ANNUAL REPORT 1992

OPERATION OF THE HIGH FLUX REACTOR

JOINT RESEARCH CENTRE

COMMISSION OF THE EUROPEAN COMMUNITIES

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ANNUAL REPORT 1992 OPERATION OF THE HIGH FLUX REACTOR

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

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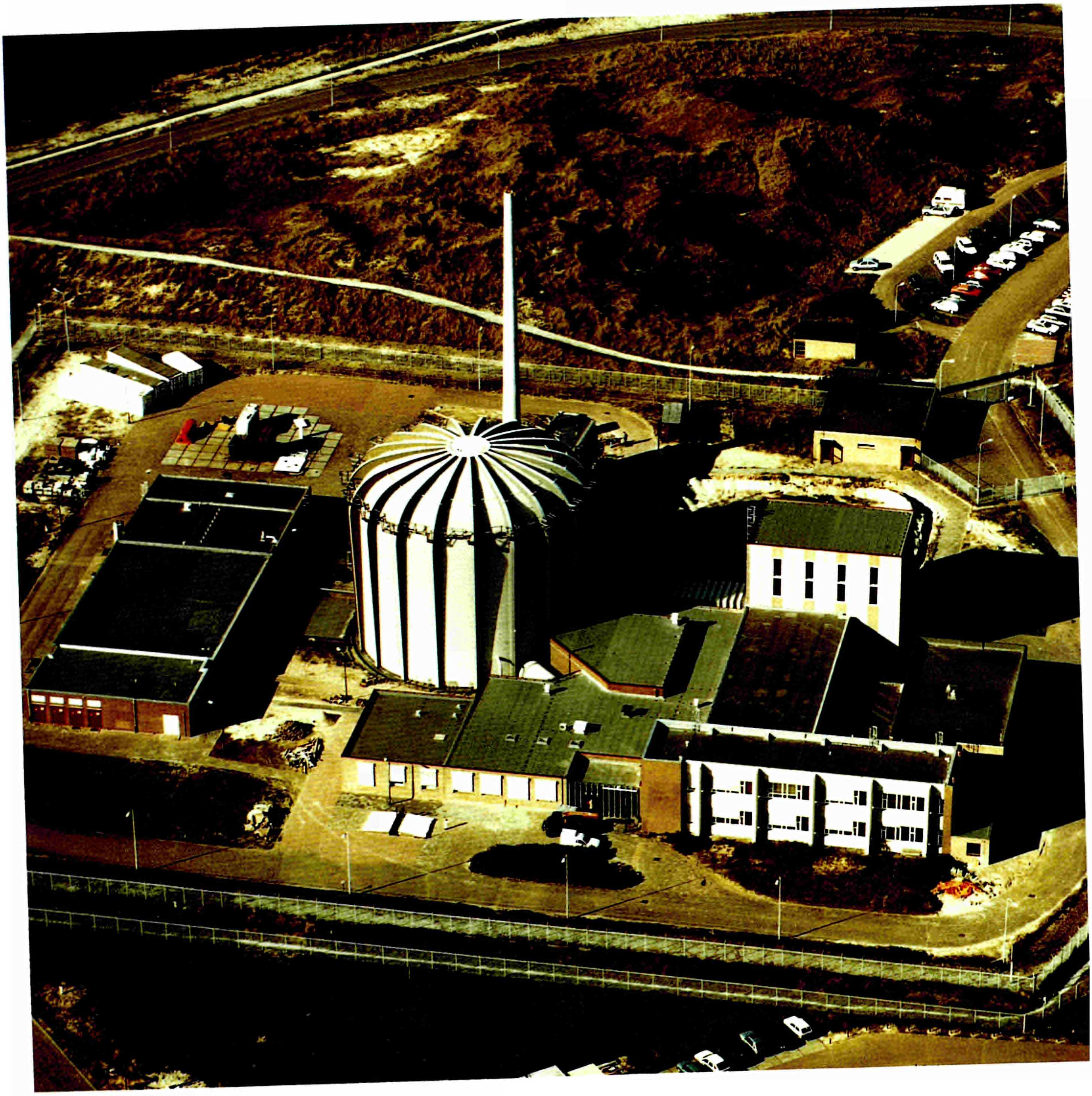


The HFR Petten

1. INTRODUCTION

The High Flux Reactor (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. 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 1992, the operation record of the HFR was excellent again. In total, 280 operation days were achieved corresponding to an overall availability of slightly higher than 75%. The utilization of the HFR decreased slightly from 69% in 1991 to 63% in 1992. Despite a significant increase in radioisotope handling, the occupational dose could be kept at a remarkably low level. A large number of regular and preventive maintenance activities were executed at schedule without loss of operation time.

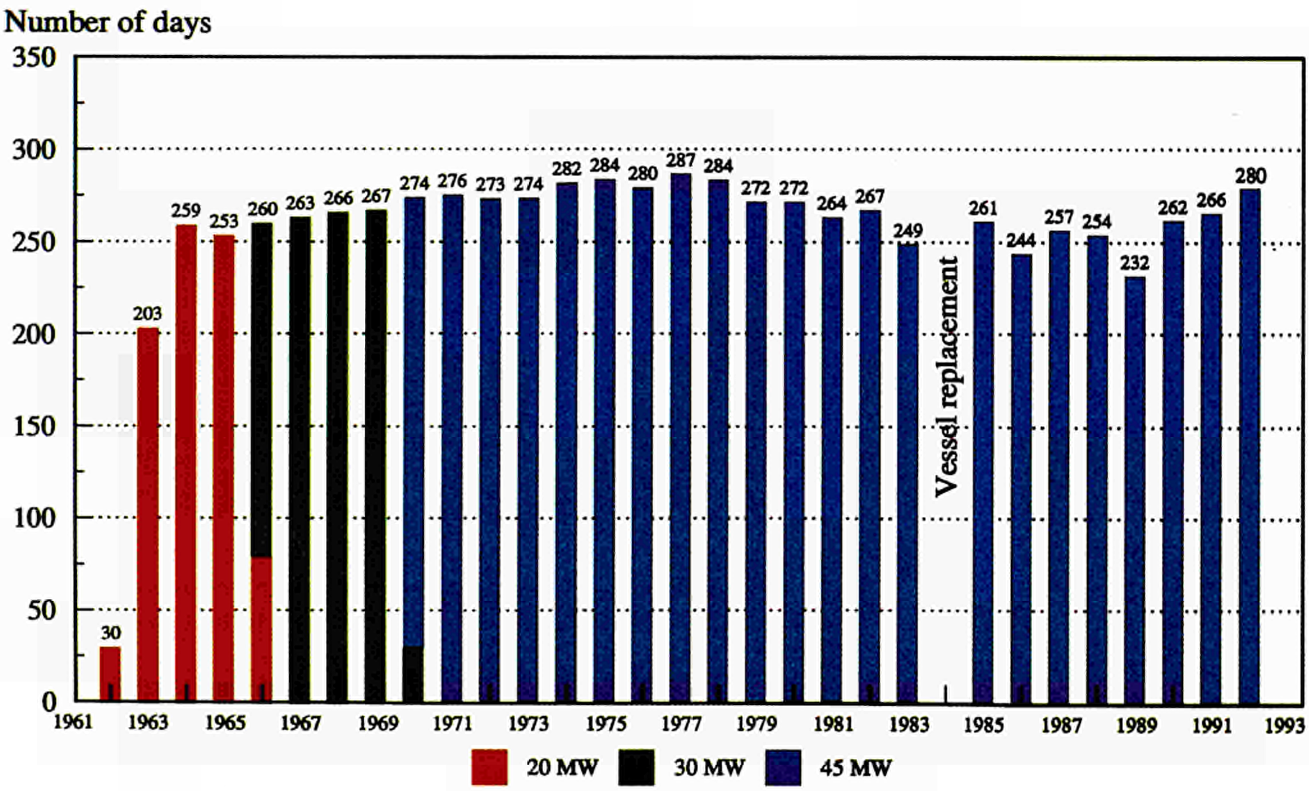
The utilization of the HFR undergoes a significant transition. Whereas the traditional materials testing programmes for fission reactors, in particular the HTR and FBR related projects, as well as fusion materials irradiations were decreasing, radioisotope production, mainly for the medical sector, increased considerably. Research towards boron neutron capture therapy contributed an important share again. Also neutron radiography and activation analysis as traditional services at the HFR maintained a stable position.

The different projects which are presently in progress at the HFR are reported in detail in the following chapters. Again a number of particularly notable achievements can be reported:

- Refabrication of test fuel rods from full length commercial fuel rods is now possible in the Petten Hot Cells for later further irradiation testing in the HFR;
- The investigation of iodine solubility and degassing from a PWR fuel rod after a LOCA scenario was terminated after the fifth in-pile ISOLDE test;
- For the EFR, three new fuel pin irradiations were successfully started,

and two experiments using nitride fuel were prepared for the advanced fuels programme of the ITU at Karlsruhe;

- The long term irradiation of zirconium alloy specimens for the CANDU operators group was successfully started;
- Within the fusion materials irradiation programme, damage studies of structural materials (mostly 316 and low activation steels) were continued; in addition, components for fusion devices, like resins, lenses, cameras were irradiation-tested and provided important design data;
- The second mid-term irradiation for the gas-cooled ceramic breeder concept for future fusion machines, EXOTIC 6, and the third irradiation experiment for the water-cooled liquid metal breeder concept, LIBRETTO 3, were successfully completed;
- A new important irradiation programme was started with the design of an irradiation experiment to study the nuclear transmutation of long-lived fission products (Tc99 and J129);
- Radioisotope production services were largely extended and are now provided to all large European companies as well as to some overseas companies, mostly for the production of radio-pharmaceuticals; also the list of products was extended, for instance a large quantity of Sr89 which is used as a painkiller in prostate skeletal malignancy, was produced;
- The qualification of the HFR based facility for boron neutron capture therapy was continued; four separate free beam measurements, a number of cylindrical and dog-head-like phantom experiments, more than 100 cell culture experiments and a further 24 in-vivo irradiations for the healthy tissue tolerance study were performed.



2. HFR OPERATION, MAINTENANCE, DEVELOPMENT AND SUPPORT

2.1. OPERATION

2.1.1. Operation Survey

In 1992 the regular cycle pattern, as planned, consisted of a scheduled number of 273 operation days, and two maintenance periods of 30 and 31 days. In reality the HFR has been in operation during 280 days **(fig. 1)**, following a normal cycle pattern, which corresponds to an overall availability of 76%.
Nominal operation power has been 45 MW. Total energy production has been approximately 12500 MWd, corresponding to a fuel consumption of approximately 16.1 kg U-235. The main operation survey characteristics for 1992 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 91.11 up to 13 January 1992. Since then the HFR was operated for 10 complete cycles at nominal power of 45 MW. At the end of the reporting period cycle 92.11 was still in progress, scheduled for completion at January 11, 1993. With the intention to make as much operation time as possible, and to compensate for lost operating time cycle 92.06 and cycle 92.10 ended later than 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.

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
91.11	01.01.92	13.01.92	302.46	304.00	568.33	-
92.01	14.01.92	10.02.92	609.57	612.00	1146.71	-
92.02	11.02.92	09.03.92	610.07	612.06	1147.65	-
92.03	10.03.92	06.04.92	609.55	615.03	1150.37	1
Maintenance period	07.04.92	06.05.92				
92.04	07.05.92	01.06.92	599.17	601.55	1126.73	-
92.05	02.06.92	29.06.92	603.32	606.44	1135.97	1
92.06	30.06.92	28.07.92	627.08	642.55	1183.27	1
Maintenance period	29.07.92	27.08.92				
92.07	28.08.92	21.09.92	576.52	604.45	1089.58	-
92.08	22.09.92	19.10.92	602.00	603.53	1131.07	-
92.09	20.10.92	16.11.92	576.45	579.00	1084.62	-
92.10	17.11.92	14.12.92	607.11	610.24	1144.66	1
92.11	15.12.92	31.12.92	313.18	317.19	590.82	2

◁ **Fig. 1**
HFR operation days, 1961-1992

Table 2
Operational characteristics

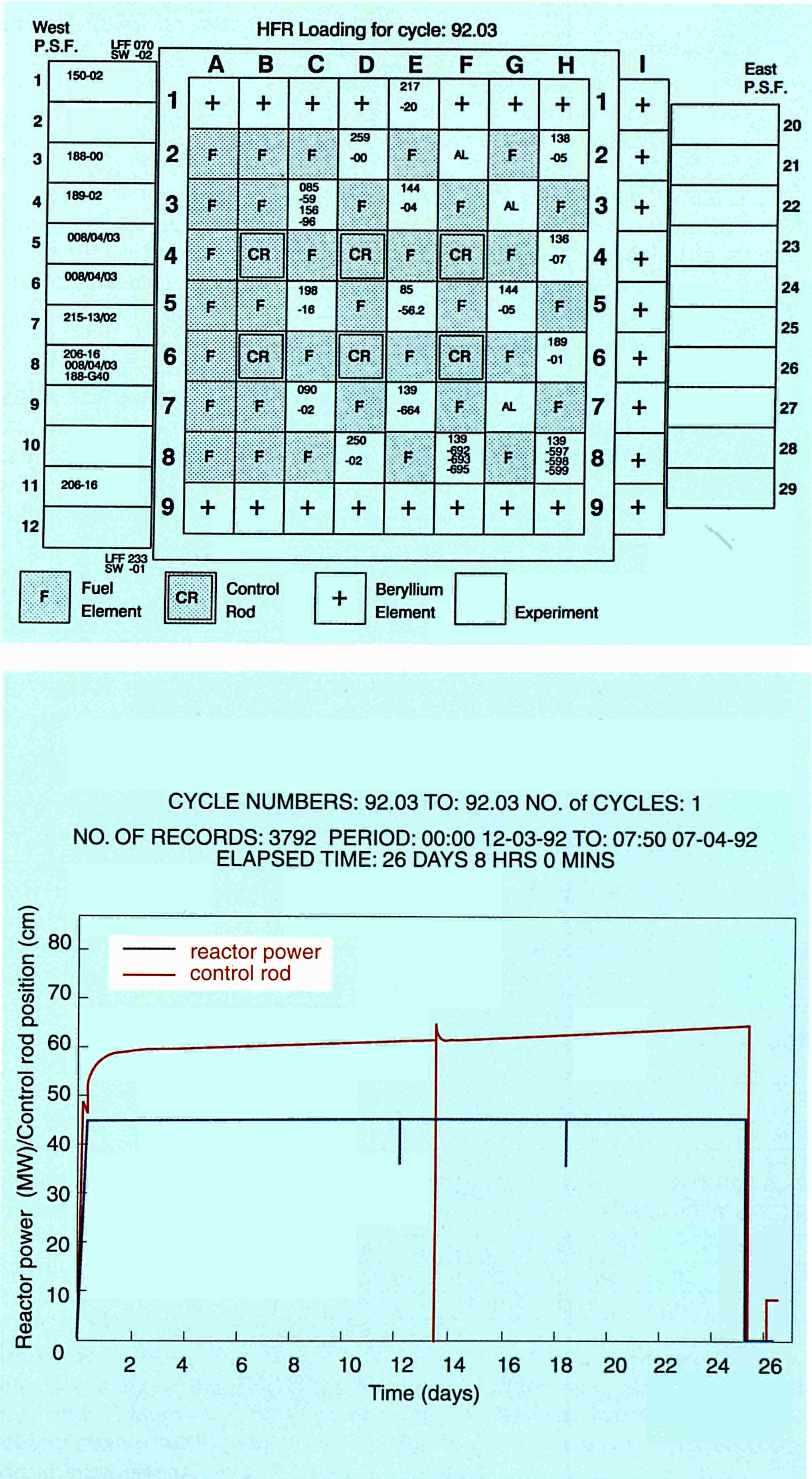
Cycle begin-end 1992	HFR cycle	Generated energy MWd	Operating time					Shut-down time		Number of interrupt-ions	Stack release (for Ar-41) GBq
			Planned hour	Low power h.min	Nominal power h.min	Other use h.min	Total h.min	Planned h.min	Un-scheduled h.min		
01.01-13.01	91.11	568.33	304	01.14	302.46		304.00	08.00		-	300
14.01-10.02	92.01	1146.71	592	02.03	609.57		612.00	60.00		-	626
11.02-09.03	92.02	1147.65	592	01.59	610.07		612.06	59.54		-	589
10.03-06.04	92.03	1150.37	592	03.25	609.55	01.43	615.03	55.52	00.05	1	605
07.04-06.05	Maintenance period							720.00			
07.05-01.06	92.04	1126.73	592	02.38	599.17		601.55	22.05		-	490
02.06-29.06	92.05	1135.97	592	03.12	603.32		606.44	65.11	00.05	1	587
30.06-28.07	92.06	1183.27	592	08.48	627.08	06.59	642.55	53.00	00.05	1	610
29.07-27.08	Maintenance period							720.00			
28.08-21.09	92.07	1089.58	592	03.41	576.52	24.12	604.45	08.00	04.22	-	442
22.09-19.10	92.08	1131.07	592	01.53	602.00		603.53	69.07		-	420
20.10-16.11	92.09	1084.62	592	02.15	576.45		579.00	80.00	13.00	-	541
17.11-14.12	92.10	1144.66	592	03.13	607.11		610.24	61.30	00.06	1	610
15.12-31.12	92.11	590.82	336	04.01	313.18		317.19	55.01	35.58	2	215
Total		12499.78	6560	38.22	6638.48	32.54	6710.04	2037.40	53.41	6	6035
Percentage of total time in 1992 (8760 h)				0.4%	75.8%	0.4%	76.6%	23.3%	0.6%		
Percentage of planned operating time (6560 h)				0.6%	101.2%		102.3%				

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 position is shown in **fig. 2**.
Detailed information on the various irradiation experiments is given in chapter 3.

2.1.3. Operational Disturbances

Deviations from nominal power level occurred 41 times during 1992. Thirty five of these were scheduled, mostly for intermediate handling or adjustment of irradiation facilities. The remaining 6 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 92.03. Experiment loading, reactor power pattern and control rod movement



Date	Time of			Elapsed time to		Disturbance code				Reactor system or experiment code	Comments
1992	Action hour	Restart or power increase hour	Nominal/ Original power hour	Restart or power increase h.min	Nominal/ Original power h.min	1	MW	2	3		
Jan 29	10.24	10.30	10.40	00.06	00.16	MP	35	E	S	136	Facility handling
Jan 31	09.19	09.25	09.30	00.06	00.11	MP	35	E	S	136	Facility handling
Febr 03	08.20	08.25	08.27	00.05	00.07	MP	35	E	S	136	Facility handling
Febr 05	00.06	00.18	00.20	00.12	00.14	MP	35	E	S	136	Facility handling
Febr 05	01.23	01.26	01.28	00.03	00.05	MP	35	E	S	136	Facility handling
Febr 26	11.07	11.15	11.16	00.08	00.09	MP	35	E	S	136	Facility handling
Febr 26	11.41	11.47	11.48	00.06	00.07	MP	35	E	S	136	Facility handling
Febr 26	19.20	19.25	19.30	00.05	00.10	MP	25	E	S	215-13/02	Experiment handling
Mar 04	00.02	00.16	00.23	00.14	00.21	MP	35	E	S	136	Facility handling
Mar 23	12.37	12.43	12.47	00.06	00.10	MP	35	E	S	136	Facility handling
Mar 25	18.04	18.09	18.23	00.05	00.19	AS	O	R	I	Interlock	Safety channel
Mar 30	00.10	00.20	00.23	00.10	00.13	MP	35	E	S	136	Facility handling malfunctioning
Mar 30	01.15	01.20	01.22	00.05	00.07	MP	35	E	S	136	Facility handling
May 13	14.35	14.41	14.46	00.06	00.11	MP	35	E	S	136	Facility handling
May 20	00.28	00.41	00.45	00.13	00.17	MP	35	E	S	136	Facility handling
June 08	08.54	09.01	09.04	00.07	00.10	MP	35	E	S	136	Facility handling
June 15	00.20	00.25	00.27	00.05	00.07	MP	35	E	S	136	Facility handling
June 19	19.19.	19.24	19.40	00.05	00.21	AS	O	R	H	Gasmonitor 2	Wrong procedure in check-out
July 03	12.23	12.47	12.53	00.24	00.30	MP	20	E	S	183	Experiment handling
July 07	10.57	11.02	11.31	00.05	00.34	AS	O	E	H	211	Changing gas mixture
July 08	00.08	00.25	00.35	00.17	00.27	MP	35	E	S	136	Facility handling
July 08	01.37	01.42	01.44	00.05	00.07	MP	35	E	S	136	Facility handling
July 15	00.28	00.43	00.56	00.15	00.28	MP	20	E	S	183	Experiment handling
July 15	01.45	01.49	01.52	00.04	00.07	MP	35	E	S	136	Facility handling
July 22	00.09	00.16	00.20	00.07	00.11	MP	35	E	S	136	Facility handling
July 22	02.44	02.51	02.56	00.07	00.12	MP	35	E	S	136	Facility handling
Aug 31	14.58	15.02	15.04	00.04	00.06	MP	35	E	S	136	Facility handling
Sep 07	00.00	00.07	00.09	00.07	00.09	MP	35	E	S	136	Facility handling
Sep 14	20.52	20.58	21.00	00.06	00.08	MP	35	E	S	136	Facility handling
Sep 21	00.15	00.35	00.38	00.20	00.23	MP	35	E	S	136	Facility handling
Nov 02	19.20	19.33	19.40	00.13	00.20	MP	15	E	S	215	Facility handling
Nov 24	11.36	11.37	11.45	00.01	00.09	AP	1	R	H	Primary	To high primary inlet temperature
Nov 25	00.07	00.15	00.17	00.08	00.10	MP	35	E	S	136	Facility handling
Nov 25	01.06	01.10	01.12	00.04	00.06	MP	35	E	S	136	Facility handling
Nov 30	00.00	00.04	00.07	00.04	00.07	MP	35	E	S	136	Facility handling
Dec 02	01.54	02.10	02.14	00.16	00.20	MP	25	E	S	215	Experiment handling
Dec 11	14.26	14.32	14.40	00.06	00.14	AS	O	A	E	Mains	Mains outage
Dec 23	00.18	00.23	00.24	00.05	00.06	MP	35	E	S	136	Facility handling
Dec 23	01.20					MS	O	E	M	136	Precautionary shut-down
Dec 24		13.00	15.01	35.40	37.41						
Dec 30	00.05	00.10	00.12	00.05	00.07	MP	35	E	S	136	Facility handling
Dec 30	01.05	01.09	01.20	00.04	00.11	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

2.2. FUEL CYCLE

During 1992 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) was still impossible. The fuel sections of a number of control rods were removed from the remainder of the rods and stored in normal fuel storage racks, in order to create room for depleted complete rods in the special control rod storage facility. Measures have been taken to ensure an uninterrupted supply voltage to the video survey system.
Agreement was reached with the IAEA and Euratom Fuel Inventory Inspectorate about the placing of depleted elements in the interim storage facilities without the presence of Inspectorate Personnel.

2.3. SAFETY AND QUALITY MANAGEMENT

2.3.1. Quality Assurance

The QA system for HFR operation has been improved and extended, i.e. a number of procedures were authorized in the field of HFR and experimental fuel administration, composition of the cycle cores and authorization for installation of these cores.

The revision of the description of the Isotope Production Facilities and the procedures and instructions for every step in the isotope production was completed.

The membership of the "Nederlands Atoom Forum Werkgroep QA" led to many valuable contacts with QA-functionaries of other reactors.

The list of "approved" suppliers was up-dated and extended with suppliers in the field of Electronics and Informatics.

2.3.2. Personnel Exposure

A survey of the registered annual doses of HFR operating personnel is given in **fig. 3**.
The total collective dose over 1992 for the operating shift personnel is again higher than that in 1991, mainly due to the continuous increase in handling of isotope irradiations. The total collective dose over all HFR concerned personnel (maintenance staff included) was about 3% lower than in 1991.

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 August 1992. Some special items are described below.

◁ **Table 3**
Full power interruptions

2.4.1. Mechanical Installations

Secondary cooling system
Two secondary pumps were overhauled, together with their valves and non-return valves. The housings of pumps and valves were steel grit blasted and coated with epoxy paint. On the insides an abrasion resistant coating of polyurethane enamel has been applied.

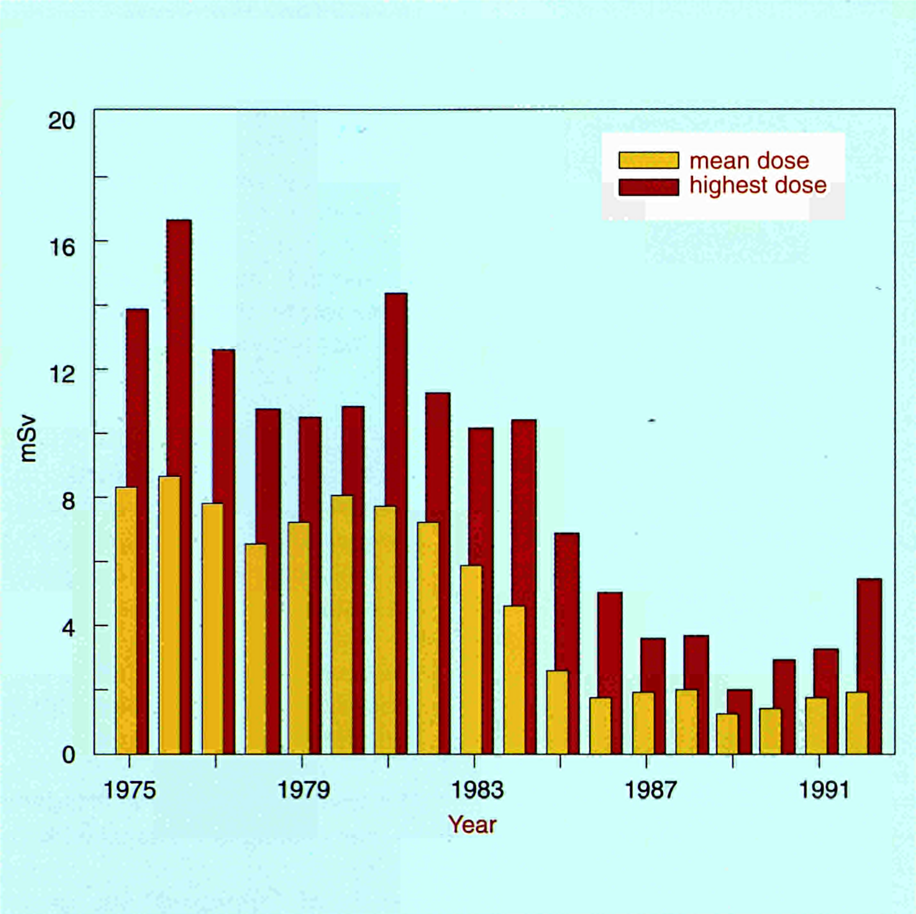


Fig. 3
Dose-equivalent HFR-operators

The renovated southern rotary tape filter unit was reinstalled.
The sliding valves between filter basin and pump basin have been renewed.
The inlet pipeline between the "Noord Hollands Kanaal" and the secondary pump building was cleaned and a number of leaking joints between adjacent pipe sections were repaired.
Provisional repairs were made to the exhaust in the pier on the beach.

Hall ventilation system
The exhaust ventilator was exchanged for a spare one and shipped to the manufacturers. All blades were exchanged for new sturdier ones.

Cranes and hoists
The 20 ton rotary crane in the Reactor Containment Building has been overhauled completely. It passed tests, carried out by a specialized firm. This firm inspects and tests all cranes and hoists once every year.

Control rods
Three complete drive mechanisms of the control rods have been overhauled.

In co-operation with the Electrical Maintenance Group one of the already tested new motors was installed on control rod F4 for in-situ tests. The results were positive. After the test the original motor was replaced.

Gridbars
The new gridbars and their locking devices were inspected regularly. They perform as expected.

Pool doors
The gaskets of the lower doors between the pools had to be renewed prematurely, due to radiation damage by the stored depleted fuel elements in the neighbourhood.

Preventive maintenance schedule
Following the intensive preventing maintenance schedule many pump units, valves, non-return valves etc. were overhauled. Many couplings between pumps and motors have been exchanged for maintenance-free types.
Much work was put into extension of the maintenance schedules and theupdating of piping diagrams etc.

2.4.2. Instrumentation Systems and Informatics
Gas monitor systems
The new "high activity" stack monitor system (gas monitor 2) was put in operation.

Containment Building Leak Tightness Test
The necessary instrumentation for the yearly Containment Building Leak Test was recalibrated.

Nuclear safety channels
The nuclear safety channels NC5, 6 and 7 have been connected in a 2 out of 3 system, with approval of the KFD. This reduces the risk of spurious scrams during for instance handling of reloadable irradiation facilities, or due to a defect in one of the channels.

Area monitor systems
The existing area- and beamtube monitors are very prone to malfunctions. A market search has been started for more reliable monitors.

Pneumatic process instrumentation
A new panel was constructed, containing transducers for the conversion of pneumatic signals to electrical ones. The panel was installed under the HFR control room and connected to the pneumatic process instrumentation.
After approval by the Safety Authorities the electric signals will be used for measurement and safeguarding.

Control rod position indicators
As part of the control room renovation project, a new simple and reliable control rod position indicator was designed. It consists of a stainless steel wire mound on a springloaded drum, the spindle of which is connected to

a precision potentiometer. The linear motion of the control rod moves the "free" end of the wire, and so rotating the drum.
A model has been built and is undergoing tests, with very positive results up to now.

Watermonitors
The new instrumentation for the watermonitor systems has been received and is presently being tested.

Data acquisition system DACOS
The plans for the removal of the DACOS hardware to a room inside the "protected area" were finished. Reconstruction work in the HFR office building for the preparation of the DACOS room is expected to start in the beginning of 1993.

The DACOS measurements network has been separated physically from the HFR office building network, to ensure undisturbed measurement data streams.

The most recent version of the VACS operating system was installed.

Courses
Courses in the use of the DACOS system were given to project engineers, project staff and HFR operating personnel.

Reactor pool leak rate measurements
The automatic leak rate measurement system for the reactor pool has been connected to the DACOS system, to provide information over the last 24, 12 and 6 hours on a VDU in the reactor control room.

2.4.3. Electrical Installations

110 V DC control voltage system
A new distribution cabinet was built and installed for the 110 V DC control voltage system, and current supply to its backup battery.

Emergency cooling pumps
The electrical circuits of the diesel- and electrical emergency pumps were physically and electrically separated as much as possible from other systems. This necessitated the construction and installation of new cabinets and cabling.

Control rod drive motors
Two reversing two phase electromotors with brakes have been bought as possible replacement for the existing control rod drive motors. Both motors were tested by braking from full speed and then reversing the direction of rotation, every 3 seconds.
After 35000 cycles neither brakes, bearings nor other parts showed wear or other signs of deterioration.

Secondary pumps
All four motors of the secondary pumps have been renovated by a specialized firm.

Emergency lighting system
Two cabinets, one containing the rectifier for supply to the battery, the other containing the distribution panel, were installed. The battery supplies only the emergency lighting and is no longer used as backup for the 110 V DC control voltage system.

Ventilation system
The new power distribution cabinet was put in operation.

Reactor hall rotating crane
The radio control system of the reactor hall rotating crane was renewed.
The switch gear cabinets for manual control in the crane cabin has been rebuilt.
The former handwheel-operated controllers have been replaced by joy-stick operated ones.

Mains Power Distribution Cabinet
The new Mains Power Distribution Cabinet HK2 has been received and put in place in the Power Switching Room in the Primary Pump Building.

Buildings
The renovation of the High Construction Hall, the Secondary Pump Building and modifications in the office buildings and reactor hall necessitated a large amount of rerouting of cables, switch gear, etc.

2.4.4. Buildings and Site

Reactor Containment Building
Inspection of the outside of the containment building showed only minor damage to the paintwork. The balcony, however, is rather badly corroded. For safety reasons entrance to the balcony had to be prohibited. The necessary repairs will be carried out together with the paintwork repairs in the first half of 1993.

Primary Pump Building
The floors in the cellars of the primary pump building were repaired and re-coated with an easily de-contaminable epoxy resin paint.

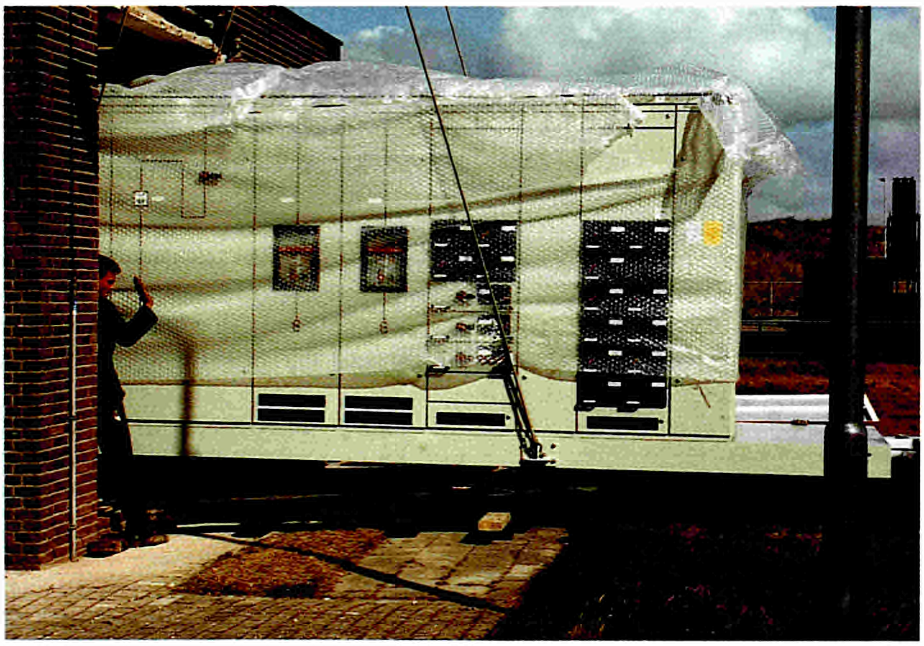
Miscellaneous
The lightning conductor system of all buildings was tested by a specialized firm and found to be in good condition.
The sea containers, used for storage of materials and spare parts were relocated to make room for a new JRC laboratory for measurements on coatings.

2.5. TECHNICAL AND EXPERIMENTAL SUPPORT

2.5.1. Assistance to Experiments

In addition to routine assistance to experiments HFR personnel contributed substantially to the work of several project-teams, a.o. BNCT and isotope production.

Fig. 4
HFR Mains Power Distribution Cabinet. Both parts being moved into position



2.5.2. 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 1992. During the maintenance spring stop of the reactor the two sample holders have been removed from their respective positions and brought to the dismantling cell associated with the reactor, where the flux monitors have been taken out for dosimetry analysis and have been replaced by new flux monitors.

2.6. UPGRADING AND MODIFICATION PROJECTS

2.6.1. Renovation of the Secondary Cooling Water Outlet
All preparatory work for the renovation of the secondary cooling water outlet pipeline was finished. The work itself will be carried out in one of the maintenance periods in 1993.

2.6.2. Ion Exchanger Drain Tanks
Tanks A and B have been installed, instrumented and put in operation. Tank C has been ordered.

2.6.3. Renewal of the Chlorine Injection System of the Secondary Cooling System
The sodium hypochlorite tank, the dosage pump and associated valves, instruments etc. have been delivered. The renovation and adaptation of the existing chlorine storage building to the sodium hypochlorite installation will start in spring 1993.

2.6.4. HFR Control Room Upgrading
The renewal of the HFR control room is split up in a number of steps. Detailed plans for each step are presently being drawn up. Some steps have already been carried out, for instance testing of a new control rod position indicating system, relocation and adaption of process instrumentation, etc.

2.6.5. Relocation of the DACOS Experiment Data Handling System
In order to incorporate the DACOS computer system in the "protected zone" near the HFR control room, extensive reconstruction of the building was necessary. All preparatory work was finished and the reconstruction ordered. Work is expected to start in January 1993.

2.6.6. Renewal of HFR Mains Power Distribution Cabinet
After extensive testing of the cabinet at the manufactures, it was delivered in August.
One of the windows and part of the wall of the Switch Gear Room had to be removed to allow passage of the cabinet **(fig. 4)**. The cabinet will be connected to the installation in the 1993 maintenance period.

2.7. NUCLEAR SUPPORT

2.7.1. Neutron Metrology
The annual core flux measurement campaign, called FLUX 92, has been carried out in cycle 92.03.

2.7.2. Nuclear Calculations
Implementation of a more detailed HFR core model, the so-called 3-zone model, has been started.
The core calculations are no longer done on a central ECN mainframe computer, but on local graphic workstations in the HFR office building. Nuclear constants calculations, required for proper core and fuel management, have been carried out for several experiments.

2.7.3. Fuel Efficiency Optimization
A study has been started into the possibilities of a reduced HFR fuel consumption scheme.

3. HFR UTILIZATION

In 1992 the average utilization rate of the HFR was 63% of the practical occupation limit. A breakdown of the utilization pattern in terms of the different programme sectors is shown in **figs. 5 and 6**.
The main results of the various irradiation projects are reported below for each sector.

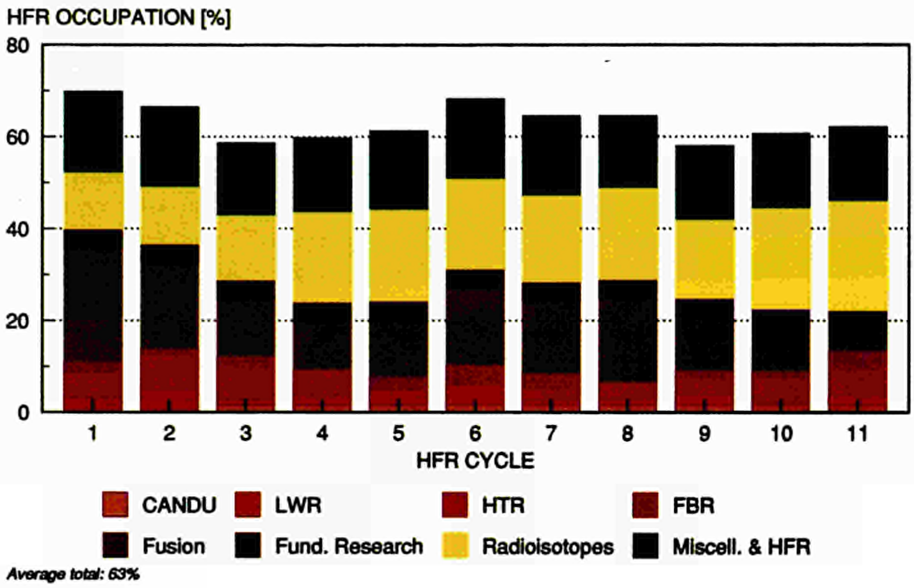


Fig. 5
HFR utilization 1992 per cycle in % of the practical occupation limit

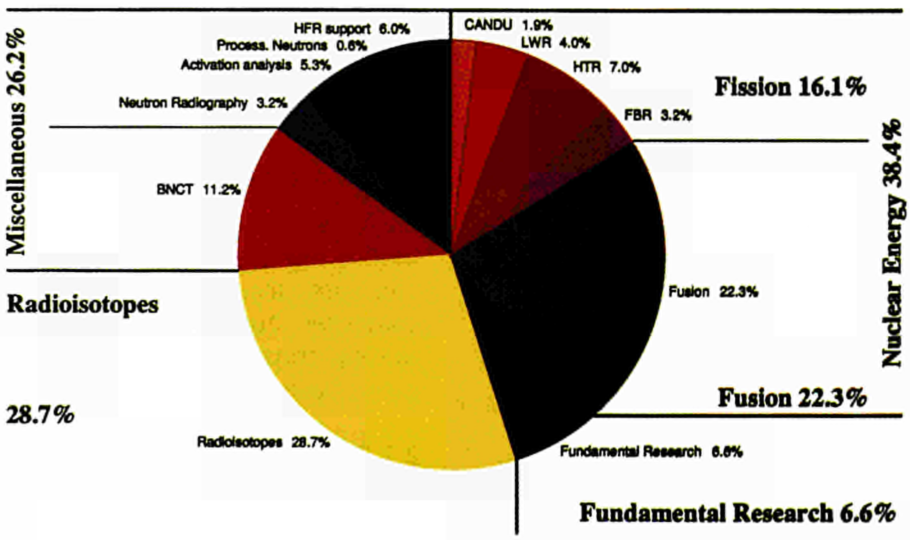


Fig. 6
HFR utilization 1992 in % of used capacity

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:
For more than two decades, the HFR is well known for its irradiation support to LWR fuel research programmes. Important contributions are made in the areas of R&D of fuel and cladding behaviour, the safe and the economic utilization of LWR fuel.
The irradiation experiments at the HFR addressed the fuel rod performance and behaviour under start-up, operational and overpower transients and/or under power cycling conditions /1/. Since 1972, most test programmes are performed with pre-irradiated fuel rod segments which originate from commercial power reactors.

Broad experience has been gained at the JRC and the Petten hot cells of ECN in application of this test method /2/. During 1992, the test capabilities were enlarged with the introduction of a re-fabrication technique at the Petten hot cells for test fuel rods made from pre-irradiated full length power reactor fuel rods /6/.

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 and BWR fuel using UO_2 and $(U,Pu)O_2$ [Mixed Oxide Fuel (MOX)] /3/. These data are now being used in operation of to-days power reactors and have led to an increase of availability and economics of the plants.

Recent R&D programmes in the LWR fuel sector are addressing mainly fuel rod behaviour at extended and high burn-up. 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 experiments at the HFR addresses the investigation of the release and behaviour of fission products after a hypothetical LOCA scenario. In particular, the iodine release, its solution and degassing after a LOCA are studied. A major contribution to this topic was already achieved through HFR experiments and hot cell tests at KFA Jülich performed at the early 80's /4/. This programme has been continued with a newly developed irradiation device allowing in-pile LOCA testing of pre-irradiated PWR fuel rods.

In 1992 the following objectives were addressed by the LWR fuel rod irradiation programmes at the HFR:
- study of the transient fission gas release in BWR fuel rods,
- investigation of power ramping behaviour of extended burn-up PWR fuel rods,

- investigation of power cycling behaviour of extended burn-up PWR fuel rods,
- preparation for ramp testing of MOX fuel rods,
- investigation of irradiation behaviour of PHWR fuel,
- irradiation testing of re-fabricated LWR fuel rods 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:
- the modernisation of the out-of-pile installation and the datalogger system for operation and control of the standard LWR fuel rod irradiation devices,
- the introduction of the re-fabrication technique at the Petten hot cells for pre-irradiated LWR fuel rodlets produced from full length fuel rods originating from commercial power reactors, and
- the evaluation of power measuring methods in irradiation devices for fuel testing.

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. In-pile pressure measurement was performed with a new technique, developed by JRC Petten. It is providing a re-instrumentation capability for pre-irradiated fuel rods. Already in 1990 two BWR fuel rods, one fresh and one pre-irradiated rod were successfully re-instrumented at the Petten hot cells. Both fuel rods were irradiated in 1990 and 1991 and returned for post irradiation examination to the Petten hot cells. During 1992, all non-destructive tests, puncturing and fission gas analysis were completed and the fuel rod prepared for shipment to the clients hot cells.

A power cycling test which was started during the last cycle in 1991 was operated following schedule and terminated after 99 day/night power cycles. During the cycling programme several intermediate inspections for fuel rod characterization took place with non-destructive techniques (e.g. neutron radiography, eddy current measurement of the cladding, profilometry and Kr-85 measurement in the plenum). The power cycling experiment was performed with an extended high burn-up PWR fuel rod (approx. 56 GWd/t(U)) using the "low power" BWFC capsule.

During the third quarter of 1992, 4 fuel rods for a ramp test programme with MOX fuel rods arrived at Petten. The fuel rods were prepared for irradiation testing at the HFR and partly transported to the HFR. Irradiation testing is scheduled for the beginning of 1993.

Irradiation testing of PHWR MOX fuel rods (project 227)

Two irradiation experiments, each using two short fresh MOX PHWR fuel rods, have been performed during 1986 and 1988/91 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].

During 1992, the irradiation programme was terminated with the completion of pending non-destructive inspections. Transport of the fuel rods to the clients hot cells is anticipated within 1993.

Irradiation testing of re-fabricated LWR fuel rods (project 263)

Six test fuel rods have been re-fabricated at the Petten hot cells from fuel rod sections which were taken from two full length fuel rods. The full length fuel rods were previously employed for three years in a commercial power reactor. It was for the first time that the re-fabrication technique /6/ was applied in the Petten hot cells. **Fig. 7** shows the main elements of a re-fabricated fuel rod. An extensive hot cell qualification programme was conducted on the fuel rods before and after re-fabrication for fuel rod characterization. In addition, prior and after irradiation testing of the fuel rods at the HFR, neutron radiographs were taken with the HFR underwater neutron radiography facility.

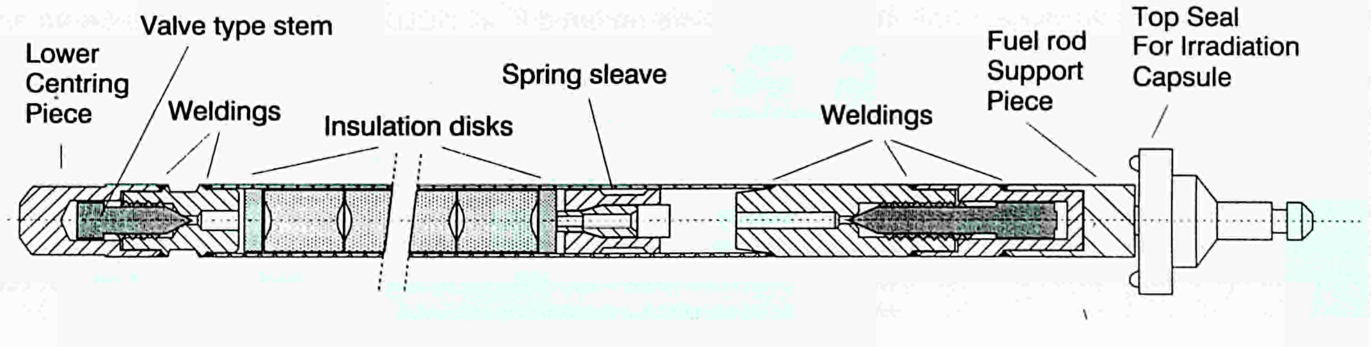
Irradiation testing of all six fuel rods was performed successfully in time within a preset tight time schedule. The tests consisted of a conditioning and transient irradiation phase. After irradiation testing, the fuel rods were returned within a week after termination of the test to the Petten hot cell for post irradiation examination.

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

During 1992 the last irradiation test of a series of five in-pile tests was performed.
The test programme addressed 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.

Each test consisted of a conditioning irradiation period in a standard LWR fuel testing capsule (BWFC-type) at a typical PWR fuel rod power level and under PWR system conditions in order to obtain a typical inventory of shortlived isotopes. Then, the fuel rod was transferred within three days into an ISOLDE irradiation device /5/. The ISOLDE irradiation device provides typical PWR system conditions at low power level (power level after a scram) and after initiation of the LOCA phase, the conditions which are typical for a LOCA situation.

Fig. 7
Lay-out of re-fabricated LWR fuel rod



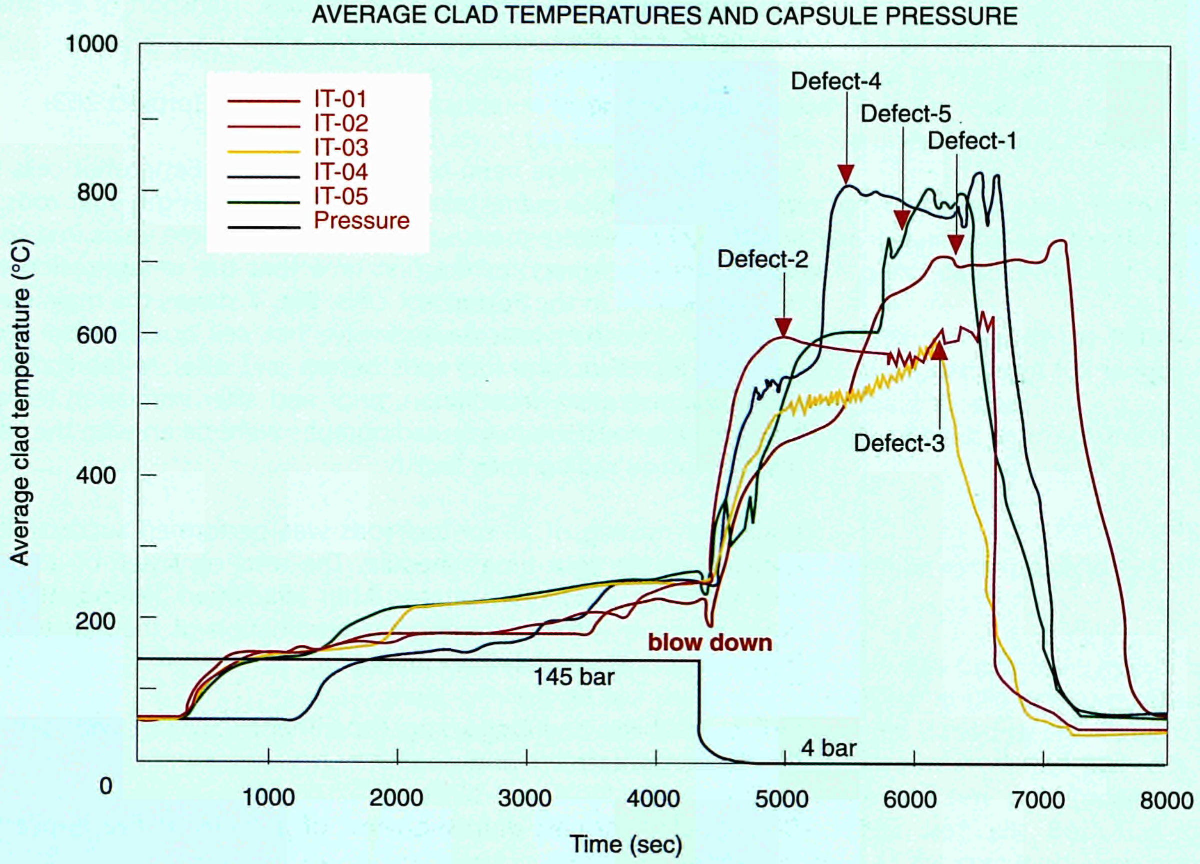


Fig. 8
Comparison of irradiation histories of ISOLDE tests no. 1 to 5

Fig. 8 shows the fuel rod temperature and system pressure versus time for all 5 ISOLDE tests performed at the HFR.

ISOLDE test no. 5 yielded a very pronounced fuel rod defect (bursting failure), ballooning of the lower section of the fuel rod, fracturing of the pellets and accumulation of the fuel fragments, originating from the middle section, in the lower ballooned area, as shown in the neutron radiographic image, **fig. 9**.

The fuel rod failure occurred in all ISOLDE tests above 873 K. Steam and water samples were immediately collected and made available within a short time for post irradiation examination by the Petten and Jülich hot cells. Separately the irradiation devices including the fuel rods were transported to the Jülich hot cells for dismantling and further examination. In view of the short half-life time of I-131 these transports were also performed shortly after completion of the HFR test. Prior to the transports the entire irradiation capsule including the fuel rod was inspected by neutron radiography. The water samples were characterized at the Petten hot cells by gamma-spectroscopy prior to shipment to the Jülich hot cells.

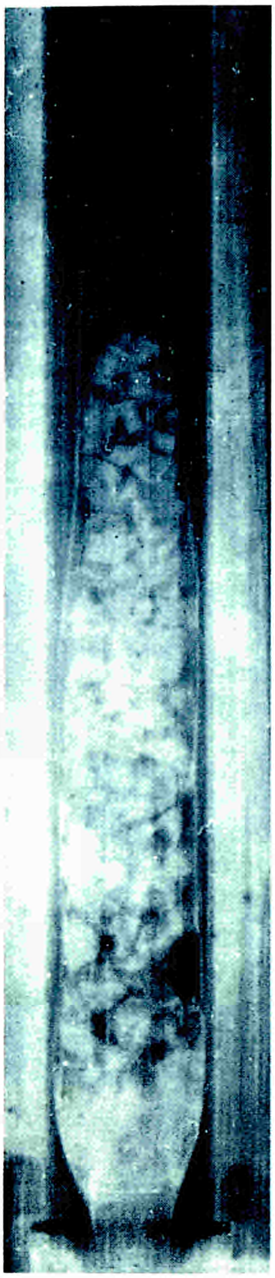


Fig. 9
Neutron radiograph of a ballooned fuel rod of an ISOLDE test

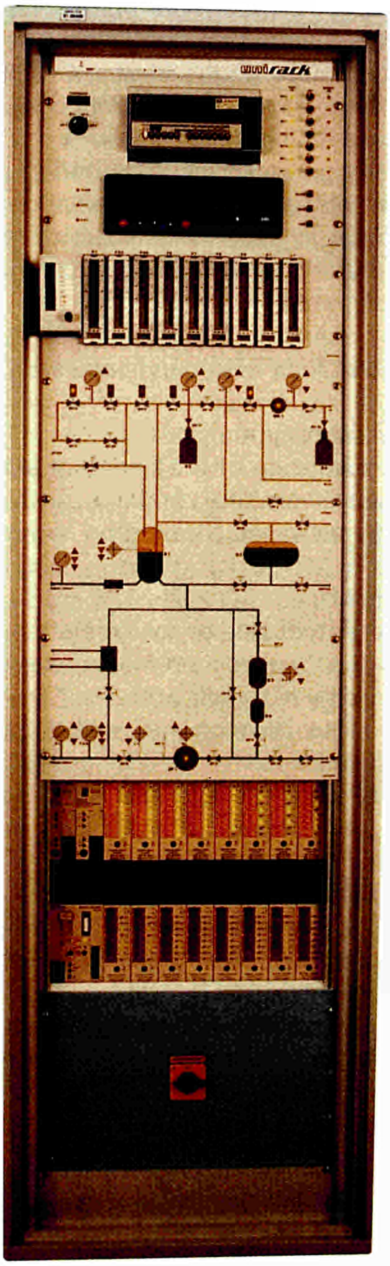


Fig. 10
New central control unit of the LWR fuel irradiation facilities (BWFC)

Development of LWR fuel testing devices

- The out-of-pile testing of the ISOLDE capsule number 5 was performed in order to characterize its thermal behaviour prior to the in-pile test.
- A new electronic control and measuring system for the central unit of the BWFC-system A **(fig. 10)** was installed and commissioned. The new fast datalogger system for all BWFC-type experiments was made operational.
- Assistance was provided to the Petten hot cells for the introduction of the re-fabrication technique at the Petten hot cells for pre-irradiated LWR fuel rodlets produced from full length fuel rods originating from commercial power reactors /6/.

- IAEA Technical Committee Meeting on "In-core instrumentation and in-situ measurement in connection with fuel behaviour" was jointly organized and held at JRC Petten between October 26 and 28, 1993. The meeting was attended by 37 specialists from 16 countries and 2 international organizations.
- For a Technical Committee Meeting organized by the European Working Group on Irradiation Technology on "Fuel power measurement in experimental devices in research reactors", held in November 1992 at Saclay/France, a contribution on the Petten experience /7/ was prepared.

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.

Progress:
Conceptual studies for irradiation testing of:
- large CT specimen made from BWR vessel material,
- in-core materials and
- various components, metal and ceramics samples under LWR and gas environment were pursued or prepared and discussed with potential clients.

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

During the late 70s and early 80s, several international R&D programmes were initiated, 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 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 remained 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 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, although recently towards the end of 1992, there has been a general reduction in FBR support in Europe. Nevertheless, the current experimental programme at the HFR remains unchanged and will be completed, with some experiments continuing into 1995.

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. Both fresh and pre-irradiated fuel pins are used. The experiments are 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

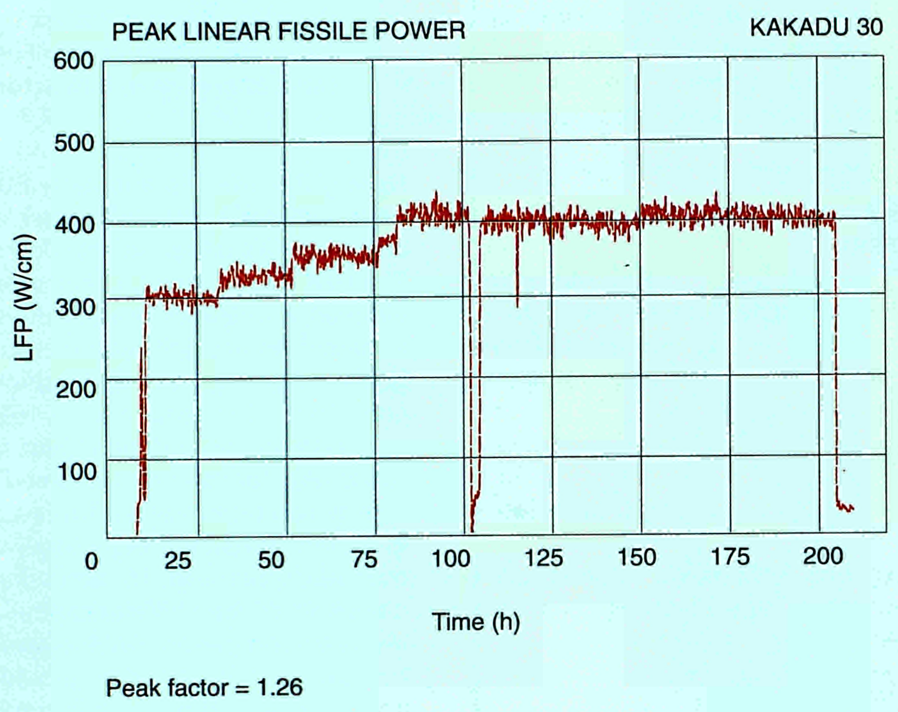

Fig. 11
Irradiation history in terms of peak linear fissile power for KAKADU 30

product kinetics in UO_2 fuel. This group of experiments is part of the JRC Specific Programme on Nuclear Fuels and Actinide Research.
A review of the FBR experiments and their facilities are presented in ref. /1/.

Progress:
Transient Tests

During the reporting period four experiments were irradiated, including 1 specific, short transient test.

KAKADU (project 183 - 30)

A special, short irradiation period of some 4 days, see **fig. 11**, was performed on an unusual fuel pin that contained a single, over-enriched fuel pellet (4x nominal enrichment of other pellets). The nominal peak linear fissile power was 400 W/cm. Following the irradiation scheme, it was apparent that the over-enriched pellet did not cause any overheating of the fuel cladding, which was considered by the Working Group on FBR fuel pin transient to be highly significant and a very useful result.

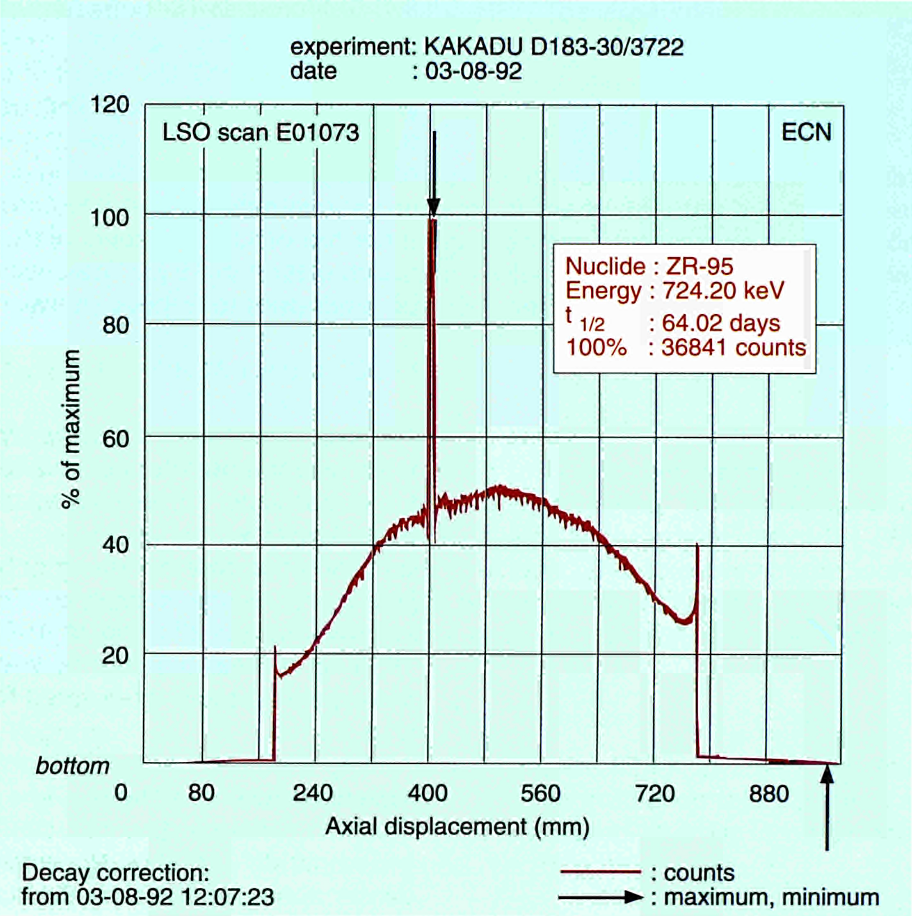

Fig. 12
Gamma spectrometry measurement of KAKADU 30 for the nuclide ^{95}Zr

In **fig. 12**, results of one of the many post-irradiation gamma spectrometry measurements is shown.
The extreme peaking, in this case for ^{95}Zr, is readily seen at the position of the over-enriched pellet.

SUPERKAKADU (project 183 - 55/56)

Preparations continued to repair the EUROS cell and modify the welding equipment. The cell will be used to load, encapsulate, sodium fill and weld seal, the pre-irradiated fuel pins /2/ for the next SUPERKAKADU experiments on 2 fuel pins. The irradiation is planned to begin in April 1993.

HYPERKAKADU (project 183 - 59/60/61/62)

Despite the fact that 3 pre-irradiated extra long fuel pins arrived at Petten from Dounreay towards the end of the year, the announced, untimely withdrawal of the UK support to the EFR project, has caused the cancellation of this most valuable irradiation experiment. The pins will be returned to Dounreay in 1993.

POTOM (projects 184)

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, and one OPOST (overpower steady state) experiment, three more POTOM experiments, nrs. 4 - 6, are currently being prepared for irradiation in 1993. These experiments will accumulate different burn-up levels prior to a special transient.

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. In previous years three experiments have been completed and reported.
Currently the fourth experiment, RELIEF 13, which began irradiation in February 1990, is in progress. The experiment has attained almost 5.0 at.% burn-up at the end of 1992. A first transient will be performed in 1993 on achieving 5.0 at.% burn-up. Due to some technical problems, the experiment was interrupted for most of the year, and has only recently re-started.

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 programme on "Optimisation of Dense Fuels" at the Institute for Transuranium Elements (ITU), Karlsruhe, 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 of 3 fuel pins each, were irradiated during 1992. The experiment NILOC 3 irradiated 2 mixed nitride fuel pins and 1 mixed oxide pin, containing UN breeder pellets. The irradiation period was 2 reactor cycles, at peak fissile powers up to 522 W/cm. Burn-ups of 1.0 at.% were reached. NILOC 4 irradiated 3 nitride pins, but of "fatter" proportions. As such, peak linear fissile powers of up to 960 W/cm were reached, with no apparent detrimental effect on the fuel pin behaviour. The irradiation period was one reactor cycle, thus attaining 0.5 at.% burn-up.

POMPEI (project 226)

The POMPEI fuel pin finally arrived at Petten, after a lengthy delay that was primarily caused due to the complex manufacturing route for the nitride fuel pellets. Also, it was decided at ITU to include 3 pellets containing 100% Tc, 50:50% Tc:Ru and 20:80%, Tc:Ru. The latter 3 pellets are part of a pathfinding irradiation to investigate transmutation of actinides by radiation in reactors, such as the HFR. The experiment is planned to start in 1993.

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 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. This is required in order to obtain the temperature of 823 K at a peripherical reactor position.

Two legs of the TRIO contain fatigue specimens and the third leg tensile-creep specimens. These three legs (139 - 597 - 598 - 599) were irradiated in position H8 in cycle 92.03 for one cycle. Specimens were dismantled in June and post-irradiation examination started in September 1992.

Project 268

Objective:
This is a continuation of the previous series of experiments with 316 L(N) steel as material for 823K irradiation temperatures, in position H8.

Progress:
Three legs 601-602-603 were designed in the first half of 1992. Manufacturing finished in November 1992. Irradiation will take place in cycle 93.02.

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

Funding by government for R&D of the German High Temperature Reactor (HTR) Technology has been terminated by the end of 1992. However, Siemens will continue marketing of the HTR-Module on small scale. Some tests will therefore be continued which are either under irradiation or for which commitments have been made. The following typical HTR-Module materials are being tested in the HFR Petten /1/.

- spherical fuel elements with low-enriched uranium (UO2) TRISO coated particles, and
- graphite as a predominant core structural and fuel element matrix material.

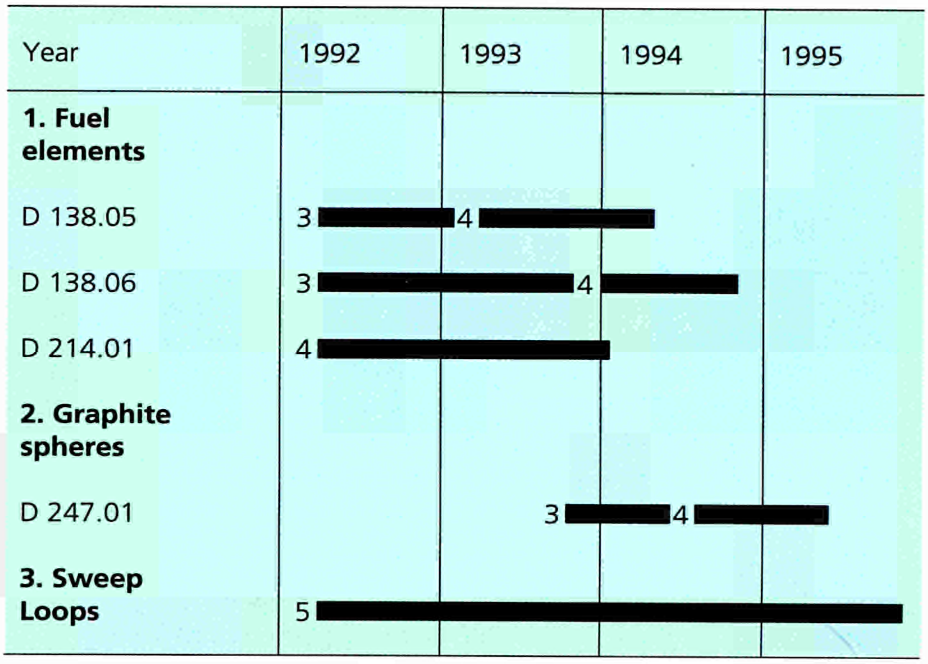
Work for the US-HTGR continued in 1992 under the "Umbrella Agreement" on the collaboration in HTR R&D within the civil programme between Germany and USA /2/.

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 German UO_2 low-enriched uranium (LEU) fuel cycle /3/. 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.

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 in the HFR Petten under conditions as close as reasonably achievable for HTR power plant characteristics, 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, burnup or fast neutron fluence and the confirmation of low "free heavy metal" (uranium and thorium) contamination of the fuel element matrix material by natural impurities and/or by defective coated particles. Therefore, the irradiation capsules are operated with 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



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

($10^{-10} < R/B < 10^{-1}$), as well as for on-line gas chromatographical analysis of the downstream purge gas.
A survey of activities for HTR fuel testing at the HFR Petten is given in **table 4**.

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 for the HTR-Module with three independently controlled capsules (BEST-rig design) continued in 1992. On-line fission gas release measurements were daily performed. 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^{-6} to 10^{-5}, which corresponds with the release of two defective particles (failure caused by manufacture). The cumulative burn-up was 8.9% fima and the cumulative neutron fluence was $4.2 \times 10^{25} m^{-2}$ (E>0.1 MeV) after 558 full power days.

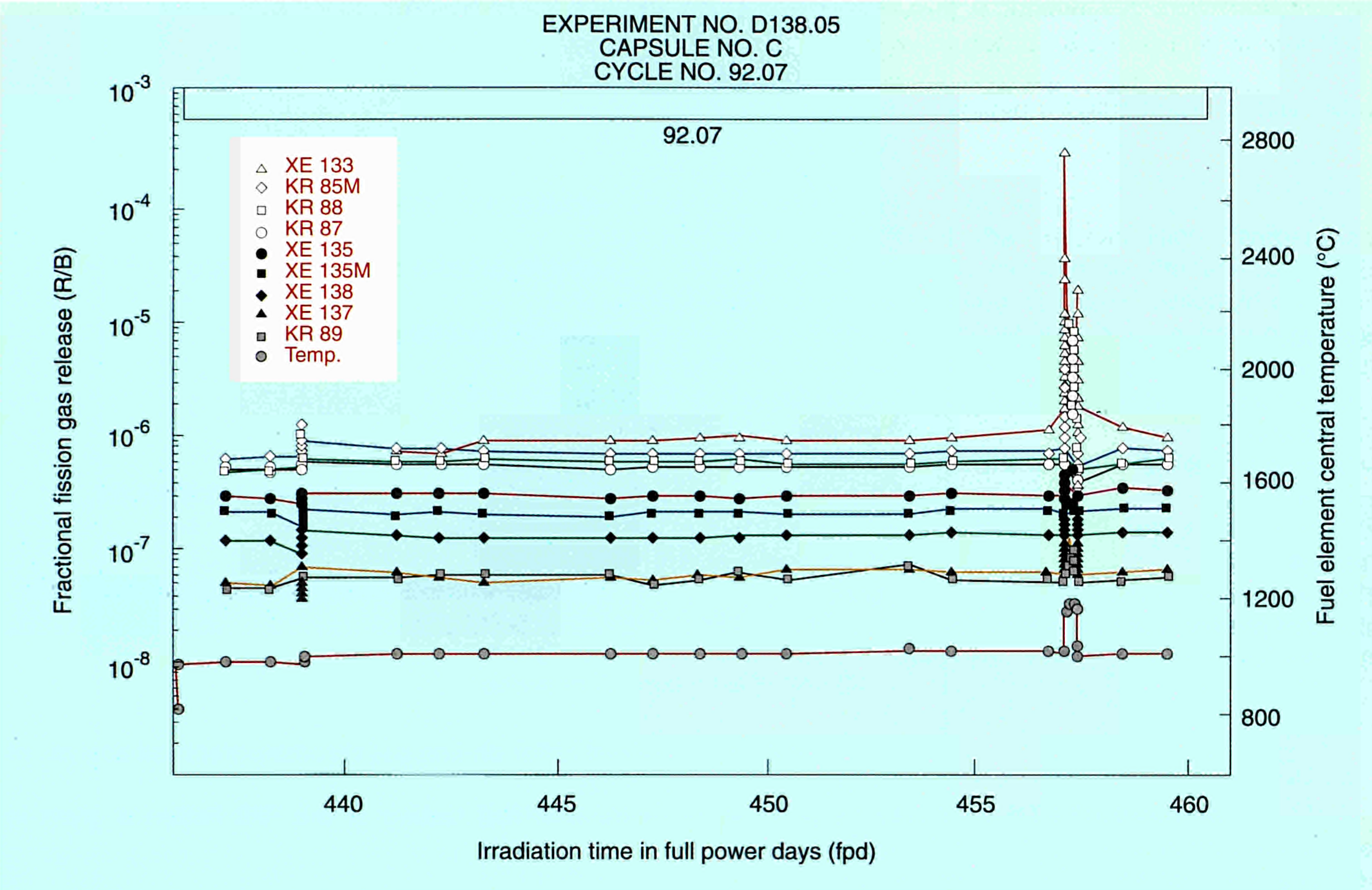


Fig. 13
Fractional fission gas release (R/B) and temperature history of capsule C during cycle 92.07 with one temperature transient from 1000 to 1200°C for a period of 5 hours. Reference test 138.05

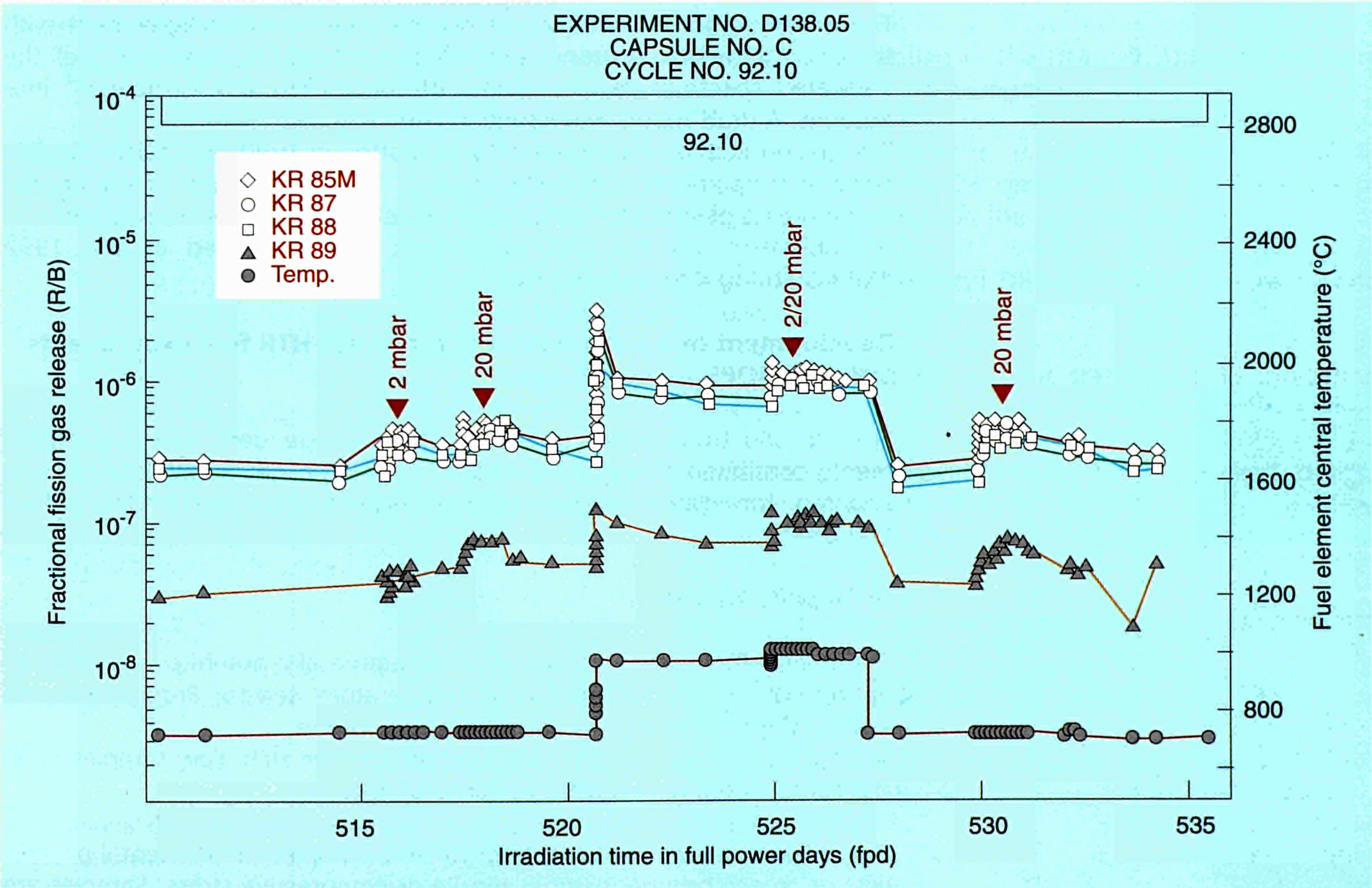
Temperature transients from 1000 to 1200°C maximum fuel element temperature were performed in all capsules during a period of 5 hours in cycle 92.07. The objective of these simulated temperature transients (ΔT=150-200K) is to evaluate the fission gas release data with existing models. The release of gaseous fission products was measured with high frequency (300 s intervals) during the entire transiental period. The history of fission gas release of capsule C for cycle 92.07 is given in **fig.13**. Diffusive release of gaseous fission products and spontaneous release of stored gas from closed pores superpose at temperature transients. The stationary values are again obtained after the transient is completed. The spontaneous release is especially pronounced at fast transients and for long-lived isotopes. The release data for transient conditions are the basis for the description of the radiological hazard resulting from fission gas release from defect particles at accidental conditions.
Water vapour injections /4/ were performed during cycle 92.10 in capsules A and C to simulate accidental conditions. The water vapour concentrations in the helium/neon purge gas was varied between 2 and 20 mbar six times during periods between 5 and 24 hours. The fission gas release was measured during the water vapour injection periods with 200 s intervals. Evaluation of the experimental data is proceeding. The frac-

tional fission gas release (R/B) history of capsule C for cycle 92.10 is shown in **fig.14**. The temperature history and the water vapour injection periods are indicated in this figure.
The irradiation is planned to be terminated with cycle 93.03.

Project 138.06

The irradiation of the second reference test for the HTR-Module with three independently controlled capsules (BEST-rig design) continued in 1992. On-line fission gas release measurements were daily performed. 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 around 10^{-6} which corresponds with the release of one defective coated particle (failure caused by manufacture). The irradiation had to be interrupted during the cycles 92.01 through 92.09 due to a double occupation problem in the H-row core positions.
The cumulative burn-up was 4.2% fima and the cumulative neutron fluence was 1.7 x $10^{25}m^{-2}$ (E>0.1 MeV) after 219 full power days. The irradiation is planned to be terminated in 1994 after 23 HFR cycles.

Fig. 14
Fractional fission gas release (R/B) and temperature history of capsule C during cycle 92.10 with several water vapour injections. Reference test 138.05



Irradiation of SiC-coated graphite spheres (project 247.01)

Objective:
Coating of the surface of spherical fuel elements with a SiC layer 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 in the temperature range 873 to 1273 K up to a fast neutron fluence of $2.6 \times 10^{25} m^{-2}$ (E >0.1 MeV).

Progress:
Problems are still encountered in preparing the SiC-coated spheres. The assembly and the irradiation start are delayed therefore until the end of 1993.

Irradiation of fuel rods for the US-HTGR

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

Fine-dismantling and PIE of two capsules (B and C) continued in 1992 at the Hot-Cells of KFA Jülich. The transport of the third capsule (A) from KFA to ORNL laboratories has been cancelled. PIE of that capsule will take place in the Hot-Cells of KFA during 1993.
The initially reported neutron fluence data were not in agreement with the calculated data. A proper evaluation is proceeding, taking as well the dedicated spectrum measurements of the "1986 flux campaign" into account. A draft report was issued in late 1992.
The final irradiation report, which was drafted in 1990, was further elaborated in cooperation with ORNL. Issue of the final revision of the irradiation report is planned for 1993 when all relevant PIE data are received.
A publication on the 214 experiment was presented at the 1992 "Jahrestagung Kerntechnik" /5/.

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

Smooth and trouble free operation of six independent HTR fuel experiments continued during 11 cycles in 1992. The gas supply station was adapted for water vapour injection experiments, see under project 138.05.

b) Graphite Irradiations

The development and qualification programme of a graphite to provide a design base to the German High Temperature Reactor Programme was launched twenty years ago and is reaching its end.
A large number of samples was irradiated in the HFR. Few samples must still be irradiated to complete the programme.

The irradiation capsules contain unstressed samples (fundamental properties) or creep specimens under tensile or compressive stress. Samples are irradiated in three to four fluence steps, with intermediate measurements of their 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 x 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 x 10^{25} m^{-2} (EDN) at higher temperatures, ranging from 773 to 1473 K.

Progress:
Two experiments ended irradiation in 1992:
- Experiment D85-56II (723 K) which started irradiation in cycle 90.03. The irradiation ran without problems. As foreseen the sample holder was unloaded at the end of cycle 92.04. After a total fluence of 1.6x10^{26} m^{-2} (EDN). Two reactor positions (C7 and E5) were used for this experiment.
- Experiment D85-59 (1173K) which started irradiation in cycle 91.07. The irradiation lasted 8 cycles in position C3. Samples reached a dose of 3.8 x 10^{25} m^{-2} (EDN).

Both sample holders were dismantled in the DM cell. The samples were then shipped to KFA Jülich, where PIE is ongoing.

The experiment D85-63 (873K) started irradiation in cycle 92.08 in position C3. It will be irradiated for 26 cycles up to a total fluence of 1.2 x 10^{26} m^{-2} (EDN). Temperatures lie in the specified range.

Two sample holders D85-64 (573K) and D85-67 (1023K) are ready and are waiting for samples.

Table 5 presents a summary of the current status of D85 irradiation series.

All the other experiments presented in /2/ have been cancelled, due to shrinkage of the German programme.

Table 5
Graphite fundamental properties programme. Survey 1992-1994

Exp. number	Irradiation period	Irradiation temperature (K)	Status
D85-63	October 92 - December 94	873	under irradiation
D85-64	to be communicated	723	waiting for samples
D85-67	to be communicated	1023	waiting for samples

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

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 have been irradiated under stress in the HFR up to very high fluences and over the temperature range 570K to 1170K. Creep measurements have been taken out-of-pile at intervals of irradiation.

Progress:
The experiment D156-96 started irradiation in cycle 91.11 and ended in cycle 92.04. This experiment, belonging to D 156-90 series (graphite ASR-1RS, 5MPa tensile stress) was the second step of a temperature change experiment.

The samples have been irradiated at 1170K up to $3.8 \times 10^{25} m^{-2}$ (EDN) in the first step and at 770K up to $2.4 \times 10^{25} m^{-2}$ (EDN) in the second step.

The design of the experiment series D156-70, 770K, 5MPa tensile stress is ready. This will be 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. Decision of the sponsor on the prosecution of the experiment is waited for.

References
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Paper presented at the ANP'92, Tokyo, October 25-29, 1992

/2/ J. Ahlf, A. Gevers (editors)
Annual Report 1991. Operation of the High Flux Reactor
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/3/ 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

/4/ R. Conrad, R. May, T. Timke
A modular designed facility for controlling purge gas chemistry of in-pile experiments.
Poster presentation for the International Conference on Irradiation Technology, May 20-22, 1992, Saclay, France

/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.
Paper presented 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/ITER design and towards future demonstration plants (Demo). 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.

Recently attention is also devoted to investigation of irradiation effects on whole components, like the in vessel inspection system of JET (consisting of cameras, lenses, cables, motors etc.) and the magnet insulation system of the same machine.

Unstressed Austenitic Stainless Steel (incl. AMCR) Irradiations

Project 139 (139-6 series)

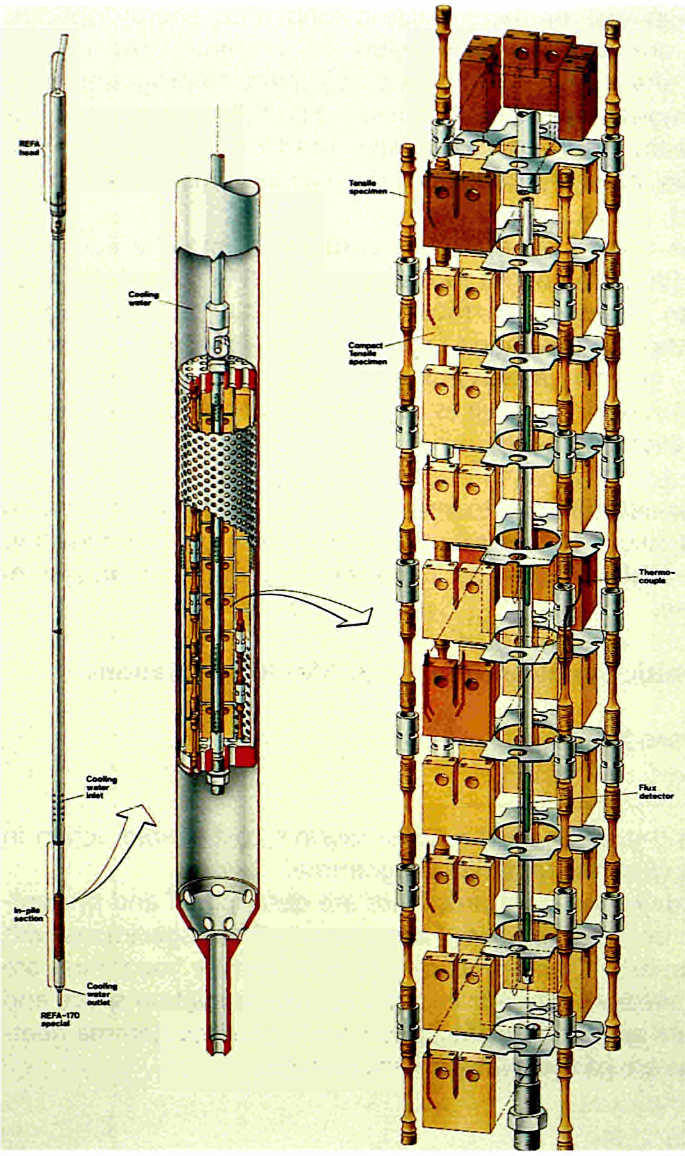
Objective:
ECN participates in the frame of the Commission's cost shared action in the European Fusion Reactor Materials Programme.
A number of candidate materials' properties are determined and presented as a comparison between irradiated and non-irradiated specimens with identical heat treatment. Crack 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 139-664 started in 91.08 and terminated in cycle 92.10.
The capsule lay-out of the experiment is shown in **fig. 15**.

SINAS (project 139-69)

This experiment consists of 8 sample holders of NET construction material, with 10 CT specimens in each holder. The specimens are in contact with liquid metal, sodium. This is necessary to minimise the temperature gradients within the CT specimens. **Fig. 16** shows an artistic impression of the



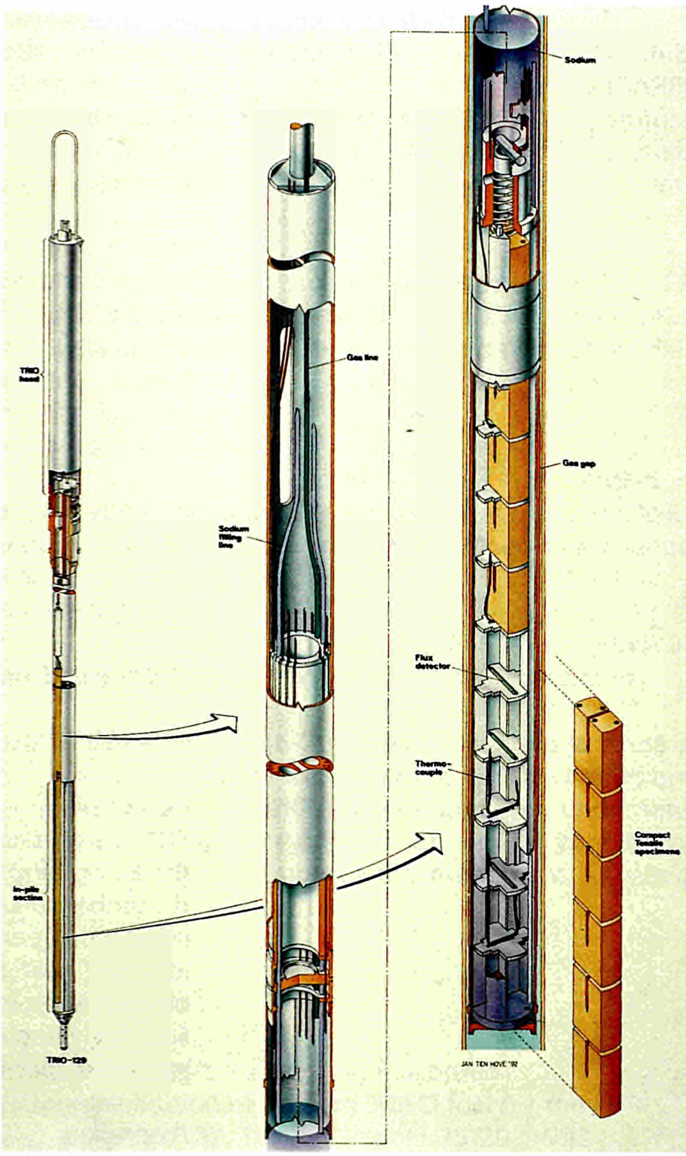


Fig. 15 (left)
General arrangement drawing of the SIWAS irradiation capsule
Fig. 16 (right)
General arrangement drawing of the SINAS irradiation device with compact tensile specimens

sample holder. The irradiation temperature is 525 K at different fluence levels (irradiation positions F8 and F2) for 5 dpa and 0.3 dpa. Irradiation of legs 692-693-695 started in cycle 90.08 and finished in cycle 92.02, in position F8. Irradiation of legs 697-698 started in cycle 92.04 and 699 in cycle 92.08, in position F2 and will finish in cycle 93.05

Projects 198-16 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)
- 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 core position C5. The capsule was definitively unloaded at the end of cycle 92.07.

JRC - IAM experiment:
Two sample holders belonging to the experiment E198-16, (temperatures: 525K, 723K) were unloaded at the end of cycle 92.07, having reached the total damage of 15 dpa.
Materials irradiated (IF alloys) are listed in **table 6**. Samples will be recovered early in 1993, and then shipped to IAM-MPR for PIE.

Table 6
Chemical composition of optimized Cr-Mn stainless steels presently irradiated in the SIENA capsule

	IF-B	IF-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 experiments:
The new experiment series R139-68/7, 8 and 9, launched at the end of 1991 was irradiated during 1992. Samples were irradiated at 525K and unloaded after damages of 1 dpa (R139-68/7) and 5 dpa (R139-68/8 and 9). The materials irradiated (316L) are listed in **table 7**.

The SIENA capsule will not be used anymore in the future. It will be replaced by a new type of insert called TRIMURTI. All sample holders irradiated during 1992 are listed in **table 8**.

Stainless steel irradiation for ENEA, SIRENA (project 250)

Objective:
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, both base and electron beam welded material in view of its use in the Next European Torus /6/.
Tensile (Ø 10, l=45 mm), charpy (27x3x4 mm) and CT (29x27x10 mm) specimens have been irradiated at 523K up to 0.15 and 2.5 dpa.

Table 7
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 8
Samples irradiated in the SIENA capsule during 1992

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
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

Progress:
The irradiation campaign ended in 1992. One sample holder (0.15 dpa) was unloaded in January 1992 (cycle 91.11). Samples were shipped to ENEA for PIE in May 1992.
The second sample holder (2.5 dpa) ended irradiation in cycle 92.08. The samples were recovered and shipped to LSO for storage. Transport to ENEA is foreseen in February 1993.

Brazings irradiation, BRAIN (project 252)

Objective:
The Italian organization ENEA, is investigating also the irradiation behaviour of Ni-brazings on AISI 316L.
The samples (tensile, Ø 8, l=56 mm) must be irradiated at low temperature (353K) and at one fluence value (0.7 dpa).

Progress:
The irradiation took place in the period November 1991 - March 1992 (cycles 91.10 up to 92.02). Samples were recovered from the sample holder in May 1992 and shipped to LSO where post-irradiation experiments were conducted in September/October 1992.

Fusion reactor materials irradiations for ECN, FURIAE (project 275)

Objective:
The experiment, sponsored by ECN falls also in the frame of the programme for the characterisation and development of first wall materials.

Miniaturised tensile specimens (Ø 4, l= 45 mm with a thread M6 x 0.75 on the head) are irradiated up to 1 dpa at a temperature of 673K. Tensile tests take place at the end of the irradiation.

Progress:
A special insert called TRIMURTI (TRIO modified for fusion reactor materials irradiations) was designed and manufactured. The insert placed in a wet channel of a TRIO capsule allows the simultaneous irradiation of three sample holders containing miniaturized tensile samples (9 per sample holder) like those of the FURIAE experiment. The sample holders are located in three independent channels of the TRIMURTI insert.

Two sample holders were designed and manufactured in 1992. They will start irradiation in cycle 93.01 in position E7 of the reactor.

MANET irradiations, MANIA (project 276)

Objective:
Characterisation/development of MANET steel for use in fusion reactors.

This experiment series foresees irradiation of miniaturized tensile samples at low temperature (353K) and at intermediate temperature (573K). Damage foreseen is 1 dpa.

Progress:
The irradiation device is a TRIO capsule provided of a TRIMURTI insert modified to allow the achievement of low temperature in one of its legs.

The modified insert is in preparation. Three sample holders (two for 573K and one for 353K) are ready. Two further sample holders (again 573K) will be available in 1993. Irradiation start is foreseen in March 1993.

Creep Testing of Fusion Materials (Austenitic Stainless Steel)

Objective:
Two irradiation facilities, namely TRIESTE and CRISP, were developed to study the effects of neutron irradiation on the creep behaviour of different steels (austenitic stainless steels, manganese containing steels and nickel based steels) as candidate structural materials for the first wall of NET.

Progress:

Intermittent creep measurement, TRIESTE (project 167)

The experimental TRIESTE programme comprises nine irradiation facilities, each irradiated for various steps with dimensional measurements on the individual tensile samples performed in hot-cells between the irradiation steps. The irradiation series E167-10 up to E167-90 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 irradiation. Irradiation samples and half-shell pairs are manufactured from different materials (AMCR-0033, AMCR-0034, AMCR-0035, AISI 316L, AISI 316, DIN 7758, DIN 7761, DIN 7763, PCA).

The following activities were pursued in 1992:

- Experiment E167-67 and E167-74 were irradiated for one cycle. Elongation of the samples was measured in the hot-cells.
- After assessment/evaluation of the available data it was decided to continue only irradiations at low temperature (350K). In this respect, experiment E167-82 was irradiated for two cycles and experiment E167-83 was irradiated for 5 cycles. Elongation of the individual samples was measured in the hot-cells.
- Manufacture of experiment E167-90 has started. This experiment foresees again irradiation at low temperature (350K) of electron beam welded specimens. Irradiation start is foreseen in 1993.

In-pile creep measurement, CRISP (project 157)

The irradiation device CRISP allows simultaneous measurements of the creep elongation of three specimens in three different rigs. Strain measurements are taken semi-continuously by comparing the sample length with the length of unstressed reference pieces.

Project 157/14-16

The assembly of this set of sample holders is almost complete. The work has been suspended, waiting for a decision of the sponsor about the continuation of the irradiation campaign.

Table 9
Chemical composition of vanadium alloys

	series 1	series 4	series 7	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.

Irradiation of vanadium alloys, VABONA (project 204)

The three sample holders R204-7/8/9 belonging to the experiment series VABONA were loaded in the SIENA capsule in cycle 91.07. A list of the materials irradiated is given in **table 9**.
Samples were unloaded from the reactor at the end of cycle 92.04 having reached the target damage of 5 dpa.
Irradiation temperatures were: R204-7: 873K; R204-8: 973K; R204-9: 1073K.
After irradiation the samples were shipped to ECN-LSO were PIE is ongoing.

Other series of vanadium alloys were loaded:
- 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

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

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 production rate and lithium burn-up,
- Comparison of materials from different fabrication routes,
- 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 breeder materials for DEMO relevant blanket concepts. The selection of materials and concepts is planned to be taken by the end of the 1992-1994 European Fusion Technology Programme. The present irradiation tests should therefore be terminated by the end of 1994.
The present irradiation programmes for blanket breeder materials at the HFR Petten are summarized in **table 10**.

Irradiation of ceramic lithium compounds, EXOTIC (project 212)

The experimental programme EXOTIC is being carried out in the HFR Petten since 1984. The EXOTIC programme comprises manufacture, characterization, irradiation and pre- and post-irradiation examination of the Li-compounds $LiAlO_2$, 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. ECN Petten acts as project coordi-

TABLE 10
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

Year	1992	1993	1994	1995
1. EXOTIC				
EXOTIC-6	3 4			
EXOTIC-7	1 2	3		4
2. LIBRETTO				
LIBRETTO-2	4			
LIBRETTO-3	2 3	4		
3. Out-of-pile facilities	5			

nator. The EXOTIC project is carried out with strong international participation. NRL Springsfield and SCK/CEN Mol, as well JAERI and ANL participated in the first four EXOTIC experiments. CEA Saclay, KfK Karlsruhe, ENEA Casaccia and AECL participate in the present EXOTIC-6/7 irradiation tests.

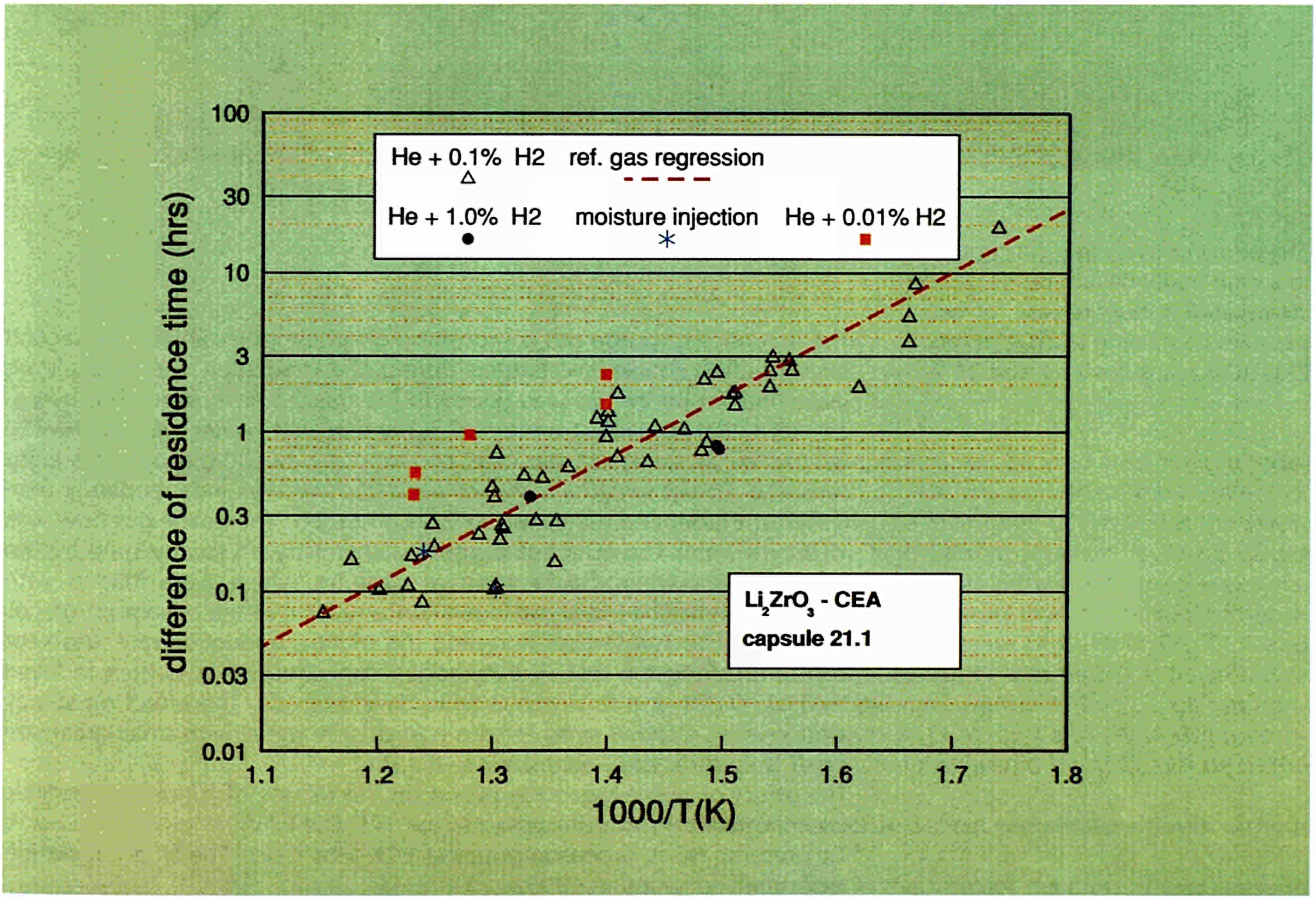
The European Fusion Technology Programme was reoriented in 1988. Three categories of irradiation experiments were defined, namely "short-, medium-, and -long-term" irradiations. One important goal was that all candidate ceramic tritium breeding materials should be tested in these tests. The "medium-term" experiments EXOTIC-5 and EXOTIC-6 were performed at the HFR Petten between 1989 and 1992. Those tests are defined as "medium-term" experiments which achieve a lithium burn-up of ~2-3%. The long-term irradiation experiment was originally planned to be performed in a fast reactor, but was transferred to the HFR Petten for a variety of reasons. A feasibility study demonstrated that lithium burn-ups of up to 10 % could be achieved within a one year irradiation in the HFR. The test will be performed under the name EXOTIC-7 in 1994.

EXOTIC-6 (project 212/21-24)

Objective:
Eight different ceramic lithium compounds were irradiated in eight independently controlled capsules with on-line tritium release measurements /1/. The objectives are almost similar with the EXOTIC-5 /2/, but with more emphasis on investigating the effects of purge gas chemistry on tritium release. The EXOTIC-6 experiment was provided with advanced techniques for temperature control, i.e. electrical heaters and two independent control gas gaps. In-situ tritium reductor beds were incorporated in each sample holder to reduce HTO traces into HT and forecome by this measure tritium losses due to tritium adsorption on the purge gas walls.

Progress:
The irradiation was terminated as planned after cycle 92.02. The irradiation lasted eight cycles. Typical performance data were: 199.32 full power days, lithium burn-up 3.2 %, fast neutron fluence 2.4 x 10^{25} m^{-2} (E>0.1 MeV). More than 1200 temperature or purge gas transients were performed to determine tritium release characteristics. The tritium production rate was changed by irradiating in different core positions with different thermal neutron fluence rates.
The temperature transients were performed in the range between 573 and 923K with positive and negative temperature steps ranging from 30 to 140K.
All relevant process data, including fast transients, are evaluated with computer codes which were developed by IAM Petten /3/. Information is obtained on the tritium residence times for positive and negative transients at different temperature levels. In-situ obtained tritium release characteristics are the most relevant data, which can be followed in the EXOTIC experiments during the course of the irradiation. The semi on-line evaluation allows us to plan the irradiation history in advance of a new cycle. As an example, the estimated tritium residence times of one capsule, loaded with Li_2ZrO_3 pellets, are plotted for the entire irradiation time in an Arrhenius diagram **(fig.17)**.

Fig. 17
Arrhenius diagram of tritium residence times for a capsule with Li_2ZrO_3 pellets.
EXOTIC-6, capsule 21.1



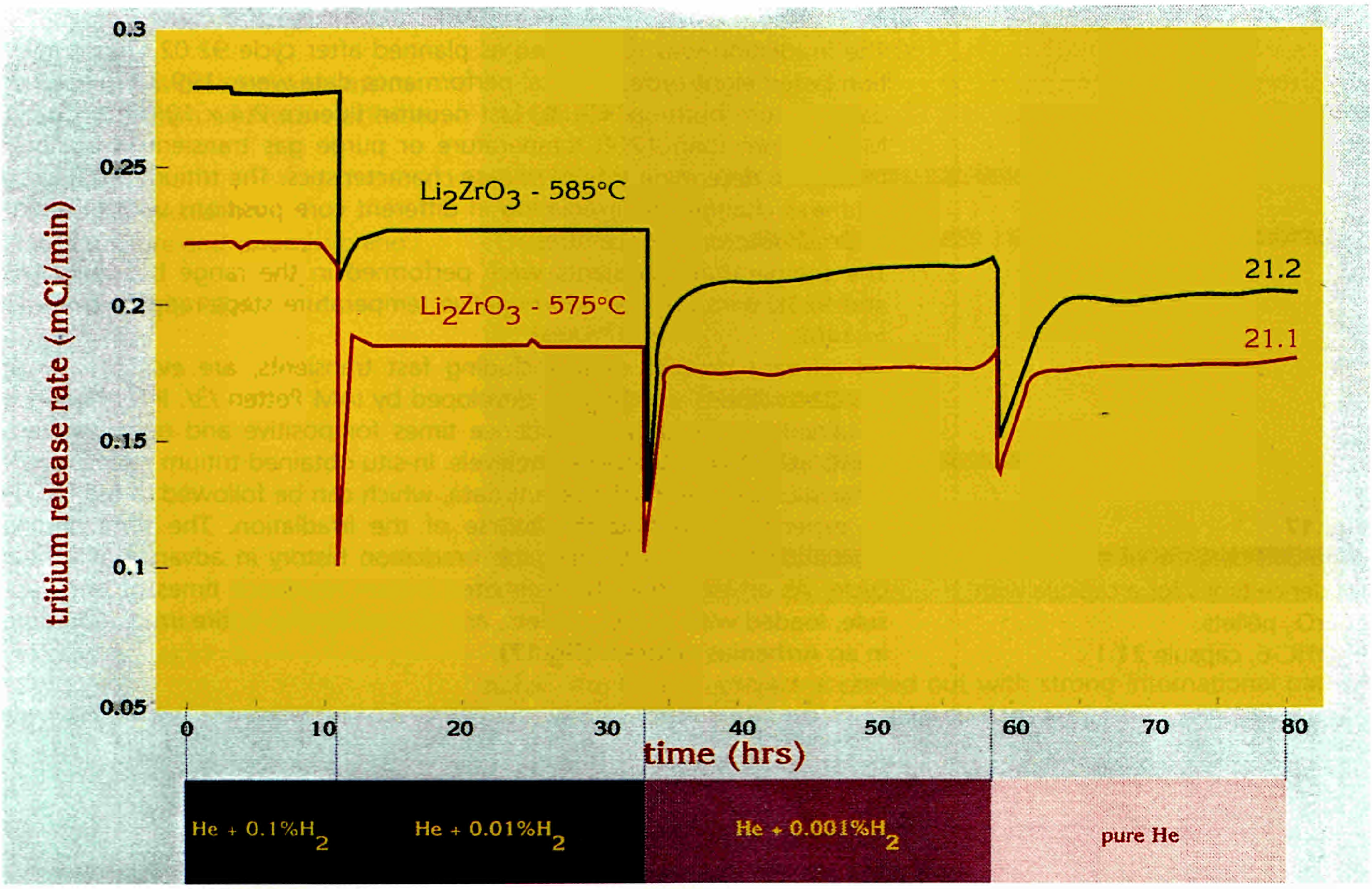


Fig. 18
The effect of hydrogen concentration in a high purity helium purge gas on steady state tritium release for two capsules containing Li_2ZrO_3 pellets. EXOTIC-6, capsules 21.1 and 21.2

The influence of purge gas composition on tritium release was the second relevant item to be investigated during the irradiation campaign. High purity helium purge gas was doped in the gas supply system with hydrogen (0, 0.001, 0.01, 0.1 and 1 vol %) and/or with water vapour (10-450 Pa partial pressure) /4/ and was continuously swept through the eight capsules. The downstream gas of each capsule was independently analyzed on tritium and water vapour concentration. The purge gas flow was ~100 cm^3/min. The effect of purge gas chemistry on steady state tritium release is shown in **fig.18** for two capsules which were loaded with Li_2ZrO_3 pellets. The initial hydrogen concentration in the helium purge gas was 0.1 vol%. The temperature and the tritium production rate was kept constant during the test. The hydrogen concentration was then reduced to 0.01, 0.001 and finally to 0 % in daily intervals. The effect on steady state release is rather small for this particular material with small grain size of ~1 μm and a small pore size of ~0.1 μm.
The effect of purge gas composition on the release of tritium for ceramic breeder materials was presented at the 17th SOFT /5/.
At present, PIE is proceeding at the ECN Hot Cells. The final irradiation report will be issued in 1993.

Table 11
Loading scheme of EXOTIC-7

Capsule no.	**25.1**	**26.1**	**27.1**	**28.1**
Material	Li_2ZrO_3	$Li_8Zr\ O_6$ (Li_6Zr_2O7)	$LiAlO_2$ doped	Li_4SiO_4
Material supplier	CEA	ECN	CEA	KfK
^6Li enrichment in %	50%	50%	50%	50%
Temperature in °C	350-700	400-700	400-700	400/550/700
Burnup Li in %	10	10	10	6.5
Purge gas	pure He, or He + X vol% H_2, or He + Y ppm H_2O			
Specimen shape	pellets	pellets	pellets	pebbles
Specimen dimensions in mm.	8 / 4	8 / 4	8 / 4	0.1 - 0.2

Capsule no.	**25.2**	**26.2**	**27.2**	**28.2**
Material	Li_2ZrO_3	Li_4SiO_4 + Be	$LiAlO_2$	Li_4SiO_4 + Be
Material supplier	AECL	KfK	ENEA	KfK
^6Li enrichment in %	50%	50%	50%	50%
Temperature in °C	350-700	400/550/700	400-700	600
Burnup Li in %	10	10	10	6.5
Purge gas	pure He, or He + X vol% H_2, or He + Y ppm H_2O			
Specimen shape	pebbles	pebbles	pellets	pebbles
Specimen dimensions in mm.	8 / 4	0.1 - 0.2 + Be Ø 2	8 / 4	0.1 - 0.2 + Be 0.1-0.2 + Be Ø 2

EXOTIC-7 (project 212/25-28)

Objective:
Eight different ceramic lithium compounds will be irradiated in eight independently controlled capsules with on-line tritium release measurements. The test matrix is given in **table 11**. The main goal of this test is the investigation of irradiation damage by high lithium burn-up. Burn-up values between 6.5 and 10 % are required from the different material suppliers. The required process parameter as temperature and purge gas composition varies between the suppliers. The materials of ECN, ENEA, CEA and AECL will be tested up to burn-ups of 10 % and within a temperature window of 623 to 973K with temperature transients and purge gas conditions as in EXOTIC-6. The materials of ECN, CEA and ENEA will be supplied in the form of pellets. The material delivered by AECL will be in the form of pebbles.
The materials of KfK will be tested at distinct temperature levels without transients.
The KfK material will be supplied in the form of pebbles. In two capsules

the pebble bed will consist of Li_4SiO_4 pebbles and Be pebbles, see **table 11**. Beryllium swelling and tritium retention in beryllium will be tested in capsule 28.2, whereas tritium retention will be investigated in the material of capsule 26.2. Provisions are made in the design of capsule 28.2 to measure Be-swelling during irradiation. This will be realized by measuring continuously the radial temperature gradient which is a direct measure of the thermal conductivity of the pebble bed. Be-swelling will enhance the thermal bonding of the Be-spheres and therefore reduce the temperature gradient.
The EXOTIC-7 experiment will be designed as the previous experiments with advanced techniques for temperature control, purge gas control and tritium measurements.

Progress:
Requests for the design and the irradiation of EXOTIC-7 were received by IAM Petten on basis of the positive outcome of feasibility studies concerning required lithium burn-ups. Proposals and commercial offers concerning design and irradiation were prepared and submitted to ECN. Design work started in 1992 on basis of the test matrix shown in **table 11**. The required irradiation conditions can be achieved in core position H6 for an irradiation period of ~11 cycles. Irradiation start is planned for the end of 1993.

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

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 objectives of the LIBRETTO experiments are the 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 tritium permeation barriers. The results of the LIBRETTO experiments are relevant for DEMO relevant liquid blanket breeder concepts.
Three irradiation campaigns have been performed since 1987. The work for the first two experimental campaigns has been terminated in 1992. The work for the LIBRETTO-3 experiment is being described hereafter.

LIBRETTO-3 (project 224/09-12)

Objective:
The LIBRETTO-3 experiment comprises four independent experiments. The loading schemes and the characteristics of the four experiments are given in **table 12**. The four independent experiments were simultaneously irradiated in one irradiation rig. Each capsule was filled with ~3 cm^3 of the eutectic breeder material Pb-17Li. The material of the capsule walls was AISI 316L. Three capsule walls were coated with tritium permeation barriers (TiC or Al_2O_3) either on the outside or on the inside. The alloy of each capsule was contained by three independent containments. The containments were connected with independent gas circuit of the Tritium Measuring Station, which provides the entire surveillance of the experiment with eight independent on-line measuring trains for quantitative measurement of the release of tritium.

The main objectives of the LIBRETTO-3 experiment were to study under irradiation tritium release from encapsulated Pb-17Li either by direct extraction from the alloy with a purge gas or/and by permeation through the capsule walls. The effectiveness of the permeation barriers should be tested at the same time.

Table 12
Loading scheme of LIBRETTO-3

Capsule No.	09	10	11	12
Test material	Pb-17Li	Pb-17Li	Pb-17Li	Pb-17Li
Material supplier	JRC Ispra	JRC Ispra	JRC Ispra	CEA Saclay
Purged by	bubbling	bubbling	bubbling	bubbling
Cladding material	AISI 316L	AISI 316L	AISI 316L	AISI 316L
Permeation layer	no	yes TiC outside	yes Al_2O_3 inside	yes Al_2O_3 inside
Li^6 enrichment	7.5%	7.5%	7.5%	7.5%
Specimen volume cm^3	3.082	2.946	3.059	2.915
Ratio diameter/length	0.1	0.1	0.1	0.1

The following process parameters were varied:
- Temperature in the range 543K to 823K
- Purge gas flow in the range 0 - 100 cm^3/min
- Purge gas composition, high purity helium + 0 - 1 vol% H_2 and/or partial pressures for water vapour between 10 to 500 Pa
- Different operation schemes.

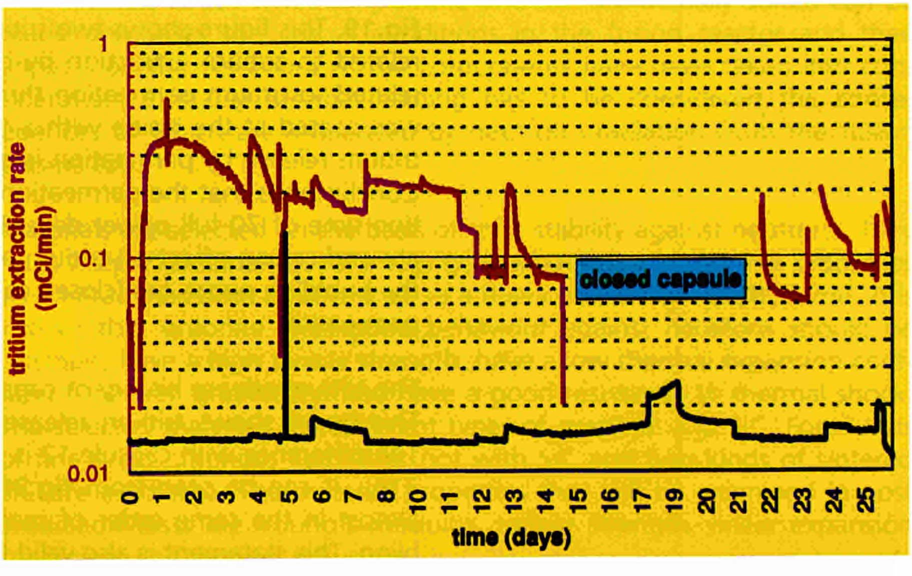


Fig. 19
Tritium release history of capsule 12 during cycle 92.06. The release curves for tritium extraction by bubbling and by permeation are shown. LIBRETTO-3

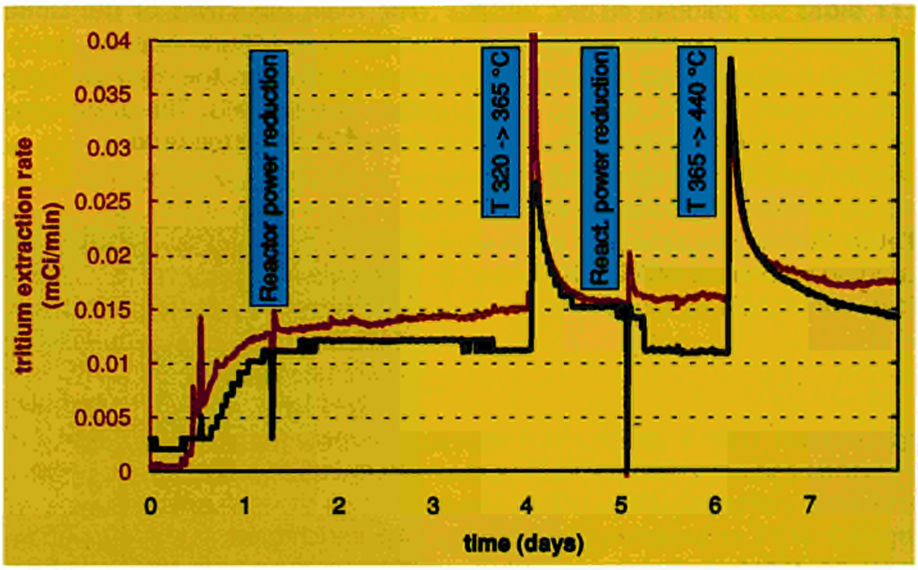


Fig. 20
Tritium release history of capsule 9 during cycle 92.06. The release curves for tritium extraction by bubbling and by permeation are shown. LIBRETTO-3

The variation of operation schemes consisted either of direct tritium extraction from the alloy by bubbling the purge gas through the alloy or by closing the primary containments and by measuring tritium permeation rates through the capsule walls by purging the secondary containments. Tritium concentrations were analyzed in the out-of-pile measuring trains.

Progress:
Assembly and commissioning of the LIBRETTO-3 experiment was completed in early 1992. Irradiation started successfully with cycle 92.04 and was terminated as planned after cycle 92.06. The cumulative burn-up of lithium was 1.1% and the cumulative irradiation time was 76.57 full power days.

The tritium release history of capsule 12 for cycle 92.06 is shown in **fig.19**. This figure shows two tritium release histories; one release curve is related to tritium extraction by bubbling and the other release curve is related to tritium permeation through the capsule wall. The capsule wall was coated at the inside with a tritium permeation barrier of Al_2O_3. The tritium release by permeation is one magnitude lower than for bubbling. Conclusion is that the permeation barrier is effective, also after an irradiation time of 70 full power days. Temperature transients have an immediate and strong effect on tritium extraction by bubbling. Flow stoppage of the bubbling purge gas (closed capsule) has only little effect on the tritium permeation.

The tritium release history of capsule 9 for cycle 92.06 is shown in **fig.20**. This figure shows tritium release histories by bubbling and permeation. The difference with capsule 12 is that the capsule wall was un-coated AISI 316L. It can be seen from **fig.20** that tritium released by permeation is almost in the same order of magnitude as for direct extraction by bubbling. This statement is also valid for temperature transients.

It must be concluded from these observations that tritium permeation through containments is an important safety issue and must be considered in the design of liquid blankets.

The LIBRETTO sample holders were prepared for transport to the ECN hot-cells. The sample holders will be dismantled there and the alloy containing capsules will be recovered and prepared for transport to the Ispra site. The entire post-irradiation examinations will be managed and performed by IST Ispra.

The final irradiation report will be issued in 1993.

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

In the frame of the European Fusion Reactor Materials Research Programme 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.

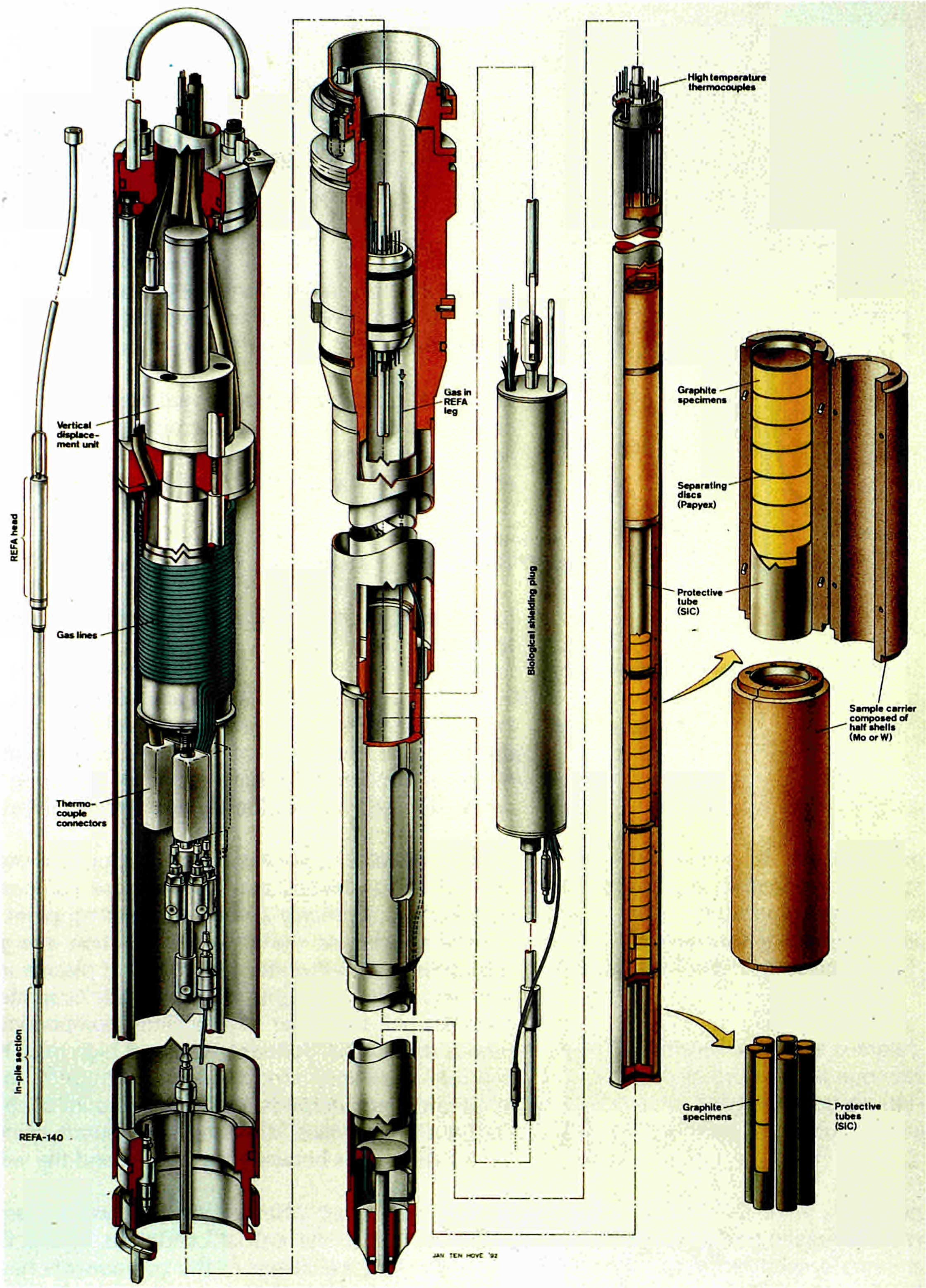


Fig. 21
Detailed loading arrangement of experiment 217-16

Project 217 - 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:
The sample holder 16 was dismantled and specimens were transported back to KFA in September 1992. An arrangement of the irradiation device is shown in **fig. 21**. It is seen that the sample holder was made with molybdenum half shells to facilitate the dismantling.

Project 217 - 17-18-19

Objective:
This experiment is a continuation of the previous series of experiments, but at lower irradiation temperatures, 873K, 1073K and 1273K and a target dose of 1 dpa.

Progress:
Irradiation of leg 17 started in cycle 92.08 and will be finished in cycle 93.01, in position G7. The irradiation temperature is 1073K and the dose 1 dpa. Assembly of legs 18-19 finished in November 1992. These two legs will be irradiated in cycle 93.03.

Project 217 - 20

Objective:
Within the scope of the European Fusion Technology Programme, KfK/IMFI is investigating various ceramic insulator materials (AlN, Al_2O_3, $MgAl_2O_4$) for the construction of millimeter-wave windows in plasma heating systems.
In view of the major role that the resistance to thermal crack formation plays for the technical applications, the following material properties have to be determined on neutron-irradiated samples: thermal conductivity, Young's modulus, bend strength, and thermal shock resistance. Swelling (volume increase) is included under more basic aspects. The required fluence is $3x10^{25}$ n/m^2 (E>0.1 MeV) at relatively low irradiation temperatures.

Progress:
Irradiation of the experiment started in cycle 90.10 and finished in cycle 92.03. Dismantling of the specimens finished in November and transportation of the specimens to KfK will take place in January 1993.

Irradiation of ceramic insulator materials at cryogenic temperatures (project 283)

Objective:
As part of the European Fusion Technology Programme it is demonstrated that present materials cannot provide the combination of low dielectric absorption and high resistance against thermal crack formation which is required to safely transmit 1MW/cw power at 145 GHz through a conventionally cooled window. Development of cryogenically cooled windows is currently under progress at KfK, because dielectric loss decreases and thermal conductivity increases strongly as temperature decreases below room temperature. The target is to define tolerable fluence levels by performing irradiations at 10^{16} to 10^{18} n/cm^2, E >0.1 MeV, at cryogenic temperatures. The materials to be irradiated are high purity single crystalline Al_2O_3 and SiO_2.

Progress:
A feasibility study started in December 1992. The irradiation is expected to take place in the pool side facility at the end of 1993.

Camera irradiation in a neutron field for JET, CARIATIDE (project 270)

Objective:
JET (Joint European Torus) makes use of an in-vessel inspection system (IVIS) to ascertain damages at its structures after plasma burning phases. IVIS consists of cameras, cables, motors, lenses, mirrors which must operate in an environment in which a mixed gamma and neutron field is present.
All the components of the equipment will be tested at HFR before final installation in JET takes place. Each component will be irradiated at five fluence levels ($3x10^{18}$,$1.2x10^{19}$, $4.8x10^{19}$, $2x10^{20}$ and $8x10^{20}$ n m^{-2}).

Progress:
An irradiation device consisting of various cylindrical layers has been designed and manufactured. It is installed on a rack which occupies positions PSF 2,3,4. Appropriate shieldings (B4C and lead) allow the tailoring of the neutron spectrum and the removal of gammas.

Two REES cameras were irradiated in cycle 92.10. Both failed at very low neutron dose ($3x10^{17}$n m^{-2}) confirming some experimental results on neutron damage of electronic components performed at CERN. Irradiation of lenses and cables is ongoing. Results will be available at the beginning of 1993.

Epoxy resins irradiation, EPIRO (project 272)

Objective:
JET operation requires magnets for the plasma confinement. Magnet insulation consists of multiple layers of epoxy resin which, under neutron irradiation looses its properties and produces gas by radiolysis. In order to assess the resin damage an irradiation campaign has been launched, foreseeing 3 irradiation levels (10^5, 10^6, 10^7 Gy) of resin samples either contained in Al-boxes or in quarts vials.

Progress:
A device has been designed and manufactured for use in the PSF (PSF 2,3,4), with appropriate thermal and gamma shielding.
Gas produced by radiation damage is continuously measured during irradiation.

The preliminary irradiation to verify gas production and temperature values has been performed in December 1992. Prosecution of the programme is foreseen at the beginning of 1993.

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3.5. RADIOISOTOPES PRODUCTION

The radioisotopes production is now a well established reality in the IAM. This activity is a major contribution to the reactor occupation and an important source of income for the Institute. Since end 1989 the activity is continuously increasing, due to the regular operation of the HFR and to the quality of the service offered, as described in /1/. In **fig. 22** the radioisotopes production in the last four years is shown. In 1992 the production was 9 times higher than in 1989. The radioisotopes production is mostly devoted to applications in the medical field (about 80% of the total production).

Products are both for diagnostic (mainly) and therapeutic use. A survey of the applications can be found in /1/.

The most important radioisotopes produced for medical applications are indicated in **table 13**. Ir^{192}, Y^{90}, Sr^{89}, I^{125} are produced on routine basis in the standard devices /2/.

Table 13
Most important radioisotopes produced for medical applications

Technetium ^{99m}Tc	Bone imaging agent to delineate areas of altered osteogenesis; general use for tumour scintigraphy; brain and renal perfusion imaging; liver, spleen, medullary, lung imaging; visualization of airways potency; labelling of red blood cells, visualization of blood pools (hearth, placenta); intestine imaging
Iridium ^{192}Ir	Destruction of malignant tumours by interstitial or intracavitary radio therapy, using needles or wires and treatment of superficial cancers; used as collimator in gynaecology, urology, surgery, pulmonology etc.
Yttrium ^{90}Y	Treatment of liver cancer; pain killer of metastatic bone cancer
Strontium ^{89}Sr	Pain palliation in prostatic skeletal malignancy
Iodine ^{125}I	Investigation of thyroid

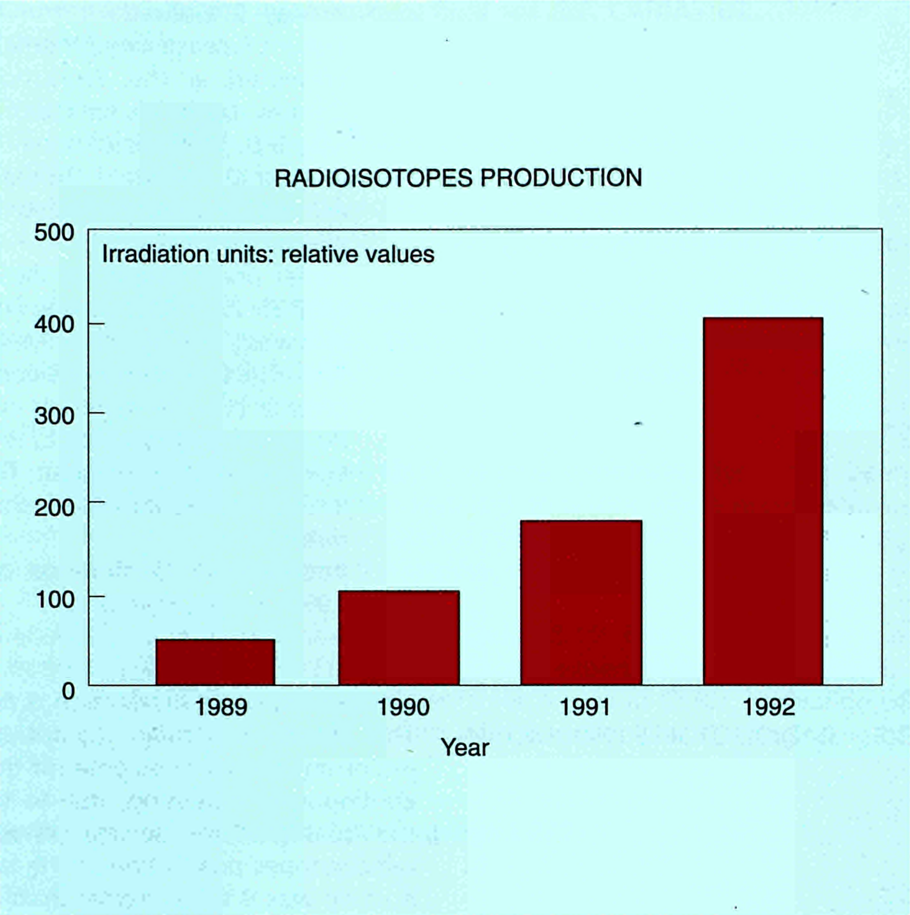

Fig. 22
Radioisotope production in the last four years; relative values

More than 100 capsules per cycle have been irradiated during 1992 in the standard devices HIFI (144), HFPIF (008) and RIF (90). Two HFPIF devices were constantly present in the PSF and, in peek periods, 5 HIFI devices were put in in-core positions.
In order to face the growing demand and to renew the park of irradiation facilities, during 1992 new devices have been designed and partially manufactured:

- a rotating device, called RODEO (273) which will be placed in the I row of the reactor and will be used for the production of Ir wires, which must be irradiated under a very uniform neutron fluence rate distribution.
- a device called FACHIRO (279) which will replace the old HIFI allowing easier handling and operation.

All these devices will be put into operation in 1993.

Fissile targets are irradiated in the facility FIT (136). The objective is the recovery of Mo^{99} from irradiated fissile targets for the manufacture of Tc^{99m} generators, widely used in medical applications for scintigraphy, angiocardiography, organs imaging etc. The main applications of Tc^{99m} are shown in **fig. 23**.

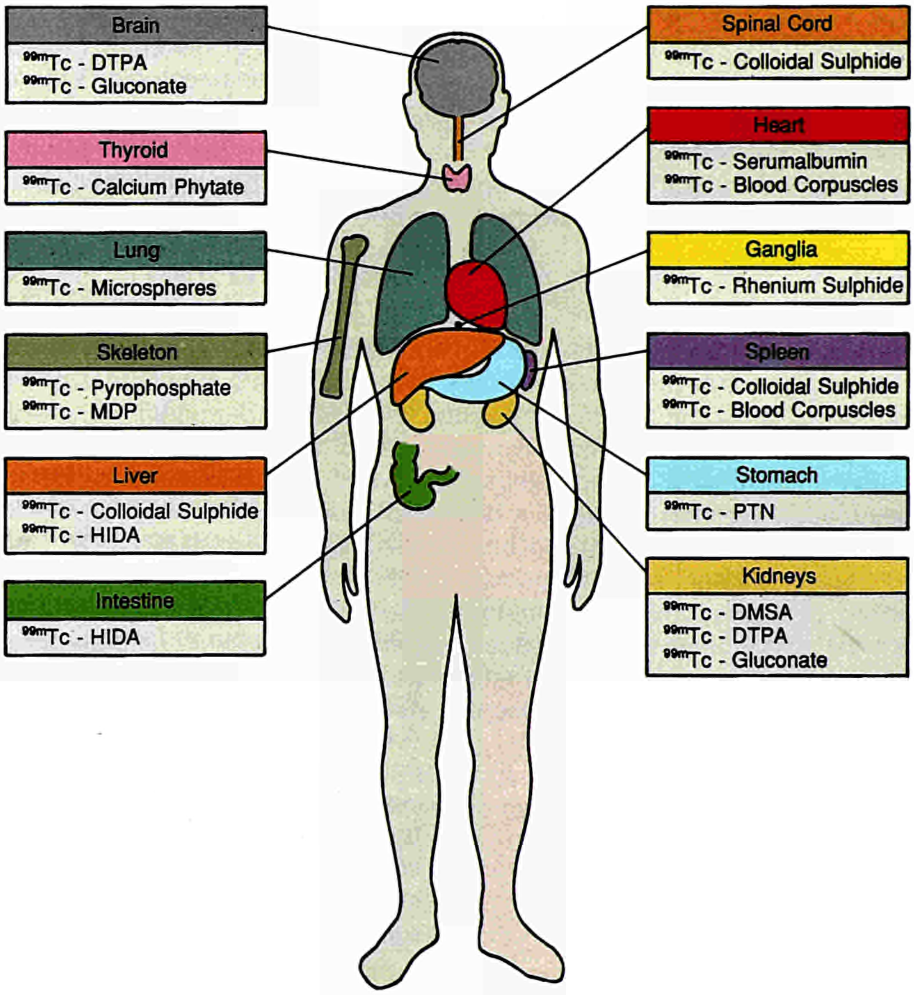

Fig. 23
Technetium (99m) as a diagnostic tool

The production in 1992 continued routinely. Targets are sent to the processing plant after each irradiation. Two new devices to obtain higher fluence rate values will be put into operation in the PSF in the first months of 1993.

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3.6. ACTIVATION ANALYSIS

Devices used for general radioisotope production are also used to irradiate various kinds of materials for scientific applications. Activation analysis is used in the archaeologic field, in geology (rare earth, sedimentary studies), in forensic applications and in environmental studies (atmosphere particles, aerosols, toxicology). In 1992 irradiations for British Universities continued (age determination of rocks, mineral composition etc.). Activation analysis of small samples of stainless steel, nickel, chromium etc., mainly for KFA Jülich, 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:
A new irradiation facility was manufactured, to be used in poolside facility position PSF 11-12, as in the course of 1992 the earlier position PSF 1-2 was occupied by another experiment. The older facility is stored in one of the pools and stays available. During the period under review 29 containers were irradiated with a total irradiation time of 2088 hours. Since the installation of the SIP facility, 200 containers have been irradiated, corresponding to a total irradiation time of 14161 hours.

3.7. SOLID STATE PHYSICS AND MATERIALS SCIENCE

The six neutron scattering facilities installed at five of the horizontal beam tubes are operated by the Characterization Group of the Service Unit ECN-Technology. Research projects are in general in the field Solid State Physics, Physical and Colloid Chemistry, and Materials Science, and are partly carried out as contract research. Subjects of research are various aspects of material-characterization, both of fundamental and applied character. Crystallographic and magnetic structures were determined by neutron diffraction on a large number of samples, either powdered polycrystalline or monocrystalline. Long-term research in this field was aimed at diluted magnetic semiconductors and intermetallic uranium compounds. Small-Angle Neutron Scattering (SANS) was applied in the investigation of structural details with dimensions from 1 to 70 nm. Some examples of research topics are: precipitates in steel, morphology of co-blockpolymers, conformation of polymers in solution, micro-bubbles in breeding materials for fusion reactors, sodium colloids in irradiated rocksalt, and mixtures of silica particles and polymers. In co-operation with the Imperial College in London pilot experiments were performed on two reference systems with the facility for residual-stress measurement. The agreement with results obtained at the Institut Laue-Langevin, Grenoble and the Rutherford Appleton Laboratory, Chilton was found to be excellent. In addition to contract research for industrial purposes, the internal stress state in the vicinity of a weld connection was studied in the frame of PISC.

A long-term research project on texture in metals and alloys, in co-operation with the Academy of Mining and Metallurgy, Cracow, was completed successfully. In spite of increasing interest in this field, this ECN/AMM project was not continued, because the operation of the neutron-beam facilities by ECN is planned to end in 1994.

3.8. BORON NEUTRON CAPTURE THERAPY (BNCT)

Boron Neutron Capture Therapy (BNCT) utilises the energy produced by the instantaneous nuclear fission of a boron-10 nucleus into an alpha particle and a lithium ion, after the capture of a slow (thermal) neutron, i.e. $^{10}B(n,\alpha)^{7}Li$. The emitted irradiation destroys those cells in which the boron capture event takes place. Hence, providing there is a sufficient amount of ^{10}B nuclei in the cancerous cells, and a sufficient differential between the ^{10}B nuclei in the cancerous cells and healthy cells, then the tumour can be destroyed without causing damage to the healthy tissue. To achieve this, one needs a suitable, preferentially tumour-seeking boron compound and a high flux of thermal neutrons at the tumour site. For the latter reason (and others), the beam tube HB11 produces an ephithermal neutron beam with the appropriate characteristics.

Following a hesitant start during the first quarter of 1992, all remaining technical problems with the facility were resolved and a very intensive programme of experiments began.
This included:

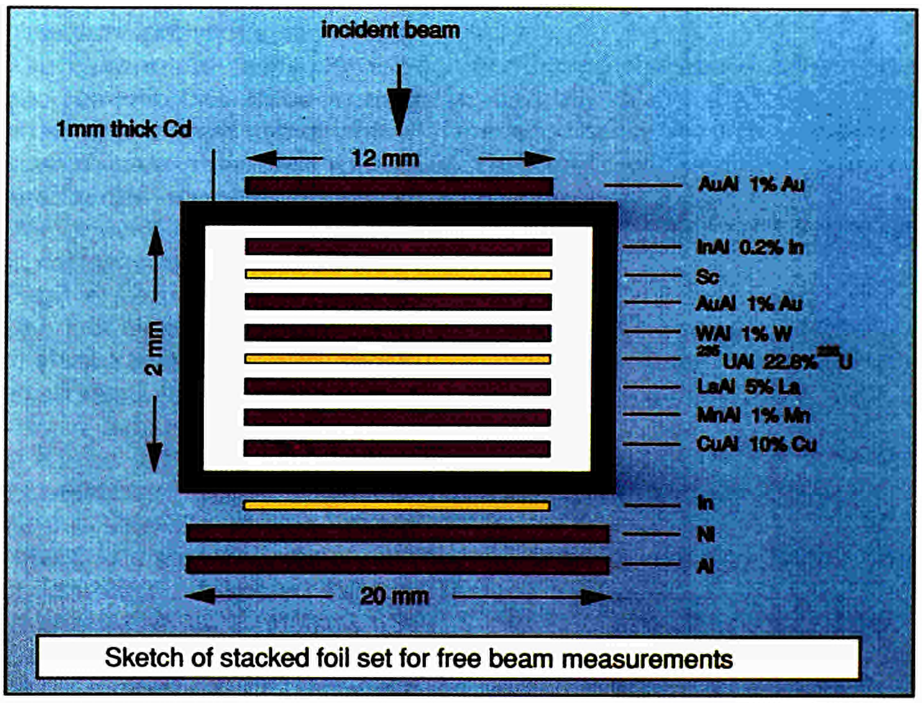

Fig. 24
Sketch of stacked foil set for free beam measurements

Free-beam measurements
To assess and confirm that the beam parameters (flux intensity and neutron energy spectrum) do not change or are significantly effected by changes in the reactor core configuration, free-beam measurements taken at the irradiation or therapy position have been performed on a regular basis. During the year, 4 such measurements were performed using a multi-foil set of 12 stacked activation foils, see **fig. 24**. The results have shown that throughout the year, the beam parameters vary by no more than ±4%.

Phantom measurements
To determine the thermal neutron flux distribution within the body or target volume, phantom irradiations are performed whereby tissue-equivalent or plastic phantoms containing activation foils or wires and thermoluminescence detectors (TLDs) are irradiated at the therapy position. As such, measurements on the beagle-head phantom were performed in June. Comparisons with similar measurements performed in July 1991 showed that the present thermal neutron flux is some 20% less than before.

Cell culture irradiation experiments
To observe the effect of the boron capture reaction at depth inside a phantom and to determine the RBE values of the various beam components, numerous cell culture experiments were performed throughout the year. Well over 100 separate irradiations were conducted on various cell lines at different depths in the phantom and containing different concentrations of 10B in the form of the boron compounds: BSH, BPA and boric acid. Participating groups included JRC and ECN Petten, AEA Harwell UK, University of Bremen FRG and the Netherlands Cancer Institute in Amsterdam.

Healthy tissue tolerance studies
Prior to patient treatment, it is mandatory that for different concentrations of boron and different radiation doses, the tolerance limits of the healthy (brain) tissue to the Petten ephithermal neutron beam are known. As such the healthy tissue tolerance study formulated in 1990, continued throughout the year with a further 24 in vivo irradiations of the canine brain.
The irradiation programme for different boron concentrations and physical doses is summarised in **fig. 25**. The study will be fully completed in 1993, whereby it should then be possible to predict the healthy tissue tolerance limits in order to specify the starting dose at which clinical trials on human glioma patients may begin.

On-line dosimetry
To assess the beam parameters during treatment, an on-line monitoring system must be available and shown to be reliable and dependable. As such, a twinned system of 2 GM tubes and 2 fission chambers have been installed behind the gamma shutter in the beam port. The system is currently being tested, with plans in 1993 to reposition the monitors further into the beam tube in order to avoid effects from back-scatter from the patient.

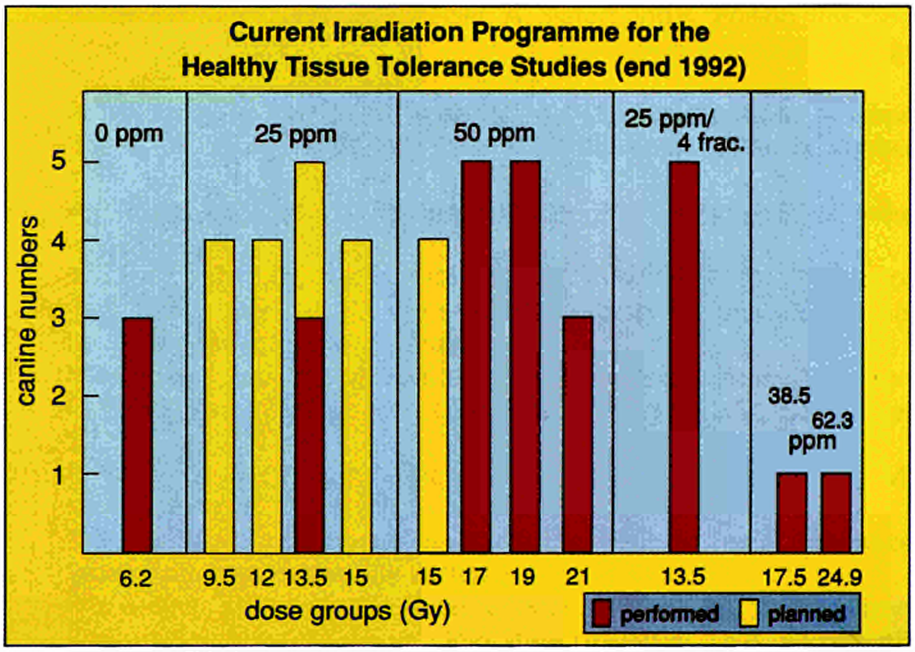

Fig. 25
Current irradiation programme for the healthy tissue tolerance studies (end 1992)

Treatment planning
To determine the radiation dose distribution in the human head during irradiation treatment, a treatment planning scheme is being developed based on the Monte Carlo code MCNP. The code has been used throughout the year to validate and compare with results from the phantom experiments.

Patient treatment room
The current set-up is sufficient for performing the above experimental programme. It will be necessary to substantially enlarge the room in order to be able to treat the patient in lateral recumbency. As such, a treatment room has been designed using a 3D computer aided design programme, see **fig. 26**.
The present set-up will be dismantled in summer 1993, and the new set-up ready towards the end of the year.

The BNCT project at Petten is entering into a critical stage, with most of the experimental programme nearing completion. During 1993, the initial experimental work will be over and the patient treatment room ready to receive patients.
It is expected that clinical trials will begin at the end of 1993 or beginning of 1994.

The above activities were reported in detail at the 5th International Symposium on Neutron Capture Therapy for Cancer at the Ohio State University, USA in September 1992.
The Petten/Amsterdam group presented 14 papers and may be seen to be at the forefront of NCT activities worldwide.

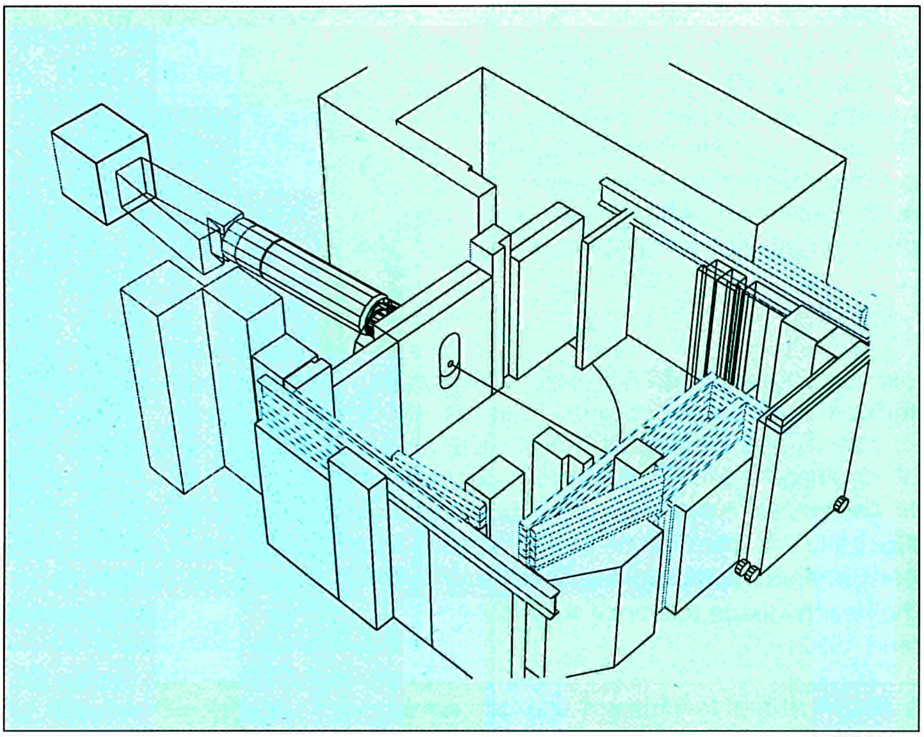

Fig. 26
Computer aided drawing of the enlarged irradiation room

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/9/ M. Konijnenberg, C. Raaijmakers, G. Constantine, L. Dewit, B. Mijnheer, R.L. Moss and F. Stecher-Rasmussen
Prompt Gamma-Ray Analysis to determine ^{10}B-concentrations
Proceedings of the 5th International Symposium on Neutron Capture Therapy for Cancer, Ohio State University, USA, September 1992

/10/ K. Philipp, P. Gavin, J. Casado, A. Siefert, R.L. Moss and R. Huiskamp
Developments in the Healthy Tissue Tolerance Studies as a Precondition for Clinical Application of Boron Neutron Capture Therapy
Proceedings of the 5th International Symposium on Neutron Capture Therapy for Cancer, Ohio State University, USA, September 1992

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.

At the HFR, two neutron radiography facilities and an image analysis system are available. The neutron radiography facilities consist of:

- an underwater camera and
- a beam tube-based neutron radiography system at the HB-8 beam tube with filtered neutrons and with a real time imaging system.

Neutron radiographic services are provided in support of HFR irradiation projects and in support of studies on the application of this technique to non-nuclear R&D and for routine inspections of EC research and industry /1/.

Progress:

The HB-8 beam tube NR facility

Image taking, evaluation of the image and compilation of a report on the findings for the first phase of a research contract on the application of neutron radiography to space components technology were completed. On several of the test items neutron radiography could be employed as a better or complementary non-destructive testing method in this field. A joint publication with the customer on the findings related to electric relays was presented at the Fourth World Conference on Neutron Radiography held in May 1992 at San Francisco /2/.

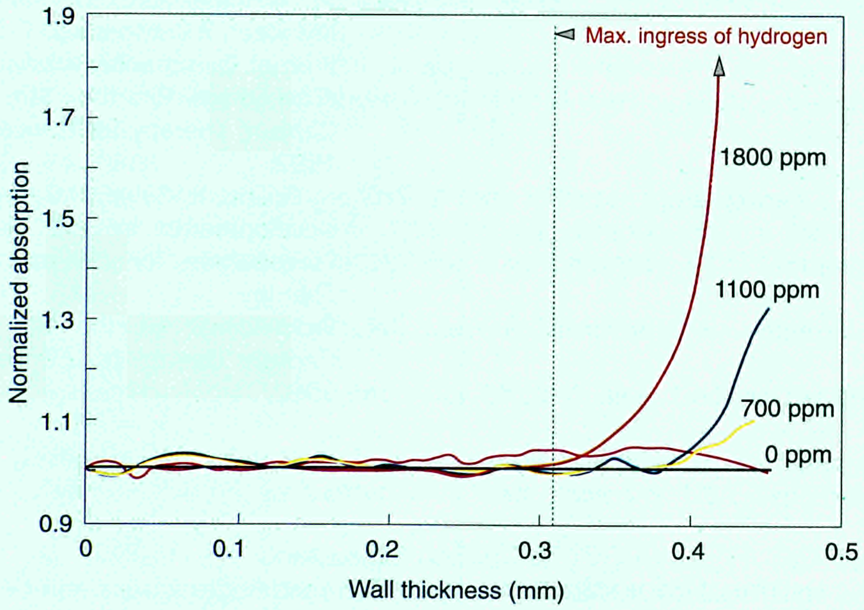

Fig. 27
Determination of hydrogen ingress into zircalloy tube walls

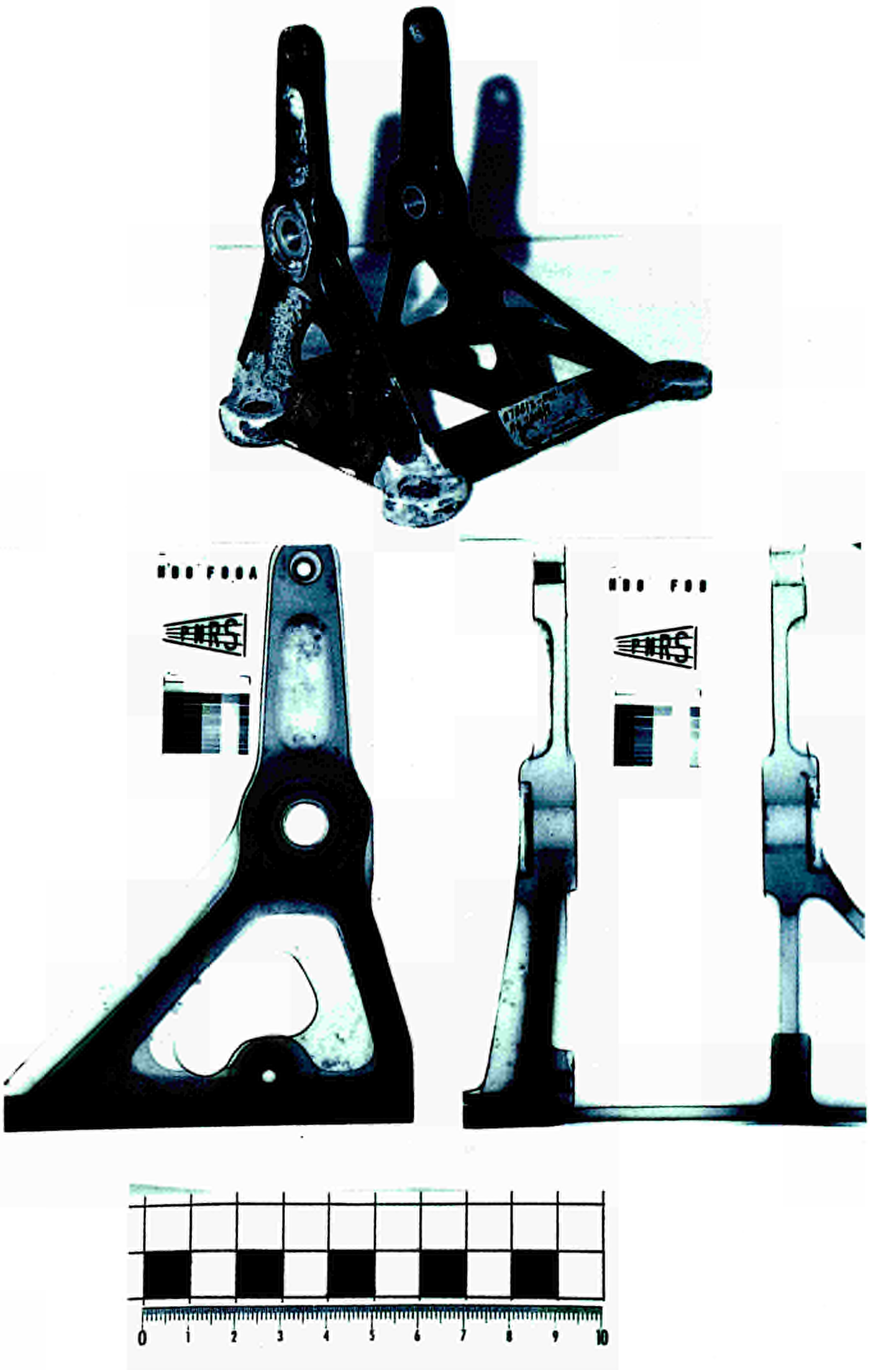

Fig. 28
Photograph and neutron radiograph of a corroded aircraft component

The project was continued with image taking with non-film-based techniques and image analysis of selected test items using a reactor-based neutron source (HFR) and a neutron tube (GENIE 46, developed within an EUREKA project) at IABG, Munich. It is anticipated to conclude this project during 1993.

Several inspections were performed as a service to industry and research, including proof testing for new applications. These inspections related to the following areas:

- determination of H2 ingress in Zircalloy tubes,
- corrosion detection in aluminium structures from aircrafts,
- check of mechanical devices for space craft and satellites.

Fig. 27 shows a result originating from image analysis with a travelling microdensitometer and further data treatment: determination of depth of H_2 ingress into zircalloy tubes.

Very promising results were obtained in some preparatory inspections of aluminium aircraft structures for corrosion /3/.
Fig. 28 demonstrates the imaging capability of corrosion in aluminium structures from aircraft.

The 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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/2/ J.F.W. Markgraf, H.P. Leeflang, L. Adams, J. Andersen, P.C. Ellen
Neutron radiography inspection of relays for satellite and space technology applications
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/3/ J.F.W. Markgraf, H.P. Leeflang
Detection of corrosion on aircraft components by neutron radiography
Fourth World Conference on Neutron Radiography, San Francisco, May 10-16, 1992

3.10. NEUTRON TRANSMUTATION DOPING OF SILICON CRYSTALS

Objective:
Irradiation of silicon crystals with thermal neutrons provides through a neutron transmutation (doping) process (NTD) a method to introduce in the silicon crystals changes which deliver in turn 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 resulting from their future use in high power and advanced electronics.

Most research reactors provide doping services to industry. At present HFR offers 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 performed during 1991 confirmed the SIDO characteristics and its capability for precise doping. On basis of these results a small scale NTD activity was started. Approx. 300 kg silicon crystals of approx. 100 mm outer diameter were successfully treated.

Design study for a NTD facility, SINET:
A design study for a PSF-based NTD facility, SINET, was completed. The SINET facility 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 target resistance of 60 Ohm cm could be accommodated at the PSF. **Fig. 29** provides a schematic overview of the SINET facility.

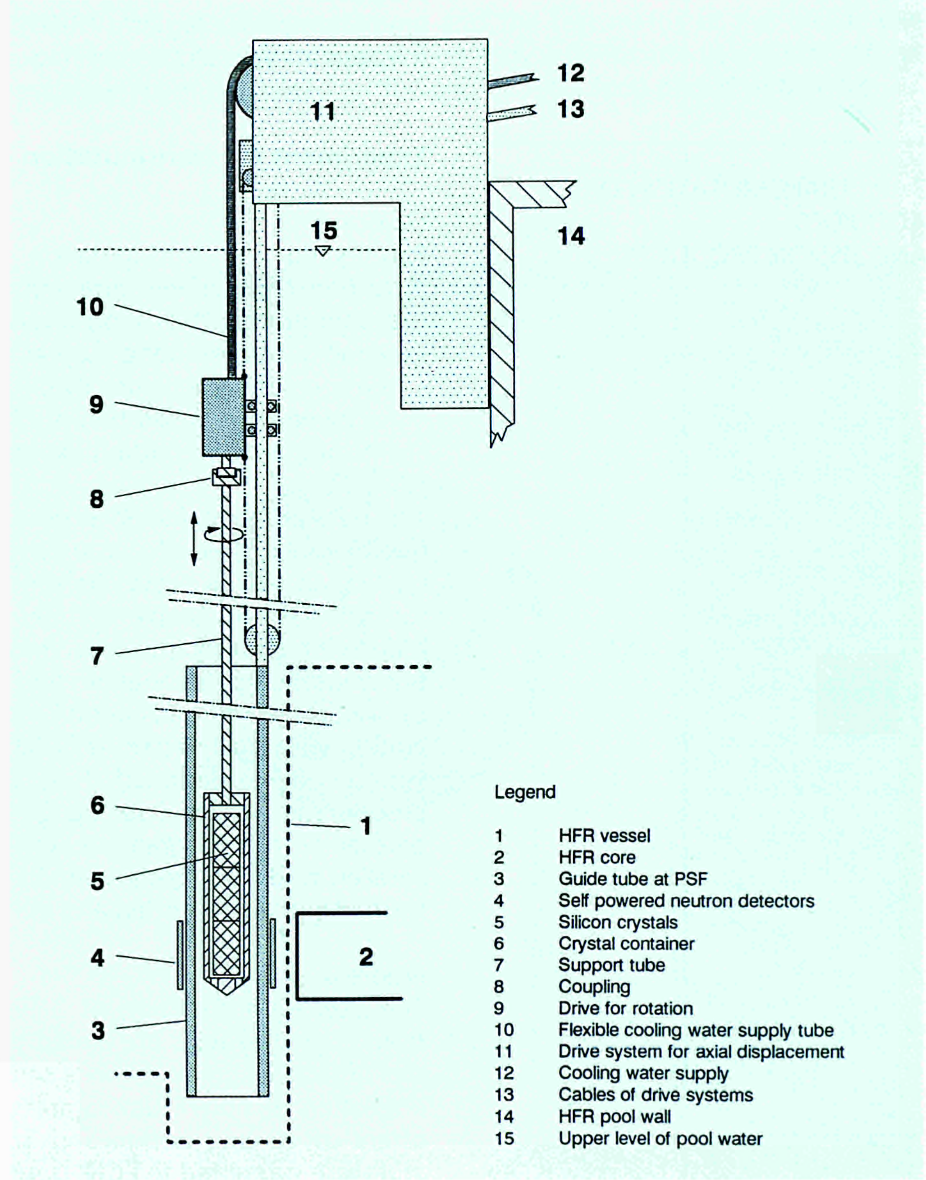

Fig. 29
Lay-out of the SINET irradiation facility

Market situation:
During 1992 a drastic reduction of demand for NTD services was observed. Thus, at present there is no incentive for any investment into a new NTD facility.

3.11. CANDU MATERIAL IRRADIATIONS

ZIRCAN (project 259)

Objective:
The objective of this experiment is to demonstrate that cold-worked Zr2.5 Wt%Nb tubing will withstand the diametral strain from operation without failing from creep rupture. The irradiation campaign in the HFR is intended to extend the data base on material behaviour of CANDU operational conditions.

Progress:
Irradiation of one leg of a TRIO-129 started in cycle 92.09 and will be terminated in cycle 93.06.

3.12. TRANSMUTATION OF ACTINIDES AND FISSION PRODUCTS

Experiment for transmutation of fission products (project 280.01)

Objective:
Partitioning and transmutation of actinides and fission products are attracting considerable attention as an option to reduce the long-term radiological impact of high level nuclear waste. Two categories of long-lived radioisotopes in the nuclear waste are distinguished:

- the α-emitting actinides (Np, Pu, Am and Cm isotopes) formed in-reactor by neutron absorption of ^{238}U
- the long-lived ß-emitting fission products ^{99}Tc and ^{129}I.

The beta-emitting fission products are among the important long-lived nuclides in high-level waste, which dominate the beta radiotoxicity for more than million years. Transmutation of ^{99}Tc and ^{129}I by neutron capture will yield the stable isotopes ^{100}Ru and ^{130}Xe, resp., and thus largely reduce the beta radiotoxicity. Recently, ECN has started a program on the transmutation of technetium and iodine, in which the physical and chemical aspects of the transmutation concepts are being studied and, in cooperation with IAM Petten, a facility for irradiation experiments at the HFR Petten is being designed. The ECN activities are part of an international programme, which is set up to study the technological aspects /1/. The partners in this programme are ITU, CEA-Cadarache, ECN, KfK and EDF. Parallel irradiation tests with identical samples are planned to be performed in the HFR Petten and in Phenix.

Progress:
Requests for the design of a first irradiation experiment were received from ECN. The tests are aimed to investigate the transmutation efficiencies of technetium and iodine samples and to test inert matrices for future irradiation of americium samples in the HFR. Proposals and commercial offers concerning design and irradiation were prepared by IAM Petten and were submitted to ECN. Design work has started in 1992.

IAM Petten proposed an irradiation facility with the following characteristics:

- reloadable irradiation rig
- flux trap to enhance thermal neutron fluence rate
- fully instrumented sample holder
- double containment
- test matrix with four levels and per level up to six capsules
- temperature control
- fluence rate control by >30% through axial displacement.

Fig. 30 shows a horizontal cross section of the in-pile section. A specially designed filler-element together with a 40 mm diameter irradiation rig (REFA-140) provides the necessary water gap to enhance the thermal neutron fluence rate by ~50%. Nuclear calculations were performed by ECN on the transmutation rate of ^{99}Tc. The required irradiation conditions can be achieved in core position C5. The achievable technetium burn-up per cycle is ~0.8 %. The programme and the test matrix of the first in-pile experiment is planned to be specified early in 1993. Irradiation start of the first experiment is planned for the end of 1993 for a period of 6 cycles.

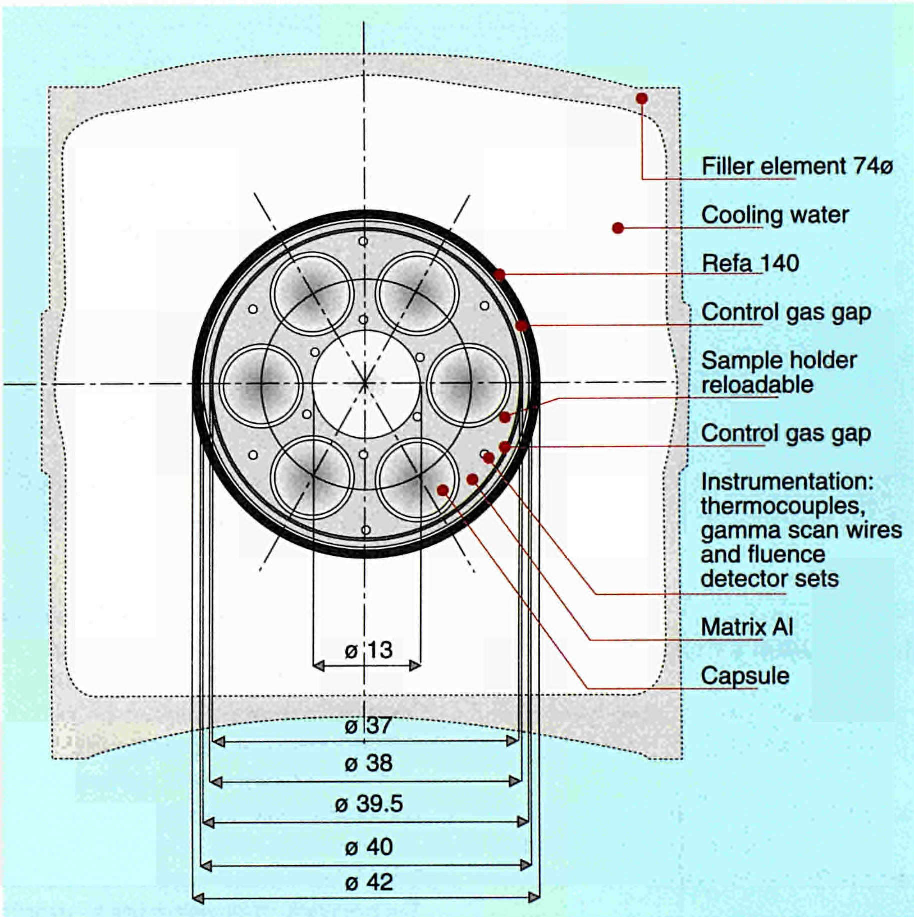

Fig. 30
Horizontal cross section of the in-pile section of the irradiation facility for transmutation of technetium and iodine

4. GENERAL ACTIVITIES

This chapter reports on 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

On the 22nd January 1992, the new and technically improved Assembly Laboratory was officially opened. The Laboratory fulfils the strict Dutch health and safety requirements. The new accommodation is completely equipped with new work tables and is a clean room area with airconditioning and sluice gate.
Directly adjacent to the Assembly Laboratory is the welding room, which is provided with several welding machines as:

- Auro Arc Tig 50 max. 50 ampere
  Precision welder, with low level current control adjustable to 3 ampere
- AMI-M-80-3 max. 100 ampere
  Automatic welding system, with low level current control adjustable to 1.5 ampere
- HOBART 300 max. 400 ampere
  Double current operation, with low level current control adjustable to 5 ampere

A smoke extractor and central argon supply are also available.
Separate from the Assembly Laboratory a small workshop is situated with a grinding-, drilling-, and turning-machine, two ultrasonic cleaning installations and a chemical extraction unit.
During the reporting period 22 in-pile and 4 PSF experiments were assembled in the Assembly Laboratory or by external firms.

4.2 STANDARD IRRADIATION DEVICES

The following standard in-core capsules, instrumented heads and PSF devices were manufactured

- 6 Instrumentation heads
- 4 In-core irradiation capsules
- 3 PSF supports
- 2 In-core irradiation capsules (modified)
- 2 PSF capsules

4.3. QUALITY CONTROL

During the reporting period the Quality Control group checked 43 irradiation devices or components and issued the related QC reports:

- 16 Sample holders
- 6 In-core capsules
- 3 Instrumentation heads
- 13 PSF experiment carriers
- 5 Miscellaneous

The demi-water purification installation for the waterpool in the Technology hall used for testing irradiation equipment has new contents

Fig. 31
The new and technically improved Assembly Laboratories

for the anionbed filter and kationbed filter. The result is an improvement of the water quality by a factor 100 and is <0.5 µS/cm.This installation is now totally modified and technically updated.
The liquid-metal-filling station has been extended with a digital rate meter for monitoring the integrity of the first containments of fuel filled experiments.
The supply tank of the sodium-filling loop has been filled with 60 litre of sodium and this tank is completed with sodium level indicators.
A dummy restraint-structure has been installed under the small PSF-table of the dummy reactor vessel.

4.4. EXPERIMENT OPERATION

Despite of increasing technical complexity of the experiments the operation team provided their services on schedule to a successful operation of the irradiations.
During the 11 cycles of 1992 3 TRIESTE sample carriers, 2 REFA and 23 TRIO sample holders were loaded into the respective reloadable irradiation devices for in-core irradiation. Furthermore 4 TRIESTE sample carriers, 2 REFA and 28 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.

4.5. HOT CELLS AND POST-IRRADIATION WORK

The cell team provided the following services:

Dismantling Cell
- Dismantling of 73 isotope capsules
- Dismantling of 66 irradiated experiments
- 35 Neutron radiography images have been taken of irradiated fuel pins and other irradiated material
- 68 External and internal transports have been executed
- General repair of cell equipment (waste container, cutting device, manipulators and neutron radiography camera)
- Disposal of reactor components (section of fuel elements and control rods)
- Disposal of 3 irradiation devices (TRIO, REFA)
- Reloading and dismantling flux detectors of experiment SURP 1 and 2
- Development of special handling and transport procedures for experiments ZIRCAN, KAKADU and SUPERKAKADU
- General cleaning of DM cell
- Installation of a new protection glass

EUROS Cell
During the reporting period the following investigations for new projects were performed:
- HYPERKAKADU: The study of re-encapsulation of fuel pins with a total length of 2.60 m shows that transformation of the existing cell and equipment will be necessary.
- ZIRCAN: In view of the time-planning of the project a careful evaluation is needed in case of a transformation of the cell. Studies and drawing work were carried out.
- KAKADU 56A: Due to a leak in the Sodium-filling line and a Na-fire in the EUROS cell the capsule was damaged in such a way that the re-encapsulation was stopped and the fuel pin recovered.

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 65 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

A new orbital-welding-installation has been ordered and will be installed in February 1993.

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/33 to HFR/35).

EWGIT (European Working Group in Irradiation Technology)
The EWGIT Select Committee prepared an International Conference on Irradiation Technology. The conference was held in Saclay, France, 20-22 May, 1992 and approximately 150 participants attended the various sessions.

NRWG (Neutron Radiography Working Group)
Assistance has been provided within the organizing committee of the Fourth World Conference on Neutron Radiography which was held in May 1992 in San Francisco/USA.
A book on "Practical Neutron Radiography" was published in August 1992 /1/.

EWGRD (Euratom Working Group on Reactor Dosimetry)
The 57th meeting of the EWGRD was held on 8th April, 1992 in Petten. The main topic of the meeting was focused on discussions concerning the future of the group. 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:

P. Gavin, Washington State University
New Cancer Therapy: Why? The Radiobiology Foundation for the Current European Collaboration on BNCT
21 January 1992

T. Kodaira, Development Division of Research Reactors, JAERI
Objectives of Research Reactor Technology
3 February 1992

Minoru Saito, JAERI, Orai Research Establishment
JMTR and Related Irradiation Technology
19 February 1992

Tom Wood, Amersham International
Ir-192 Brachay-Therapy Wires; Production and Use
4 March 1992

R. Gähler, TU München, Fakultät für Physik
Theory and Technique of the Munich Spin-Echo-Spectrometer
13 April 1992

S. Peake, Amersham International
Application of Metastron SrCO3
9 June 1992

C. Pelt & W. Scharroo, ECN Petten
Status Report on the Dacos System
9 July 1992

H. Kawamura, JAERI
R&D of ITER Blanket Concepts at JAERI
21 September 1992

G. E. Kohse, MIT
Irradiation Programmes at MIT
19 October 1992

F. J. Wheeler, INEL
BNCT Physics at the INEL
28 October 1992

H. Kobayashi, Rikkyo University
Neutron Radiography Facilities on Research Reactors in Japan and its Institute for Atomic Energy Application to Basic Research
30 October 1992

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3 December 1992

R. May, IAM Petten
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9 December 1992

A. Siefert, IAM Petten
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5. QUALITY ASSURANCE

Because of the specific organizational structure and nature of the activities at the HFR, the concept Quality Assurance is closely linked to the one of Safety Culture, i.e. the assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear safety issues receive the attention warranted by their significance. The means to further develop Safety Culture are the "Work and Action Plan for HFR Petten" as well as the set-up of an "Integral Quality Assurance Handbook", the state and progress of which are reported below.

5.1. WORK AND ACTION PLAN FOR HFR PETTEN

The "Work and Action Plan for HFR Petten", which resulted from the 1988 KFD-audit and which comprised fifty five requirements was updated. The fulfilment of the requirements was continued in close co-operation between IAM and ECN. The completion of eleven requirements is still in progress or pending, whereas the rest of them are considered as completed.

In this frame, the "HFR Incident Reporting System" (HFR-IRS) with its related procedures was developed and implemented establishing the reporting lines for events of category "3" and "4" to Kernfysische Dienst.

Also the document "Relation Schemes between IAM-JRC and ECN with regard to the High Flux Reactor Petten" was issued. In this way, the relations between both organizations concerning HFR Operation & Exploitation as well as Quality Assurance are regulated.

The "Tasks Description" exercise within the IAM-HFR Unit was completed. As a consequence, a draft of the "Technical Training Plan for the IAM-HFR Unit Staff" was developed including among others different courses on radiological protection, nuclear and reactor physics/safety, HFR technology and quality training. Its implementation will start at the beginning of 1993.

5.2. INTEGRAL QUALITY ASSURANCE HANDBOOK

Significant progress has been made in preparing a comprehensive and consistent "HFR Integral Quality Assurance Handbook" (HFR-IQAD), also as a consequence of the referred "Work and Action Plan for HFR Petten". HFR-IQAD includes two levels of documents:

a) the quality management level including documents regarding objectives, general policy, tasks and responsibilities, licensing and contractual aspects, as well as to the structures and relations between both involved parties; and
b) the quality working level including documents related to the current and future HFR operating license, quality handbooks for operation and exploitation, events and emergencies, safety assessment of experiments, as well as other services.

Concerning the renewal of the technical safety documentation DOKPAK, the "Technical Description of the Installation" was updated progressively, whereas the other two main documents, i.e. the "Safety & Accident Analysis" and the "Safety & Technical Specifications" have been reviewed and the corresponding upgrading is planned for 1993. These two documents will be the basis for the public "Design & Safety Report of HFR", which is ready in draft form.

Within the frame of the "Quality Handbook for the HFR Exploitation", underlying document of HFR-IQAD, seven different instructions and procedures have been issued during 1992. Some of them were issued as QA-notes, e.g. the procedure "Approval within the IAM-HFR Unit of the main documents related to HFR experiments" including an internal review. In this regard, twenty four Design and Safety Reports related to experiments and installations passed this internal review during 1992.

The working group on welding specifications (WGWS) developed a draft working document, on which specifications and operational instructions will be based.

6. SUMMARY

6.1. HFR OPERATION, MAINTENANCE, DEVELOPMENT AND SUPPORT

In 1992 HFR operation was carried out as planned. The total availability of the reactor was more than 100% of its scheduled operating time, i.e. 280 in stead of 273 days.
Routine maintenance and modification activities were carried out in the two main stop periods.
Good progress was made in the scheduled upgrading projects.

6.2. HFR UTILIZATION

In 1992 the average utilization of the HFR was 63% of the practical occupation limit. The reactor was utilized for research programmes in support of nuclear fission reactors and thermonuclear fusion, for fundamental research with neutrons, for radioisotope production, for BNCT, and for various smaller activities.

6.3. 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.

6.4. QUALITY ASSURANCE

Full attention was given to quality assurance as a means to further develop safety culture. The "Work and Action Plan for HFR Petten" which resulted from the 1988 KFD-audit was updated. Significant progress was made in preparing a comprehensive and consistent "HFR Integral Quality Assurance Handbook".

7. HFR PUBLICATIONS

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Neutron radiography inspection of relays for satellite and space technology applications
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J.F.W. Markgraf, H.P. Leeflang
Detection of corrosion on aircraft components by neutron radiography
Fourth World Conference on Neutron Radiography, San Francisco, May 10-16, 1992

SCIENTIFIC OR TECHNICAL ARTICLES

H. Nabielek, H. Nickel, G. Pott, W. Schenk, R. Conrad
Development and qualification of modern TRISO fuel for the HTR
Submitted for publication in "Nuclear Engineering and Design", 1992

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
CARIATIDE	CAmeRa IrrAdiaTIon in neutron fielD for jEt
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
EPIRO	EPoxy resIns iRradiatiOn
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
FACHIRO	FACility with HIgh flux for Radioisotopes prOduction
FBR	Fast Breeder Reactor
FIT	Fissile Isotope Target
FPD(or f.p.d.)	Full Power Day
FURIAE	FUsion Reactor materials IrrAdiations for ECN
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
MANIA	MANet IrrAdiations for ECN
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
RODEO	ROtating DEvice for radiOisotope production
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
SURP	SURveillance Programme
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 measuremen
TRAMP	Travelling Measuring Probe (STICK) Gamma calorimeter
TRIESTE	TRIO Irradiation with Experiment of Steel-Samples under Tension
TRIMURTI	TRIo Modified for fUsion Reactor maTerials Irradiations
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
ZIRCAN	ZIRconium specimens for CANada

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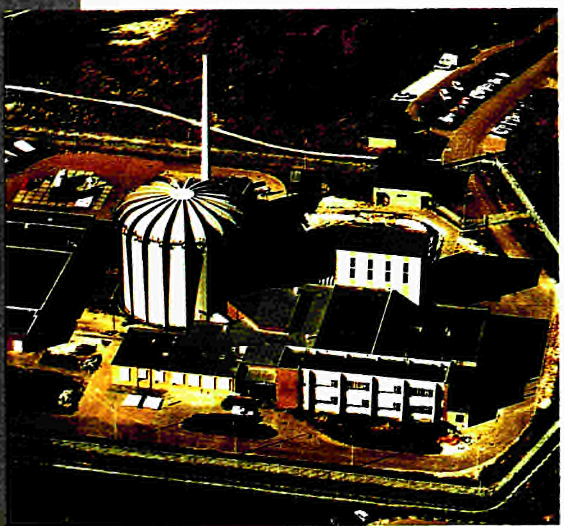
High Flux Reactor Petten



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