manufacture and installation of the facility, including the radiobiology and dosimetry experiments. For example, during the year, the ECN Nuclear Physics group, contributed to the development in carrying out and giving advise on beam design and characterisation, a description of nuclear reactions in phantoms, and investigating boron - determination methods, such as gamma-ray spectroscopy and gamma-ray imaging. For the European activities, the European Collaboration Group on BNCT were successful this year in their application to the CEC in Brussels, to obtain financial support (400 KECU over 3 years) from the Medical and Health Research Programme, for a Concerted Action on BNCT.

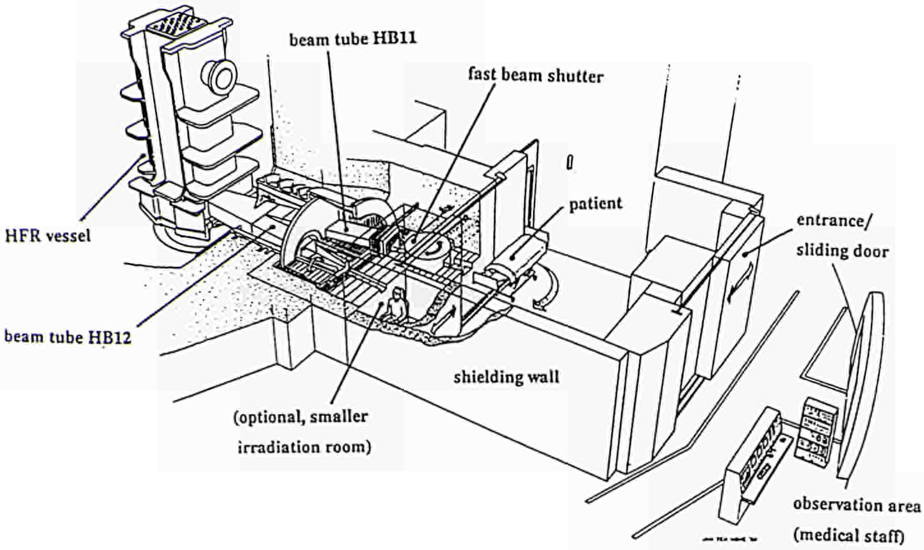


Fig. 44
The Petten BNCT treatment room.

The European Collaboration group, which consists of over 60 members, including neurosurgeons, radiotherapists, radiobiologists, chemists and nuclear physicists, from 10 countries throughout Europe, have dedicated the set-up of the BNCT facility at Petten for the treatment of glioblastoma (brain tumour), as their first priority. The second priority is to consider alternative neutron sources for developing BNCT facilities and the treatment of alternative types of cancer.

During the year, numerous meetings on BNCT were held at Petten and attended elsewhere throughout Europe and the U.S.A. Visitors from as far a field as the U.S.A., U.S.S.R. and Australia came to Petten to discuss the project here and to present lectures on their own BNCT work.

The ultimate aim remains to be in a position to treat the first patients before the end of 1991. The envisaged facility, with therapy room, observation area for medical staff and an outer building to temporarily receive patients is shown schematically in **Fig. 43 and 44.**

4.13. HFR LOCAL AREA NETWORK (LAN)

To face the needs of HFR personnel who use computer codes running on host computers, it was decided to build-up a local area network based on the existing personal computers.

Communications products were installed at the beginning of 1989 which let personal computers and remote mainframes communicate with each other via X.25 packet switched networks.

Hardware and software purchased take full advantage of X.25 networks. Moreover the system offers the possibilities to communicate under IBM-SNA (System Network Architecture) environment under QLLC (Qualified Logical Link Control) data links.

Fig. 45 illustrates, in a schematic way, the basic structure of the LAN. One personal computer (PC), the "communication or gateway server" is con-

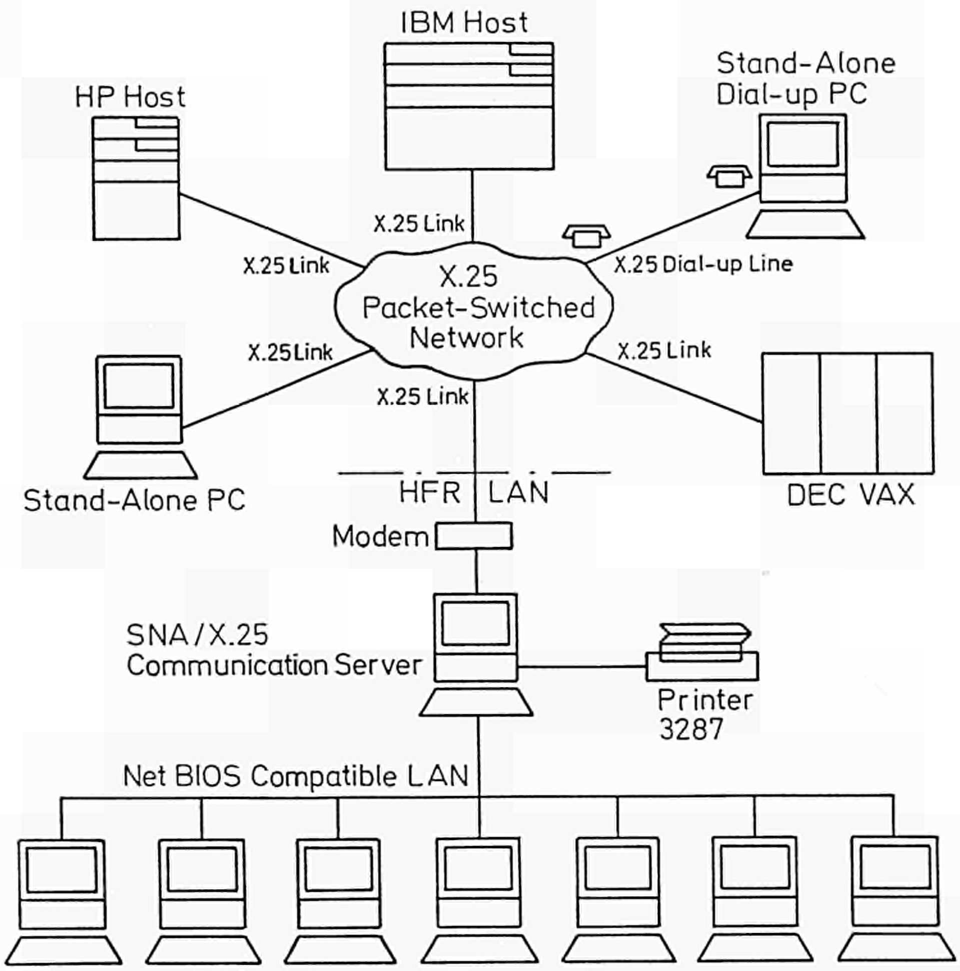


Fig. 45
HFR-LAN with possible remote connections.

nected to the Datanet-1 (PTT network) by means of a modem. The physical interface between the PC and the modem is a network adapter card. This PC contains also an Ethernet card which allows the connection, through thin ethernet cables, with other PCs, equipped with ethernet cards, designated as "redirectors".

All PCs have access to the X.25 network and are able to communicate with host computers. The server and the redirectors, even when performing networking functions, are available for PC tasks.
A complete description of the HFR-LAN is given in *1*.

Reference:

1. G.P. Tartaglia
The HFR Local Area Network
Technical note P/F1/90/2

4.14. SPENT FUEL MANIPULATIONS FOR CIEMAT

A contract with Transnuclear SA Madrid for assistance in the decommissioning of the CIEMAT reactor, Madrid has been signed. The execution of the work is depending on free storage place in the HFR-building for the CIEMAT spent fuel elements. This free storage place can only be created after shipment for reprocessing of a sufficient number of HFR-spent fuel elements.

4.15. PROGRAMME MANAGEMENT AND MISCELLANEOUS

Planning
During the reporting period the HFR Planning Meeting was held four times and four editions of the loading chart were issued (from no. HFR II/23 to no. HFR II/26).

EWGIT (European Working Group on Irradiation Technology)
The EWGIT Select Committee met on September 26, 1989 at JRC Petten to discuss the preparation of an International Conference on Irradiation Technology to be held in 1991.

NRWG (Neutron Radiography Working Group)
The 11th Plenary NRWG Meeting and subgroup meetings on "Measurements" and "Practical Neutron Radiograhy" took place at Risø National Laboratory, Denmark, on September 19/20, 1989.
The results of the NRWG Test Programme have been published (EUR 12121).
Editing work on the publication on "Nitrocellulose Film" is in progress. Publication is now scheduled for 1990.
The preparations for the intended publication of the "Handbook on Practical Neutron Radiography" were continued.

EWGRD (Euratom Working Group on Reactor Dosimetry)
The 54th Meeting was held April 12, 1989 at JRC Petten. The technical topic of the meeting was "Fast reactor dosimetry" and five contributions from various centres were presented.
On the agenda there were a.o. also the following discussion points: "personnel neutron dosimetry", "retrospective dosimetry in plant life extension" and "normalisation and standardisation activities". The above subjects are considered as possible new tasks to be pursued by the group in the future.

For the normalisation and the standardisation activity the German standard DIN 25 456 "Neutron fluence measurement" was proposed and accepted as a first working document.
The subgroups on "Radiation Damage", "Nuclear Data" and "Dosimetry Materials" met on April 11, 1989 also at JRC Petten. A new "Nuclear Data" which has been prepared within the framework of the subgroup "Nuclear Data" has been published as EUR report (EUR 12354).

According to a decision taken by the EWGRD in May 1978 the above report has to be considered as an official recommendation by the EWGRD.

The EWGRD Programme Committee for the organization of the 7th ASTM EURATOM Symposium (Strasbourg, France, 27/31 August 1990) met on April 13, 1989 also at JRC Petten.
It discussed further details of the organization. A "Call for Papers" was distributed in May, 1989.

The next meeting of the EWGRD Programme Committee took place in Strasbourg, 14/15 November, 1989.
The main topic of the agenda was the organization and paper allocation of the 7th ASTM-EURATOM Symposium. A "Second Announcement" was prepared.

Fig. 46
Dr. H. Blix visits the HFR.

ACPM
The Advisory Committee on Programme Management met in Petten on June 9 and December 14, 1989.
It reviewed the status and progress of the HFR Programme on the basis of documents prepared by JRC-IAM Petten.

HFR Users' Meeting
A Colloquium on Prospects and Future Utilization of the HFR was held in Petten on 20/21 April, 1989. Invited lectures given by major partners and clients gave a good impression of their programmes and future plans. The HFR Programme was presented in a poster session.

Visits
On 3rd May, 1989 Dr. H. Blix, Director General of the IAEA and on 19th May, 1989 Dr. K. Uematsu, Director General of the OECD Nuclear Energy Agency visited the HFR.

Seminars organized by the HFR Division in 1989

G. Constantine, AERE Harwell
"Design of an epithermal neutron beam for a BNCT facility"
20th January 1989

L. Debarberis, JRC-IAM Petten
"Tritium extraction from ceramic blanket breeder materials"
26th January 1989

H. Ragoß, Interatom Bensberg
"Experimental verification of data base of fuel element behaviour for HTR-Module"
17th February 1989

W. Scharroo. ECN Petten
"The central data acquisition system DACOS at the HFR Petten"
2nd March 1989

Pfister, IKE Stuttgart
"Neutron tomografie"
20th March 1989

R. Fairchild, Brookhaven National Laboratories
"BNCT activities in the USA"
13th June 1989

H. Scheurer, JRC
"The Phebus fission product experiment"
19th June 1989

F. Genet, JRC-IAM Petten
"Planning system by software package 'Super Project Expert'"
29th June 1989

I. Riaboukhine, World Health Organisation
"Sources for BNCT in the USSR"
3rd July 1989

J. Konrad, JRC-IAM Petten
"Radio-nuclide production facilities at the HFR Petten"
19th July 1989

B. Allen, NSW Australia
"BNCT in Australia"
6th October 1989

J.L. Carden, Theragenics Corporation
"Application of radio-nuclides"
17th October 1989

K. Sumita, University of Osaka
"The regulations on experimental reactors in Japan"
9th November 1989

H. Nakata, JAERI
"The present status of irradiation experiments at JMTR"
9th November 1989

H.U. Staal, ECN Petten
"Hot Cell Laboratories at ECN Petten"
22th November 1989

G. Sordon, JRC-IAM Petten
"On the heat transfer in packed beds"
22th November 1989

5. SUMMARY

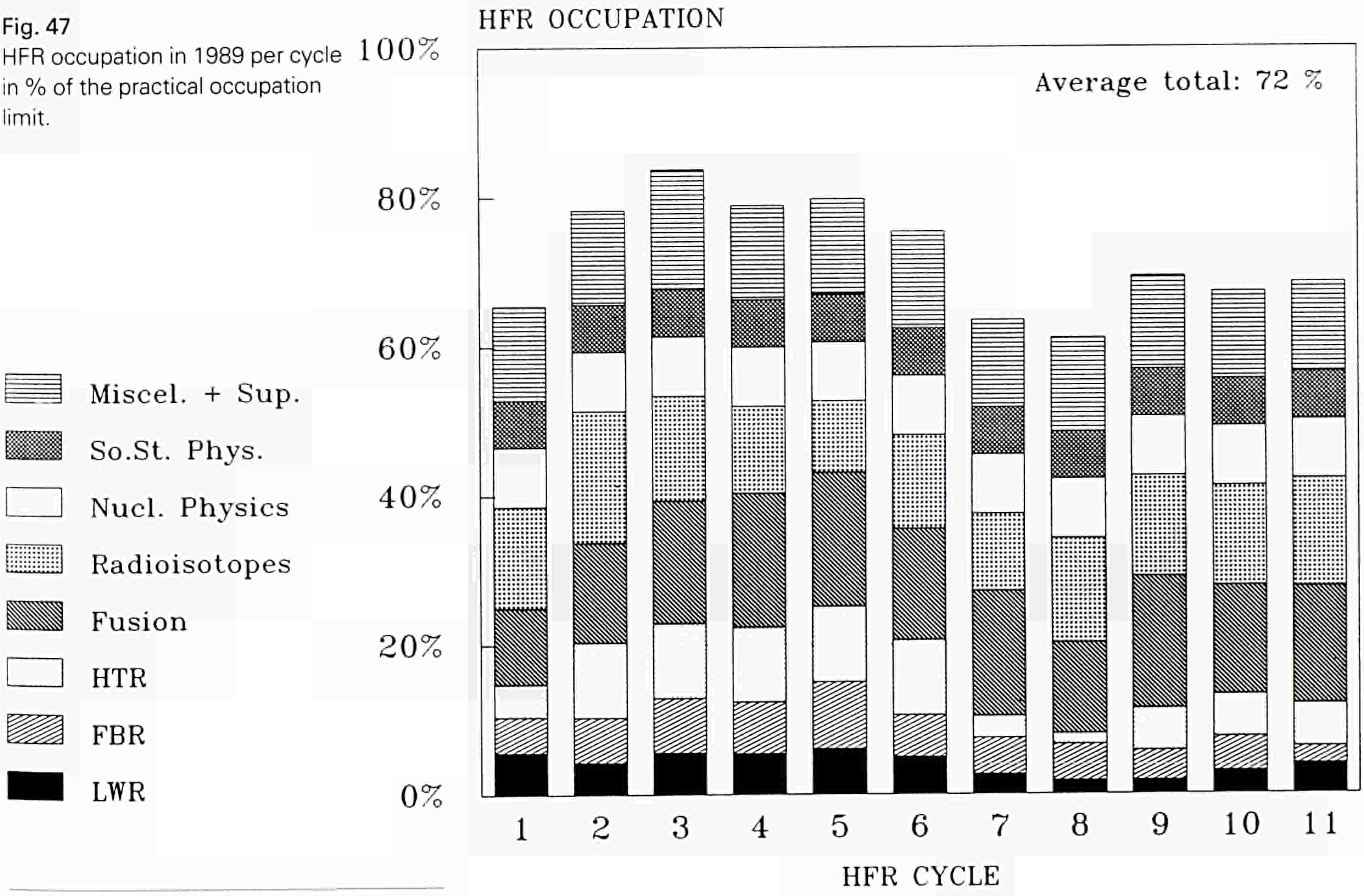
5.1. HFR OPERATION, MAINTENANCE, DEVELOPMENT AND SUPPORT

In 1989 HFR operation was carried out as planned.
The total availability of the reactor was 106% of its scheduled operation time, i.e. 246 in stead of 232 days.
Routine maintenance and modification activities were carried out in the main stop periods in March and July/August, 1989.
Good progress was made in the scheduled upgrading projects.

5.2. HFR UTILIZATION

In 1989 the average occupation of the HFR by experimental devices was 72% of the practical occupation limit.
Breakdown of the occupation pattern in terms of the different programme sectors is shown in **Figs. 47 and 48.**
Programmes related to nuclear energy had again the largest share, the contribution of fission reactor related research being somewhat larger 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.

Fig. 47
HFR occupation in 1989 per cycle in % of the practical occupation limit.



5.3. 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.
Development activities addressed upgrading of irradiation devices, neutron radiography and neutron capture therapy.

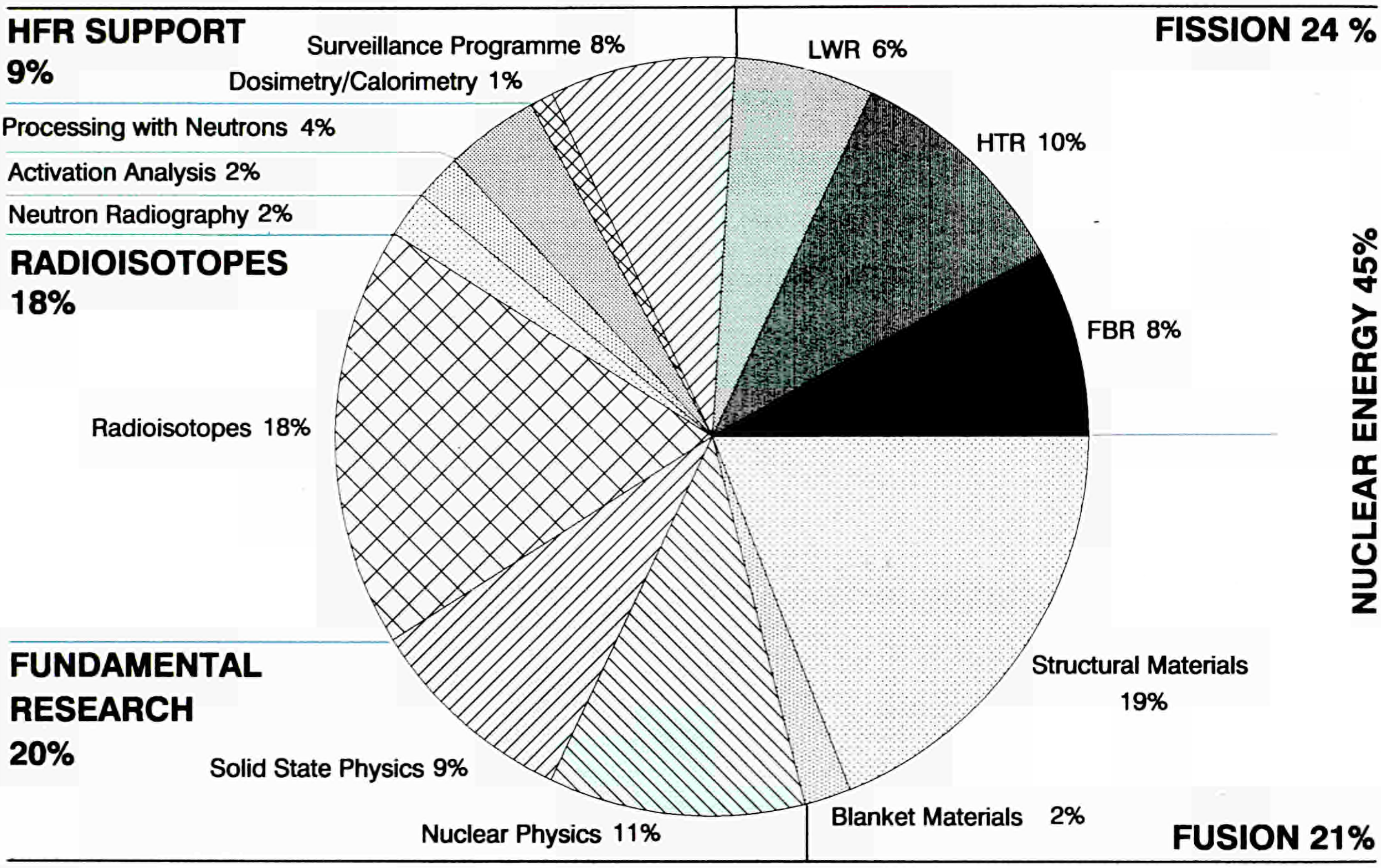


Fig. 48
HFR occupation in 1989 in % of used capacity.

6. HFR PUBLICATIONS, JANUARY – DECEMBER 1989

Topical Reports

J. Ahlf, H. Röttger (editors)
Annual Progress Report 1988
Operation of the High Flux Reactor
EUR 12271 EN (1989)

J. Ahlf, H. Röttger (editors)
The HFR Petten, Prospects and Future Utilization
Proceedings of a Colloquium held in Petten (NL),
20-21 April 1989
EUR 12522 (1989)

H. Kwast, R. Conrad, S. Preston
EXOTIC Annual Progress Report 1988
ECN-224 (1989)

Contributions to Conferences

J. Ahlf, W.L. Zijp
Upgrading Activities for the HFR Petten
International Symposium on Research Reactor Safety, Operations and Modifications
Chalk River, Canada, October 23-27, 1989

G. Fischer, W. Goll, J. Markgraf, I. Ruyter
Transient Behaviour of PWR U/Pu – mixed Oxyde Fuel Rods
Jahrestagung Kerntechnik 1989, Kerntechnische Gesellschaft e.V. & Deutsches Atomforum e.V.,
Dusseldorf, May 9-11, 1989

B. Fischer, K.W. de Haan, J. Markgraf, D.J. Perry, P. Puschek
Re-instrumentation Technique of Irradiated LWR Fuel Rods for Pressure Monitoring during Irradiation Testing at the HFR Petten
Annual Meeting of the EC Working Group on Hot Cells,
Karlsruhe, September 27-28, 1989

H. Hansen, W. Sch le, M.R. Cundy
Irradiation Creep Experiments on Fusion Reactor Candidate Sturctural Materials
Fourth International Conference on Fusion Reactor Materials, ICFRM-4,
Kyoto, Japan, December 4-8, 1989

G.P. Tartaglia
Irradiation Facilities for Thermal Fatigue and Biaxial Creep Experiments
Fourth International Conference on Fusion Reactor Materials, ICFRM-4,
Kyoto, Japan, December 4-8, 1989

G.P. Tartaglia, H. Over, H. Kröckel
Integration of a F.E.M. code into a material properties data bank
Fourth International Conference on Fusion Reactor Materials, ICFRM-4,
Kyoto, Japan, December 4-8, 1989

R. Conrad, L. Debarberis
Irradiation of Liquid Breeder Material Pb-17Li with in-situ Tritium Release Measurements in the LIBRETTO 2 Experiment
Fourth International Conference on Fusion Reactor Materials, ICFRM-4, Kyoto, Japan, December 4-8, 1989

R. Conrad, L. Debarberis
Irradiation Facilities for Testing Solid and Liquid Blanket Breeder Materials with in-situ Tritium Release Measurements in the HFR Petten
Fourth International Conference on Fusion Reactor Materials, ICFRM-4, Kyoto, Japan, December 4-8, 1989

J.F.W. Markgraf
The practical utilization of nitrocellulose film in neutron radiography
The Third World Conference on Neutron Radiography, Osaka, May 14-18, 1989

E.J. Bleeker, H.P. Leeflang, J.F.W. Markgraf, K.H. van Otterdijk
Experience with the HB-8 facility at the HFR Petten for thermal and sub-thermal neutron radiography
The Third World Conference on Neutron Radiography, Osaka, May 14-18, 1989

H.P. Leeflang, J.F.W. Markgraf, K.H. van Otterdijk
Application of image processing techniques in dimensional analysis
The Third World Conference on Neutron Radiography, Osaka, May 14-18, 1989

H.P. Leeflang, J.F.W. Markgraf, K.H. van Otterdijk
Comparison of optical density profiles from a travelling microdensitometer and a PC-based image analysis system
The Third World Conference on Neutron Radiography, Osaka, May 14-18, 1989

H.P. Leeflang, J.F.W. Markgraf, K.H. van Otterdijk
The Petten Neutron Radiography Services (PNRS), facilities and methods
The Third World Conference on Neutron Radiography, Osaka, May 14-18, 1989

J.F.W. Markgraf
Neutron Radiography in Europe for Industry and Research, techniques, facilities and applications
International SITEF NDT symposium 1989, Toulouse, October 17-19, 1989

H.P. Leeflang, J.F.W. Markgraf
Neutron Radiography Activities in Europe
First Canadian Neutron Radiography Workshop on Neutron Radiography and its Applications, Chalk River, December 12-13, 1989

R.L. Moss
Progress towards Boron Neutron Capture Theraphy at the High Flux Reactor Petten

Workshop on Neutron Beam Design, Development and Performance for Neutron Capture Therapy,
MIT, Boston, March 30-31, 1989

Scientific or Technical Articles

J. Ahlf, R. Conrad, M. Cundy, H. Scheurer
Irradiation experiments on High Temperature Gas-Cooled Reactor fuels and graphite at the HFR Petten
Journal of Nuclear Materials 171 (1990)

Patent

A.R. Korko, J.F.W. Markgraf
A pump with an electronically controllable stroke volume
European Patent granted under
nb. EP 0 202 714 B1, 1989

7. RELATIONS TO EXTERNAL ORGANIZATIONS AND COMPANIES

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

Organization	Place	Type of relations or topics	Remarks
I.R.E.	Fleurus, Belgium	Radioisotope production	Commercial contract
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 Radionuclide production	Outline contract
Siemens, UB KWU	Erlangen, Germany	LWR fuel testing	
Oris Saclay	Gif-sur-Yvette, France	Cobalt 60 production	Commercial contract
ECN	Petten, 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	Research contract
Nederlands Kanker Instituut	Amsterdam, Netherlands	Neutron capture therapy	Collaboration agreement
Rutherford Aplleton Lab.	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
ANL	Argonne, Ill, USA	Reduced enrichment fuel development	Collaboration contract (through ECN)
Hungarian Academy of Sciences	Budapest, Hungary	Radionuclide production	Commercial contract
Inzinta, Isotope	Budapest, Hungary	Radionuclide production	Commercial contract

Table 21
HFR Programme. Relations to external organizations.

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 Reflector Irradiation
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
IAM	Institute for Advanced Materials
IDA	Irradiation Device for fast neutron Activation
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
LAN	Local Area Network
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
NEMESIS	NEt MEtalS IrradiationS
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 (29mm)
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 caspsule)
SIP	Silicium Investigation Philips
SISSI	Safety Investigation by Stainless Steel Irradiation
SNR	Schneller Natriumgek hlter 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

LIST OF AUTHORS

JRC

Editors
J. Ahlf
A. Gevers

Contributors
R. Conrad
H. Hausen
C. Jehenson
J. Konrad
H. Lohner
J. Markgraf
L. Metten
R. Moss
G. Sordon
G.P. Tartaglia
G. Tsotridis

ECN

Editor
R.J. Swanenburg de Veye

Contributors
F. Dekker
W. Kempers
G. Luif
E. Merelle
A. Nolten
R. van der Pol
H. Pruimboom
J. Schinkel
G. Teunissen
J. Visser
W.P. Voorbraak
W. Wijkenga
D. de Zaaijer

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ABSTRACT

In 1989 the operation of the High Flux Reactor Petten was carried out as planned. The availability was more than 100% of scheduled operating time.
The average occupation of the reactor by experimental devices was 72% of the practical occupation limit.
The reactor was utilized for research programmes in support of nuclear fission reactors and thermonuclear fusion, for fundamental research with neutrons and for 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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