ANNUAL REPORT 1991

OPERATION OF THE HIGH FLUX REACTOR

JOINT RESEARCH CENTRE

COMMISSION OF THE EUROPEAN COMMUNITIES

ANNUAL REPORT 1991 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

INTRODUCTION

The High Flux Reactor (HFR) Petten belongs to the Institute for Advanced Materials of the Joint Research Centre of the European Communities.

The HFR is a high power (45 MW) multi-purpose research reactor. It provides of high flux in-core positions for irradiation testing of reactor materials, as well as for high grade radioisotope production. A large, versatile, pool-side facility outside the reactor vessel is extensively used for transient testing of reactor fuel, as well as for processing of materials with neutrons, such as silicon transmutation doping. In addition, 12 horizontal beam tubes are available for serving a neutron scattering laboratory and a number of other purposes.

The present programme largely profits from this variety of irradiation possibilities. It covers the fields of nuclear fission energy with fuel and structural materials investigations, thermo-nuclear fusion with damage studies on all kinds of structural materials as well as performance testing of blanket breeder materials, fundamental research with neutrons mainly in solid state physics and materials science, large scale radioisotope production for medical and industrial applications, neutron activation analysis, neutron radiography and research towards cancer therapy with neutrons (boron neutron capture therapy).

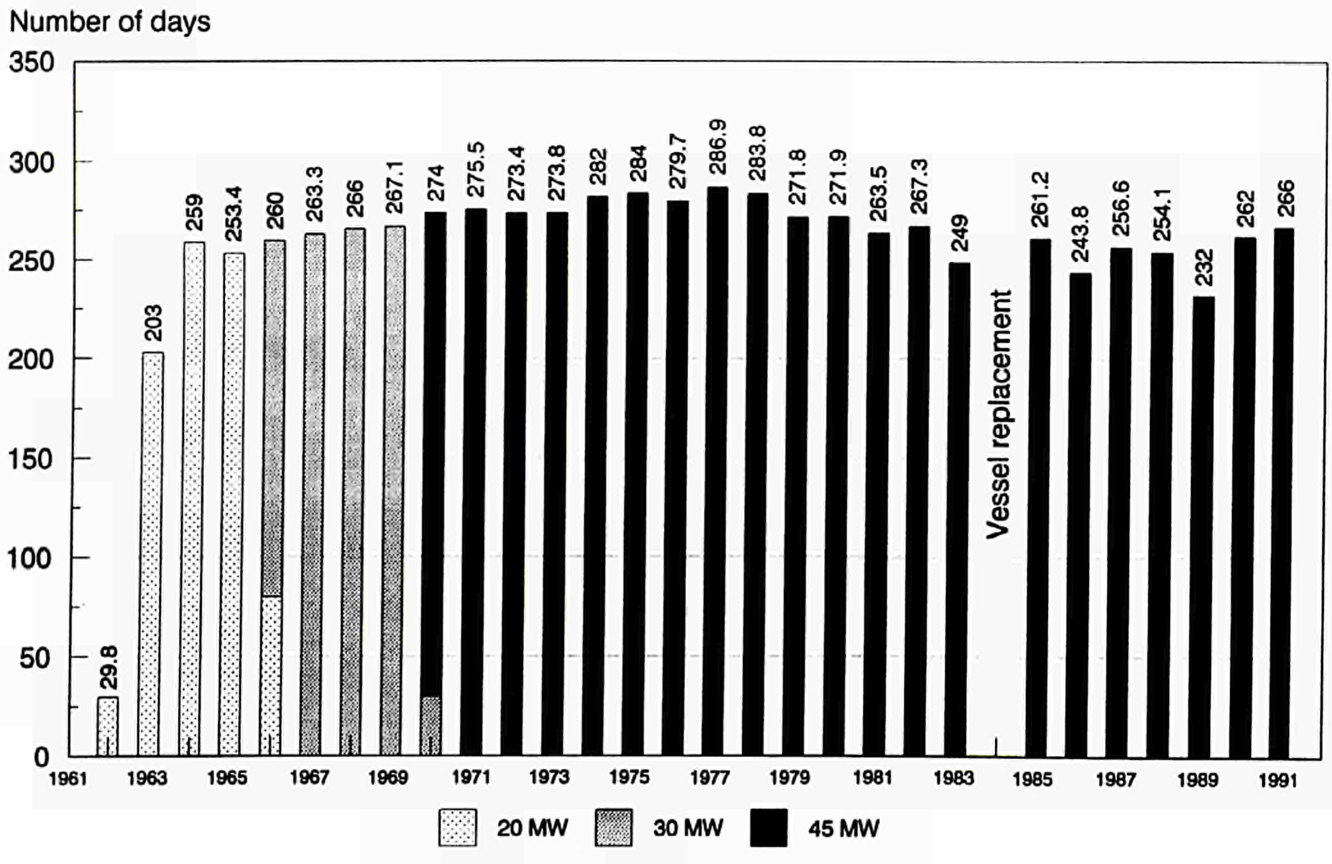
Full attention is given to quality assurance towards safe and efficient operation of the reactor which in itself is an explicit programme objective.

In 1991, the achieved performance record was satisfactory in all respects:
- high availability, 266 operation days
- high utilisation, 69% of capacity
- low radiation exposure of staff and negligible release of radioactivity to the environment
- as scheduled progress on maintenance and upgrading of the reactor.

The experimental programmes at the HFR which are reported in detail in the following chapters, made very satisfactory progress. The following achievements are particularly noted:

- first, long term, in-pile test with re-instrumented, pre-irradiated BWR fuel rod completed
- transient tests on pre-irradiated FBR fuel pins for the EFR project currently in preparation
- large programme on radiation damage studies of structural materials for fusion devices, now including vanadium and -under contract to ENEA- brazed joints of 316 steels
- in-pile investigation of tritium release characteristics of lithium ceramics under temperature transients in reducing and oxidizing, purge gas atmospheres
- contract signed with COG (CANDU Operators Group) on long term irradiation of Zirconium alloy specimens
- radioisotope production services extended to nearly all European and some overseas companies, for radioisotopic sources and, more importantly, for radiopharmaceuticals, including new products such as ^{133}I from ^{133}Xe

- design of a facility for large scale neutron transmutation doping of silicon
- first operation of the boron neutron capture therapy facility at full reactor power, and start of cell culture experiments, phantom studies and healthy tissue tolerance studies on the canine brain
- international workshop and plenary meeting "Towards clinical trials of glioma with BNCT" with more than 100 participants from Europe, USA, Japan, and Australia.



2. HFR OPERATION, MAINTENANCE, DEVELOPMENT AND SUPPORT

2.1. OPERATION

2.1.1. Operation Survey

In 1991 the regular cycle pattern, has been maintained with a scheduled number of 264 operation days, and two scheduled maintenance periods of 20 and 25 days.

The HFR has been in operation during 266 days **(fig. 1)**, following a normal cycle pattern, which corresponds to an overall availability of 72%.

Nominal operation power has been 45 MW. Total energy production has been approximately 11880 MWd, corresponding to a fuel consumption of approximately 14.8 kg U-235. The main operation survey characteristics for 1991 are given in **table 1.**

2.1.2. Operational Characteristics

At the beginning of the reporting period, the HFR was in operation for the completion of cycle 90.11 up to 5 January 1991. Since then the HFR was operated for 10 complete cycles at nominal power of 45 MW. At the end of the reporting period cycle 91.11 was still in progress, scheduled for completion at January 13, 1992. With the intention to make as much operation time as possible, and to compensate for lost operating time cycle 91.01 and cycle 91.04 started two days earlier then scheduled.

The operating characteristics for the period are given in **table 2.**

Special operation runs, mostly at low power, were carried out for neutron spectra measurements in preparation for the Boron Neutron Capture Therapy facility and other irradiation projects.

Regular reactivity measurements in context of the testing of advanced fuel elements have been carried out.

An example of a typical core loading with corresponding power pattern and control rod positions is shown in **fig. 2.**

Table 1

Main operation survey characteristics

TABLE 1: MAIN OPERATION SURVEY CHARACTERISTICS

HFR cycle	Beginning of cycle	End of cycle	Nominal power h.min.	Total operating time h.min.	Energy production MWd	Unscheduled operation interruptions
90.11	11-12-90	05-01-91	116.00	116.00	235.15	1
91.01	06-01-91	06-02-91	682.54	690.45	1287.16	1
91.02	07-02-91	04-03-91	549.12	555.19	1031.73	-
91.03	05-03-91	04-04-91	545.50	561.22	1025.53	1
Maintenance period	05-04-91	23-04-91				
91.04	24-04-91	19-05-91	560.03	564.28	1053.12	1
91.05	20-05-91	17-06-91	632.24	637.25	1188.68	-
91.06	18-06-91	13-07-91	555.50	570.05	1041.59	-
Maintenance period	14-07-91	29-08-91				
91.07	30-08-91	23-09-91	584.25	608.43	1111.30	-
91.08	24-09-91	21-10-91	614.31	617.30	1154.08	2
91.09	22-10-91	19-11-91	579.06	583.24	1080.85	1
91.10	20-11-91	16-12-91	577.00	579.55	1085.87	1
91.11	17-12-91	31-12-91	306.07	307.50	575.70	-

◁ **Fig. 1**

HFR operation days, 1961-1991

Table 2
Operational characteristics

TABLE 2: OPERATIONAL CHARACTERISTICS

CYCLE BEGIN-END 1991	HFR CYCLE	GENERATED ENERGY MWd	OPERATING TIME PLANNED hour	LOW POWER h.min	NOMINAL POWER h.min	OTHER USE h.min	TOTAL h.min	SHUT-DOWN TIME PLANNED h.min	UN-SCHEDULED h.min	UN-SCHEDULED INTER-RUPTIONS	STACK RELEASE (for Ar-41) GBq
-05.01	90.11	235.15	160		116.00		116.00		44.00	1	565
06.01-06.02	91.01	1287.16	640	07.51	682.54		690.45	74.45	02.30	1	531
07.02-04.03	91.02	1031.73	544	02.15	549.12	03.52	555.19	68.41		-	-
05.03-04.04	91.03	1025.53	592	01.52	545.50	13.40	561.22	117.08	40.30	1	557
04.04-23.04	Maintenance period							480.00			533
24.04-19.05	91.04	1053.12	592	04.25	560.03		564.28	17.52	41.40	1	3619 *
20.05-17.06	91.05	1188.68	592	05.01	632.24		637.25	58.17		-	
18.06-13.07	91.06	1041.59	552	03.40	555.50	10.35	570.05	53.55		-	442
14.07-25.08	Maintenance period							1032.00			536
26.08-23.09	91.07	1111.30	592	02.26	584.25	21.52	608.43	87.17		-	596
24.09-21.10	91.08	1154.08	592	02.59	614.31		617.30	55.17	00.13	2	603
22.10-19.11	91.09	1090.85	592	04.18	579.06		583.24	71.10	41.26	1	
20.11-16.12	91.10	1085.87	592	02.55	577.00		579.55	68.00	00.05	1	
17.12-	91.11	575.70	288	01.43	306.07		307.50	52.10		-	8547
	Total:	11880.76	6328	39.25	6303.22	49.59	6392.46	2236.32	170.24	8	
Percentage total time in 1991 (8760 h) :				0.5 %	72.0 %	0.6 %	73.0 %	25.5 %	2 %		
Percentage of planned operating time (6328 h):				0.6 %	99.6 %						
	Total 1990:	11892.67	6544	96.16	6282.50	107.01	6486.07	2051.49	223.04	12	5417
Percentage total time in 1990 (8760 h) :				1.1 %	71.7 %	1.2 %	74.4 %	23.4 %	2.6 %		
Percentage of planned Aperating time (6544 h):				1.5 %	96 %						
	Total 1989:	10451.56	5568	111.59	5627.28	47.52	5787.19	2802.22	171.19	9	4973
Percentage total time in 1989 (8760 h) :				1.3 %	64.2 %	0.5 %	66.1 %	32 %	2 %		
Percentage of planned operating time (5568 h):				2 %	101 %						

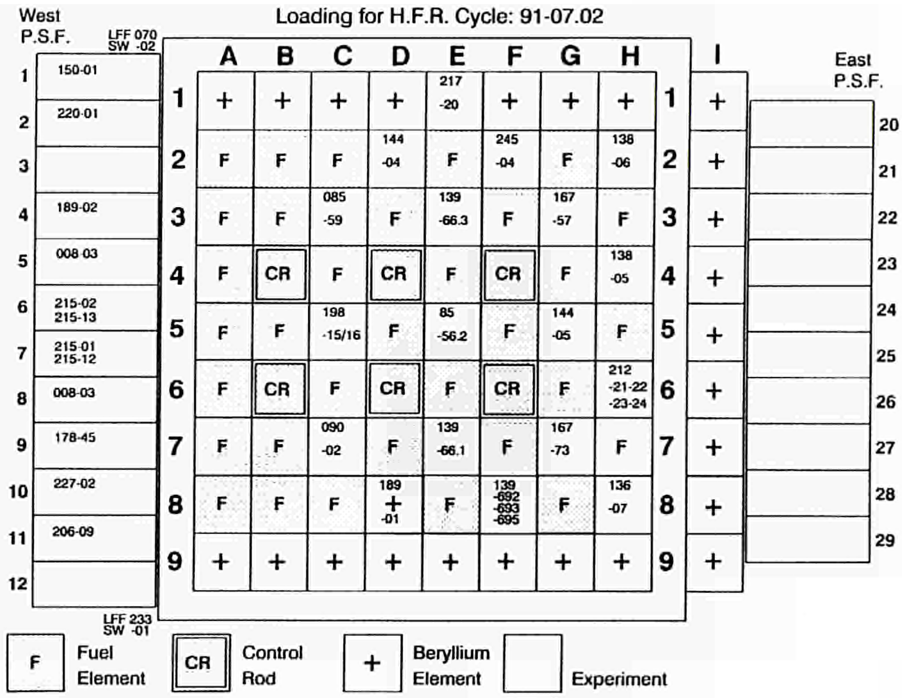
* Increased during week 27/28 due to released Ar-41 from BNCT-test.

Detailed information on the various irradiation experiments is given in chapter 3.

2.1.3. Operational Disturbances

Deviations from nominal power level occurred 33 times during 1991. Twentyfive of these were scheduled, mostly for intermediate handling or adjustment of irradiation facilities. The remaining 8 were related to technical failures, human interactions or experiment related events. Detailed characteristics of all power disturbances are given in **table 3.**

Fig. 2
HFR cycle 91.07. Experiment loading, reactor power pattern and control rod movement



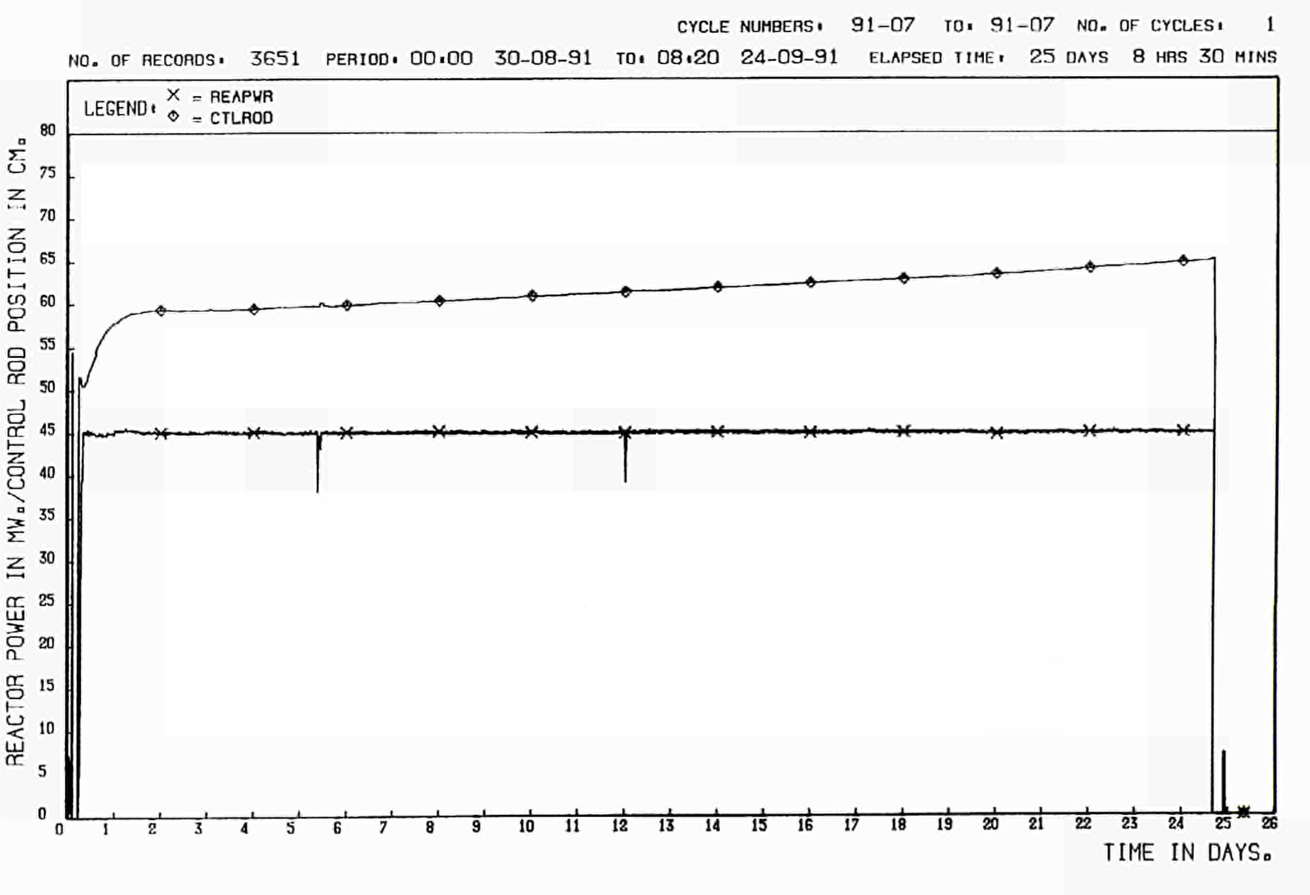


TABLE 3: FULL POWER INTERRUPTIONS

DATE 1991	TIME OF ACTION hour	TIME OF RESTART OR POWER INCREASE hour	TIME OF 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
Jan 05	20.00					AS	0	R	H	Interlock	Wrong action taken with
											gasmonitor 1 during check-out
Jan 09	01.30	04.00	05.06	02.30	03.36	MS	0	R	H	156-95	No data transfer
											Reactor start interrupted
Mar 13	04.06	04.12	04.14	00.06	00.08	MP	35	E	S	136	Facility handling
Mar 13	05.22	05.27	05.29	00.05	00.07	MP	35	E	S	136	Facility handling
Mar 21	09.30					AS	0	A	E	Mains	Mains outage,
Mar 23		02.00	03.37	40.30	44.07						caused xenon poisoning
May 01	04.30	04.38	04.40	00.08	00.10	MP	35	E	S	136	Facility handling
May 01	06.00	06.03	06.05	00.03	00.05	MP	35	E	S	136	Facility handling
May 03	19.20	19.28	19.38	00.08	00.10	MP	25	E	S	215-12/13	Experiment handling
May 08	00.05	00.26	00.33	00.11	00.28	MP	35	E	S	136	Facility handling
May 08	01.49	01.56	02.02	00.07	00.13	MP	35	E	S	136	Facility handling
May 12	19.20					MS	0	A	M	Ventilation	Broken fan belt,
May 14		13.00	13.55	41.40	43.35						caused xenon poisoning
May 30	11.39	11.46	11.53	00.07	00.14	MP	15	E	S	206-17	Experiment handling
Jun 03	09.05	09.13	09.23	00.08	00.18	MP	15	E	S	206-17	Experiment handling
Jun 03	14.40	14.46	14.50	00.06	00.10	MP	15	E	S	206-17	Experiment handling
Sep 04	09.00	09.07	09.10	00.07	00.10	MP	35	E	S	136	Facility handling
Sep 04	10.23	10.30	10.33	00.07	00.10	MP	35	E	S	136	Facility handling
Sep 11	00.09	00.16	00.24	00.07	00.15	MP	35	E	S	136	Facility handling
Sep 26	14.42	14.46	14.58	00.04	00.16	AS	0	E	I	Interlock	Safety channel set-point adjustment
Oct 02	00.12	00.16	00.18	00.04	00.06	MP	35	E	S	136	Facility handling
Oct 06	22.00	22.09	22.25	00.09	00.25	AS	0	E	I	215-13	Coolant disturbance
Oct 30	04.42	04.51	04.55	00.09	00.13	MP	35	E	S	136	Facility handling
Nov 04	15.48	15.59	16.00	00.11	00.12	MP	35	E	S	136	Facility handling
Nov 04	16.43	16.52	16.53	00.09	00.10	MP	35	E	S	136	Facility handling
Nov 05	14.50	15.00	15.05	00.10	00.15	MP	15	E	S	206-09	Experiment handling
Nov 11	00.10	00.27	00.31	00.17	00.21	MP	15	E	S	136 / 206-09	Facility / experiment handling
Nov 11	14.08	14.18	14.23	00.10	00.15	MP	15	E	S	206-09	Experiment handling
Nov 12	03.04					AS	0	A	E	Mains	Mains outage, caused Xenon
Nov 13		20.30	22.12	41.26	43.08						Poisoning
Nov 25	15.05	15.14	15.18	00.09	00.13	MP	35	E	S	136	Facility handling
Dec 02	05.05	05.27	05.30	00.22	00.25	MP	35	E.	S	136	Facility handling
Dec 02	06.54	07.04	07.06	00.10	00.12	MP	35	E	S	136	Facility handling
Dec 06	11.57	12.02	12.20	00.05	00.23	AS	0	R	I	Interlock	Interferance spike
Dec 09	22.03	22.27	22.30	00.24	00.27	MP	25	E	S	215/227	Experiment handling
Dec 23	09.12	09.15	09.17	00.03	00.05	MP	35	E	S	136	Facility handling

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
- human H

Table 3
Full power interruptions

2.2. FUEL CYCLE

During 1991 the ordered new fuel elements and new control rods were delivered on schedule by the manufacturer.

Transfer of depleted fuel elements to the reprocessing facility at Savannah River (USA) has been delayed further. For temporary accommodation of spent fuel an interim storage system has been installed in the storage pool of the HFR.

In accordance and collaboration with the controlling institutions IAEA-Vienna and Euratom-Luxembourg a continuous video camera survey system was installed above the pool in which the interim storage system is placed.

2.3. SAFETY AND QUALITY MANAGEMENT

2.3.1. Documents Management System

A computerized document management system is being implemented. This will result, amongst other features, in a reliable and rapid update of the detailed technical description of the basic technical documents necessary or licensing purposes.

2.3.2. Renewal of Technical Safety Documentation

In the context of a future renewal of the HFR Operating License the Safety and Accident Analysis as well as the Technical Safety Specifications were updated. The internal review of these documents is in full progress. These documents will be the basis for the new public Design and Safety Report. The other license document, the Technical Description of the Installation, is already operational.

2.3.3. Quality Assurance

The implemented quality system for HFR operation has been improved according to the rules mentioned in the "Hoofdregel Kwaliteitsborging" and the directives of the amended Safety Guides (Nuclear Safety Rules) issued by the Dutch Licensing Authorities (KFD).
The instructions and procedures have been updated.
Measures are taken for the selection of suppliers. A start is made with the revision of the installation description and the recording of the isotope production process with the help of a flow diagram.
The membership of the "Nederlands Atoom Forum, Werkgroep QA" offers the possibility of information exchange about QA-matters of research reactors and nuclear power stations within the Netherlands and the European Community.
The Work and Action Plan resulting from the 1988 audit of KFD was updated. In this sense, a new Incident Reporting System for the HFR was developed and will be operational in the first quarter of 1992.

2.3.4. Personnel Exposure

A survey of the registered annual doses of HFR operating personnel is given in **fig. 3**.
The total collective dose over 1991 is slightly higher than that of 1990, due to a further steep increase in handling of isotope irradiations. Furthermore, two extensive neutron flux measurements were carried out. Loading and unloading of the flux detector foils caused another slight increase in dose levels.

2.4. TECHNICAL MAINTENANCE

Inspection, overhaul, repair and replacement of the technical systems and components have been carried out mainly during the planned maintenance periods in April and July/August 1991. Some special items are described below.

2.4.1. Mechanical Installations

- In-service inspection
  According to the procedures agreed with the Netherlands licensing authorities the three-years-interval in-service inspection of the reactor vessel has been carried out. The inspection consisted of:

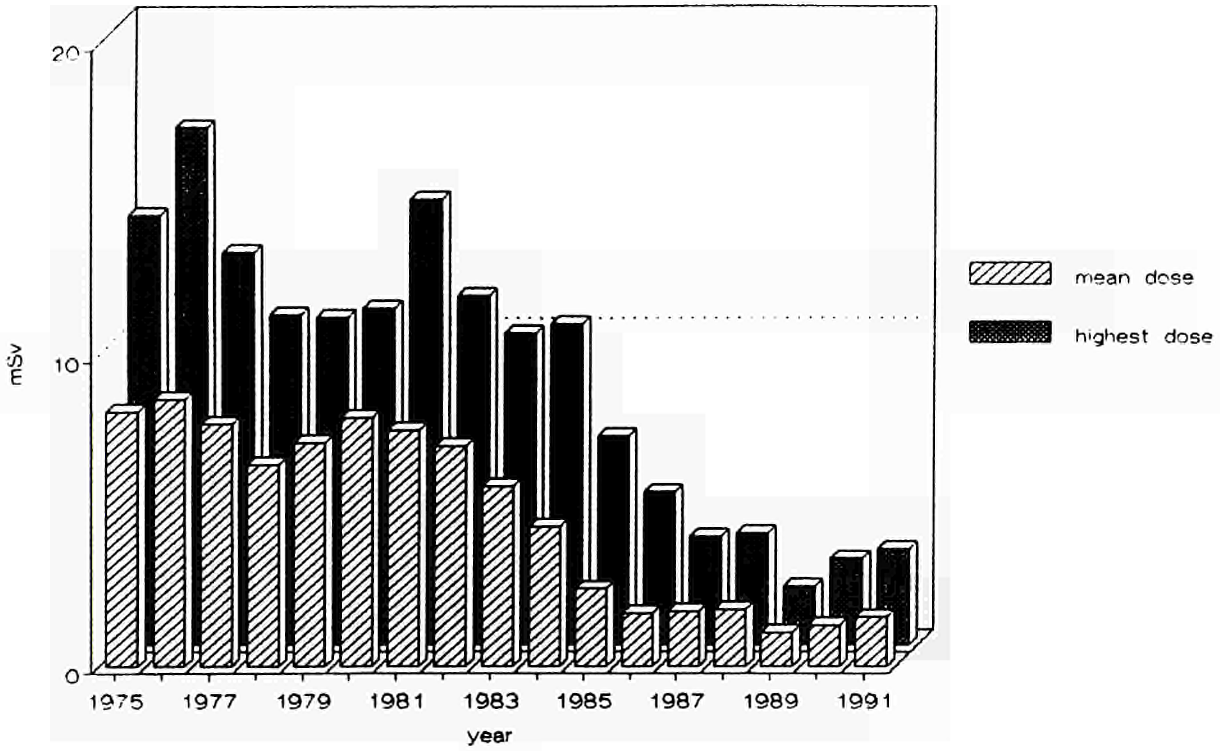


Fig. 3
Dose-equivalent HFR-operators

- Ultrasonic and eddy current testing of representative welds and walls of the core box
- Ultrasonic testing of all other important welds
- Dimensional checks of all the significant dimensions of the core box and reactor vessel
- Visual inspection of the welds and reactor vessel surfaces
- Surface penetrant check on the side-lids and deflectors.

The result of the in-service inspection was that reactor operation can be continued without supplementary limitations.

- Ion exchanger drain tanks
  The engineering for the three ion drain tanks including the piping lay-out has been completed. The first two tanks are installed and the third tank has been ordered. The installation of the piping is being carried out. After the delivery of the third tank the whole system will be completed in 1992 **(fig. 4)**.

- Rotary tape filter
  One of the rotary tape filters installed in the basin of the secondary pump building has been overhauled completely and has been reinstalled. The second rotary tape filter will be overhauled in 1992.

- Secondary inlet valves
  The technical specifications for the replacement of the secondary inlet valves are drawn up. The inlet valves have been ordered.

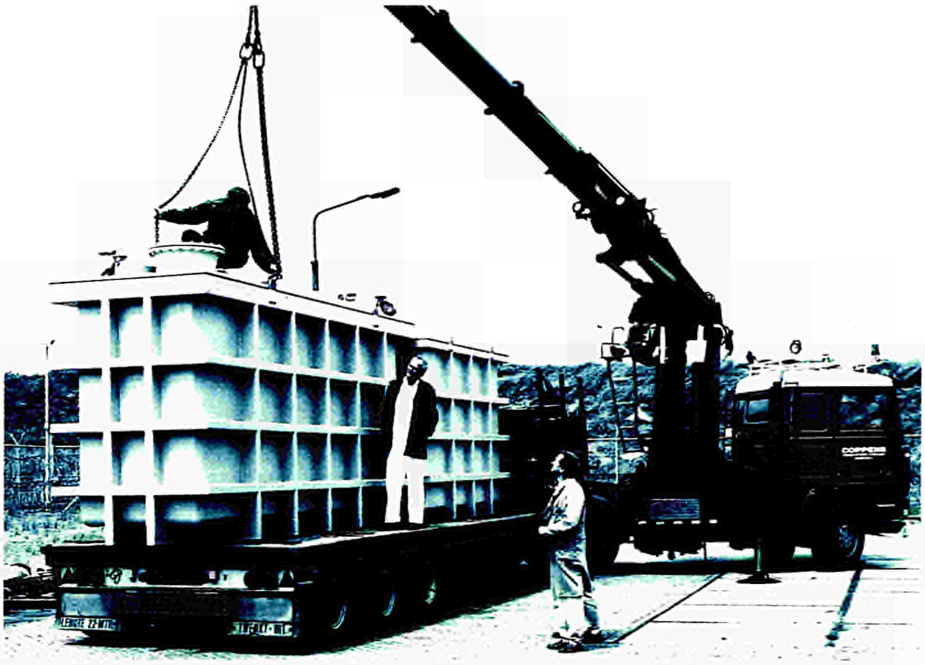


Fig. 4
Delivery of the first two new ion exchanger drain tanks

- Renovation of the secondary outlet section
  In past years many repairs were made on the outlet section of the secondary cooling water pipeline.
  In 1991 technical specifications were drawn up for a definitive repair i.e. a plastic liner inside the existing pipe, and complete exchange of the diffuser at the seaward end. The specifications have been submitted to JRC for formal approval.

- Cell cooling system
  The cooling system of the cells in the primary pump building has been renewed.

- Preventive maintenance schedule
  Following the intensive preventive maintenance schedule many pump units have been overhauled and valves, non-return valves, ducts, and the cranes were inspected. Where necessary corrective actions were taken. Three complete drive mechanisms of the control rods have been overhauled.

2.4.2. Instrumentation Systems and Informatics

- Gas monitor systems
  The outdated off-gas monitor system was renewed. To improve the operability a second system has been installed in parallel. The licensing procedure has been finished. After the completion of the operating instructions the system was put in operation.

  Technical specifications have been drawn up for the renewal of the high activity monitor (gas monitor 2) system. The new system has been delivered.
  After testing, and completion of the licensing procedures the system will be operational at the end of the maintenance period in April 1992.

To improve the periodic calibrations of the gas monitor systems a testing and calibration system has been installed in the monitor area.

- Cladding rupture monitor
  The new cladding rupture monitors have been connected in a two out of three system thus preventing spurious scrams. The new monitor system has been put in operation.

- Containment Building Leak Tightness Test
  Preparatory work for the containment test has been carried out and assistance has been given with respect to the data collection before and during the test.
  A new turbine flow meter for calibration purposes has been installed.

  The software for the containment test has been adapted to make use of the standard data loggers of the HFR instead of the outdated "Monlab" data logger.
  The data acquisition system (DACOS) now treats the data of the leak test in the same way as a standard experiment.

- Network
  The technical specifications for a network server and the network communication provisions have been drawn up. The server has been installed. It is now possible to exchange information between all computers at HFR and JRC site.

- Preventive maintenance schedule
  Following the preventive maintenance schedule maintenance has been carried out on the standard instrumentation and data acquisition systems. Great effort was put into extension and up-dating of the standard maintenance procedures and the HFR documentation.

- Miscellaneous
  A new N16 measuring equipment has been installed and put into operation.

  The Horizontal Beam tube (HB) monitor system has been extended with monitors for HB-4 and HB-11.

  An automatic leak measuring system for the reactor pool has been installed in order to measure the leak rate and to survey the effectiveness of the CO_2 suppletion.

2.4.3. Electrical Installations

- Dismantling Cell
  The renewal of the power distribution and control units for the power manipulator and further equipment of the HFR dismantling cell has been finished.

- Experiment support
  Several electrical power supply provisions and control units have been made for a number of experiments and irradiation facilities.

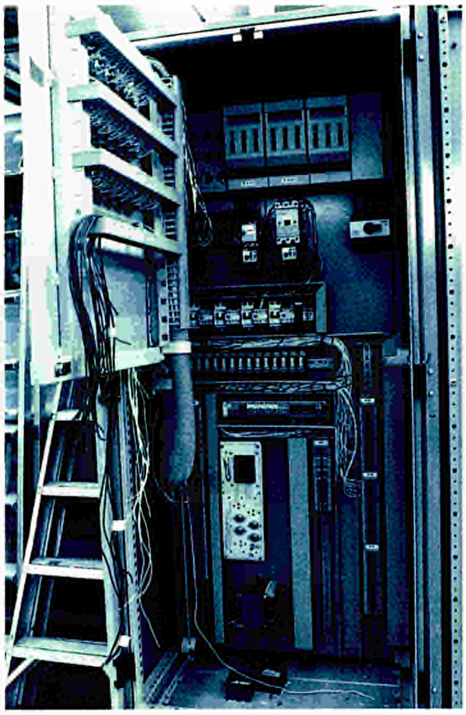


Fig. 5
The new ventilation building power distribution cabinet

- Rotary tape filters
  The electrical installation of the overhauled rotary tape unit has been modified.

- Ventilation building power distribution cabinet
  The engineering of the renewal of the power distribution cabinet, including the valve position indications, has been finished. The new cabinet will be installed in the ventilation building in the course of 1992 **(fig. 5)**.

- Magnet Units
  A study was performed on control rod magnet units with increased holding power without degradation of release characteristics. A prototype of an advanced magnet unit has been fabricated and tested.

- No-break emergency current supply
  One of the no-break supply units broke down. As consequence one of the diesel generators in the emergency power station was kept running continuously to supply the primary cooling system emergency pump without delay in case of a site supply failure.

- 110 V-DC control voltage system
  A new 110 V-DC control voltage supply system has been designed. It consists of a rectifier supplying load and a back-up battery.
  The battery capacity is chosen for 6 to 7 hours supply. The wiring of the necessary distribution cabinet is started.

- Miscellaneous
  Several modifications and repairs of the electrical installation of the HFR security building have been carried out.
  All fluorescent lamps in the reactor building have been renewed.

2.4.4. Buildings and Site

- The renewal of the roofs, including the improvement of the physical protection of the control room and adjacent buildings has been completed.
- The airtightness of the ventilation building has been improved.
- Inspection of the reactor hall painting showed a good condition, besides some minor defaces.
- Renovation of the High Construction Hall has been completed. Unexpected problems met during disassembly caused delay.
- An inspection survey showed the necessity of extensive renovation of diverse buildings. After this renovation a plan for routine maintenance will be drawn up and will be carried out on regular basis.
- Renovation of the Secondary Pump Building was carried out. The condition of the building was even worse than expected.
- Plans for the upgrading of the physical protection system are finished.
- A temporary housing for the BNCT project is provided.
- The plans for the decentralisation of the building heating system are in progress.
- Maintenance of reactor hall, control room, buildings, roofs and walls has taken place.
- A workshop has been built for handling of irradiated minerals.

2.5. TECHNICAL AND EXPERIMENTAL SUPPORT

2.5.1. Assistance to Experiments

Above routine assistance to experiments HFR personnel contributed substantially to the work of the project-teams of BNCT, ISOLDE and Isotope Production.

2.5.2. Vessel Material Fatigue Testing

The Licensing Authority requested as a condition of approval of the vessel design report, information on the fatigue properties of unirradiated and irradiated HFR construction material Al 5154. Because this information was not available from literature, an experimental testing programme has been performed to measure the fatigue life and fatigue crack growth properties.

The work performed by ECN was divided in two parts:
a) fatigue life and fatigue crack growth testing of unirradiated specimens from stock material of the new HFR vessel.
b) fatigue crack growth testing of irradiated specimens from material located at the core centre of the old HFR core box.
The experimental results have been reported and have been recently assessed by GEC-Alsthom, designer of the HFR vessel, with regard to the fatigue resistance of the vessel material. The overall conclusion drawn from these works is that continued operation of the HFR is fully justified with the parameters specified in the vessel design report.

2.5.3. Reactor Vessel Material Surveillance (SURP)

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 and in the pool side facility. These irradiations have been continued throughout 1991.

2.6. UPGRADING AND MODIFICATION PROJECTS

2.6.1. Replacement of Beryllium Elements

All core and reflector positions of the HFR have been provided with new beryllium elements. Replacement of the original elements was necessary due to degradation of the old elements.
A working document has been prepared on the operational and practical experiences with the former elements.
The tentative conclusions from this report are:
- the elements have stood 25 years of reactor operation
- the neutron fluence (E>1MeV) during this period is $2.56 \times 10^{26}/m^2$
- numerous surface cracks have been observed
- radiation damage due to helium formation
- the average swelling after 21 years of operation (1962-1983) was 0.9%. The maximum and minimum swelling data are 1,39% and 0,61% respectively.

2.6.2. Improvement of Gridbar Locking System

In order to avoid further technical problems with the existing locking devices and to improve operational ease, a new gridbar locking system had to be provided. After delivery, the new locking system was mounted in a testing frame. During these out of pile tests it turned out that the system worked satisfactorily **(fig. 6)**.

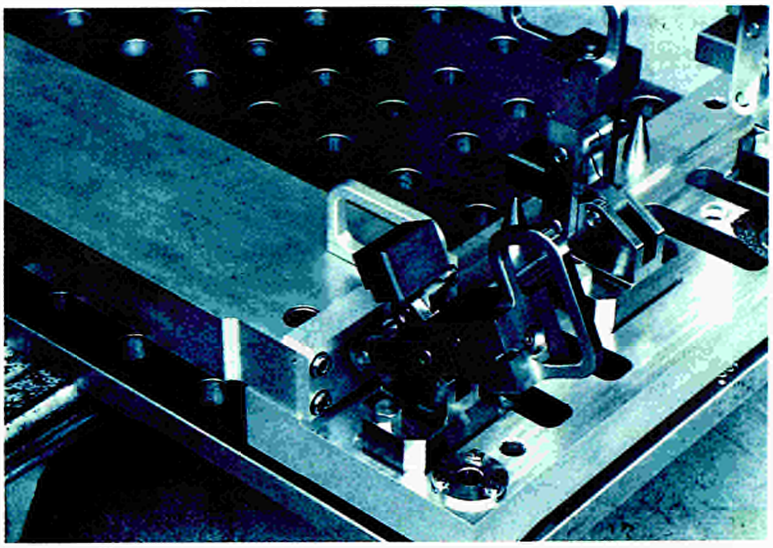


Fig. 6
Dry testing of the new gridbar locking system

After the in-service inspection the locking system has been mounted in the reactor vessel and during the last reactor reloadings the system proved to operate perfectly.

2.6.3. Renewal of HFR Main Power Distribution Cabinet

Rearrangements of the electrical power installations at the HFR have necessitated adaptation of the main distribution cabinet. Furthermore spare parts of the existing cabinet are no longer available, endangering future reliability. Therefore the technical specifications for a new distribution cabinet have been drawn up and the cabinet has been ordered. Preparatory work for the first step of the installation consisting of the rearrangement of several cable routings for fire protection reasons is being carried out.The actual installation of the cabinet is planned for July 1992.

2.6.4. Renewal of Chlorine Injection System of the Secondary Cooling System

To avoid algae growth in the piping and heat exchanger systems of the HFR, chlorine is being injected. On request of the Dutch Labour Inspection authorities the use and storage of chlorine has to be avoided, so alternatives had to be investigated.

Sodium hypochlorite has been chosen for safe handling and storage and for improved environmental effects. An investigation of the dose of sodium hypochlorite needed to avoid algae growth has been carried out. After analyzing the results, the technical specifications for a sodium hypochlorite injection system have been drawn up. The present storage building has to be adapted to future safety demands. The engineering for this adaptation is being carried out.

2.6.5. HFR Control Room Upgrading.

Re-configuration and upgrading of the HFR control room functions and equipment is becoming necessary in order to replace outdated equipment and to introduce modern ergonomic principles in the fields of display of and access to reactor-data and experiment-data.

The last study into requirements, budgetary consequences and timing has been finished. It turned out that if all the preparatory work has been carried out, it will be possible to upgrade the control room within two reactor stops of six weeks each. A second conclusion of the last study is that the preparatory work and the project management will be very time consuming.

2.6.6. Replacement of the Experiment Data Acquisition Computer

Increasing demands by project engineers necessitated upgrading of the data acquisition computer system with respect to scanning speed, storage capacity and graphic display.

A new VAX 4300 computer has been delivered and has been tested including all communication provisions. For future use of all utilities offered by the new version of the operating system the software is being adapted. Full effort has been put into the implementation of the software which had to be modified to the latest data collection standards and project engineers demands.
Since the old data acquisition system is still running satisfactorily, parallel testing of the new system is possible. This opportunity is being used to improve the software structure for maintenance purposes and to make full use of the improved system and programme protection possibilities.

2.7. NUCLEAR SUPPORT

2.7.1. Neutron Metrology

The annual core flux measurement campaign, called FLUX 91, has been carried out in cycle 91.03. The aim of the measurements is:

- to provide key data for the thermo hydraulic assessment of HFR cycle cores
- to check the computed neutron flux densities from the HFR-TEDDI fuel and core management program with the values measured in the standard core
- to investigate the feasibility of the determination of the local power production in fuel elements with a different detector type
- FLUX 91 comprised two identical flux mappings, one at the beginning and one at the end of cycle 91.03.
  The difference between the two measurement series shows the influence of burn-up and control-rod withdrawal. Results will be used for refinement of the burn-up and power distribution calculations. This in turn is expected to lead to even better fuel economy in the future. As an example **fig. 7** shows the change in fast and thermal neutron flux over the cycle in the fuel element in core position E6.
- The final results of the flux mapping at the end of 1989 have been reported.

2.7.2. Poolside Facility Neutron Flux Spectrum

The neutron flux spectrum in the western pool side facility has been calculated and the results have been reported.

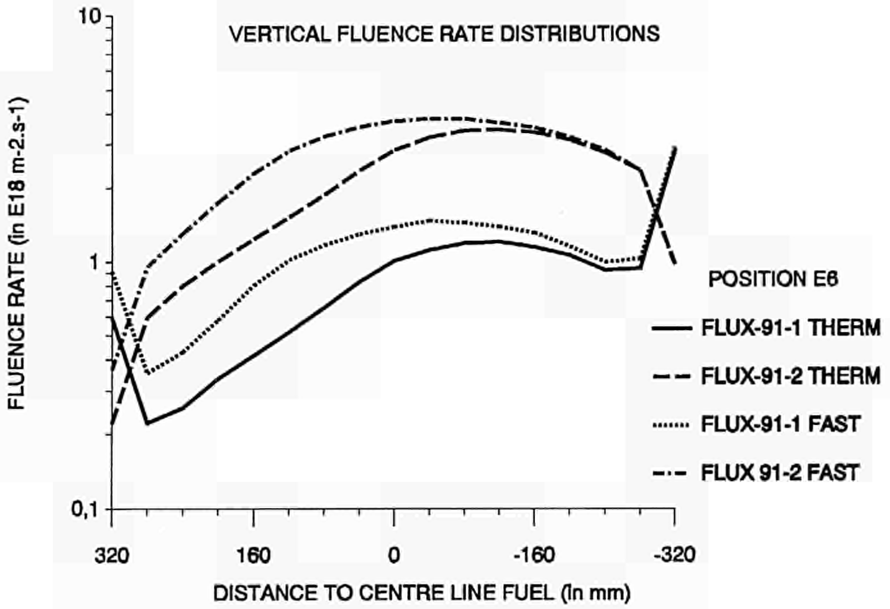
2.7.3. Nuclear Calculations

Nuclear constants calculations, required for a proper core and fuel management, have been carried out for the experiments MEDUSE, in-core

Fissile Isotopes Targets FIT and HIFI. The same type of calculations have been performed for the experiments FRUST and TRIESTE.

A start has been made with the construction of a new HFR-TEDDI core and fuel management program based on a more detailed description of the HFR core. The purpose of this operation is a more accurate description of the reactivity behaviour and neutron flux distribution required for fuel burn-up calculations.

Fig. 7
Comparison FLUX-91-1 to FLUX-91-2



3. HFR UTILIZATION

In 1991 the average utilization rate of the HFR was 69% of the practical occupation limit. A breakdown of the utilization pattern in terms of the different programme sectors is shown in **figs. 8 and 9**.
The main results of the various irradiation projects are reported below for each sector.

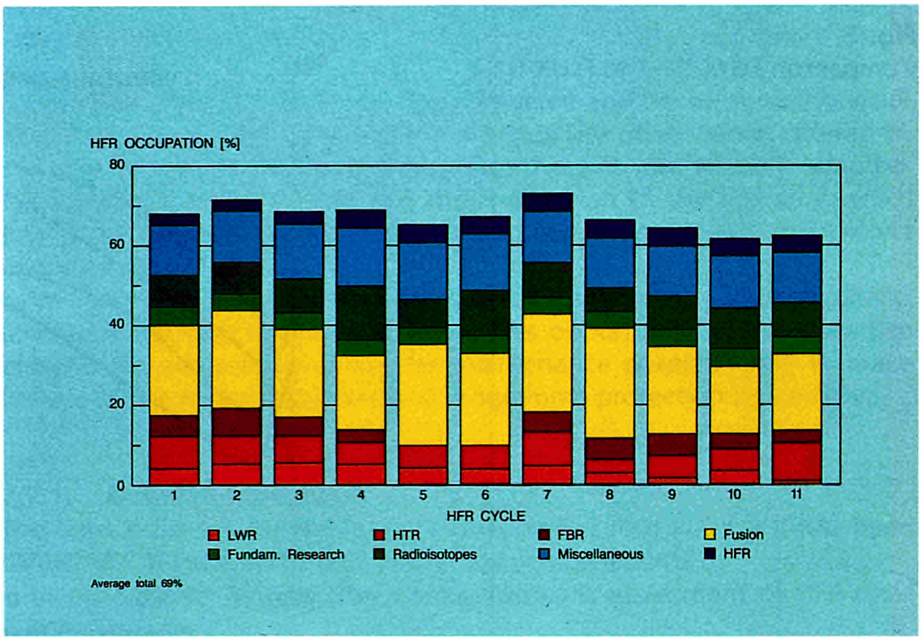


Fig. 8
HFR utilization 1991 per cycle in % of the practical occupation limit

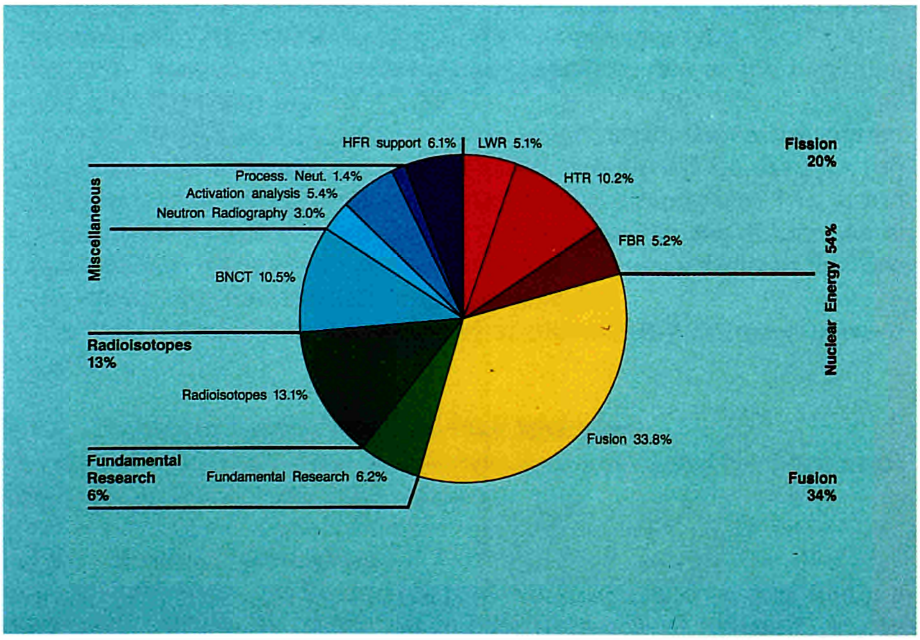


Fig. 9
HFR utilization 1991 in % of used capacity

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

Although the technology of light water reactors can be regarded as rather mature, there is still sufficient incentive for research reactor programmes with regard to the optimization of fuel cycle cost, as well as with regard to plant life extension.

a) Fuel Rod Irradiation

Objective:
Since more than 20 years the HFR contributes through irradiation testing of LWR fuel rods to the R&D on safe and economic utilization of light water reactor fuels. In earlier times the irradiation support to the LWR fuel community addressed the fuel rod behaviour under start-up, operational and overpower transients and/or under power cycling conditions /1/. Since the beginning 70's the test programmes employ mostly LWR fuel rod segments pre-irradiated in commercial power reactors. Broad experience in application of this test procedure has been gained at JRC /2/ and at the Petten hot cells of ECN since that time. Important data on the fuel rod behaviour with respect to its transient behaviour, e.g. safe transient speed, safe power steps and allowable power thresholds have been obtained through these programmes for standard PWR & BWR fuel using UO_2 and Mixed Oxide Fuel $(U,Pu)O_2$ /3/. These data are now being employed at todays power reactors and have lead to an increase of availability and economics of the plants. Recent R&D in the LWR sector is addressing fuel rod behaviour at high burn-up mainly. However, also performance testing of new fuel rod concepts with respect to better waterside corrosion resistance, improved economics (e.g. utilization of MOX) and fine tuning of its characteristics are pursued.

A second line of irradiation support by HFR addresses the investigation of the release and behaviour of fission products after a hypothetical LOCA scenario. In this field a major contribution to the understanding of iodine release, its solution and degassing after a LOCA was made through HFR experiments performed at the early 80's together with KFA Jülich /4/.
This programme is now being pursued with a newly developed irradiation device allowing in-pile LOCA testing of pre-irradiated PWR fuel rods.

The 1991 LWR fuel rod irradiation programmes at the HFR addressed the following objectives:
- study of the transient fission gas release,
- investigation of power cycling behaviour of extended burn-up PWR fuel rods,
- investigation of the irradiation behaviour of PHWR fuel and
- study of the iodine release under simulated in-pile LOCA conditions.

The objectives of R&D for LWR fuel testing devices were related to:
- development activities for a "low power fuel testing capsule" providing characteristic PWR fuel rod surface temperatures from approx. 150 W/cm linear heat generation rate onwards and suited for power cycling tests and investigation of the fuel rod behaviour at extended burn-up,
- modernisation of the out-of-pile installation for operation and control of the standard LWR fuel rod irradiation devices and
- commissioning of an in-pile profilometry rig.

Progress:

Power ramp tests of pre-irradiated LWR fuel rods (projects 125, 176, 178, 201)

For the investigation of transient fission gas behaviour, in-pile measurement of the fuel rod pressure is employed. A new technique, developed by JRC Petten, providing a re-instrumentation capability for irradiated fuel rods /4/ and being performed at the Petten hot cells, was successfully applied in 1990, firstly on a fresh BWR fuel rod under simulated hot cell conditions, and secondly on a pre-irradiated BWR fuel rod.

Irradiation of both tests was started during 1990. The fresh BWR fuel rod was only irradiated for a short time in order to check the performance of the new technique. This test confirmed the anticipated capabilities of the measuring system. The pre-irradiated fuel rod was ramptested at the beginning of the irradiation period and then continued in irradiation for burn-up accumulation of additional 10 GWd/t(U) which were reached during the third quarter of 1991. The pressure in the fuel rod has been monitored during all the test periods until the desired target burn-up level. **Fig. 10** shows a summary of the irradiation history.

The post irradiation examination was started with a multi-isotope gammascan and will be continued with a puncture test for fission gas analysis, void volume determination and fuel rod internal pressure. Furthermore non-destructive characterisation by neutron radiography, eddy current check and profilometry is foreseen.

A power cycling test programme was initiated with irradiation testing during the last HFR cycle in 1991 using an extended high burn-up PWR fuel rod (> 50 GWd/t(U)) and the "low power" BWFC capsule. The power cycling scheme of this test series follows the day/night power scenario of a PWR operated in load follow mode. During the anticipated test programme several intermediate inspections are scheduled using neutron radiography, eddy current measurement, profilometry and Kr-85 measurement for fission gas analysis.

The hardware preparations for ramp testing of MOX fuel rods to be performed during 1992 were completed. Delivery of the fuel rods is anticipated for the beginning of 1992.

In-pile Measurements in LWR fuel (project 128)

The project has been terminated at JRC Petten during 1990. The destructive PIE on the last two tests has been completed at the KFA Jülich hot cells during 1991.

Irradiation testing of PHWR MOX fuel rods (project 227)

Two irradiation experiments, each using two short fresh MOX PHWR fuel rods, are being performed at the HFR in order to study the fuel rod power ramping behaviour at approx. 15 GWd/t(M) [e.g. end-of-live (EOL) conditions].

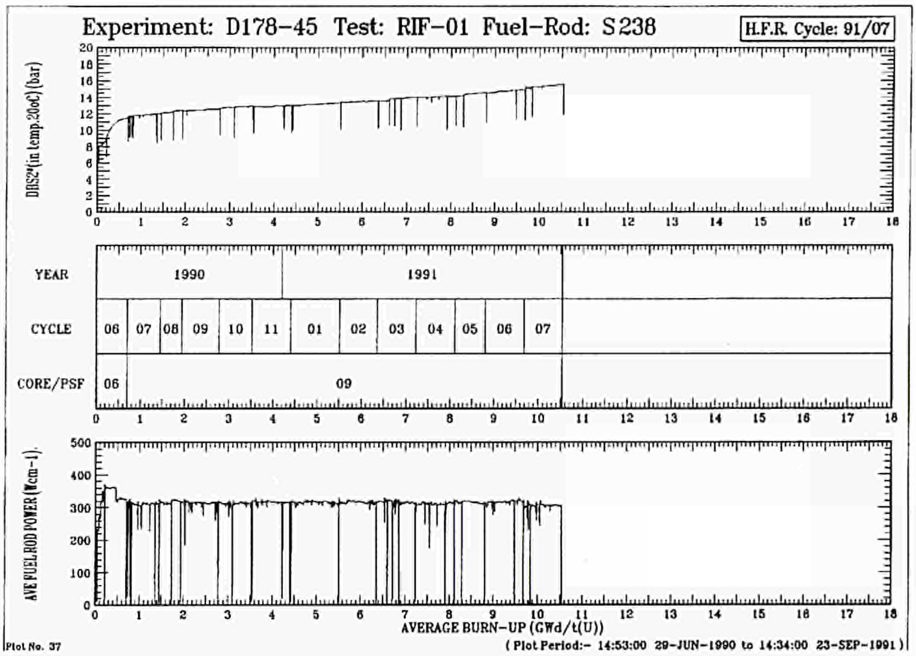


Fig. 10
Summary of irradiation history

The first test, a simulated EOL test, has been completed in 1986 in the HFR and has been sent to the clients hot cells for further PIE.

The second test consisting of a burn-up accumulation phase to 15 GWd/T(M) and a transient test with one fuel rodlet, has also been completed during the last quarter of 1991. The irradiation for burn-up accumulation was performed in the HFR core and the PSF until HFR cycle 91.08. This experiment is the first of its kind which was partly irradiated in the HFR core and partly in the PSF whilst using the same irradiation capsule.

Iodine Solubility and Degassing Experiment (ISOLDE) with pre-irradiated PWR fuel rods (project 206)

The test programme addresses the determination of the rate of iodine release from PWR fuel rods and its solution in steam and water for a LOCA scenario starting from PWR conditions.

Tests number 3 and 4 of the anticipated five in-pile tests with pre-irradiated PWR fuel rods have been performed during 1991.

Each test consists of a conditioning period at typical PWR fuel rod power and conditions in order to obtain a typical inventory of short lived isotopes. The fuel rod is then transferred into the ISOLDE irradiation device. The test scenario of the ISOLDE test number 3 is shown in **fig. 11**. The ISOLDE device provides typical PWR system conditions at low power level and after initiation of the LOCA phase typical LOCA conditions. **Fig. 12** shows the fuel rod temperature and system pressure versus time for all ISOLDE tests performed until to-day. Test number 4 was operated after the initial blow down step with the highest temperature increase rate

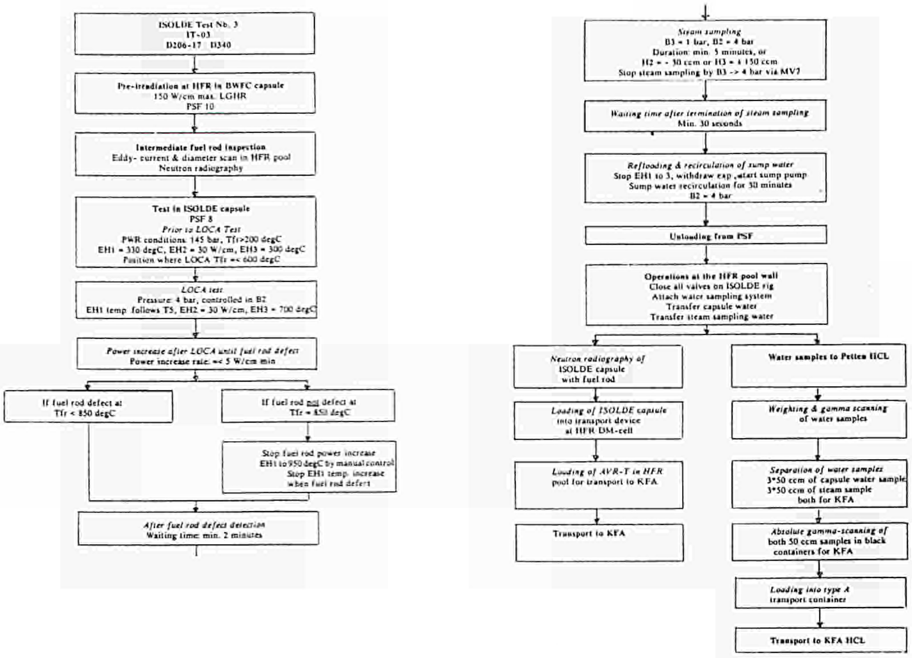


Fig. 11
ISOLDE 3 test scenario

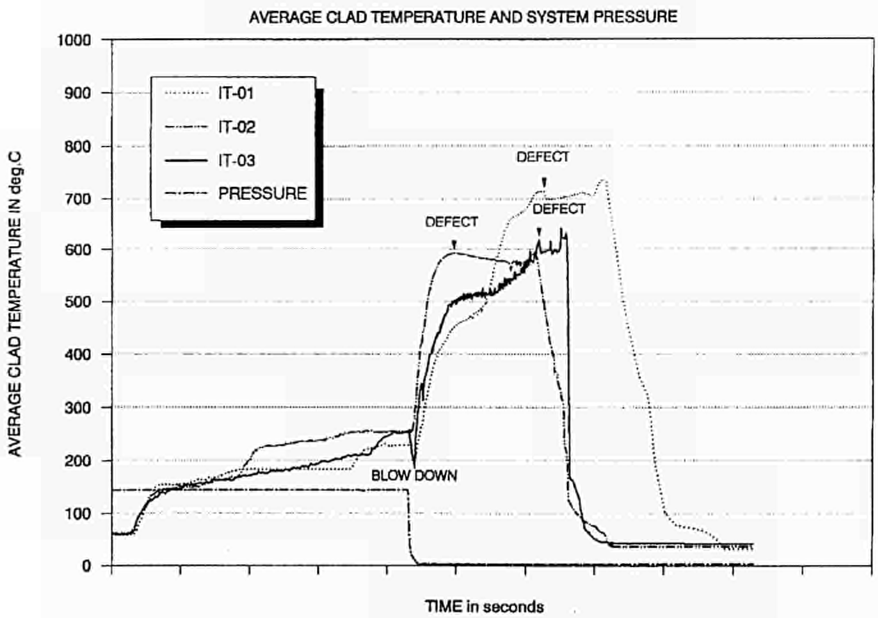


Fig. 12
Comparison of ISOLDE tests IT-01/02/03

feasible with the ISOLDE device. This operation mode leads to a more pronounced fuel rod defect (bursting failure).

In all ISOLDE tests performed, the fuel rod failure occurred above 600 °C. As planned, steam and water samples were collected and made available for PIE at the Petten and Jülich hot cells. The irradiation devices including the fuel rods were transported to the Jülich hot cells for PIE. In view of the short half-life of I-131 all transports were performed shortly after the HFR test. Prior to the transports of the entire irradiation capsule the fuel rod condition was investigated by neutron radiography. The water samples were characterized at the Petten hot cells by gamma-spectroscopy prior to shipment to the Jülich hot cells.

Irradiation proposals

The following proposals for irradiation testing of pre-irradiated LWR fuel rods have been forwarded to the interested customers:

- power ramp testing of 13.5 mm (outer diameter) fuel rods, re-fabricated at the Petten hot cells from full length fuel rods,
- power cycling, power ramp and bump testing and pre- & post irradiation examination of different types of pre-irradiated LWR fuel rods (1992 programme for ongoing test programmes).

Development of LWR fuel testing devices

- The development work on the "low power" BWFC capsule was terminated. A "low power" BWFC capsule with an electrical heater was manufactured. Its thermo-hydraulic characteristics were tested with a simulation heater in place of a fuel rod. It was found that the onset of boiling at the fuel rod surface could be lowered by approx. 35 W/cm. This device will be utilized in the anticipated irradiation test with high burn-up LWR fuel.
- The out-of-pile testing of two more ISOLDE capsules was continued in order to characterize their thermal behaviour prior to the in-pile tests.
- The in-pile profilometry rig was set up for a commissioning test out-of-pile. **Fig. 13** gives an overview on the in-pile profilometry measurement system.

b) Structural Materials Irradiation Testing

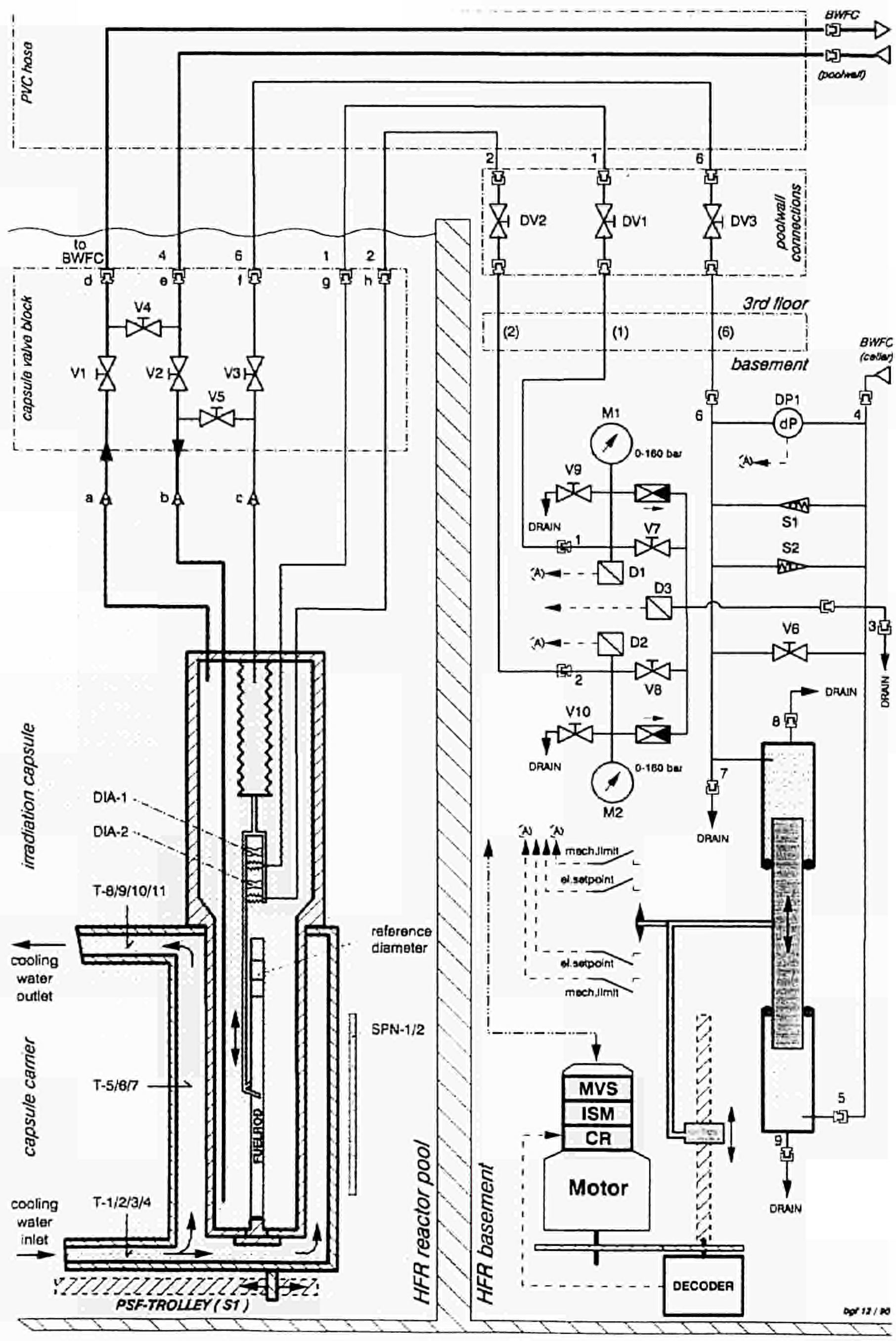
Objective:
The extension of the operational life time of water reactors requires investigations on the corrosion and mechanical behaviour of the structural materials in the core region and of the pressure vessel.

For structural materials irradiation testing feasibility studies to the following objectives were continued:
- design and feasibility study on corrosion testing of Zr-based alloys in the reactor coolant (in both, light and heavy water) and
- conceptual studies on irradiation testing of large CT specimen made from BWR vessel material.

Progress:
Feasibility study on corrosion testing of Zr-based alloys in the reactor coolant (in both, light and heavy water)

During the preceding period a design study for a miniature high pressure loop for irradiation of a sample stack of corrosion samples in a TRIO-type

Fig. 13
In-pile profilometry measurement system



irradiation device was performed and yielded feasibility for application of both coolant media, light water and heavy water. The irradiation device is reloadable and provides intermediate inspection capabilities of the irradiated samples. During this period an additional study was performed and confirmed for the light water system feasibility of accommodation of two independent loop systems in a TRIO-type irradiation rig.

Conceptual studies on irradiation testing of large CT specimen made from BWR vessel material

The basic lay-out for a new test facility at a HFR beam tube has been elaborated during the preceding period. The irradiation device will be situated at one of the horizontal beam tubes and include an autoclave providing the BWR environment and a loading system. It is assumed that the main irradiation component enhancing the crack propagation is originating from chemical radicals formed under gamma irradiation. Therefore it is considered that only the gamma beam will be utilized within this experiment. A more extensive feasibility study is in progress in order to prove that the HFR is suitable to provide gamma-spectra typical for commercial BWR's at the inside of their pressure vessel.

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Proceedings of a colloquium on "the HFR Petten, prospects and future utilization", EUR 12522, 1989

/4/ E. Groos, R. Förthmann
Determination of iodine 131 release from defect, irradiated fuel rods under simulated LOCA conditions
International meeting on thermal nuclear reactor safety, Karlsruhe, 1984

/5/ T.D.A. Kennedy, J.F.W. Markgraf, S. McAllister, I. Ruyter
Development of a two-dimensional computer code for the prediction of two-phase heat transfer in an experimental light water reactor irradiation capsule
Nuclear Energy 30, 1991, No. 3, June, pages 165 to 172

3.2. FAST BREEDER REACTOR (FBR). FUEL AND STRUCTURAL MATERIAL IRRADIATIONS

During the late 70s and early 80s, several international R&D programmes were being pursued, each with their own goal of qualifying various FBR fuels and materials under normal and off-normal conditions.
The HFR played an important role in performing many experiments for the German and Dutch programmes. From the mid-80s and onwards, it became apparent that significant measures had to be taken to achieve specific goals including acceptable safety features, within acceptable economic constraints. Consequently, in 1984, a five- nation collaboration to develop a demonstration European Fast Breeder Reactor (EFR) was made. The raison d'être for the FBR remains the same in that at least 60 times more energy can be produced from a given quantity of uranium in an FBR than in a thermal reactor, being equivalent therefore to twice as large as the known world coal resources and 15 times larger than the known oil resources. The objectives of the EFR are: capital and generating costs should

be comparable with competing PWR's; availability and reliability should be similarly comparable; construction should be assured within a defined time-scale; and there should be a minimum extrapolation to a commercial plant.
All existing and future FBR experimental programmes at the HFR, now fall within the design aims of the EFR. The objectives remain essentially the same.

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: features investigated include start-up behaviour, power cycling and ramping, fuel melting, transient overpower (TOP) and simulated loss-of-flow (LOF) behaviour. 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 UO2 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 ref. /1/.

Progress:
Transient Tests

During the reporting period three transient experiments were irradiated over a total of 23 reactor cycles, including 1 specific, short transient test.

HYPERKAKADU (project 183)

A new KAKADU series of experiments consisting of extra long pins (>2 m), have necessitated a re-design of the special α-tight EUROS cell, ref. /2/. The loading and sodium filling of these longer fuel capsules will be carried out in a modified EUROS cell without too much rebuilding and expenditure. It is agreed that 4 pre-irradiated fuel pins, originating from the PFR Dounreay, will be transported to Petten in 1992.

POTOM/OPOST (projects 184/192)

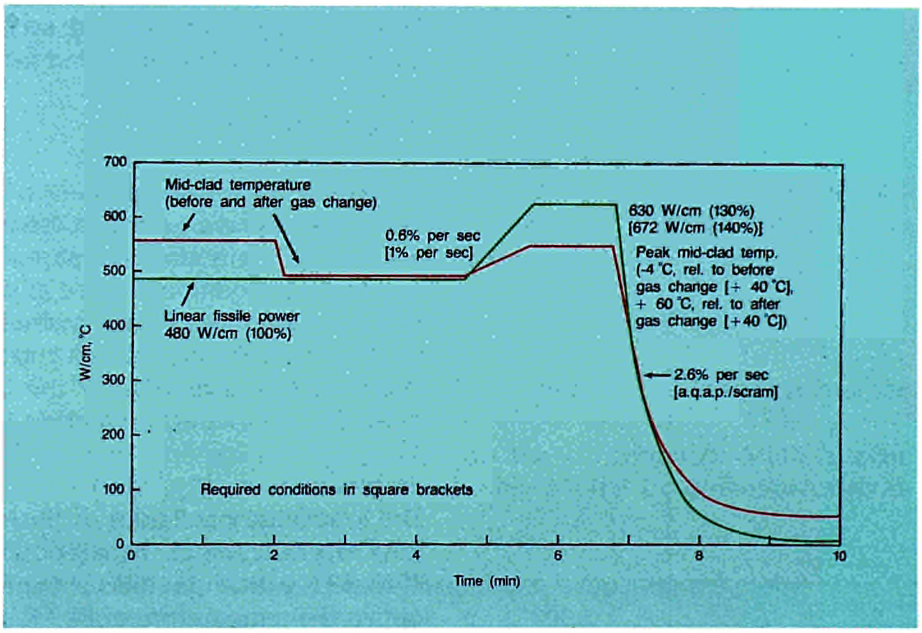
The aim of the POTOM series of experiments is to determine the power at which melting of the fuel first occurs, as a function of material composition (Pu-content), fuel type (homogeneous/heterogeneous) and duration of pre-conditioning. Following 5 POTOM experiments, reported in previous annual reports, the first OPOST experiment was started in 1990.

The aim of this series of experiments is to demonstrate fuel behaviour and operability of partially melted fuel pins. Following a short 3.5 day irradiation of three fuel pins at 550 W/cm, i.e. just at the power-to-melt temperature as determined from the previous series of POTOM experiments, each fuel pin has been separately irradiated in position G5 at 550 W/cm. Due to the horizontal flux gradient in this position, only one fuel pin per cycle was irradiated. The 3 fuel pins (27,28 and 29) were irradiated for 1,2 and 3 cycles respectively.
The last irradiation (29,3 cycles) was completed in May 1991. The 3 pins were gamma scanned at the LSO hot cells, where they now await transport to KfK Karlsruhe for PIE.

RELIEF (project 215)

The experiment aims to study, by means of in-pile measurement, the differential and absolute fuel and cladding axial displacements during operational transients. At present two RELIEF experiments (RELIEF 12 and RELIEF 13) are in irradiation. At the end of 1991 RELIEF 12 had completed almost 30 cycles of irradiation at a steady power of 480 W/cm. The attained burn-up is approximately 9.0 at.%. After attaining 5.0 at.% burn-up in 1990, the first transient was performed. In December 1991, the second transient, being a repeat of the first was performed. The planned and achieved conditions are shown in **fig. 14**. A third transient is planned for 1992 (at 12 at.% burn-up).
RELIEF 13 began irradiation in February 1990. The experiment had attained 4.8 at.% burn-up at the end of 1991. A first transient will be performed in 1992 on achieving 5.0 at.% burn-up.

Fig. 14
A comparison of the achieved and required peak linear fissile power and peak cladding temperature changes during the RELIEF 12 transients



TRAGA (project 235)

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

Mixed nitride (U,Pu)N is the reference fuel for a fast reactor cycle with a denser optimised fuel than the currently used mixed oxide.
The JRC Karlsruhe programme "Optimisation of Dense Fuels" aims at optimising "pure" mixed nitrides for high burn-up fast reactors. Part of this program involves the irradiation testing of fuel in the HFR.

NILOC (project 211)

The third and fourth NILOC experiments are now ready for irradiation. The experiment NILOC 3 will irradiate 2 mixed nitride fuel pins and 1 mixed oxide pin, containing UN breeder pellets simultaneously. NILOC 4 will irradiate 3 nitride pins. The irradiations are planned for the beginning of 1992.

POMPEI (project 226)

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 the start of 1992.

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 and neutron fluence. They have supplied accurate information of material embrittlement by helium formation and fast neutron displacements.

Project 139-59

Objective:
This new irradiation programme will provide sufficient specimens for continuous cycling and creep-fatigue post-irradiation testing. The irradiation and testing conditions will be as close as possible to the conditions of the EFR (European Fast Reactor) above-core structures. The objectives of this work are to provide data on creep- fatigue properties of irradiated stainless steel type 316 L(N) for the EFR design data-base, and to verify the creep-fatigue interaction models.

Progress:
The irradiation conditions of this experiment are 823 K at a very low dpa (one reactor cycle in the H8 position) and the irradiation takes place in a TRIO-131 with a double container **(fig. 15)**. This is required in order to obtain the temperature of 823 K at a peripherical reactor position.

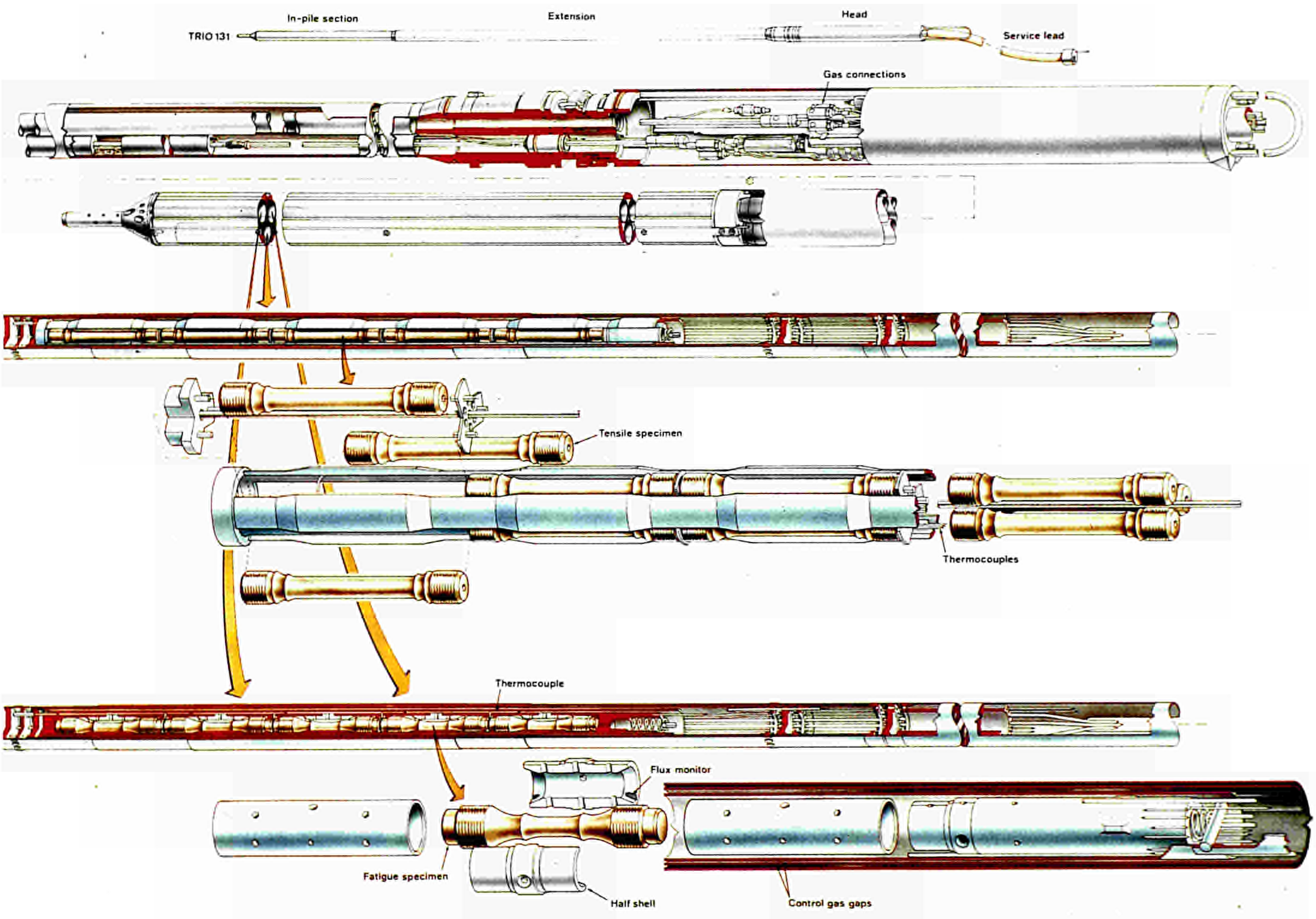


Fig. 15
TRIO-131 containing fatigue and tensile specimens in a double containment

Two legs of the TRIO contain fatigue specimens and the third leg tensile-creep specimens. Assembly of these three legs (139-597-598-599) has been completed. Irradiation will start in cycle 92.03.

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

The continuation of R&D in Germany for the High Temperature Reactor (HTR) technology through industry and governmental support came under discussion in 1991. Therefore, irradiation experiments for HTR R&D in support of the German funded programmes continued only for those which are currently under irradiation.

Under the terms of their joint venture, ABB and Siemens pursued three types of HTR power plants for different market segments, but reduced the programme to one type, namely the HTR-Module (200 MW_{th}). This reactor type is based on the established technology of the AVR (Arbeitsgemeinschaft Versuchsreaktor) for heat and power for industry and public supplies.

In this frame, test irradiations are being performed in the HFR Petten on materials which are typical for the HTR-Module /1/:

- spherical fuel elements with low-enriched uranium (UO_2) TRISO 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 as well being performed at the HFR Petten under the "Umbrella Agreement" between Germany and USA on the collaboration in HTR R&D within the civil programme.

a) Fuel Element Irradiations

Spherical fuel elements for the German HTR Programme

High Temperature Reactor (HTR) fuel testing is being performed at the HFR Petten on reference coated particle systems and production fuel elements for the UO2 low enriched uranium (LEU) fuel cycle. The fuel elements are the reference 60 mm diameter spheres with LEU-TRISO coated particles, as developed by NUKEM/HOBEG in the framework of the "High Temperature Fuel Cycle"-Project HBK for all future HTR applications in Germany /2/.

The irradiation testing of HTR reference fuel elements is performed in two phases. In phase I, which is meanwhile completed, irradiation experiments were performed for different objectives such as particle failure, fission product transport, fuel element integrity etc. at target and extreme operating conditions. Not a single coated particle became defective in the sense of irreversibly increased fission gas release. In phase II, "near-to-production" fuel elements are being tested at the HFR Petten under conditions as close as reasonably achievable for HTR power plant characteris- tics, including simulation of fuel reloading systems. The main objectives of the irradiation tests are the confirmation of low coated particle failure rates caused by temperature , temperature transients/cycling, burn-up or fast neutron fluence and the confirmation of low "free heavy metal" (uranium and thorium) contamination of the fuel element matrix material by impurities and/or by defective coated particles. Therefore, the irradiation capsules are coupled to specially developed SWEEP-LOOPS for on-line measurements of the release of volatile fission products under a wide R/B (Release to Birth rate) range ($10^{-10} < R/B < 10^{-1}$), as well as for on-line gas chromatographical analysis of the downstream purge gas. A survey of these activities at the HFR Petten is given in **table 4**.

YEAR	1991	1992	1993	1994
1. Fuel Elements:				
D 138.05	3 ▬	▬ 4	▬	▬
D 138.06	3 ▬	▬	▬ 4	▬
D 138.07	p.m.			
D 214.01	4 ▬	▬		
2. Graphite spheres				
D 247.01	1 ▬	2 ▬ 3 ▬ 4	▬	
3. Out-of-pile facilities	5 ▬	▬	▬	▬

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

Table 4
HTR fuel irradiation experiments.
Survey of present and future activities

Reference tests for the HTR-Module (project 138.05/06)

Objective:
These reference tests should confirm the design fission product release data set for "near-to-production" fuel elements under conditions which simulate realistic power reactor operating and multiple-pass fuel loading conditions of the HTR-Module /2/. The irradiation experiment 138.05 is the first test in phase II on LEU-TRISO reference HTR fuel element for the HTR-Module.
Project coordinator is KFA Jülich and HBK/HTA-Project.
HRB is responsible for the test specifications.

Progress:
Project 138.05

The irradiation of the first reference test /3/ for the HTR-Module with three independently controlled capsules (BEST-rig design) continued in 1991. On-line fission gas release measurements were performed daily. The fractional fission gas release data of two capsules (A and B) correspond still with the heavy metal contamination of the graphite matrix material. The higher fractional fission gas release of the third capsule (C) is still in the range of 10^{-7} to 10^{-6}, which corresponds with the release of one to two defective (manufacture caused failure) particles /3/. The fractional fission gas release (R/B) and the fuel temperature history versus irradiation time is shown for one capsule (C) in **fig. 16**. The influence of temperature and temperature transients on the fission gas release can clearly be recognized. The cumulative burn-up is meanwhile 5.9% fima and the cumulative fast neutron fluence is 2.7×10^{25} m^{-2} (E>0.1 MeV) after 360

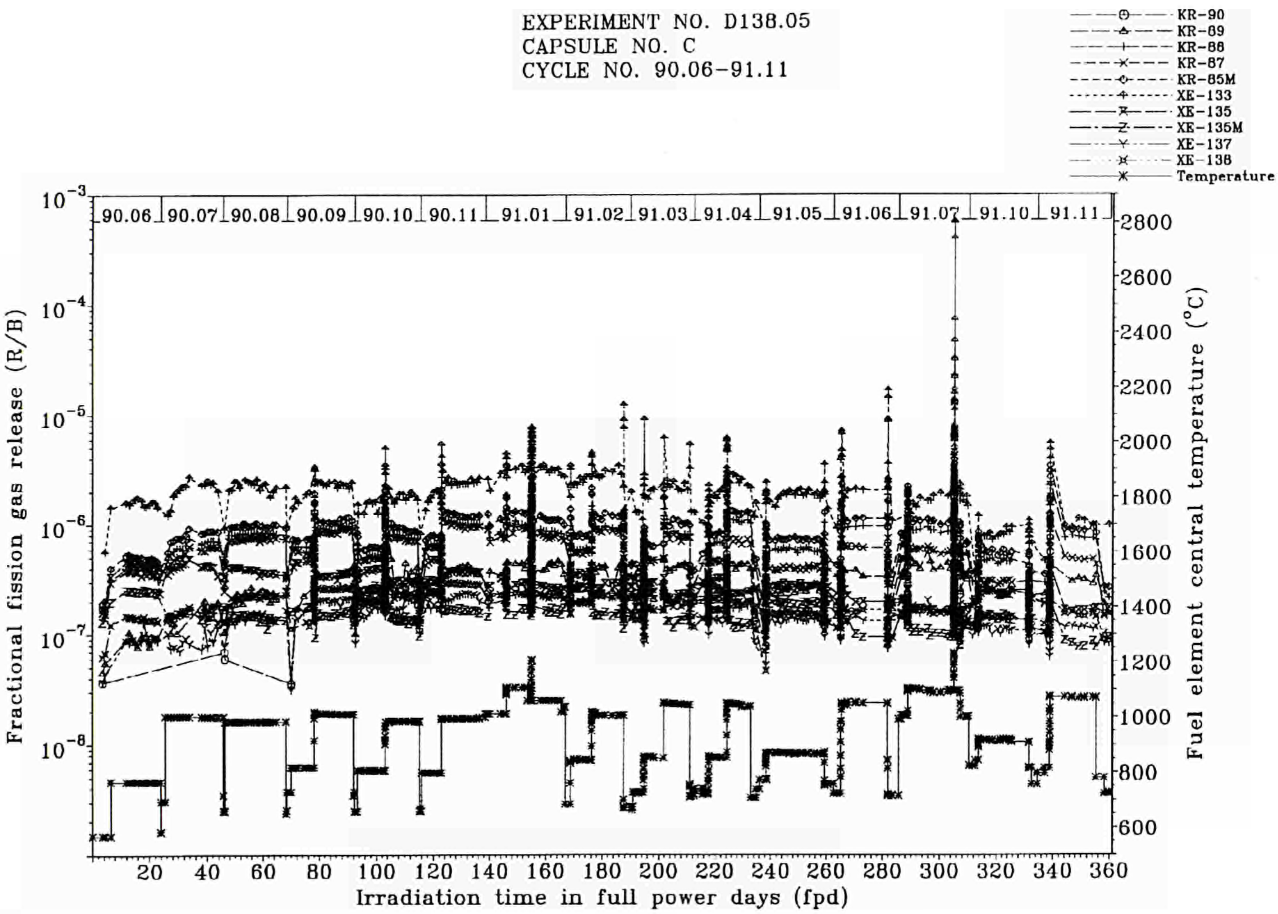

Fig. 16
Fractional fission gas release (R/B) and fuel temperature vs. irradiation time for capsule C of the reference test 138.05

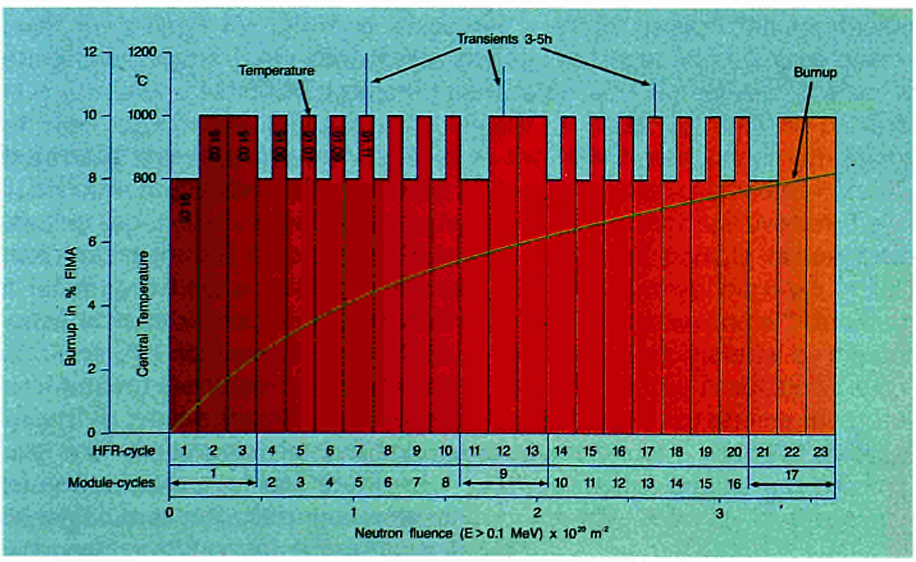

Fig. 17
Irradiation history for the reference test 138.06

full power days. The thermal neutron fluence became lower during recent cycles in H-row positions due to experiments with higher neutron absorption. The effect on the burn-up/fast fluence correlation for the 138 experiments could be reduced by specially designed filler elements to enhance the thermal neutron flux. Irradiation progress was reported in cycle reports. The irradiation is planned to be terminated by the beginning of 1993.

Project 138.06

The irradiation of the second reference test for the HTR-Module started as planned with cycle 91.01. The designed irradiation conditions were achieved. The irradiation history, initially planned to simulate the HTR-500 operating conditions, follows now the HTR-Module scheme **(fig. 17)** for reasons mentioned in the introductory section. Seven cycles were completed in 1991.
The irradiation had to be interrupted during the cycles 91.04, 91.05, 91.08 and 91.10 due to double occupation problems in the H-row positions. Similar measures as for 138.05 were taken to enhance the thermal fluence rate by using a moderating filler element. The cumulative burn-up was 3.4% fima and the cumulative fluence was 1.3 x $10^{25}m^{-2}$ after 172 full power days. On-line fission gas release measurements were performed daily. The fractional fission gas release of capsules A and B are in correspondence with the U/Th-contamination level of the matrix and structural capsule materials. A defective coated particle, caused most probably during manufacture of the fuel element, was observed in capsule C. The temperature history, shown in **fig. 17** has the same effect on fission gas release as reported for 138.05 **(fig. 16)**. Irradiation progress reports were issued after each cycle. The planned irradiation duration is 23 HFR cycles, to be terminated in 1994.
The progress of the HTR-Module reference tests was reported during the Second Soviet-German Seminar on Fuel and Graphite for the HTR /4/.

Reference test for the HTR-500 (project 138.07)

All activities have been stopped for the reasons mentioned in the introductory section.

Irradiation of SIC-coated graphite spheres (project 247.01)

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 graphite spheres (without coated fuel particles) of 60 mm diameter will be examined by in-pile testing. The test specimens should be irradiated between 873-1273 K up to a fast neutron fluence (E>0.1 MeV) of 2.6 x $10^{25}m^{-2}$.

Progress:
Problems are still encountered in coating the graphite spheres with SiC layers. Therefore, the assembly and the irradiation start are delayed into 1992.

Irradiation of fuel rods for the US-HTGR

Irradiation of GA fuel rods in segments of the bloc-type fuel element (project 214.01)

Objective:
This experiment is a joint effort involving General Atomics Technologies (USA), KFA-HBK Project and IAM Petten under the auspices of the US/FRG "Umbrella Agreement" for co-operation in High Temperature Gas-Cooled Reactor developments for the TRISO-LEU fissile/TRISO-ThO_2 fertile US-HTGR reference fuel system. The overall objective of this irradiation test 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 on the effects of temperature cycling (1000 - 1500 K) and water vapour injections (18 - 1060 Pa) on fission gas release during the irradiation campaign.

Progress:
Fine-dismantling and PIE for two capsules (B and C) started in 1991 at the Hot-Cell laboratories of KFA Jülich. The transport of the third capsule (A) from KFA to ORNL is still under preparation. The neutron fluence detector sets of two capsules (B and C) were transported to ECN Petten for evaluation. The initially reported neutron fluence data were not in agreement with the calculated data. A proper evaluation, taking the dedicated spectrum measurements of the "1986 flux campaign" into account, is in progress. Nevertheless, the final version of the final irradiation report, drafted in 1990, was elaborated in co-operation with ORNL at Petten. The issuance of the final report is planned for 1992. A publication on the 214 experiment was accepted by the organising committee of the forthcoming Jahrestagung Kerntechnik, 1992 /5/.

Development of a control system for swept HTR fuel experiments, SWEEP-LOOPS

The main activities in the development of the SWEEP-LOOPS in 1991 were concentrated on the operation of the 138 experiments with in total six independent control circuits. The gas sampling station and the gamma spectrometer were prepared for the measurement of low radio-activities ($<10^4$ Bq), in order to measure initial irradiation fission gas release originating from heavy metal contamination of structural materials.

b) Graphite Irradiations

In the frame of a graphite development and qualification programme, a large number of graphite samples have been irradiated during more than twenty years in the HFR at Petten. The HFR graphite irradiation programme supplies the necessary design base for the German High Temperature Reactor Programme. The irradiation capsules contain unstressed samples (fundamental properties) or creep specimens under tensile or compressive stress. They are irradiated in three to four fluence steps, with intermediate measurement of their physical properties.

Fundamental properties graphite programme (project 85)

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^{26} m^{-2} (EDN)*, at relatively low temperatures between 573 and 873 K
- matrix material, for lower neutron fluences, in the order of 4×10^{25} m^{-2} (EDN) at higher temperatures, ranging from 773 to 1473 K.

Progress:
Post irradiation measurements have been performed at KFA Jülich on some experiments which ended last year, namely D85-55 and D85-58.

Two experiments have been irradiated during 1991 and are still under irradiation:
- Experiment D85-56II (723 K) which started irradiation in cycle 90.03. It is presently irradiated in reactor position E5; the temperatures lie in the specified range. The foreseen irradiation duration is 24 cycles.
- Experiment D85-59 (1173K) started irradiation in cycle 91.07. Total duration foreseen is 8 cycles in position C3. Temperatures lie in the specified range.

Two sample holders have been manufactured during 1991, D85-63 (873K) and D85-64 (573K). Due to changes in the KFA programme they will be irradiated as follows:
Experiment D85-63 will start irradiation in cycle 92.02, while experiment D85-64 will start irradiation in cycle 93.01 at a temperature of 723 K. Damage values foreseen are: 6×10^{25} m^{-2} (EDN) for D85-63 and 10×10^{25} m^{-2} (EDN) for D85-64.
A summary of current and planned D85 irradiation series is presented in **table 5**.

Graphite creep experiments, DISCREET (project 156)

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.
Creep measurements are taken out-of-pile at intervals of irradiation.

Progress:
The following activities have taken place in 1991.
D156-90 series ASR-1RS, 5MPa tensile stress.
Irradiation D156-95 started in cycle 90.09 and finished in cycle 91.05. This is the first irradiation step of a temperature change experiment. The samples have been irradiated at 1170K up to a fluence of about 3.8×10^{25} m^{-2} (EDN). After length/diameter change measurements the samples were

* traditional graphite exposure unit ("Equivalent DIDO Nickel")

Table 5
Graphite fundamental properties programme.
Survey 1991-1994

Exp. number	Irradiation period	Irradiation temperature (K)	Present state
56 II	March 90 - June 92	723	under irradiation
59	August 91 - March 92	1173	under irradiation
60	January 93 - July 93	1323	planned
62	April 93 - September 93	1323	planned
63	February 92 - April 93	873	waiting for samples
64	January 93 - October 94	723	waiting for samples
67	May 92 - January 93	1023	planned
68	December 92 - June 93	1173	planned
70	November 93 - September 95	873	planned
71	September 93 - February 94	1023	planned
72	January 94 - July 94	1173	planned

re-encapsulated in a new sample holder (D156-96) for irradiation at 770K. Irradiation started in cycle 91.11 and will finish in cycle 92.04.

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 spring 1993.

References

/1/ 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), 31-36

/2/ N. Kirch, H.U. Brinkmann, H. Nabielek
Bestrahlungserprobung von HTR-Komponenten. Stand und zukünftige Anforderungen
Proceedings of a Colloquium held in Petten, EUR 12522 (1989)

/3/ J. Ahlf, A. Gevers (editors)
Annual Report 1990. Operation of the High Flux Reactor EUR 13590 EN (1991)

/4/ R. Conrad
First results of the Proof Tests (HFR-K5/6) at the HFR Petten

Paper presented at the 2nd Soviet-German Seminar on Fuel and Graphite for the HTR, held at KFA on July 8-12, 1991

/5/ R. Conrad, R.D. Burnette, H. Nabielek, G. Pott
The release of fission products from uranium oxycarbide fuel in simulated HTGR elements during irradiation in the HFR Petten over a range of temperatures and periodic injections of water vapour.
Accepted for presentation at the Jahrestagung Kerntechnik, May 5-7, 1992

3.4. FUSION REACTOR MATERIAL IRRADIATIONS

Fusion is regarded as one of the promising long term energy options. Important efforts are ongoing worldwide to promote this option. Whereas the larger share of the resources is still spent on programmes to demonstrate the physical feasibility, it is meanwhile fully realized that it is essential to expand the effort on technology. The HFR plays a major role as test bed for fusion materials irradiations since a long time.

The different fusion related projects are incorporated into 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 of irradiation experiments 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

Project 139 (139-6 series)

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

Progress:
SIWAS (project 139-66)

This irradiation will accommodate NET construction material. 40 CT specimens, 10 tensile and 20 fatigue are currently under irradiation in core position E7, at reactor ambient temperature (about 360K). The required damage is 5 dpa. The experiment takes place in a REFA 170 and the specimens are in contact with reactor coolant water. Irradiation of 139-661 started in cycle 90.06 and terminated in cycle 91.07. The next series 139-662 started in 91.08 and it will be terminated in cycle 92.08.

Experiment 139-662 and 139-663 were irradiated in position E3 since a lower dpa of 0.3 was required. 139-662 and 663 were irradiated for 2 cycles respectively in 91.05 and 91.07. The capsule lay-out of the experiment is shown in **fig. 18**.

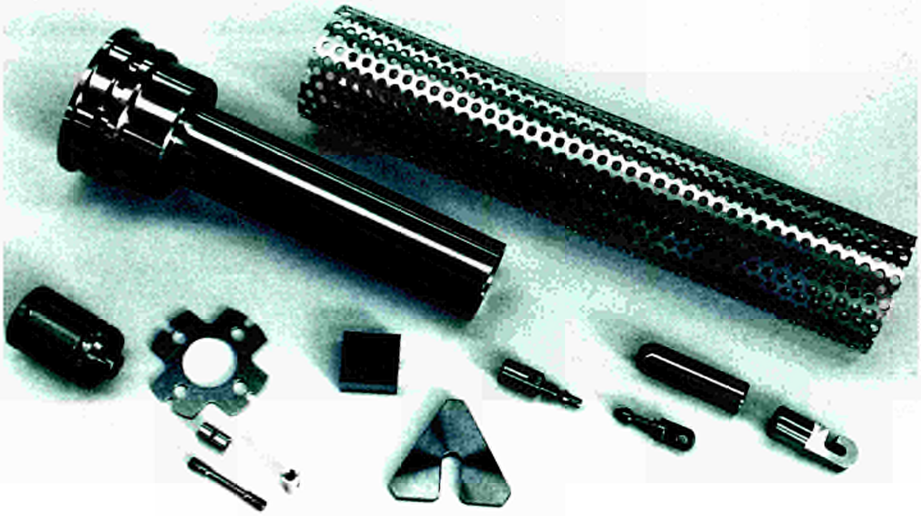

Fig. 18
Capsule lay-out of experiment 139-66

SINAS (project 139-69)

This experiment consists of 8 sample holders of NET construction material, with 10 CT specimens in each holder. The irradiation temperature is 525 K at different fluence levels (irradiation positions F8 and F2). Five legs are planned for 5 dpa and three legs for 0.3 dpa. Irradiation started in cycle 90.08 and it will be continued up to cycle 93.02 in position F8 and until end of 1993 in position F2. A typical temperature distribution during a reactor cycle is presented in **table 6**.

Projects 198-15/16 and 139-68 in SIENA

Objective:
The NET Team stressed in the year 1985 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 in the range 423K - 773K for stainless steel
- helium/dpa ratio as close as possible to 13 for austenitic steel (NET operating conditions) which can only be obtained in a special capsule designed for "spectrum tailoring".

The design was given the name SIENA, standing for Steel Irradiation in Enhanced Neutron Arrangement.
Parties involved in this irradiation are:
- JRC - IAM, Ispra: tensile samples (316L, AMCR, Cu and Cu-Cr-Zr)
- KfK - IMF, Karlsruhe: tensile and charpy samples (DIN 1-4914)

Table 6
Experiment 139-693. Typical statistical analysis of a temperature distribution in a reactor cycle (91.04)

CYCLE NO: 91-04 "D A C O S S Y S T E M" DATE: 09:57:23 11-JUN-91

ANALYSIS BY ENGINEERING UNITS FOR PERIOD FROM: 16:40:00 24-APR-91 TO 09:10:00 21-MAY-91

EXPERIMENT NO. : R139-693
NAME : SINAS
START DATE : 20-09-90
REACTOR LOCATION: F8
GAS PANEL USED : TRIO-D

NOMINAL DEGREES "C": 250.00
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	STANDARD ERROR	TOTAL RECORD	ANALYSIS OF DATA RECORDS (BY PERCENTAGE) REACTOR < 43.MW	NO DATA	< LOW LIMIT	> HIGH LIMIT	WITHIN LIMITS
215	TC10	Deg. C	253.02	221.96	261.65	4.228	0.073	3844	12.67	0.00	0.05	0.00	87.28
214	TC9	Deg. C	253.92	223.84	261.77	4.078	0.070	3844	12.67	0.00	0.03	0.00	87.30
213	TC8	Deg. C	250.32	226.97	255.64	2.949	0.051	3844	12.67	0.00	0.00	0.00	87.33
212	TC7	Deg. C	250.91	227.72	256.05	3.024	0.052	3844	12.67	0.00	0.00	0.00	87.33
211	TC6	Deg. C	246.19	224.65	249.83	1.927	0.033	3844	12.67	0.00	0.03	0.00	87.30
210	TC5	Deg. C	246.11	224.68	250.00	2.032	0.035	3844	12.67	0.00	0.03	0.00	87.30
209	TC4	Deg. C	251.86	228.27	260.84	2.218	0.038	3844	12.67	0.00	0.00	0.00	87.33
207	TC2	Deg. C	238.87	214.87	252.28	2.786	0.048	3844	12.67	0.00	0.13	0.00	87.20
206	TC1	Deg. C	240.91	216.92	254.08	2.873	0.050	3844	12.67	0.00	0.10	0.00	87.23

RELATIVE POSITIONAL GRAPHIC REPRESENTATION OF ABOVE ENGINEERING UNITS.

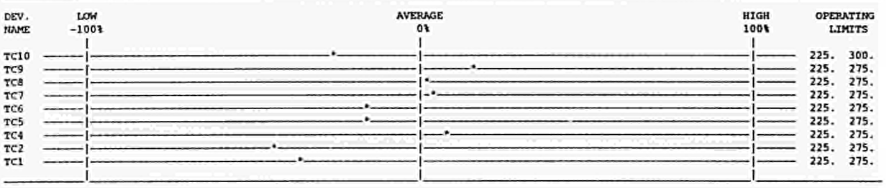

Table 7
Chemical composition of optimized Cr-Mn stainless steels presently irradiated in the SIENA capsule

	IF-BI	F-D
	(wt%)	
Fe	74.22	69.77
Cr	12.37	10.24
Mn	10.62	16.92
Ni	0.23	0.13
Mo	0.023	0.026
C	0.31	0.26
N	0.036	0.080
Si	0.17	0.50
V	0.64	0.032
W	1.38	2.04
	(ppm)	
S	70	30
P	140	80
Cu	290	240
Al	30	45
Nb	50	50
Ta	50	50
Pb	1	1
Co	200	200
B	3	3
Bi	1	0.5
Ag	1	1
Ti	10	20

- ECN, Petten: tensile and fatigue samples of 316 L and vanadium alloys

The duration of the first experiment (E198-14) was initially fixed to 35 dpa in stainless steel.
The targets of NET changed and the experiment was concluded at 15 dpa.
The device has therefore been used as "reloadable device" for all the other experiments described below.

Progress:
The irradiation of the SIENA capsule continued, as scheduled, in HFR position C5.

JRC - IAM experiments:
Two sample holders (nr. 15 and 17) belonging to the experiment E198-15, started in cycle 90.06, were unloaded at the end of cycle 91.03, having reached the scheduled damage of 10 dpa.
Details about the irradiation have been reported.
Samples will be shipped to Ispra at the beginning of 1992 for PIE. Some details of the dismantling are shown in the **figs. 19 and 20**.

The other sample holders (nr. 16 and 22) belonging to the experiment E198-15 were unloaded at the end of cycle 91.09, having reached the scheduled damage of 15 dpa, together with two sample holders (nr. 5 and 10) belonging to the experiment E198-16, which had reached the scheduled damage of 10 dpa. Dismantling of these sample holders has taken place in December 1991. Shipment to Ispra for PIE is foreseen in spring 1992. The remaining sample holders of E198-16 will continue irradiation until a total damage of 15 dpa. Materials presently irradiated are shown in **table 7**.

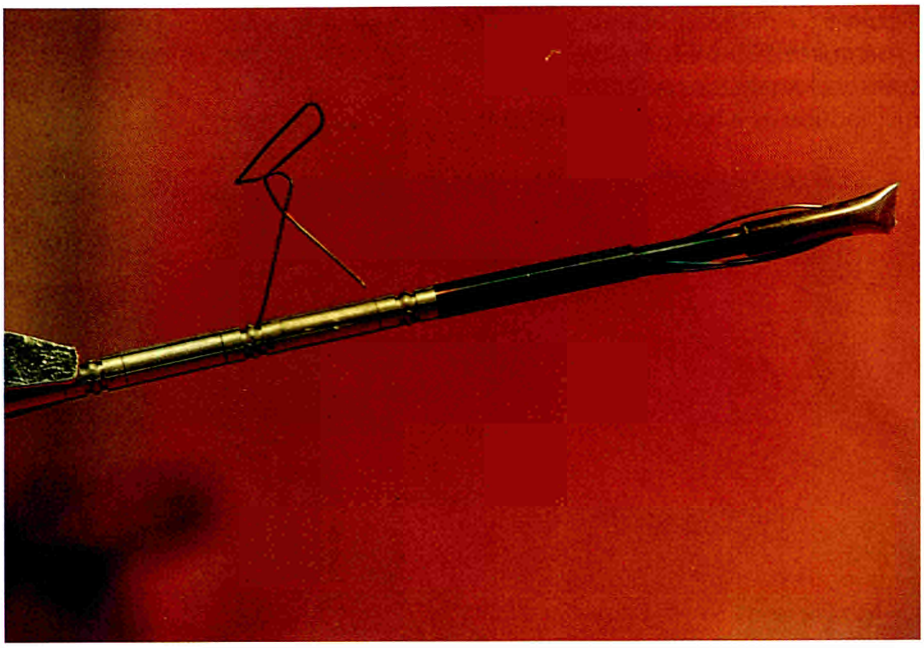

Fig. 19
Dismantling of a sample holder: extraction of thermocouples

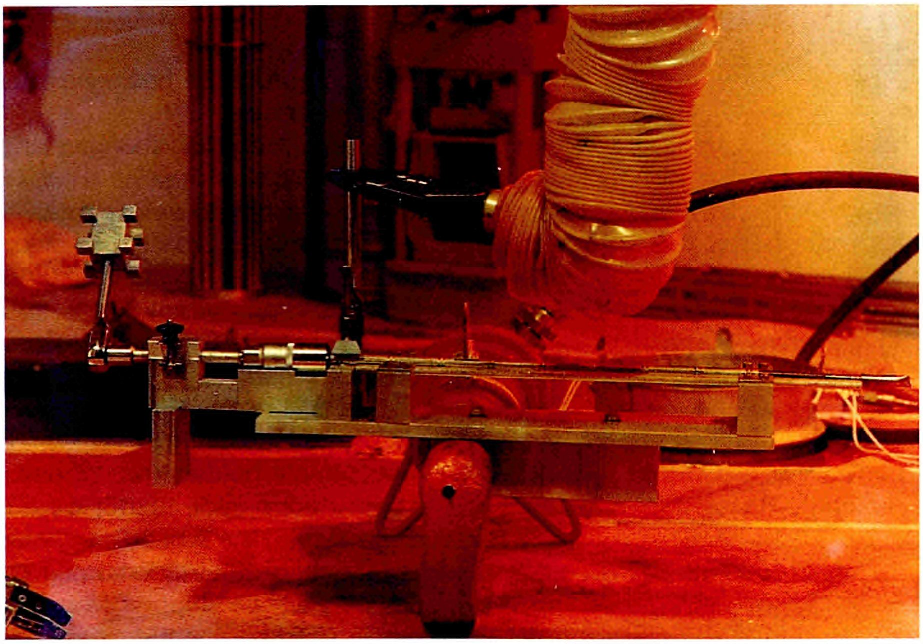

Fig. 20
Dismantling of a sample holder: recovery of the samples

ECN - experiments:
The experiment R139-68 (sample holders 2 and 4) have been unloaded at the end of cycle 91.03, having reached the scheduled damage of 5 dpa. Three new sample holders (R139-68/7,8 and 9) have been loaded in the capsule in cycle 91.11. They will be irradiated up to 0.6, 5 and 5 dpa respectively. Material irradiated is stainless steel 316L for tensile tests (see **table 8**).

An overview of the irradiation and testing programme has been presented in /1/.
The present occupation of the SIENA capsule is given in **table 9**.

Table 8
Chemical composition (wt%) of the European 316L reference heat ERHI and ERHII

	ERHI		ERHII	
	Specified	Measured	Specified	Measured
C	≤ 0.03	0.021	≤ 0.03	0.019
Cr	17/18	17.5	17/18	17.25
Ni	12/12.5	12.3	12/12.5	12.17
Mo	3.2/2.7	2.41	2.3/2.7	2.31
Mn	1.6/2.0	1.79	1.6/2.0	1.75
N	0.06/0.08	0.059	0.06/0.08	0.074
Si	≤ 0.5	0.43	≤ 0.5	0.35
Cu	< 1.0	0.21	< 0.3	0.07
Co	< 0.25	0.18	< 0.10	0.078
S	< 0.025	0.009	< 0.01	0.0006
P	< 0.035	0.029	< 0.035	0.019
Ta	< 0.15	0.05	< 0.15	0.002
B	< 0.0025	0.0023	< 0.0015	0.0009

Table 9
Present occupation of the SIENA capsule

Legend:
Sample Type: 1 = Tensile Samples; 2 = Charpy Samples; 3 = Fatigue
Sample Material: A = AISI 316L; B = 1.4914 Stainless Steel; C = AMCR; D = Vanadium Alloys

Channel nr.	Irrad. temp.(K)	dpa	Client	Sample material	Sample type	Sample holder	Irrad. start	Irrad. end
2	873	5	ECN	D	3	Zr	91.07	92.04
3	523	0.6	ECN	A	1	Al	91.11	91.11
4	973	5	ECN	D	3	Zr	91.07	92.04
7	523	15	JRC	C	1	Al	90.06	92.07
8	523	5	ECN	A	1	Al	91.11	92.07
12	523	5	ECN	A	1	Al	91.11	92.07
13	723	15	JRC	C	1	Cu	90.06	92.07
15	1073	5	ECN	D	3	Zr	91.07	92.04

Stainless steel irradiation for ENEA, SIRENA (project 250)

Objective:
In the frame of their programme for the material development and characterization of NET, the Italian organization ENEA (Comitato Nazionale per la Ricerca e lo Suiluppo dell' Energia Nucleare e delle Energie Alternative) is investigating the irradiation behaviour of stainless steel 316 L. The irradiation campaign consists of two irradiation series of the material at a temperature of 523K and at two different damage values (~0.15 and 2.5 dpa).
Tensile (ø 10, l=45 mm), charpy (27x3x4 mm) and CT (29x27x10 mm) specimens are irradiated **(fig. 21)**.

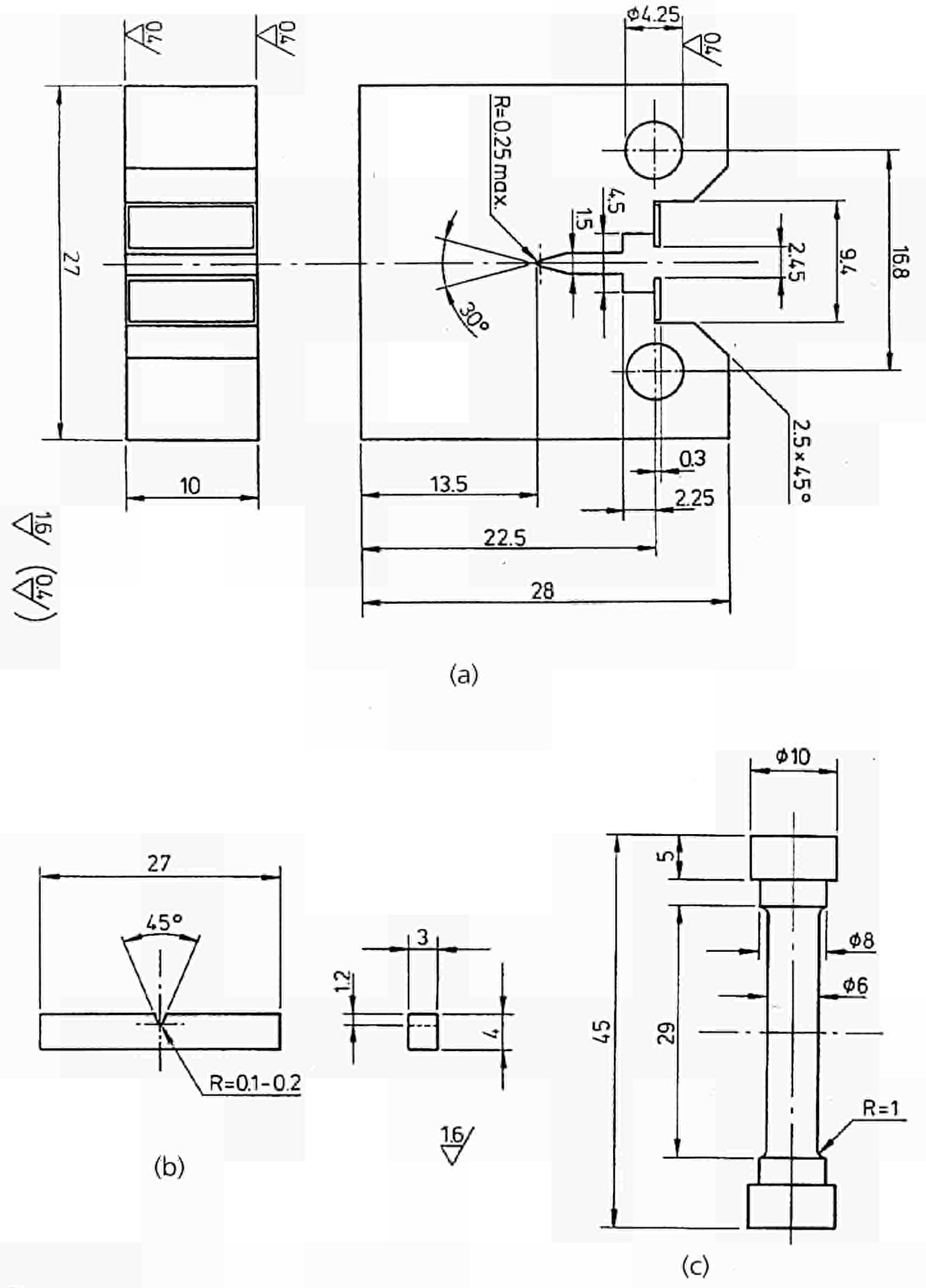

Fig. 21
Samples irradiated in the SIRENA experiment:
(a) CT sample;
(b) Charpy sample;
(c) Tensile sample

Progress:
During 1991 the two sample holders (one to be irradiated in position D2, the second in F2) have been designed, manufactured and assembled. Irradiation has started in cycle 91.10 for the first series and in cycle 91.11 for the second series.
Temperatures lie in the specified range.

Brazings irradiation, BRAIN (project 252)

Objective:
The Italian organization ENEA, beside its interest in irradiation effects on 316 L (see experiment SIRENA) is also investigating the irradiation behaviour of Ni-brazings on AISI 316L.

The irradiation campaign will consist of an irradiation of the materials at low temperature (353K) to a fluence corresponding to 0.7 dpa. Twenty eight tensile samples (ø 8, l=56 mm) will be irradiated.

Progress:
The sample holder was designed, manufactured and assembled in 1991. A partial view of the components during assembly is shown in **fig. 22**. Water flow is foreseen around it to allow the achievement of low temperatures.
Irradiation has started in cycle 91.10, in position F2 and will last for about 4 cycles.

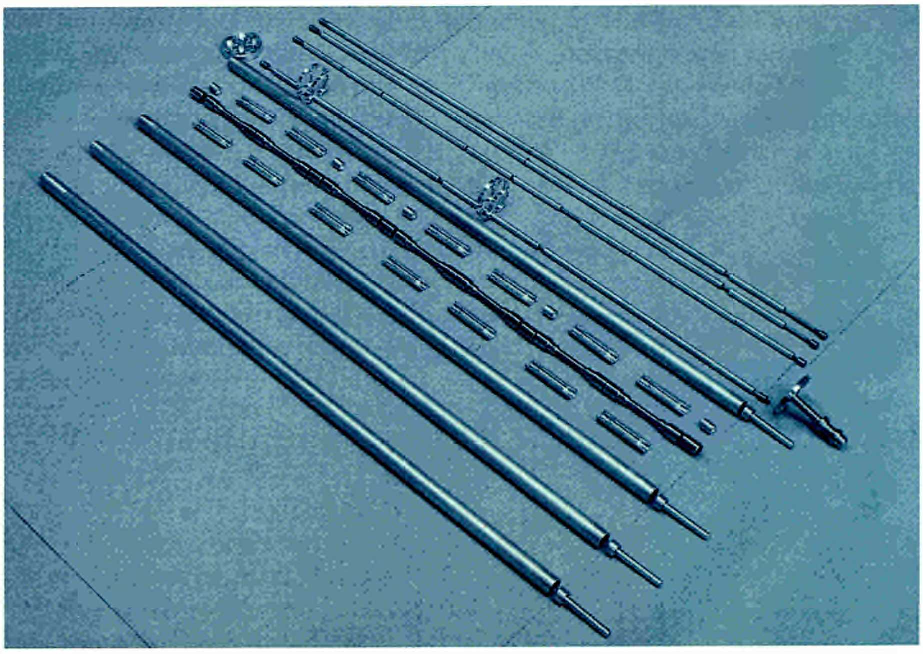

Fig. 22
View of components of BRAIN experiments before starting assembly

Creep Testing of Fusion Materials (Austenitic Stainless Steel)

Objective:
Different steels have been considered as candidate structural materials for the first wall of NET: austenitic stainless steels, manganese containing steels and nickel based steels. In order to study the effects of neutron irradiation on the creep behaviour of these materials, two irradiation creep facilities were developed for the HFR at Petten, namely TRIESTE and CRISP.

Progress:
Intermittent creep measurement (MAT-5), TRIESTE (project 167)

The entire experimental TRIESTE programme comprises eight 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 350 and 673 K) and the applied stresses (between 25 and 300 MPa) during the irradiation. Irradiation samples and half-shell pairs are manufactured from nine different materials (AMCR-0033, AMCR-0034, AMCR-0035, AISI 316L, AISI 316, DIN 7758, DIN 7761, DIN 7763, PCA).

The following activities were pursued during the reporting period:
- Irradiation continued in 1991. Experiments E167-66 and E167-29 were irradiated for four cycles, experiments E167-57 and E167-73 for three cycles and experiments E167-48 and E167-67 for two cycles.
- Elongation of the individual samples of the experiments E167-29, E167-48, E167-56, E167-66 and E167-73 were measured in hot-cells.
- Designated as E167-80 series, irradiation of stainless steel samples at low temperature (about 350K) started in cycle 91.05. After one cycle the elongation of the samples was measured. The samples were irradiated in another cycle in 1991 as E167-82. The irradiation E167-82 will continue for two more cycles, starting in cycle 92.01.

In-pile creep measurement (MAT-5), CRISP (project 157)

In the irradiation device CRISP the creep elongation of three specimens in three different rigs can be measured simultaneously. Strain measurements are taken semi-continuously by comparing the sample length with the length of an unstressed reference piece of the same material.

Project 157/11-13

The irradiation of a second set of three sample holders, started in cycle 90.07, finished in cycle 91.03.
The irradiation temperature was the same for the three legs (673K). The applied stresses were respectively 120 MPa, 100 MPa and 60 MPa.
The sample material was AISI 316L as received, AISI 316L 5% and 20% cold worked respectively. The strain measurement system has not properly worked in two legs for a part of the irradiation.

Project 157/14-16

The assembly of this third set of these sample holders is presently being carried out. Materials and irradiation conditions are the same as those of experiment 157/11-13. Irradiation start is planned for cycle 92.03, depending on decision of the sponsor.

Irradiation of superconducting materials, SUPRA (project 202)

Objective:
In these experiment series, sponsored by KfK, materials are being irradiated whose changes under irradiation give data on the performance of the coil in superconducting magnets of fusion reactors.

Progress:
Specimens of $YBa_2Cu_3O_7$ are irradiated on random basis. The maximum fluence reached has been 1.5×10^{22} n m^{-2} at 323K.

It is foreseen to irradiate specimens of the same material up to $1.5x10^{23}$ n m^{-2}.

Irradiation of vanadium alloys, VABONA (project 204)

Objective:
ECN is investigating the radiation damage of vanadium for fusion reactors and more specifically the assessment of the viability of boron doping of the vanadium samples prior to neutron irradiation as a means to simulate the effects of fusion reactor irradiation.

Progress:
The three experiments R204-7/8/9, launched in 1987 and delayed because the sponsor has had many difficulties in delivering the samples, have finally started irradiation in cycle 91.07 in the SIENA capsule in C5.
The three sample holders are being irradiated at the following temperatures: R204-7 : 873 K, R204-8 : 973 K, R204-9 : 1073 K.
Irradiation end is foreseen in cycle 92.04, when a damage of 5 dpa will be reached.
The materials irradiated are listed in **table 10**.

Table 10
Chemical composition of vanadium alloys

	series A	series B	series C	series D
	(wt%)			
Fe	7.	4.	–	–
Mn	–	–	3.6	–
Si	–	1.	1.	–
Ti	3.	–	–	20
Y	0.2	0.2	0.3	–
W	0.5	–	0.5	–
V	89.3	94.8	94.6	80.

Three other series of samples will also be irradiated:
- series A and B containing vanadium with a commercial purity of 99.9%
- series C containing vanadium with a high purity of 99.999%

Blanket Breeder Materials Irradiations

Three experimental programmes, namely EXOTIC, LIBRETTO and COMPLIMENT, are carried out in the HFR Petten and within the European Fusion Technology Programme on Blanket Breeder Technology. Both ceramic lithium compounds for the solid blanket concept and the eutectic alloy Pb-17Li for the water cooled liquid blanket concept, are being tested in these experimental programmes.

The main objectives of these irradiation tests are:
- study of tritium release kinetics by in-situ tritium release measurements in function of temperature, purge gas chemistry, tritium burn-up rate and lithium burn-up,

- irradiation damage studies,
- compatibility studies up to high Li burn-up,
- tritium permeation studies through reference cladding materials,
- study of tritium extraction methods,
- study of tritium permeation barriers.

The results of the Petten experiments will contribute to the selection of blanket breeder materials for DEMO relevant blanket concepts. The material selection is planned to be taken by the end of the 1992-1994 European Fusion Technology Programme. The HFR Petten activities on blanket breeder irradiations are summarized in **table 11**.

YEAR	1991	1992	1993	1994
1. EXOTIC experiments:				
EXOTIC-5	4 ▬	▬		
EXOTIC-6	2 ▬ 3 ▬	4 ▬	▬	
EXOTIC-7 (Option)		1 ▬ 2 ▬	3 ▬	4 ▬
2. LIBRETTO experiments:				
LIBRETTO-2	4 ▬			
LIBRETTO-3	2 ▬	3 ▬ 4 ▬	▬	
3. ELIMA experiment:				
D 237.01	4 ▬			
4. Out-of-pile facilities	5 ▬	▬	▬	▬

Table 11
Fusion blanket breeder experiments. Survey of present and future activities

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

Irradiation of ceramic lithium compounds, EXOTIC (project 212)

The experimental programme EXOTIC is being carried out since 1984 as a joint project by ECN Petten, NRL Springsfield, SCK/CEN Mol in co-operation with IAM Petten. The Fusion Technology Steering Committee (FTSC) decided to concentrate the European effort within the 1988-1992 European Fusion Technology Programme. Therefore, three other European laboratories, namely CEA Saclay, KfK Karlsruhe and ENEA Casaccia, joined the EXOTIC project in 1988. More insight is needed on mechanisms and kinetics of tritium release and on irradiation damage. Three categories of irradiation experiments were defined, namely "short-, medium-, and long-term" irradiations. All candidate ceramic tritium breeding materials should be tested in these tests. The "medium-term" experiments (EXOTIC-5/6 in the programme period) should be performed at the HFR Petten. "Medium-term" experiments are defined as those tests with a lithium burn-up of ~2%.

The EXOTIC programme comprises manufacture, characterization, irradiation and pre- and post-irradiation examination of the Li-compounds $LiA1O_2$, Li_2SiO_3, Li_4SiO_4, Li_2O, Li_2ZrO_3, $Li_6Zr_2O_7$ and Li_8ZrO_6 with a variety of specific characteristics. The present EXOTIC programme within the 1988-1992 European Fusion Technology Programme consists of six irradiation experiments. Five experiments were performed until 1990 in the HFR Petten /3,4,5,6/. PIE is presently being performed at the participating laboratories. The sixth experiment is currently being performed in the HFR. A seventh EXOTIC experiment within the next European Fusion Technology Programme (1992-1994) has been proposed. This experiment will be designed as a long-term experiment with a lithium burn-up of >20%. Feasibility calculations were performed, showing that required burn-ups can be achieved by increasing the 6Li enrichment above natural abundance.

EXOTIC-5 (project 212/17-20)

Objective:
- Comparison of tritium release characteristics and irradiation behaviour of eight different ceramic materials, tested in-pile in eight independently purged and controlled capsules,
- Determination of tritium release properties as a function of temperature, burn-up and purge gas chemistry,
- Selection of fabrication processes for ceramic materials to be tested in "long-term" irradiations.

Progress:
The irradiation was terminated in 1990 after 6 HFR cycles, i.e. 135.67 full power days. The influence of different operating conditions on tritium release kinetics was investigated by performing and analyzing ~500 temperature transients between 573 and 923 K at different ^6Li burn-up steps and with a variety of hydrogen concentrations (0.001 - 1%) in the high-purity helium purge gas. The irradiation data were compiled in /3,4,5/ and published at the 16th SOFT conference in London in 1990 /6/. PIE continued in 1991 at the Hot Cell laboratories of ECN.

The evaluation of tritium release data as obtained from EXOTIC type irradiation experiments with on-line tritium release measurements was presented at the Third International Specialists Workshop on Modelling Tritium Behaviour in Ceramic Fusion Blankets, June 11-12, 1991 /7/.

EXOTIC-6 (project 212/21-24)

Objective:
The EXOTIC-6 experiment is the second "medium-term" experiment. Two laboratories have withdrawn from the EXOTIC programme, namely

SCK/CEN and NRL. Eight different materials are irradiated in eight independently controlled capsules with on-line tritium release measurements /4/. The objectives are almost similar with EXOTIC-5, but with more emphasis on investigating the effects of purge gas chemistry on tritium release. The EXOTIC-6 experiment is provided with advanced techniques for temperature control (electrical heaters and two independent gas gaps) and in-situ tritium reduction beds, in order to reduce HTO traces in the purge into HT. The reductor material is zinc and operates at ~680 K. The reductor beds are located ~300 mm above centre-line core.

Progress:
Assembly and commissioning of the sample holders was terminated in 1991. The EXOTIC-6 experiment consists of four independent sample holders, each containing two independent capsules. The irradiation started successfully with cycle 91.05 in position H6. The irradiation, scheduled for six cycles, was completed in 1991. Typical performance data were: 148 full power days, 38% ^{6}Li and 2.9% lithium burn-up, 1.6x10^{25} m^{-2} (E>0.1 MeV) fast fluence. More than 1000 transients (either temperature or variation in purge gas composition) were performed to arrive at the targets mentioned above. The tritium production rate was changed by irradiating in different core positions at different thermal neutron fluence rates. The temperature transients were performed in the range between 573 and 923 K with positive and negative steps between 30 to 140 K. The effect of a temperature transient on the tritium release of two different Li_2ZrO_3 materials is shown in **fig. 23** for a positive temperature transient of 100 K and steady state tritium release (i.e. tritium production rate is equal to the tritium release rate) before and after the transient. The different microstructures of the materials (mainly T.D., grain size and grain size distribution) /4/ is obviously reflected in the time constants for tritium release. The

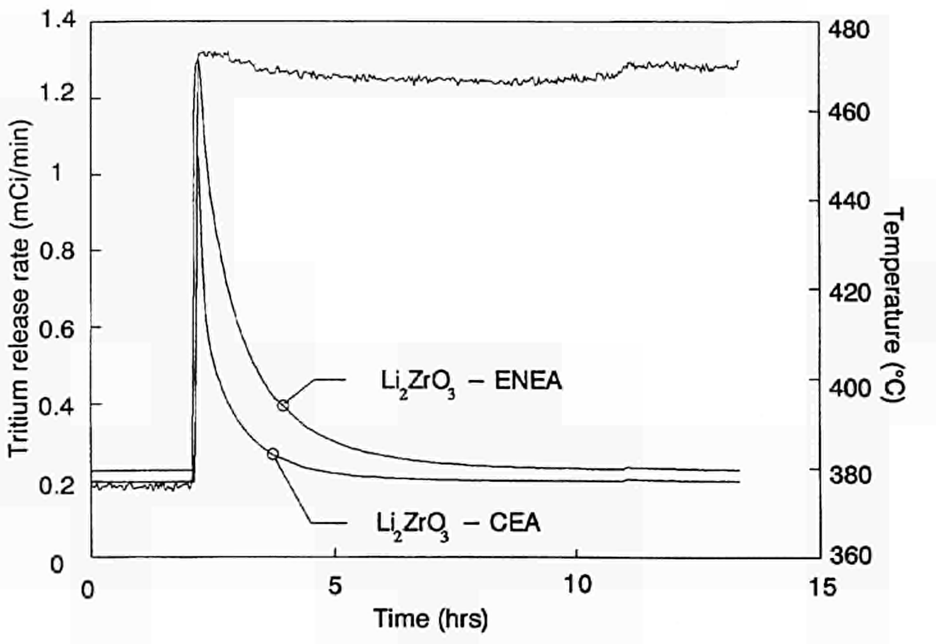

Fig. 23
Tritium release after a positive temperature transient for two Li_2ZrO_3 materials with different microstructure at identical operating conditions. Li_2ZrO_3 - CEA material is less dense and has a smaller grain size than the Li_2ZrO_3 - ENEA material

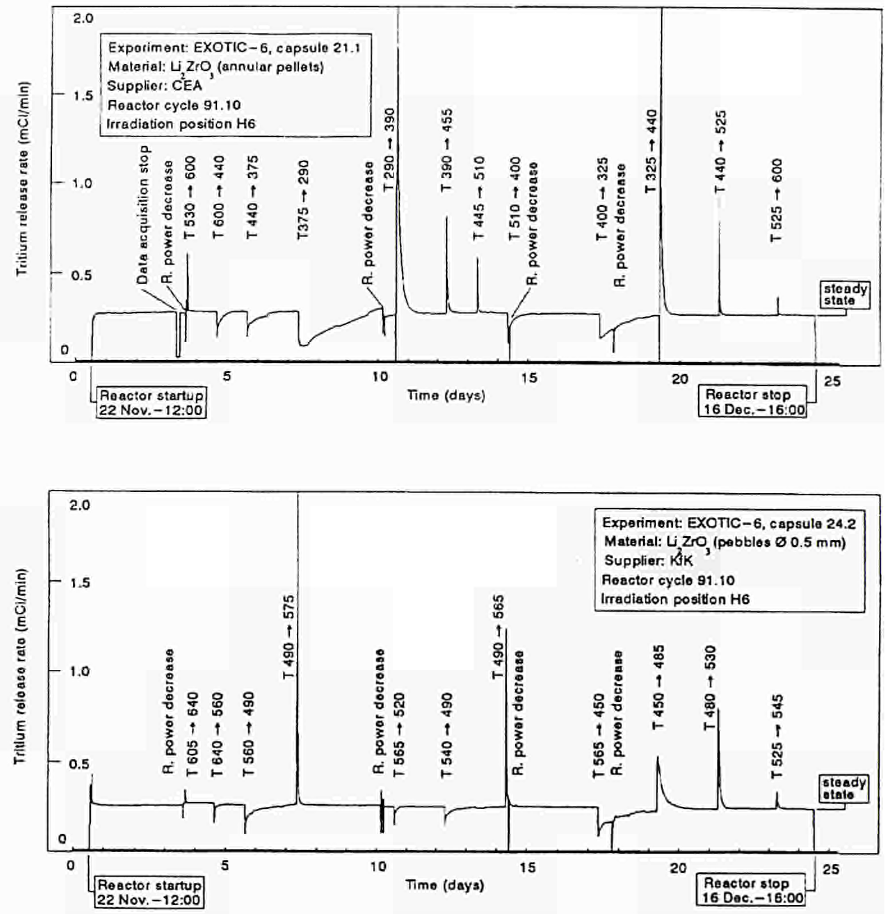

Fig. 24
Tritium release history of two EXOTIC-6 capsules for cycle 91.10, showing the effects of numerous temperature transients on tritium release

less dense material of CEA with the smaller grain size releases tritium faster under identical conditions. For the evaluation of the temperature transients computer codes, developed by IAM Petten /7/, are employed, where as a result the typical tritium residence times for different temperatures are plotted in Arrhenius plots for the different ceramic breeder materials. The tritium release kinetics of breeder materials are relevant characteristics, which can be followed in the EXOTIC experiments during the course of the irradiation. The "on-line" evaluation allows to plan the irradiation history in advance of a new cycle. The tritium release history of two capsules is shown in **fig. 24** for the sixth irradiation cycle. One capsule (21.1) contains Li_2ZrO_3 annular pellets and the other capsule contains Li_2ZrO_3 pebbles of 0.5 mm diameter. Steady state tritium release (production rate equals release rate) was achieved in both capsules throughout the cycle.
Capsule 24.2 contains material with a T.D. of 94% and a grain size distribution between 10-40 μm, whereas capsule 21.1 contains material with a T.D. of 74% and a uniform grain size distribution of 1 μm. These material characteristics reflect immediately on the tritium release behaviour during temperature transients. Capsule 21.1 shows significantly better release characteristics at low temperatures, 573 - 673 K. Irradiation performance was described in cycle reports.

Irradiation of ceramic lithium compounds under a fast neutron spectrum, COMPLIMENT (project 237-01)

The final irradiation report of the COMPLIMENT experiment /4/ (comparative irradiation programme to study irradiation damage effects through fast neutrons and through tritons and alpha recoil particles) was issued by Petten.

Irradiation of liquid blanket breeder material, Pb-17Li, LIBRETTO (project 224)

Objective:
The experimental programme LIBRETTO is being carried out as a joint programme between JRC Ispra and CEA Saclay in co-operation with IAM Petten. The programme consists of four irradiation experiments. The objectives of the LIBRETTO experiments are the in-pile testing of the eutectic alloy Pb-17Li in a mixed 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. The results of the LIBRETTO experiments are relevant for the design of liquid blanket breeder concepts for DEMO.

Progress:
LIBRETTO-1 and 2 (project 224/01-8)

The work for the first two experiments was completed in 1991 /5,8,9/.

LIBRETTO-3 (project 224/09-12)

Objective:
The LIBRETTO-3 experiment comprises four independent capsules filled with static Pb-17Li. The capsule wall material is AISI 316L. Three capsules will be coated by a tritium permeation barrier, either on the outside or on the inside of the capsule tube.
The main objective of this experiment is to study the tritium release and extraction from the alloy by either bubbling a high-purity purge gas directly through the alloy or by purging the outer surface of the closed capsules and measure the tritium permeation rates. These experiments will be performed in-pile with in-situ tritium release measurements, within a temperature range of 623 to 723 K and with varying hydrogen concen-trations in the purge gas.

Progress:
The design of the third LIBRETTO experiment /5/ was completed in 1990. The pre-assembly of the capsules with layers of permeation barrier material was delayed in 1990 for several reasons. The planned irradiation start in 1991 had to be delayed for reasons of double occupation of the out-of-pile installation with the EXOTIC-6 experiment (EXOTIC-6 was ready earlier than LIBRETTO-3; therefore LIBRETTO-3 had to be delayed until the end of EXOTIC-6). The irradiation of LIBRETTO-3 is planned for a duration of three cycles. The sample holders are being assembled and partially commissioned.

Development of irradiation facilities for fusion blanket materials, TMS

The up-grading of the Tritium Measuring Station (TMS) /10/ for the EXOTIC-6 and the LIBRETTO-3 experiments continued in 1991. This concerned mainly the extension of the gas supply system by a variety of high-purity purge gasses and the extension of the out-of-pile control cabinets by a control system for electrical in-pile heaters. The electrical in-pile heaters are necessary for high precision temperature control and post-cycle tritium inventory measurements, as well as for temperature control of in-pile reductor beds.

Irradiation of ceramic first wall and insulators material, CERAM (project 217)

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).

In the first wall of a nuclear fusion reactor, non-metallic materials are eligible for use as limiters and liners. These components require high heat resistance i.e. primarily a very high melting point and good resistance to thermal shocks. As the losses of radiation energy from the plasma rise substantially with the atomic number of plasma impurities, only materials with low atomic weights are admitted. Graphite and SiC are favoured materials.
All the other high melting compounds of light atoms exhibit serious drawbacks: borides because of high (n,α) helium generation under neutron irradiation, nitrides due to $^{14}N(n,p)^{14}C$ reactions and dissociation at elevated temperatures, oxides on account of their low thermal and low electric conductivities, the latter compounds being suspected of promoting arc discharges between the plasma and the wall.

The decision about whether graphite and SiC are actually suited can be made only after the crucial conditions in the fusion reactor and their impacts on the behaviour of the components have been taken into consideration. Primarily thermal loading has to be considered the consequences of which are influenced by neutron irradiation from the fusion plasma too.

Materials are selected on the basis of their stability against neutrons. They must keep their dimensional integrity, mechanical and thermal properties when irradiated with neutrons up to a fluence of $\geq 10^{26}$ neutrons/m^2. It is known that graphite with good behaviour against neutrons should be isotropic, have a high tensile strength, have a low thermal expansion coefficient, be well graphitized and have a good resistance to thermal shock. The selected materials are different types of graphite and SiC. Four kinds of fine grain graphites coated or not with SiC and two kinds of sintered SiC are irradiated. The material properties that will be examined in post irradiation tests are Young's modulus, tensile strength, linear expansion coefficient and thermal diffusivity.

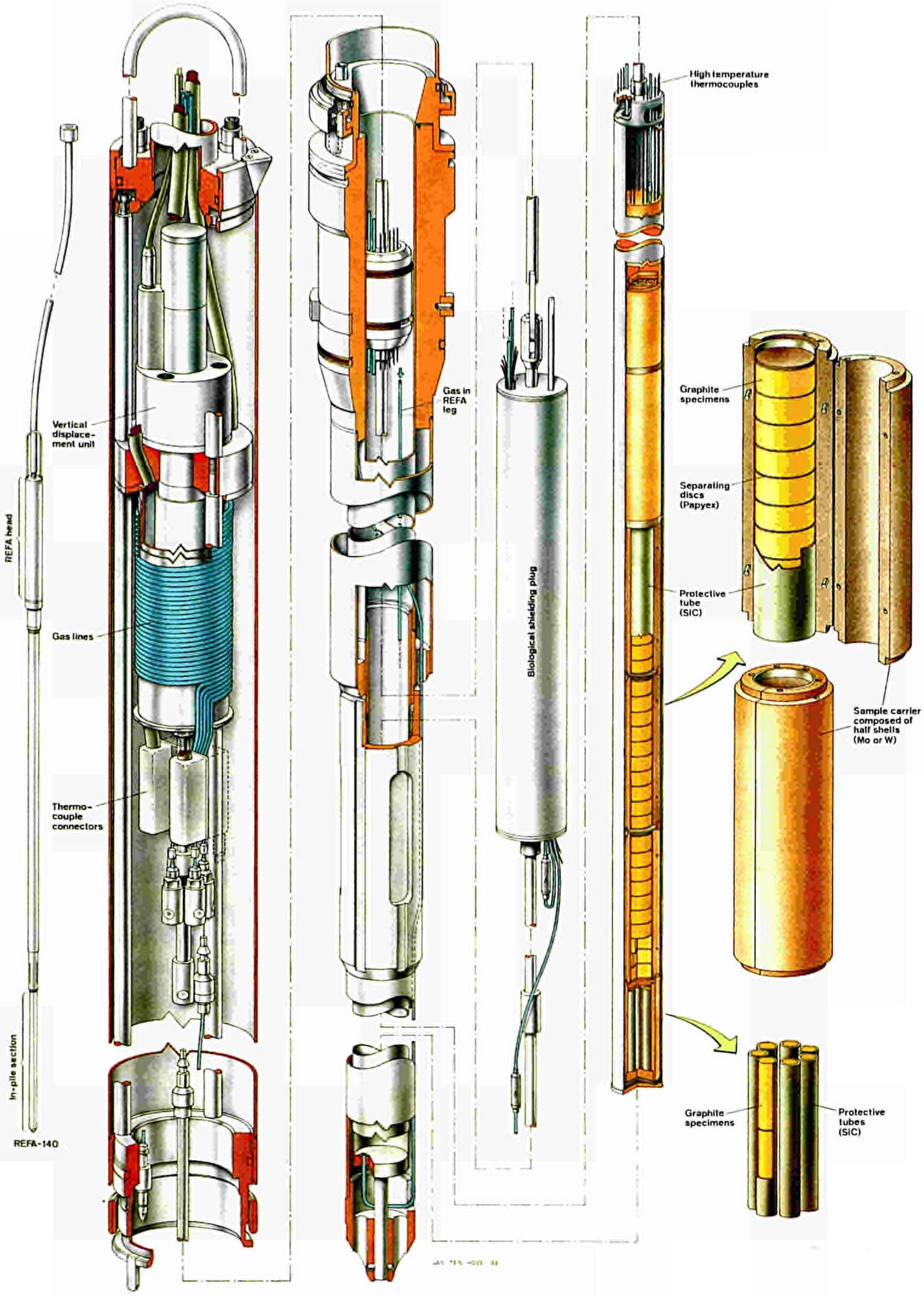

Fig. 25
Detailed loading arrangement of experiment 217-16

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 and the target dose 3 dpa. The materials are different types of SiC and carbonite materials.

Progress:
Holder 14 was transported to KfK at the first quarter of 1990. Sample holder 15 was transported to CEA Saclay at the first half of 1991. Dismantling of sample holder 16 will finish in the first quarter of 1992. An arrangement of the irradiation device is shown in **fig. 25**. It is seen that the sample holder was made with molybdenum half shells to facilitate the dismantling.

Legs 17-18-19

Objective:
This experiment is a continuation of the previous series of experiments. Irradiation temperature is 1473 K and the target dose 5 dpa.

Progress:
Manufacturing of the sample holders is finished. Assembly of this experiment was delayed due to difficulties in manufacturing of the specimens. It will start at the beginning of 1992.

Leg 20

Objective:
Within the scope of the European Fusion Technology Programme, KfK/IMFI is investigating various ceramic insulator materials for the construction of millimeter- wave windows in plasma heating systems. The materials under irradiation are Al_2O_3, $MgAl_2O_4$ and MgO. The required fluence is $3x10^{25}$ n/m^2 (E>0.1 MeV) at relatively low irradiation temperatures, 353 K.

Progress:
Irradiation of the experiment started in cycle 90.10 and it will continue up to cycle 92.07.

First wall coating graphite irradiations, GRIPS (project 241)

Objective:
The aim of the experiment is to investigate the irradiation behaviour of several types of nuclear graphites (fine grained, superfine grained, oriented pyrolytic) which are potential candidates for the first wall protection in NET. The 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.

Progress:
The irradiation campaign ended in March 1991. Ten sample holders were irradiated in total at five neutron fluence values (E>0.1 MeV) in the range 10^{20} - 10^{24} n m^{-2} and two temperatures : 673 K and 873 K.
All the samples have been sent back to the sponsor who is busy with PIE.

Divertor materials irradiations, NEMESIS (project 245)

Objective:
KFA Jülich is investigating the irradiation behaviour of molybdenum and molybdenum alloys, candidates for the divertor component of NET. The divertor of a fusion reactor has the following functions: extraction of impurities and thermal energy from the plasma and protection of the first wall against heat and particle flux. Materials with high atomic number like molybdenum are candidates for this last function.
The experiment NEMESIS consists of two irradiation series (0.2, 1 dpa) at three temperatures (353 K, 673 K, 973 K). Specimens irradiated are 3 points load (2x2x50 mm) and charpy (6x6x44 mm).

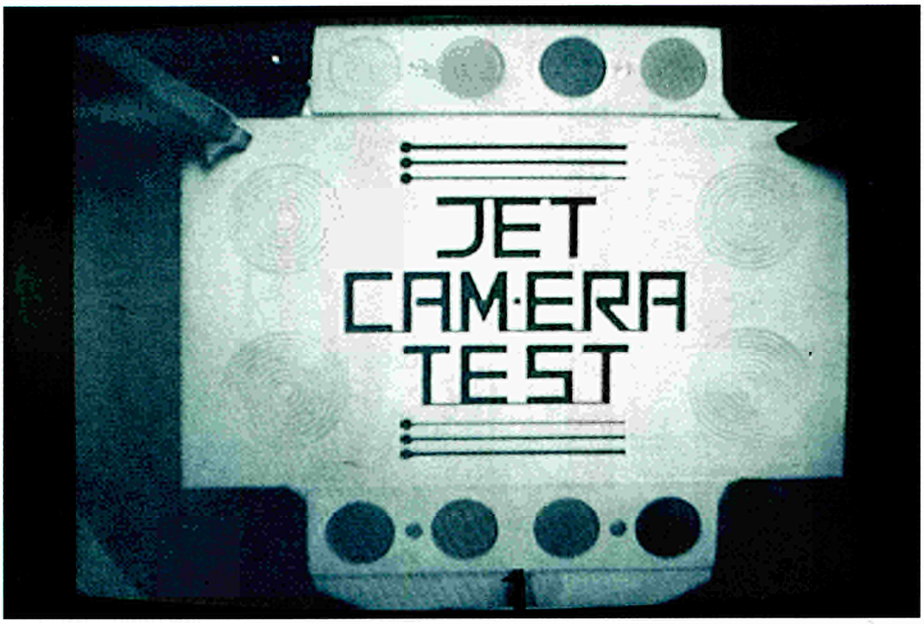

Fig. 26
JETI experiment: camera view at irradiation start

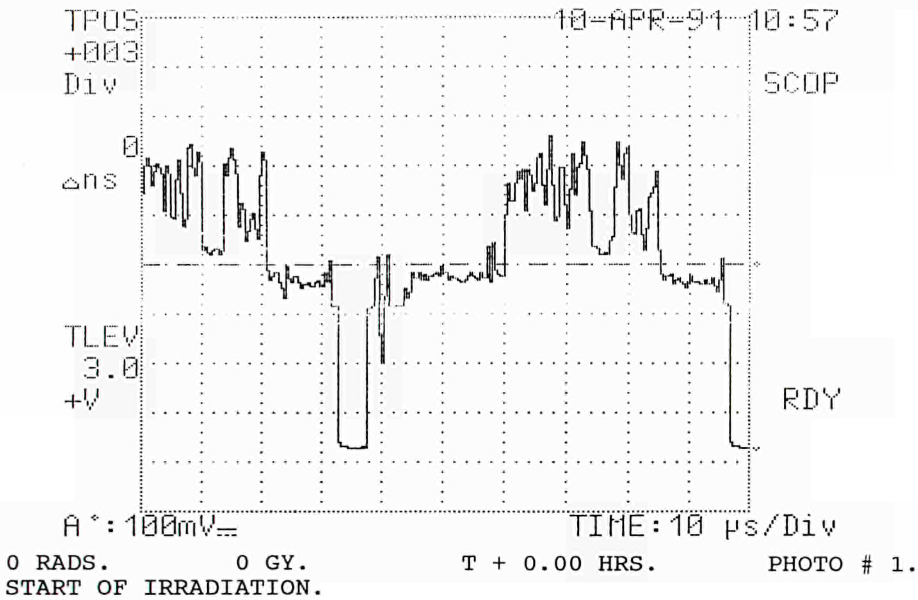

Fig. 27
Oscilloscope signal of the picture shown in fig. 26

Progress:
The irradiation campaign was conducted as scheduled. The first irradiation series started in cycle 90.11 and ended in cycle 91.01. Sample holders were dismantled at the end of May and the samples were shipped to the client in June for PIE. The second irradiation series started in cycle 91.02 and ended in cycle 91.07. All the samples have been recovered and will be shipped to KFA in January 1992.

Irradiation of cameras, JETI (project 246)

Objective:
JET (Joint European Torus) makes use of the cameras to record possible damage of the torus first wall after operational periods of the machine: the cameras are operating under gamma irradiation. Aim of the experiment was to establish the total dose tolerance of the cameras at a dose rate of about 2 Gy/h.

Progress:
The irradiation rig was ready at the beginning of 1991. The irradiation campaign (3 different cameras were irradiated) was performed in the period March - July. The rig was put near the spent fuel storage racks where the required gamma field could be provided. A view of the image recorded during irradiation is shown in **figs. 26 and 27**.

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/9/ R. Conrad, L. Debarberis
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3.5. RADIONUCLIDE PRODUCTION

Radioisotopes for Medical and Industrial Use

In 1991 there has been a continuation of the increase in radioisotope production recorded in 1990.

The radioisotope production is indeed the most important source of third party income for the Institute, and it is a contribution to the improvement of quality of life because of the wide range of applications in the biomedical field, for which more than 70% of the radionuclide production is destined.
The devices HIFI (144), HFPIF (008) and RIF (90) are suitable for the general production. More than 60 capsules per cycle have been irradiated during 1991. Radionuclides routinely produced have been Ir^{192}, P^{32}, Y^{90}, Sr^{89}, Pd^{103}, I^{125} etc.
Medical applications have been described in /1/. In general we recall here that the products are used both for diagnostic (radiography, pulmonary perfusion, measurement of local blood flow etc.) and therapeutic use (treatment of malignant tumours, pain-killer etc.)

Irradiation of fissile targets, FIT (project 136)

Objective:
The objective of these irradiations is the recovery of Mo^{99} from irradiated fissile targets for the manufacture of Tc^{99m} generators and other products (Xe^{133}, I^{131}).
Tc^{99m} is widely used in medical applications for scintigraphy, angiocardiography, organs imaging etc.

Progress:
The production in 1991 continued routinely. After each irradiation the targets are sent to the production plant. A new device is being designed to reach higher fluence rate values.

Medical use of molybdenum, MEDUSE (project 261)

Objective:
The objective of this experiment is the same as described for the 136 experiment, but a modified irradiation device is used.

Progress:
The rig was designed and manufactured in spring 1991 and the irradiation campaign was performed in May/June 1991. Both low enriched targets and high enriched targets in form of plates were irradiated. At the end of each irradiation the plates were sent to the client for reprocessing.

Irradiation of cobalt, COBI/CORRI (projects 197/203)

Objective:
Irradiation of cobalt for use in sterilization plants. Specific activity requested: 1500 - 3000 GBq per gram.

Progress:
The production of cobalt in form of strips ended in July 1991 (cycle 91.07). It is foreseen to irradiate in the future cobalt in form of pellets.

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3.6. ACTIVATION ANALYSIS

Devices used for general radioisotope production are also used to irradiate various kinds of materials used for scientific applications. Activation analysis is used in the archeologic field, in geology (rare earth, sedimentary studies), in forensic applications and in environmental studies (atmosphere particles, aerosols, toxicology). In 1991 irradiations for the British Universities continued (age determination of rocks, mineral composition etc.). A series of irradiations were carried out for the JRC Institute for Environment. They were concerned with the examination of human and animal tissues, and other biological materials /1/. Activation analysis of small samples of stainless steel, nickel, chromium etc. took also place in the standard radioisotope devices (HIFI, RIF, HFPIF).

Activation analysis of industrial silicon samples, SIP (project 220)

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 inch 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:
During the period under review 19 containers have been irradiated. Since the installation of this facility 171 irradiations have been carried out, corresponding to a total irradiation time of 12073 hours.

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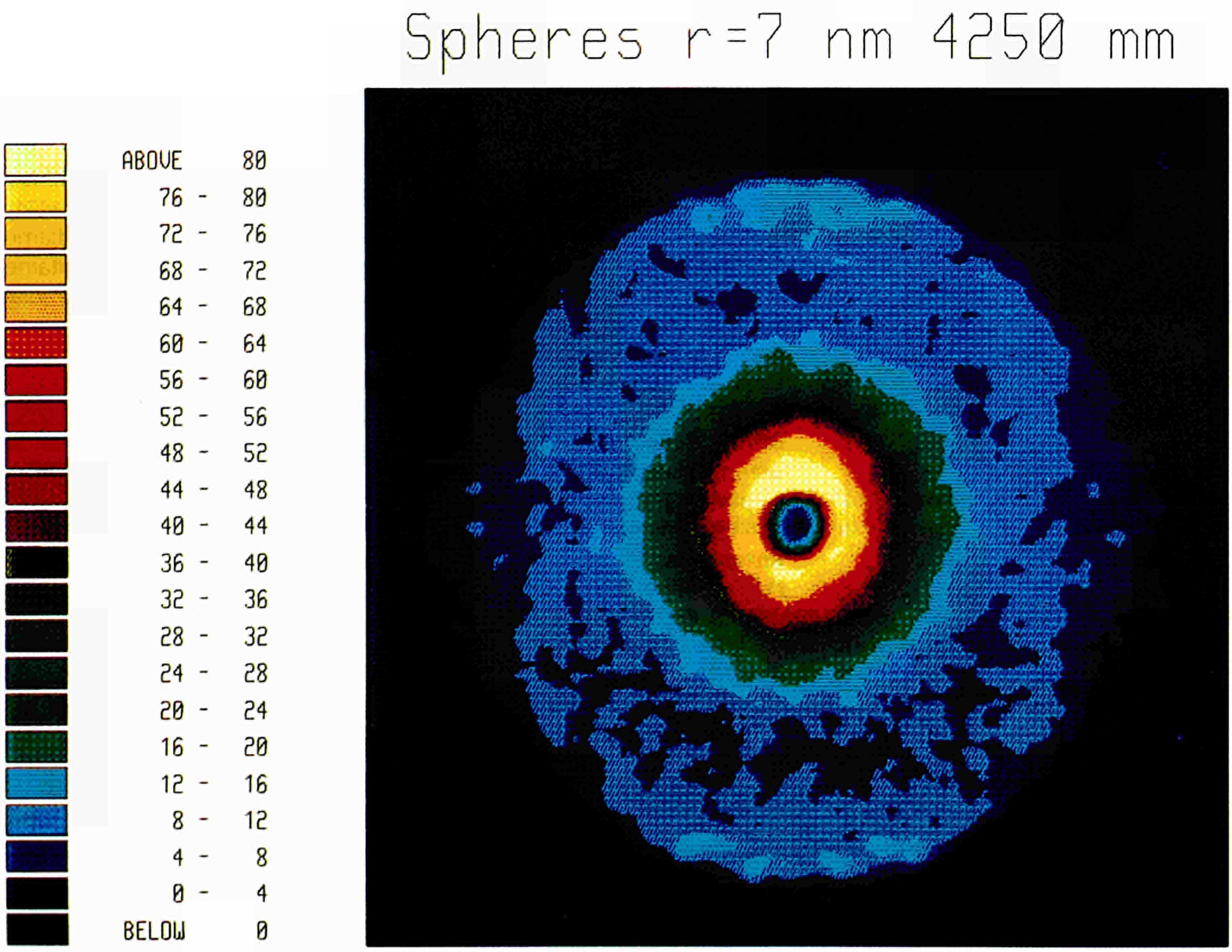
Application of radiotracers with high specific radioactivity to metallotoxicological studies
2nd International Conference on Methods and Applications of Radioanalytical Chemistry, Kona, Hawaii, April 21-27, 1991

3.7. SOLID STATE PHYSICS AND MATERIALS SCIENCE

The 6 neutron scattering facilities at the horizontal beam holes of the HFR are operated by the Solid State Physics Group of the Service Unit Materials of ECN. Research carried out is in the field of Solid State Physics, Chemistry and Materials Science and it is both of fundamental and applied character. It comprises the determination of crystallographic and magnetic structures of both powdered and mono-crystalline specimens, the study of atomic and magnetic short-range correlations, dynamic studies using neutron inelastic scattering. Small-Angle Neutron Scattering (SANS) was used for investigating micro-structural properties in steel, ceramics, polymers and the behaviour of colloidal suspensions **(fig. 28)**.

The facility for residual stress measurement became fully operational, and specially in this field the contacts and co-operation between ECN and IAM have largely grown a.o. in the frame of PISC and ACC, but also internationally in co-operative research in the BRITE-project. Combination of stress and texture measurements have been used in further developing the method for determining the mutual dependence of stress and texture.



3.8. BORON NEUTRON CAPTURE THERAPY (BNCT)

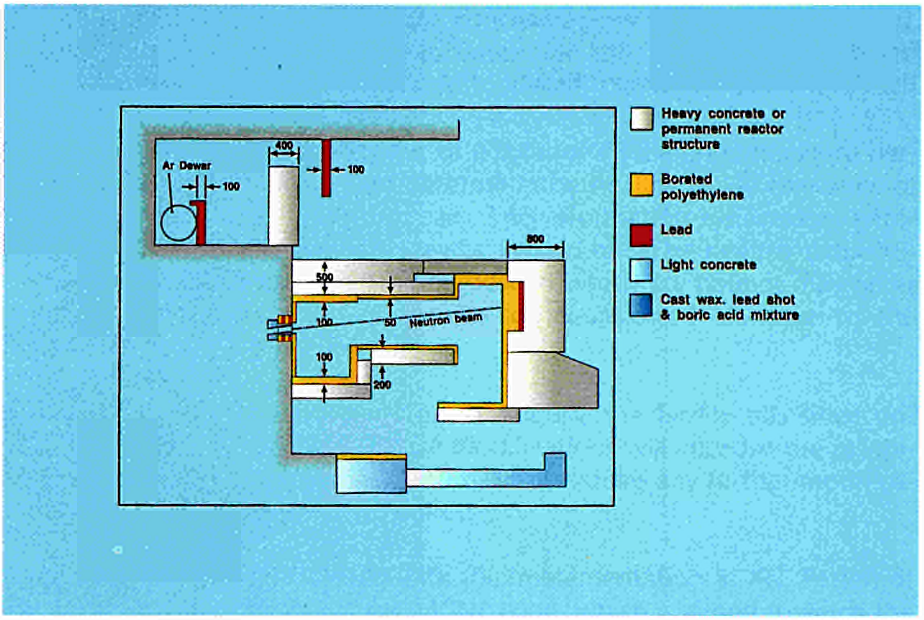


Fig. 29
Cross-section through the current, experimental room for BNCT studies at HB11

Fig. 28
Legend: Small-Angle Neutron Scattering (SANS) is a technique used for characterizing sizes (size distributions) and shapes of inhomogeneities in materials and in some cases their mutual interactions. The accessible size range for the ECN SANS facility is roughly 1 - 100 nm. The kinds of inhomogeneities studied, range from pores in ceramics or precipitates in steels to colloidal particles in solution, to mention only a few. The illustration shows the intensity distribution on the two-dimensional detector of the ECN SANS instrument scattered from a 2% dispersion of spherical silica particles in cyclohexane. The average radius of the particles is about 7 nm. The two-dimensional detector also allows for the observation of scattering from a non-isotropic medium such as a lamellar system.

As reported previously, BNCT is the utilization within a cancer cell of 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, i.e. 10 $B(n,\alpha)^7Li$. The emitted irradiation destroys those cancer cells in which the boron capture event takes place. To achieve this phenomenon, one needs a suitable, preferentially tumour-seeking boron compound and a high flux of thermal neutrons at the tumour site. For this latter reason and others, the beam tube HB11 was designated a suitable facility for developing a neutron beam with the appropriate characteristics. The current set-up of the irradiation room is shown in **fig. 29**. This is sufficient for the planned experimental programme before the facility will be extended to a patient treatment room, see **fig. 30**.
In the early part of 1991, it was necessary due to stringent reactor safety requirements to modify certain components of the facility that are potential sources of unacceptably high background radiation. Also many safety valves, for example, and other technical components had to be duplicated before the reactor safety committee was satisfied that the facility could be operated in a safe manner. It was finally possible therefore to open the facility for the first time at full reactor power in July.
During the period in June/July nuclear measurements were performed to determine the neutron and gamma properties of the beam. Measurements were carried out at low reactor power using proton recoil spectrometry techniques in collaboration with colleagues from AEA Harwell UK, and at full reactor power using activation foil sets and thermoluminescence detectors, in collaboration with colleagues from INEL, Idaho, USA and ECN Petten. The results of the measurements determined the flux rates and spectra of the neutron and gamma fields of the beam, both in free air and in polyethylene phantoms.
The results were compared with calculations performed at JRC Petten, using the MCNP code, and JRC Ispra, using the DORT code. Both sets of calculations agreed within acceptable limits. However, both over-predic-

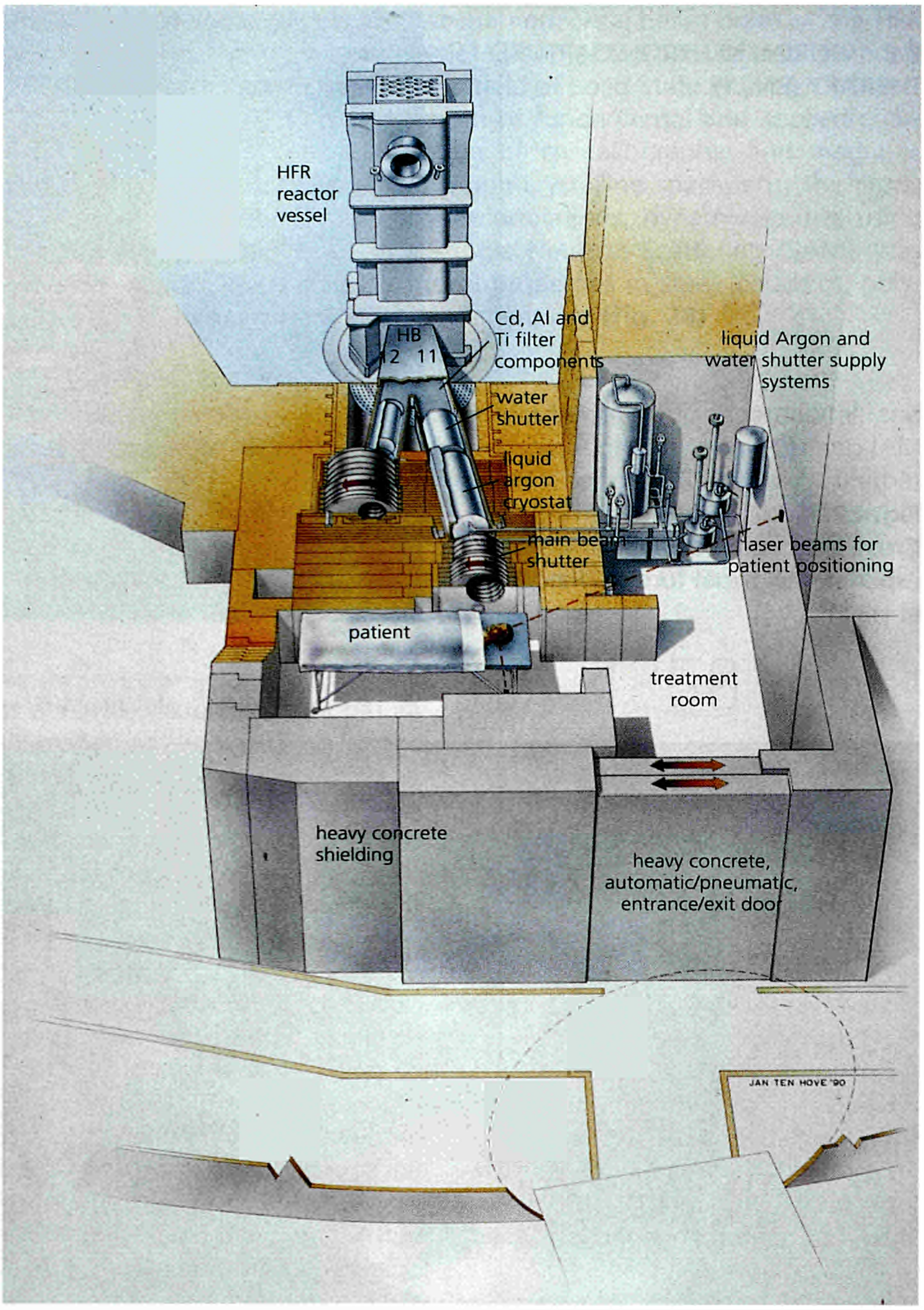


Fig. 30
The Petten BNCT treatment facility

ted the results found in the measurements. This was later found to be due to inadvertently, both at Petten and Ispra, not taking into account the relatively high thermal neutron capture property of ^{36}Ar that is present to only 0.34% in natural argon. The argon, in a liquified state is one of the major filter components in the beam tube. Following revised calculations, both sets of results agreed with measurements.

With agreement reached, it was then possible to perform some initial radiobiology experiments at the open beam. Cell culture irradiations were performed in tissue equivalent phantoms. Cells at different depths in the phantom and containing different concentrations of boron were used. The aim of these experiments is to determine the "killing" effect of the beam as a function of boron and depth.

The first 2 canine experiments out of a total of 45 experiments were performed. The experiments are to determine the healthy tissue tolerance of the canine brain to the neutron beam. This information is necessary before treatment of glioma patients may be carried out. The healthy tissue tolerance study determines the limiting dose at which the patient may be irradiated without causing any physical or neurological damage to the healthy brain.

Following the reactor summer stop in August, the facility has since undergone major modifications. These modifications will improve the reliability and operation of the system, and will not require any further modifications when patient treatments begin.

Computer modelling continued with the implementation at JRC Petten of the latest available version of the MCNP code, which is aimed towards the development of a treatment planning code that will be used by the radiotherapists at the hospitals where the patients will be pre-treated prior to BNCT. The code will be verified by comparison of results from phantom experiments.

The progress of the project depends strongly on collaboration with European partners belonging to the Concerted Action on BNCT, ref /1/, and on obtaining additional funding from appropriate research sources. In comparison with similar projects worldwide, the Petten BNCT facility will be the first such facility in Europe and remains as the first such facility in the world that could treat cancer patients with epithermal neutrons. The Petten work has been reported at several International Workshops during the year /2-10/, including a meeting organized at Petten, with over 100 participants.

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"Healthy Tissue Tolerance Studies for BNCT at the High Flux Reactor in Petten - First Results", in: Proceedings of an International Workshop "Towards Clinical Trials of Glioma with BNCT", Petten, Plenum Press, New York, 1991

/4/ C.P.J. Raaijmakers, M.W. Konijnenberg, B.J. Mijnheer,
L. Dewit, R.L. Moss, and F. Stecher-Rasmussen
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/7/ P.R.D. Watkins
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/8/ G. Constantine
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3.9. NEUTRON RADIOGRAPHY

Objective:

Neutron radiography is a non-destructive inspection and testing technique capable of producing images of components, assemblies and materials, on film or real time devices. In comparison to X- and gamma- rays, neutrons penetrate heavy metals like steel, lead and uranium much more easily, whilst at the same time having the unique capability to image light materials such as hydrogen bearing materials. The joint ECN & JRC service called the "Petten Neutron Radiography Services" serves with an HFR underwater camera, the HFR HB8 beam tube based neutron radiography system with filtered neutrons and the LFR based thermal neutron radiography system, with its real time imaging system at the HFR HB8 facility and its image analysis devices the following tasks:

- Promotion and provision of neutron radiographic services and support of EC research and industry /1, 2/ and
- support of HFR irradiation projects with non-destructive inspection capability.

Progress:

The HB8 beam tube NR facility

- Image taking for the first phase of a research contract on the application of neutron radiography to space components technology was completed. The results have been discussed with the client and yielded that neutron radiography could be employed as a better or complementary non-destructive testing method in this field. A joint publication with the customer of some results is scheduled for the World Conference on Neutron Radiography to be held in May 1992.
- Several inspections were performed as a service to industry and research, including proof testing for new potential clients. These inspections related to the following areas:
  - high-tech ceramics,
  - composite structures,
  - determination of H_2 impurities in Zry cladding tubes for LWR's,
  - corrosion detection in aluminium structures from aircrafts,
  - check of bonding joints on steel structures for aircraft industry,
  - check of mechanical devices for space craft and satellites,
  - aircraft fuselage structures.
- Preparations for a multi-client project on the systematic investigation of various types of corrosion in aircraft structures were started.
- The capabilities of neutron radiography were displayed and presented at a joint ECN/GAMMASTER/IRI/JRC/RTD seminar for the Dutch industry held in February 1991 at Petten on "Straling en produktverbetering" /2/.

HFR underwater NR camera

- Routine neutron radiographic inspections as a service to irradiation experiments have been performed following the requirements of the various HFR irradiation programmes.

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Compilation of the HFR Petten contributions to the Third World Conference on Neutron Radiography and the SITEF symposium 1989 - EUR 12727 EN, 1990

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Niet-destructief onderzoek (NDO) met behulp van straling, Materialen, 1991, Nr. 2 pages 19 to 23 and symposium in Febr. 1991 at Petten on "Straling en produktverbetering"

3.10. NEUTRON TRANSMUTATION DOPING OF SILICON CRYSTALS

Objective:
Thermal neutrons are used for neutron transmutation doping (NTD) of silicon crystals in order to provide them with the semiconductor characteristics. About 20% of the silicon used for semiconductors/chips needs to be treated with neutrons. This is due to the high requirements of uniformity in doping required for their future use in high power electronics.

Most research reactors provide doping services to industry. HFR offers at present with the SIDO-facility an experimental NTD device and could serve the market with a new 20 t/y PSF-based NTD facility, SINET.

Progress:
R&D and operation of SIDO:
- Doping trials have been performed for various interested NTD customers using 3 and 4 inch outer diameter crystals of up to 500 mm length. These trials confirmed the SIDO characteristics and its capability for precise doping.

Feasibility of HFR for NTD services:
- Technically, HFR could provide NTD services for silicon crystals ranging between 2 and 6 inch outer diameter. A production system with an annual throughput of approx. 20 t based on 4 inch crystals and a final resistance of 60 Ohm cm could be accommodated.

Market situation:
- A market study performed in 1990 yielded that the world market for NTD silicon is not yet saturated and that a new NTD facility would have good chances to be successful.
- Contacts with European and international industry have been established in order to explore needs and to get commitments for future utilization of NTD services from HFR.

Design study for a NTD facility, SINET:
- A design study for a PSF-based NTD facility, SINET was initiated. At the end of the reference period the basic lay-out of the SINET system has been completed.

4. GENERAL ACTIVITIES

This chapter concerns services supporting a number of projects and 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
- technical support to the running irradiation programme.

4.1. ASSEMBLY LABORATORY

During the reporting period 35 in-pile and 2 PSF experiments were assembled in the assembly room or by external firms.

4.2. STANDARD IRRADIATION DEVICES

The following standard in-core capsules, instrumented heads and PSF devices were manufactured internally or by external firms.
- 2 LWR-capsules
- 1 PSF-support
- 1 LIBRETTO-head
- 1 TRIESTE-head
- 3 TRIESTE-carriers
- 1 TRIESTE-capsule
- 1 REFA-170 capsule
- 1 RELIEF-head

New orders were placed for the following devices.
- 3 TRIO instrumentation heads
- 3 TRIO-129 capsules
- 1 TRIO-29/31/29 capsule

4.3. QUALITY CONTROL

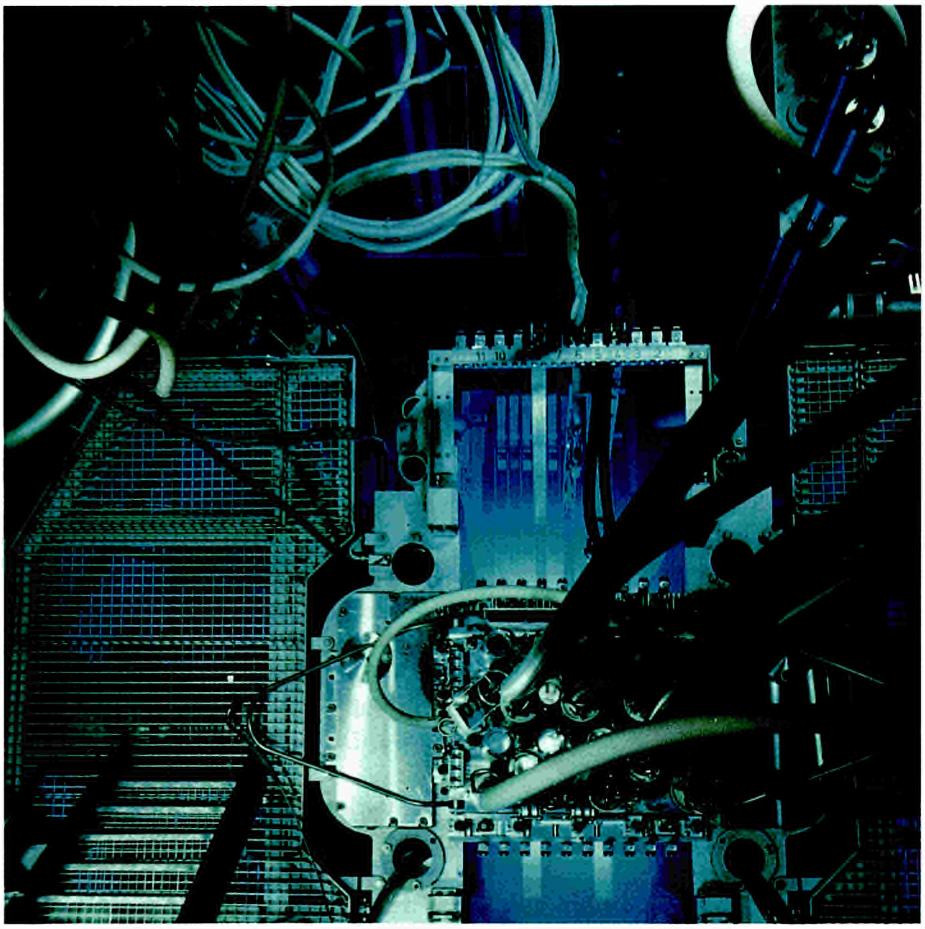
During the reporting period the Quality Control and Assurance group issued 40 reports with the following items:
- 38 Sample holders
- 4 In-core capsules
- 2 Instrumentation-heads
- 2 PSF-carriers
- 6 Dummy experiments

A wide range of Q.C. Calibers were ordered and are now in operation for the Dimension-checks such as irradiation-channels, in-core-sections of sample holders, biological-shieldplugs, in-core-sections of irradiation rigs.
The sodium-filling station has been moved from the former ECN-side of the Technologyhall to a special controlled laboratory. This station is modified for Na and NaK-filling and technically up-dated to the latest safety regulations. Handling procedures have been written for Sodium and Sodium/Potassium filling of experiments. The licence to operate this Liquid Metal filling station has been received.
New measurement equipment to control inner- and outer- dimensions with a resolution of 0.001 mm is now in use. The Quality Assurance and Quality Control of welded structures like experiment containments are now consistently executed according to the specifications of the DIN 8563-AS.

4.4. EXPERIMENT OPERATION

Despite of increasing technical complexity of the experiments the operation team provided on schedule their services to a successful operation of the irradiations.
During the 11 cycles of 1991 8 TRIESTE sample carriers, 6 REFA and 26 TRIO sample holders were loaded into the respective reloadable irradiation devices, for in-core irradiation. Furthermore 9 TRIESTE sample carriers, 5 REFA and 20 TRIO/QUATTRO sample holders were unloaded and prepared for dismantling.
The PSF-irradiation device for 215-type fuel pins, installed in 1990, has been upgraded, and was successfully operated over the whole year. The device for locking sample holders into the instrumented head has been upgraded, to avoid unlocking during reactor operation. This device worked perfectly.

Fig. 31
View into the reactor pool



4.5. HOT CELLS AND POST-IRRADIATION WORK

The cell team provided the following services:

Dismantling Cell
- Dismantling of 127 isotope capsules
- Dismantling of 54 sample holders
- 18 Waste transports
- 40 Neutron radiographs
- Dismantling of 5 diamond capsules

- Visual control of 35 Be elements and plugs
- 12 External transports
- 8 Internal transports
- Development of a dismantling device for experiment E198
- General repair of cell equipment (waste container, cutting device, manipulators etc.)
- Inspection of transfer machine
- Dismantling of reactor components, trollies and irradiation devices

G5/G6 Cells

- Dismantling and dimension measurements on experiments E167-29/1; 29/2; 29/3; 48; 56; 65; 66; 67; 72; 80; 81; modification on cell shielding control and modification on measure device
- Dismantling and dimension measurements on experiments D156-95/96; 53 and D85-59
- Assembly of experiment D156-96
- Development of dismantling device for flux detectors
- Training with a new "Syntacs container"

EUROS Cell

During the reporting period investigations were performed to carry out the weldings on the KAKADU and HYPERKAKADU capsule remotely according to stringent quality requirements. Meanwhile different components in the EUROS Cell were replaced and tested.

4.6. JOINING TECHNIQUES

The Electron-Beam-Welding and High-Temperature-Brazing group provided the following services:

- routine weldings for sample holder assembly
- welding of more than 50 samples for the materials department
- specific weldings for irradiation devices fabricated at outside firms
- heat treatment of minerals
- welding tests for the high-temperature-materials programme with ODS-alloys

4.7. PROGRAMME MANAGEMENT AND MISCELLANEOUS

Planning

During the reporting period the HFR Planning Meeting was held three times and three editions of the loading chart were issued (HFR/30 to HFR/32).

ACPM

The Advisory Committee on Programme Management met in Petten on May 24, 1991. It reviewed the status and progress of the HFR Programme on the basis of documents prepared by JRC-IAM Petten.

EWGIT (European Working Group on Irradiation Technology)

The EWGIT Select Committee met in Saclay on November 15, 1991 to prepare an International Conference on Irradiation Technology. The Conference will be held in Saclay in May 1992.

NRWG (Neutron Radiography Working Group)
The 13th Plenary NRWG Meeting and the 7th Subgroup meeting on "Practical Neutron Radiography" took place at BAM, Berlin on September 30 - October 1, 1991 and on October 2, 1991 respectively. The NRWG reviewed the status and progress of its programme of work. The subgroup discussed the final preparations for the intended publication of the handbook on "Practical Neutron Radiography".
Assistance was provided within the organizing committee for the preparation for the 4th World Conference on Neutron Radiography to be held in May 1992 in San Francisco/USA.

EWGRD (Euratom Working Group on Reactor Dosimetry)
The 56th meeting of the EWGRD was held on 6-8th May, 1991 in Ispra. The main topic of the meeting was improved techniques in neutron diagnostics in fusion reactors. Organizational matters of the 8th ASTM-Euratom Symposium on Reactor Dosimetry which will take place in 1993 were also discussed.

Seminars organized by the HFR Division

Dr. Yang Yue, Southwest Center of Reactor Engineering, Changdu, China
"Material - Bestrahlungs - Programme in der VR China"
10 January 1991

Dr. D. Preston, AEA, NRL Springfields
"Thermophysical Properties Measurement Techniques on Irradiation Creep Graphite Samples"
12 March 1991

Haruhiko Ito, DGM, Irradiation Section 1, JMTR Project, Orai, Japan
"Irradiation Technology at JMTR"
13 March 1991

P. Watkins, IAM Petten
"An Overview of the Nuclear Sector in the UK"
14 March 1992

M. DeAbrau, AECL, Chalk River
"NRU and its Experimental Facilities and a Video Film of the 1974 Reactor Vessel Replacement"
12 April 1991

Prof. W.D. Dover, University College, London
"The Alternating Current Potential Drop (ACPD) and Alternating Current Field Measurement (ACFM) Techniques for Crack Sizing"
18 April 1991

M. Bieth, IAM Petten
"An Overview of the Nuclear Sector in France"
26 April 1991

A. Siefert, Department of Radiotherapy, University of Göttingen, Germany
"Healthy Tissue Tolerance Studies for Boron Neutron Capture Therapy at the HFR Petten"
20 June 1991

Dr. E. Steichele, TU, München
"Moderne Verfahren der Neutronstrahlführung"
26 September 1991

J.P. Boogaard, R. v.d. Pol, ECN Petten
"Control Room Upgrading of the HFR Petten"
24 October 1991

T. Yamahara, JAERI
"PIE Activities of JAERI's Reactor Fuel Examination Facilities by Using OHP"
30 October 1991

Dr. Y.T. Kurosu, NPEC, Tokyo
"Current Plan of Nuclear Fuel Development in NUPRC"
22 November 1991

5. SUMMARY

5.1. HFR OPERATION, MAINTENANCE, DEVELOPMENT AND SUPPORT

In 1991 HFR operation was carried out as planned. The total availability of the reactor was more than 100% of its scheduled operating time, i.e. 266 in stead of 264 days.
Routine maintenance and modification activities were carried out in the main stop periods in April and July/August 1991.
Good progress was made in the scheduled upgrading projects.

5.2. HFR UTILIZATION

In 1991 the average utilization of the HFR was 69% of the practical occupation limit. A breakdown of the utilization pattern in terms of the different programme sectors is shown in **figs. 8 and 9**.
Programmes related to nuclear energy had again the largest share, the contribution of fusion research being substantially larger than that of fission related research.
Fundamental research at the beam tubes decreased its share compared to previous years. Instead an increase is shown for BNCT.
The increase in radioisotope production reported in the previous annual report was consolidated in 1991.
Development activities addressed upgrading of irradiation devices, neutron capture therapy, neutron radiography and neutron transmutation doping of silicon.

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.

6. HFR PUBLICATIONS

Topical Reports

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Operation of the High Flux Reactor
EUR 13590 EN, 1991

H. Kwast
EXOTIC Annual Progress Report 1990
ECN-C-91-069, 1991

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Jahrestagung Kerntechnik, Bonn, May 1991

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G.P. Tartaglia, G. Sordon, P. Fraipont, H. Hausen
Irradiation of Fusion Reactor Structural Materials
Reaktortagung 1991, 14-16 May 1991, Bonn

E. Sabbioni, M. Bonardi, M. Gallorini, R. Pietra, S. Fortauer, G.P. Tartaglia, F. Groppi
Application of Radiotracers with High Specific Radioactivity to Metallotoxicological Studies
2nd International Conference on Methods and Applications of Radioanalytical Chemistry, Kona, Hawaii, April 21-27, 1991

R. Conrad
First Results of the Proof Tests (HFR-K5/6) at the HFR Petten
Paper presented at the 2nd Soviet-German Seminar on Fuel and Graphite for the HTR, held at KFA on July 8-12, 1991

R. May, R. Conrad
Evaluation of nuclear quantities and tritium release from ceramic blanket breeder irradiation experiments in the HFR Petten
Contribution to "Third International Specialists Workshop on Modeling Tritium Behaviour in Ceramic Fusion Blankets", held at KfK Karlsruhe, June 11-12, 1991
IEA, Proceedings of the Workshop, edited by H. Werle, KfK Karlsruhe, 1991

P. Bode, C. van Dijk, J.Th. Eering, H.P. Leeflang, J.F.W. Markgraf, K. van Otterdijk
Niet-destructief onderzoek (NDO) met behulp van straling
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Scientific or Technical Articles

R. Conrad
Irradiation Experiments on Liquid Tritium Breeding Material Pb-17Li in the HFR Petten
Fusion Engineering and Design 14, 1991, 289-297

R. Conrad, L. Debarberis
Irradiation of Liquid Breeder Material Pb-17Li with in-situ Tritium Release Measurements in the LIBRETTO-2 Experiment
Journal of Nuclear Materials 179-181, 1991, 875-878

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Journal of Nuclear Materials 179-181, 1991, 1158-1161

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Kerntechnik 56 (1991), Nr. 2, April 1991, pages 118 to 123

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Development of a two-dimensional computer code for the prediction of two-phase heat transfer in an experimental light water reactor irradiation capsule
Nuclear Energy 30, 1991, No. 3, June, pages 165 to 172

GLOSSARY

ACC	Advanced Coating Centre
ACPM	Advisory Committee on Programme Management
AMCR	Acier Mangan Chrome (Low activation material)
ASTM	American Society for Testing and Materials
BEST	Brenn Element SegmenT
BNCT	Boron Neutron Capture Therapy
BOL	Beginning Of Life
BRAIN	BRAzings IrradiatioN
BRITE	Basic Research in Industrial Technologies for Europe
BU (or bu)	Burn-up
BWFC	Boiling Water Fuel-element Capsule
BWR	Boiling Water Reactor
CEA	Commissariat à l'Energie Atomique
CEN	Centre d'Etudes Nucléaires
CERAM	net CERAMics
CERCA	Compagnie pour l'Etude et la Réalisation de Combustibles Atomiques
CFC	Carbon Fibre Compound
COBI	CObalt Isotope production
COMPLIMENT	COMParison of LIthium Materials damage Effects by fast Neutrons and ^{6}Li(n,α)T-reactions
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
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
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 ReacktorBau GmbH
HTR(HTGR)	High Temperature Reactor
IAEA	International Atomic Energy Agency
IAM	Institute for Advanced Materials
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	Japenese Atomic Energy Research Institute
JETI	Joint European Torus Irradiation
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
LWR	Light Water Reactor
MD	Materials Division
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
NTD	Neutron Transmutation Doping
ODS	Oxide Dispersion Strengthened
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
PISC	Project for the Integrity of Steel Components
POMPEI	Pellets Oxyde Mixte, PEtten Irradiation
POTOM	Power to melt irradiation
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)
R&D	Research and Development
REFA	Reloadable Facility
RELIEF	FBR fuel/cladding, axial displacement measurement experiment
RIF	Reloadable Isotope Facility
SANS	Small Angle Neutron Scattering
SCK	StudieCentrum voor Kernenergie (Mol,B)
SIDO	Silicon Doping Facility
SIENA	Steel Irradiation in Enhanced Neutron Arrangement
SIMONE	Test Irradiation for low enriched Silicide fuel elements
SINAS	Simplified NAST (irradiation capsule)
SINET	SIlicon NEutron Transmutation doping facility
SIP	Silicium Investigation Philips
SIRENA	Stainless steel IRadiation for ENeA
SIWAS	SImplified WAter-Steel irradiation
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

LIST OF AUTHORS

JRC

Editors:
J. Ahlf
A. Gevers

Contributors:
M. Bieth
J. Boels
K.H. Cloes
R. Conrad
C. Jehenson
J. Konrad
H. Lohner
J. Markgraf
L. Metten
R. Moss
D. Pithan
G. Sordon
G.P. Tartaglia
G. Tsotridis
A. Zurita

ECN:

Compiler:
G. v.d. Koogh

Contributors:
H. Bergmans
C. v. Dijk
R. Kempers
R. Kuperus
G. Luif
B. Nieuwendijk
A. Nolten
R. v.d. Pol
H. Pruimboom
J. Schinkel
K. Terpstra
G. Teunissen
J. Visser
W. Wijkenga
D. de Zaaijer

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ABSTRACT

In 1991 the operation of the High Flux Reactor was carried out as planned.
The availability was more than 100% of scheduled operating time.
The average utilization of the reactor was 69% of the practical limit.
The reactor was utilized for research programmes in support of nuclear fission reactors and thermonuclear fusion, for fundamental research with neutrons, for radioisotope production, and for various smaller activities.
Development activities addressed upgrading of irradiation devices, neutron capture therapy, neutron radiography and neutron transmutation doping of silicon.
General activities in support of running irradiation programmes progressed in the normal way.

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