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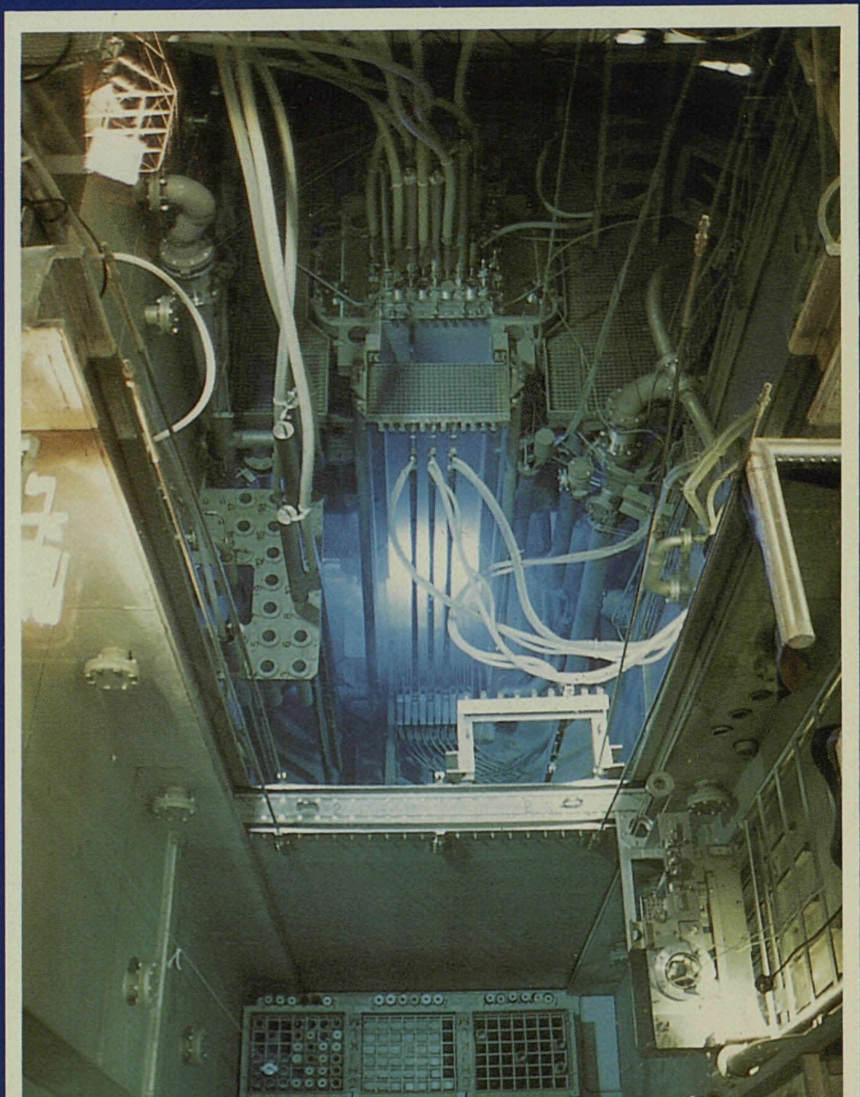
COMMISSION OF THE EUROPEAN COMMUNITIES

Multiannual programme
of the Joint Research Centre
1984-1987

# ANNUAL REPORT 1985

## OPERATION OF THE HIGH FLUX REACTOR



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# OPERATION OF THE HIGH FLUX REACTOR

*Directorate-General*

**Science, Research and Development**

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**High Flux Materials Testing Reactor**
**HFR Petten, 1985 Annual Report**

| | | |
|---|---|---|
| **Research Staff** | | **41 persons** |
| **1985 Budget (commitment credits)** | | |
| **Programme funding, incl. new equipment** | | **16.5 Mio ECU** |
| **Support by other JRC programmes** | | **2,6 Mio ECU** |
| **Use by commercial clients** | | **0,4 Mio ECU** |
| | **Total** | **19,5 Mio ECU** |

**Projects**

**Unlike most of the other JRC Programmes, "Operation of the High Flux Reactor" is not formally subdivided into individual research projects. For practical reasons, however, three projects have been defined for the 1985 work:**

1. **Reactor Operation, Maintenance and Development**
2. **Reactor Utilization**
3. **General Activities**

**On a lower level of subdivisions, the term "project" is used for activities under one of the three above headings.**

**Programme Manager:**
**P. von der Hardt**

# 1. INTRODUCTION

As one of the most powerful materials testing reactors in Europe, the High Flux Reactor at Petten supports research and development in a number of areas, e.g.

- the development of nuclear fission energy, especially under safety aspects,
- irradiation behaviour studies of potential materials to be used in controlled fusion devices,
- neutron activation analysis for geological and environmental studies,
- fundamental research with neutron beams, in particular solid state and nuclear structure physics,
- the production of radioisotopes for scientific, industrial, medical and agricultural purposes.

The reactor, its experimental facilities, and the ancillary services have been continuously upgraded with the goal of maintaining a high degree of reliability and of responding to the permanently changing requirements of scientific/technical research.

The replacement of the reactor vessel by a redesigned model has to be seen against the background of this policy. As a result, plant and equipment have demonstrated a consistent availability near to 100% of scheduled operating time. Simultaneously, the reactor occupation has been on a very high level, i.e. an average of

71% in 1980
78% in 1981
81% in 1982
84% in 1983*

confirming that reactor, facilities, and services are usually in a position to handle a large experimental work volume on schedule.

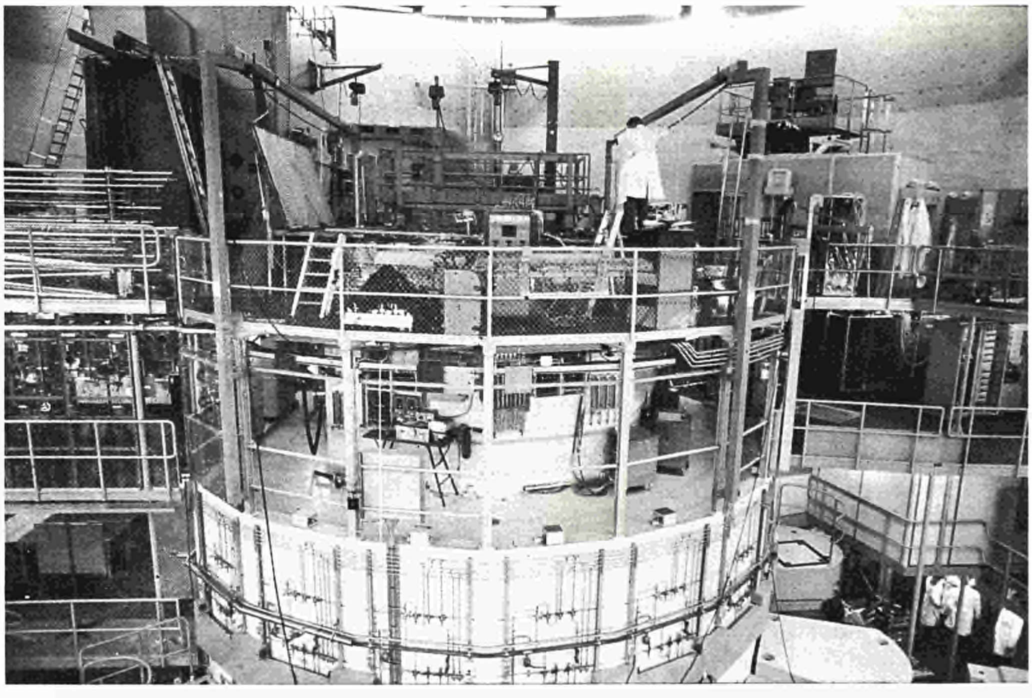
* In 1984 the reactor was shut down for vessel replacement.

# 2. OBJECTIVES

The HFR Programme objectives for 1985 were set out at the beginning of the year when the final stages of plant requalification, after vessel replacement, had met with considerable success.

In summary it was intended

a. to return to routine operation as soon as possible with one short test cycle in February and ten normal (= 4 weeks) reactor cycles for the remainder of the year,
b. to continue work concerning other development and upgrading activities (new heat exchangers, new beryllium elements, instrumentation improvements, ...)
c. to begin studies on a reactor power increase from 50 to 60 MW
d. to re-install all experimental equipment removed during vessel replacement and/or install new components in case of replacement
e. to continue work on a large number of irradiation projects.



**HFR PETTEN**
View into reactor hall showing second and third floor working platforms

# 3. RESULTS

## 3.1. Facilities and Services

### 3.1.1. Reactor

During the last phase (Testing and Commissioning) of the vessel replacement, first criticality was again reached on January 25, and full power routine operation began on February 14, 1985.
The first cycle lasted only for two weeks and was intended for testing of all systems under full power and for partial consumption of $^3$He, a neutron poison, which had accumulated in the Be reflector elements. Only a few irradiation devices were loaded.
The remaining ten cycles of the year resumed the traditional rhythm of 25,5 days of 45 MW operation and 2,5 days shutdown. The new reactor performed without any problem through this entire period.
Due to a pump motor failure, the last cycle of the year was completed with only two primary pumps and a reduced primary flow rate. The rather low secondary circuit inlet temperature made this mode of operation possible within the usual safety margins.
A steering group was set up to control and manage all development and upgrading activities for the reactor, e.g.

- replacement of primary and pool circuit heat exchangers,
- improvement of various instrumentation and control systems,
- building extension and adaptation,
- power increase from 50 to 60 MW,
- safety-related analyses and improvements.

New primary heat exchangers with a nominal capacity of 66 MW, together with pipework, valves, strainers, and instrumentation, were ordered in August 1985.
Files were prepared for the ordering of a new pool cooling circuit heat exchanger, new beryllium elements, extensions to the data acquisition and processing system, and various minor components.
Studies continued on reactivity behaviour and possible fuel cycle costs of an HFR core with 20% enriched uranium. Two papers on the topics were presented during the International Meeting on Reduced Enrichment for Research and Test Reactors, Petten, 14-16 October 1985. Contractual procedures were started and draft specifications compiled for manufacture and irradiation testing of four to eight low enriched, high density, silicide fuel elements.
An overall schedule indicates that conversion of HFR Petten would not be feasible before the 1990's.

### 3.1.2. Other Facilities

**Hot cells**

The remote encapsulation facility "EUROS" which had become operational in 1984 was used for loading of three pre-irradiated LMFBR fuel pins into their irradiation devices, with subsequent sodium filling.
The Dismantling (DM) Cell inside the reactor building required a thorough overhauling after the transfer of about 4 tonnes of aluminium scrap of the old reactor. New manipulators were ordered, to be installed during another maintenance period early in 1986.
In the lead (G) cells the installations for strain measurment and re-encapsulation of graphite and steel creep samples came into full scale operation.

**Computers**

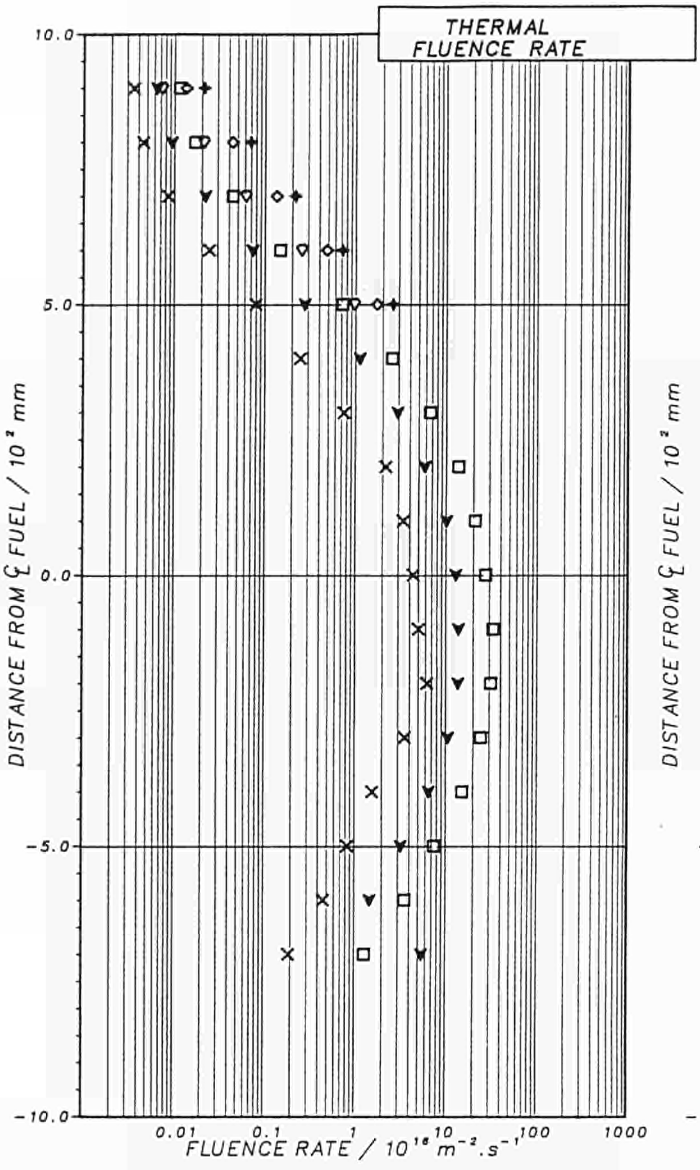
Two new desk top computers were acquired.
Equipment and software have been specified for upgrading the central data acquisition and processing installation "DACOS".

**Standard irradiation facilities**

All standard in-tank and pool side devices had been renewed in the scope of the vessel replacement.
New developments covered, among others, a standard in-tank capsule containing four parallel thimbles which can be loaded with specimens and controlled individually ("QUATTRO"). This design incrcascs thc nct efficiency of reactor utilization by 30%, for the position concerned.

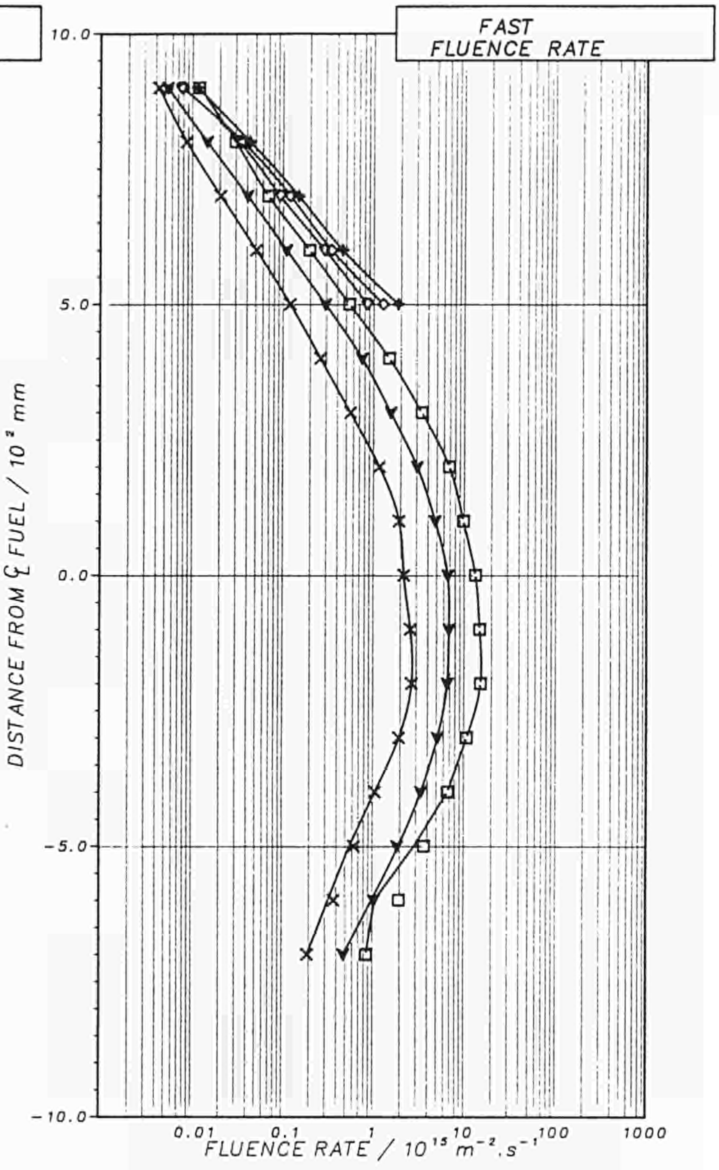
# 3.1.3. Neutron Metrology and Related Damage Studies

Property changes of materials introduced in the HFR are in general dependent on the neutron fluences they received. Neutrons with specific energies have to be considered. For this reason a good knowledge of the neutron spectrum is essential for the interpretation of irradiation damage. An example is the planning and preparation of irradiation testing of fusion reactor materials, requiring a specific ratio for the helium generation and the number of displacements.
This ratio could not be achieved with the available experiment holders. For this reason a new device was developed. In the design of this irradiation device care was taken to adjust the dimensions and the amount of water around the experiment in such a way that the required ratio can be expected.
During the design a number of calculations have been carried out with a four-groups reactor physics code. The results which were predicted by this code will be verified with help of fluence rate measurements inside the irradiation rig, while also two-dimensional multigroup calculations are performed to obtain more detailed information for the various positions inside the rig.
Detailed calculated spectrum data became available at the end of the year by means of the code XSDRN. This code, which is essentially a transport code, calculates spatially dependent fluence rate averaged cross-sections in a group structure up to 123 groups. These cross-sections can be utilized by the code itself or by other two- or three-dimensional codes to calculate fluence rates and neutron spectra in detailed locations within various reactor positions.
A rough validation is made by measuring the helium generated in steel during irradiation. The results were compared with the values obtained from a fluence mapping and a calculation procedure. The comparison shows a reasonable agreement from which it can be concluded that the calculation procedure is valid. A relatively high uncertainty remains, due to lack of accurate knowledge of the initial amount of boron present in the steel.




THERMAL FLUENCE RATE DISTRIBUTIONS
ABOVE AND BELOW THE CORE IN PSF−II(EAST)
PSF−POSITIONS 25 AND 27
( MEASUREMENTS 1985 )

+ = PSF 25; DISTANCE TO CORE BOX WALL 25 MM
◇ = PSF 25; DISTANCE TO CORE BOX WALL 50 MM
▽ = PSF 25; DISTANCE TO CORE BOX WALL 85 MM
□ = PSF 27; DISTANCE TO CORE BOX WALL 125 MM
▼ = PSF 27; DISTANCE TO CORE BOX WALL 175 MM
× = PSF 27; DISTANCE TO CORE BOX WALL 260 MM




FAST FLUENCE RATE DISTRIBUTIONS
ABOVE AND BELOW THE CORE IN PSF−II(EAST)
PSF−POSITIONS 25 AND 27
( MEASUREMENTS 1985 )

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◇ = PSF 25; DISTANCE TO CORE BOX WALL 50 MM
▽ = PSF 25; DISTANCE TO CORE BOX WALL 85 MM
□ = PSF 27; DISTANCE TO CORE BOX WALL 125 MM
▼ = PSF 27; DISTANCE TO CORE BOX WALL 175 MM
× = PSF 27; DISTANCE TO CORE BOX WALL 260 MM

HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR PETTEN
HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR PETTEN

# 3.2. Reactor Utilization

## 3.2.1. General

The reactor can be considered as an intense source of neutrons serving numerous research areas. The particular characteristics of neutrons and of their interaction with matter have been reviewed recently in several international meetings and there is no doubt about long term future needs of intense neutron sources. Reactors, however, are faced with several problems, like

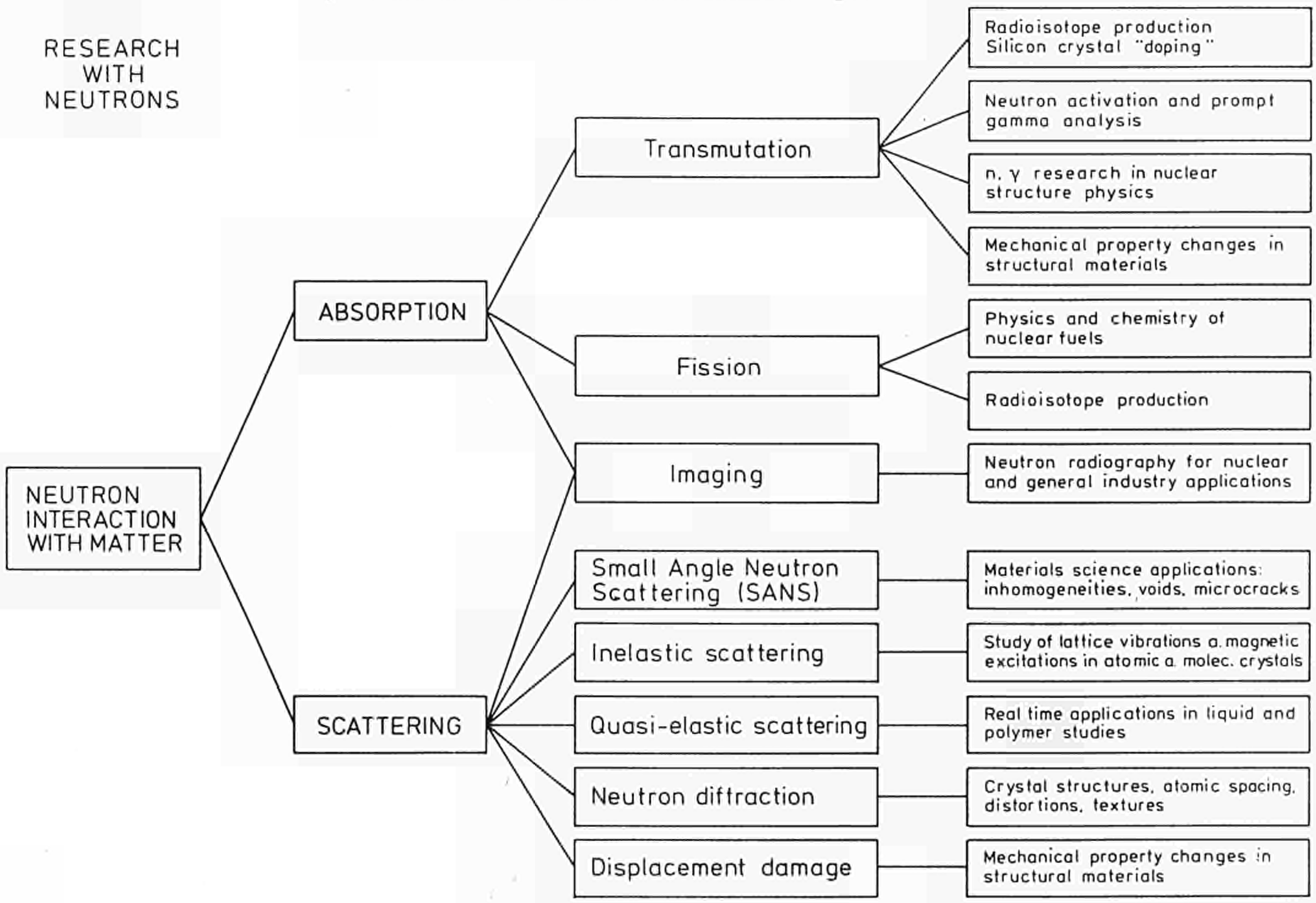
- the absolescence of certain installations
- competition for funding
- advances in accelerator technology (spallation neutron sources).

The response has been, apart from the final shutdown of many facilities, modernization and upgrading of the remaining reactors and their experimental equipment. There is also a small number of projects for new research reactor facilities which should supply essentially higher neutron fluxes in the 1990's and beyond.

Permanent modernization and upgrading, together with the search for new applications, have been part of the HFR programme management ever since.

In 1985 the utilization of HFR was influenced by the preceeding vessel replacement period: whereas a certain accumulation of tests to be carried out had occurred during the 14 months shutdown period, many components had been removed temporarily or permanently and required refitting or replacement. This caused delays in several areas of experimental utilization of the plant.

All in all, the average annual occupation was satisfactory at 57% of the theoretical maximum, although lower than in the past.



# 3.2.2. Nuclear Fission Energy

**High temperature gas cooled reactor**

The high temperature gas cooled reactor (HTR or HTGR) offers a number of advantages:

- high thermal efficiency, i.e. improved utilization of resources and reduced waste heat release,
- large flexibility of its fuel cycle, including proliferation-resistant solutions,
- high inherent safety,
- utilization for high temperature chemical processes, including coal gasification and liquefaction (substitution of natural gas and oil), and for electricity generation.

The development of this reactor type is actively pursued in the Federal Republic of Germany, the U.S.A. and in Japan with contributions from a number of other countries.

HFR Petten has been in charge of test irradiations for two materials which are typical for the HTR:

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

The HFR graphite irradiation programme supplies the necessary design base for future HTR types, starting with the steam generating plant, but including the nuclear process heat and the direct cycle concepts.
The irradiation capsules contain unstressed samples (fundamental properties programme) or creep specimens under tension or compression. They are irradiated in three to four fluence steps, with intermediate measurement of their changed physical properties. For the reflector graphite materials, irradiation temperatures range between 300° C and 1150° C.
In total 16 new graphite specimen carriers were loaded for irradiation during the year, eight with unstressed and eight with creep specimens.
In the area of HTR fuel two new devices were loaded, one with spherical, the other with cylindrical fuel elements. The large out-of-pile control installation ("sweep loops") for those experiments was thoroughly overhauled.

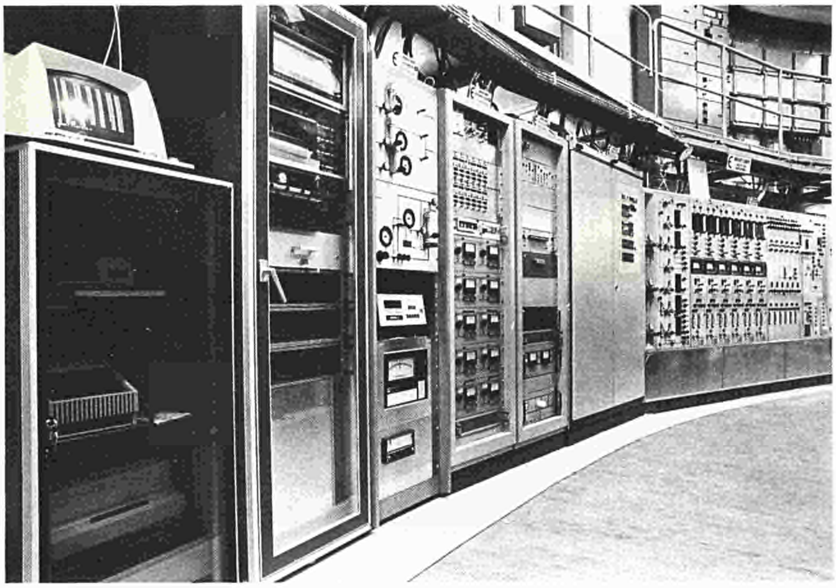
**Light water reactors (LWR)**

A large part of the experiments caried out in HFR Petten concerns the behaviour of nuclear reactor core materials under transient and abnormal conditions. Fuel pins which have already operated for two to four years in light water power reactors are submitted to transients in specially developed irradiation capsules in order to test their resistance against abnormal conditions (overpower, power increases).
The accurate knowledge of this behaviour allows large power reactors to be operated with a maximum of assurance against the release of radioactivity (fission products).
The HFR BWFC (Boiling Water Fuel Capsule) experimental programme usually features 20 to 25 experiments per year, including their non-destructive tests before and after irradiation.
The first months of 1985 were used to service and to recalibrate the equipment. Irradiation testing started again in April. Two new long-term tests with special instrumentation were taken into operation, and seven short term ramp tests carried out.
Design, computation and laboratory tests continued on a novel in-pile blow-down facility for studies on fission product release under severe fuel damage conditions.

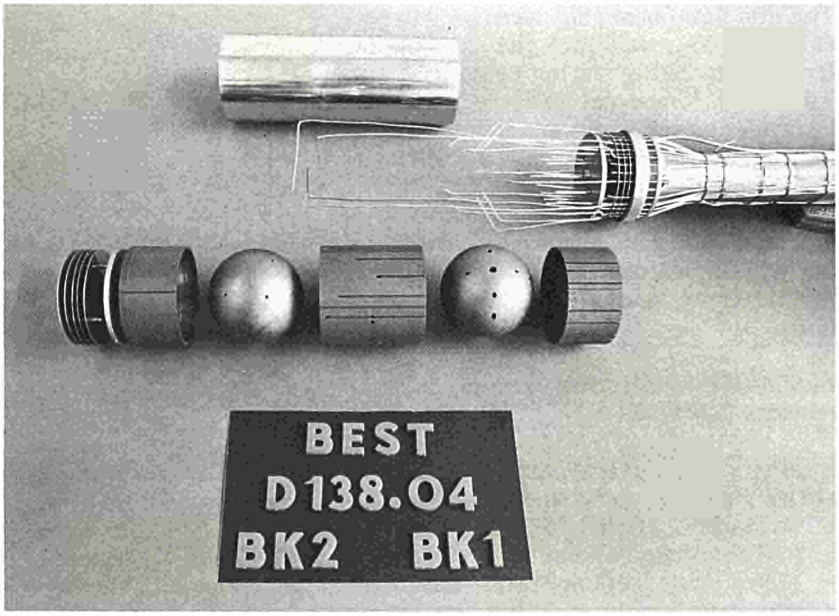
**Liquid metal cooled fast breeder reactors (LMFBR)**

Internationally several R&D programmes are pursued with the goal of qualifying

- advanced LMFBR fuel under normal and abnormal conditions,
- mixed oxide fuel under start-up and in-situ operational transients,
- structural materials.



NUCLEAR FISSION ENERGY
High temperature gas cooled reactor
Fission product transport and analysis system

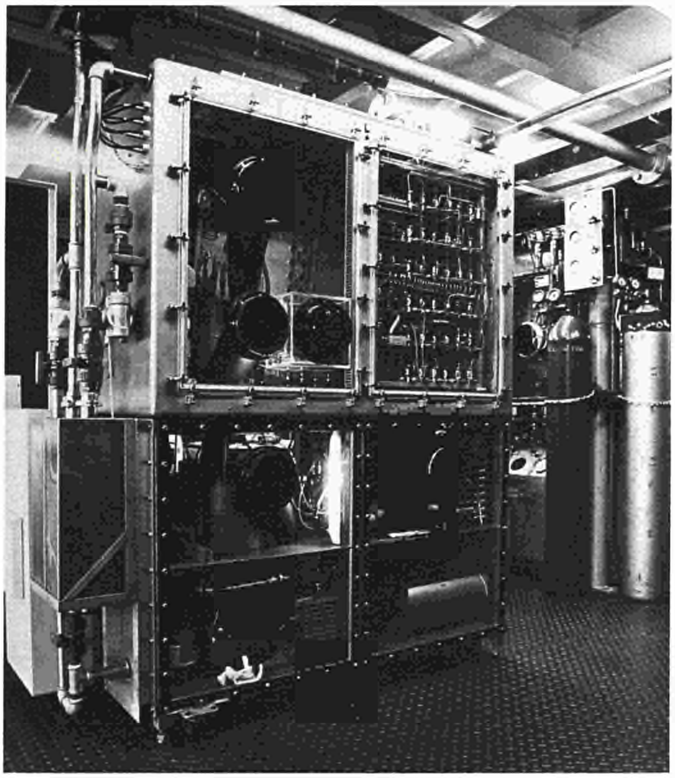


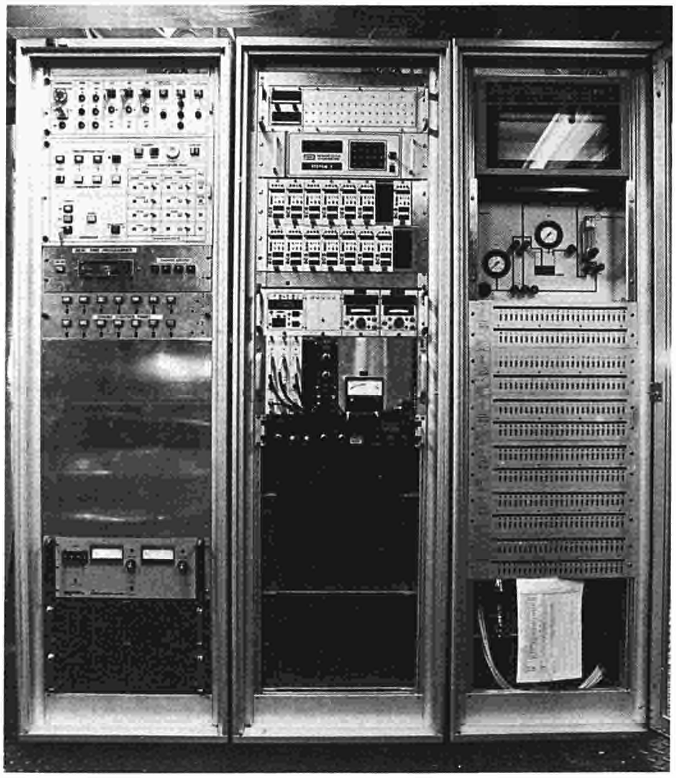

Fuel element irradiation test rig under assembly

Transient irradiation testing has been performed on over 50 LMFBR fuel pins during the past ten years.
The translation of the HFR environment into real fast reactor conditions is achieved by a combination of special neutron flux measurements and computer calculations. Certain irradiation devices use cadmium filters to simulate the fast reactor neutron spectrum.
Neutron gradient problems which had occurred in pool side facility irradiations of fast breeder fuel were eliminated by specially designed directional absorber screens.
Breeder reactor safety also concerns the response of neutron irradiated structures to mechanical stresses including vibration and shock. More than 2000 stainless steel specimens have been irradiated in HFR over the past eight years, and transferred to post-irradiation mechanical testing in shielded laboratories ("hot cells"). The irradiations have supplied accurate information of material embrittlement by helium formation and fast neutron displacements.
In 1985 a new in-pile facility was taken into operation which enables fuel pin profiles to be measured between power transients. Seven other operational transient tests and three (safety-related) transient overpower tests were carried out.
About 120 stainless steel samples were irradiated in sodium-filled capsules for investigations into the mechanical safety of structural fast breeder reactor components.
Design studied have been pursued on two small in-pile sodium loops as multi-purpose devices for future LMFBR fuel pin testing.

# 3.2.3. Thermonuclear Fusion

Fusion reactors, together with fast fission breeders and solar energy, are considered to be the potential new primary energy sources, able to solve the problem of energy supply in the next century. For this reason, large efforts are being devoted worldwide to research related to the controlled thermonuclear system.
During the past several years there have been notable developments in this field. The physics of confinement and heating of plasmas has been investigated in a number of experimental machines in Europe, Japan, the USA and the USSR.
As confidence on the potential of plasma systems to reach conditions for ignition grows, more attention is paid to the steps toward the achievement of commercial fusion power reactors and the related technological problems which are, amongst other things, materials problems. Fission test reactors like HFR can be used for irradiation testing of candidate fusion reactor materials. Work in HFR Petten is embraced by the 1985/90 European Fusion Technology Programme, an implementing agreement sponsored by the International Energy Agency, and the Fusion Technology Programme of JRC Ispra.
Particular efforts were deployed in 1985 for the correct determination of relevant irradiation and damage parameters (see paragr. 3.1.3.).
Collaboration with other European laboratories in different areas of fusion materials neutron irradiation testing has been intensified.
Whereas several structural material projects continued as scheduled and in an uneventful fashion, the successful operation of two new ceramic breeder experiments ("EXOTIC") marked a step into a novel research area.





**THERMONUCLEAR FUSION**
In-pile tritium release studies "EXOTIC"
Tritium measuring station and electronic control panel

Survey of fusion materials irradiation tests in HFR Petten

| **HFR proj. number** | **Project name** | **Specimen material** | **Test type** | **Status, end 1985** |
|---|---|---|---|---|
| R 139 | SINAS | ↑ Austenitic stainless steel ↓ | Post-irradiation tensile and creep tests Post-irradiation crack growth experiment | Continuous programme, enlarged towards higher fluences |
| | FRUST 10 | | Post-irradiation tensile | Irradiation completed |
| E 198 | FRUST 01-03 11-13 | ↑ Austenitic stainless steel, incl. AMCR ↓ | Post-irradiation tensile | Finished |
| | FRUST 04-06 | | | Irradiation finished |
| | FRUST 07-09 | | | Irradiation continues |
| | SIENA 14 | | High fluence, includes ferritic steel | Under manufacture. Iradiation in 1986/90 |
| E 157 | CRISP | ↑ Austenitic stainless steel ↓ | In-pile creep measurements continuous | Under assembly. Irradiation in 1986/87 |
| E 167 | TRIESTE | | intermittent | Irradiation to be continued |
| E 199 | LOCFIRE | | In-pile fatigue | Under development. Irradiations in 1987 |
| E 200 | FATMAC | | In-pile crack growth | (Dormant) |
| E 207 | INFANTE | | | |
| D 202 | SUPRA | $V_3Si$ | Fundamental research on radiation damage in superconducting materials | Several irradiations finished. Programme continues |
| R 204 | VABONA | V-5Ti | Radiation damage studies | First irradiation finished. Sec. rig under manufacture |
| R 212 | EXOTIC | Ceramic breeder compounds e.g. $Li_2O$ $LiAlO_2$, $Li_2SiO_3$ property changes | Irradiation testing with parameter variation and studies of T-release and T-recovery with in-pile loop | Two irradiations completed. Programme continues |
| E 224 | LIBRETTO | Liquid breeder Li17Pb83 | In-pile T breeding and permeation testing. Post-irradiation T-recovery | Under development Design started |
| D 217 D 225 | CERAM } CEFIR } | Insulator and first wall ceramics. Might include graphite | Radiation damage studies | Under manufacture. Irradiation in 1986/87. |

## 3.2.4. Protection of the Environment

Neutron activation analysis is a very efficient and accurate method for the determination of a large number of trace impurities and contaminants. Therefore it is a method, which can be used as an effective instrument for environment pollution control, e.g. for the determination of arsenic, mercury, cadmium, uranium, selenium and antimony in residues from coal-firing plants, in biological material, in soil samples, etc. In the field of activation analysis HFR Petten offers several facilities over a wide range of irradiation times and sample volumes, using both conventional and prompt gamma ray techniques, i.e.

- the epithermal low flux facility in the pool (PROF),
- the fast rabbit system FASY in HB-10,
- the prompt capture gamma ray facility in HB-4.

The re-installation of the fast rabbit system FASY in HB-1, the prompt capture gamma-ray facility in HB-4 and the PIF and PROF positions for the long term simultaneous irradiation of many samples, has been the main theme of this year's activities. All mentioned facilities work well again.

As usual, the applications ranged from multi-trace element analysis of silicates (rocks and sediments) to the assay of just one single important element for which the HFR is well suited. An example of this second situation is the determination of selenium in small biological samples.

Possibilities of in-core activation analysis, using quartz capsules, were investigated for the determination of trace elements in high-purity $Si_2O_2$ based on irradiation in the RIF. Specific count rates, as determined on international Standard Reference Materials, were determined for 15 important trace elements.

The measurement of the relative flux per individual sample by way of small iron-rings, such as in use in the PIF and PROF facilities, was tested. The influence of other than (n, $\gamma$) reactions was taken into consideration.

The new parameters of the neutron beams for nuclear physics at the HFR

| Beam no. | Flux density ($cm^{-2}s^{-1}$) | Neutron energy | Remarks |
|---|---|---|---|
| HB2 | $2.10^7$ (estimated) | thermal (polarized) | Nuclear polarization (T = 5 mK, H = 8 tesla) |
| HB4 | $10^7$ (estimated) | 2 keV | In preparation |
| HB7 | $2.10^7$ | thermal (polarized) | Analyser for gamma ray circular polarization |
| HB11 | $3.10^9$ (estimated) | thermal | |
| HB12 | $6.10^6$ | 24 keV | Proton polarizer in preparation |

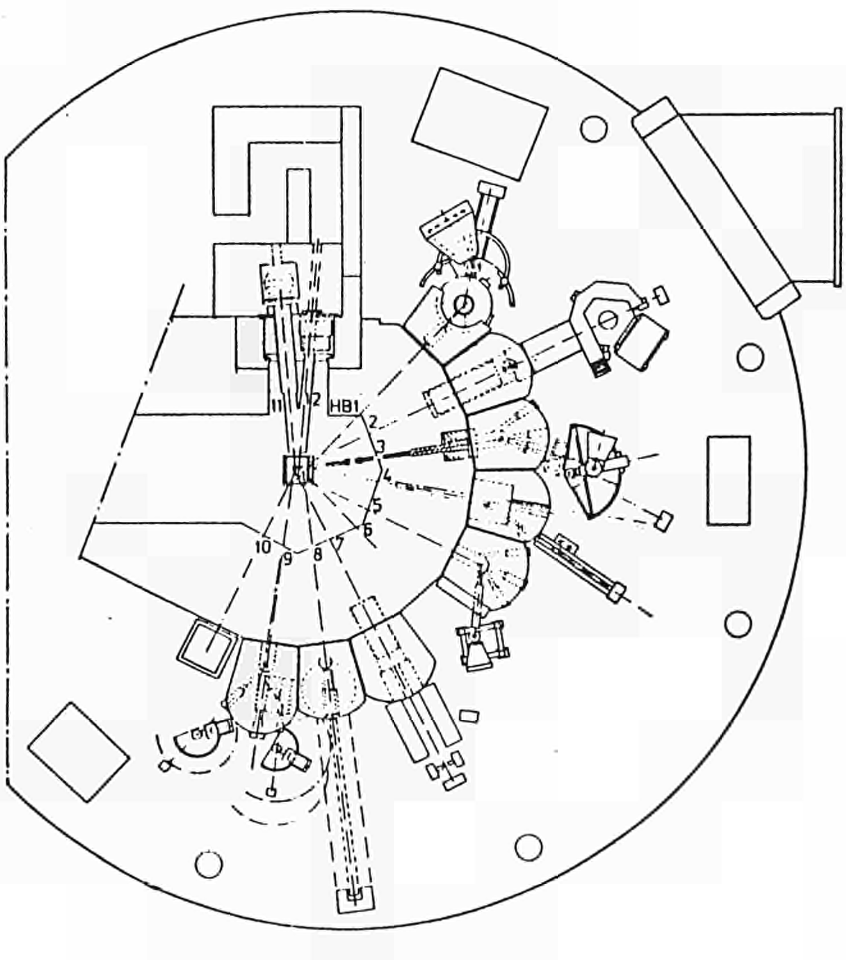
# 3.2.5. Fundamental Research

Certain interactions of neutrons with matter, like prompt gamma emission after neutron capture, scattering, diffraction, etc. can be used for studies of fine structures of nuclei or crystal structures of solids. The installations around the reactor use "beams" of neutrons extracted from the core through horizontal tubes. Spectrometers arranged around the target area measure intensity, energy orientation and polarization of the emitted radiation, which are then analysed by means of computer codes.

- **Nuclear Physics**

**General**

The replacement of the HFR vessel has been taken as an opportunity to upgrade three of the four neutron beam facilities, in use by the Nuclear Physics Group before the vessel exchange, and to construct new equipment. The major operation in this respect was the replacement of the old thermal column by a high flux twin beam (HB11/12).




HORIZONTAL BEAM-HOLE NEUTRON EXPERIMENTS

HB1 diffuse scattering / triple-axis spectrometer

2 nuclear polarization set-up

3 triple-axis / time-of-flight spectrometer

4a filtered beam facility
4b prompt gamma-ray experiment

5 double-axis diffractometer

6

7 polarized neutron capture set-up

8 thermal / sub-thermal radiography

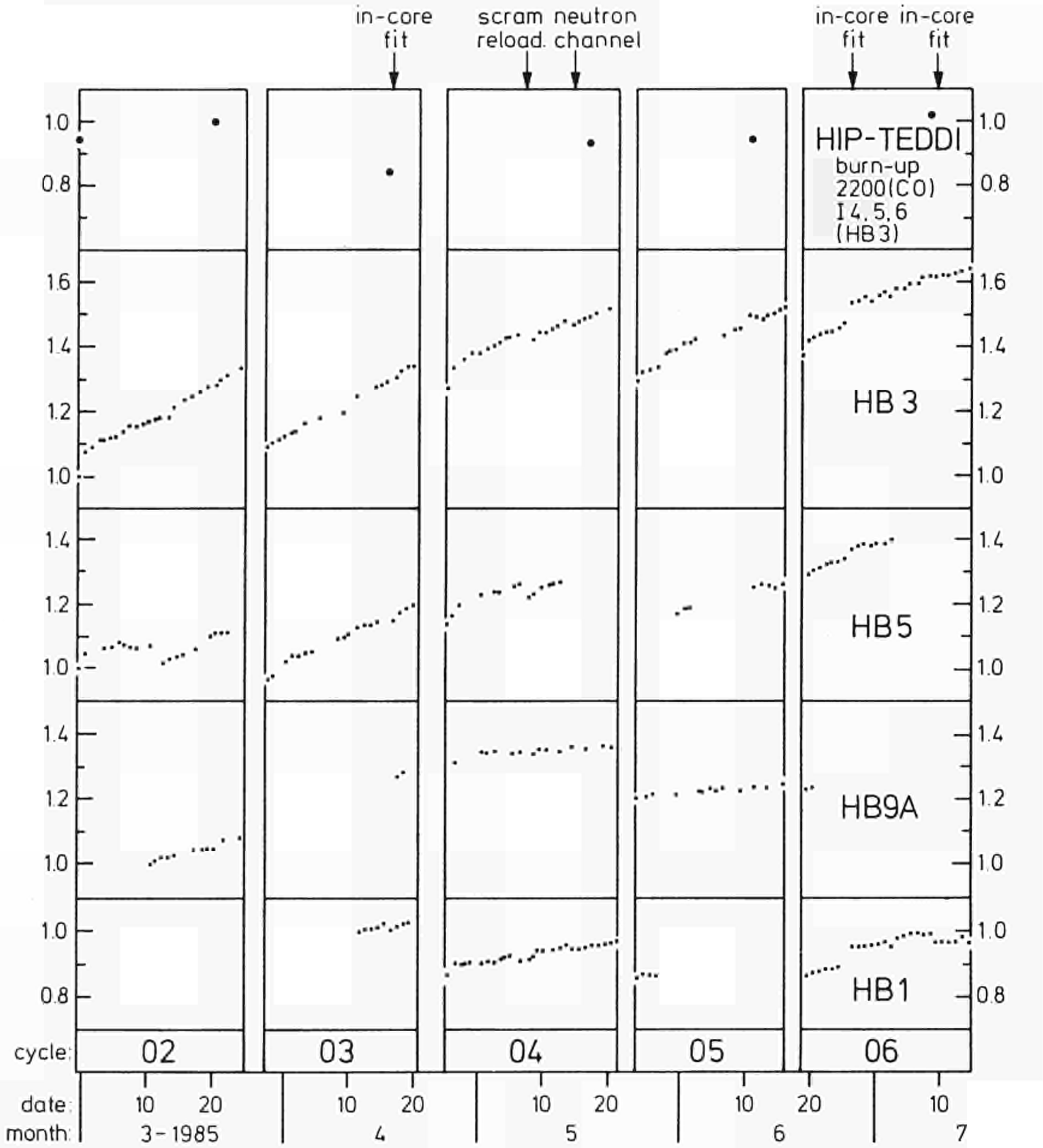
9a single-crystal diffractometer
9b polarized neutron diffractometer

10 fasy

11 neutron capture set-up

12 filtered beam facility / proton polarization set-up

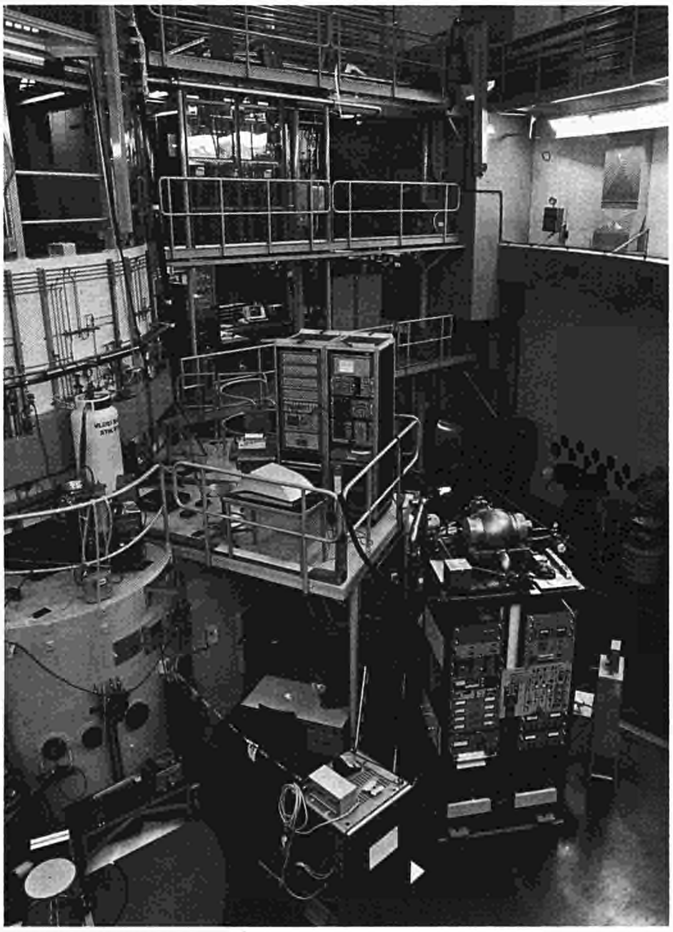
RELATIVE INCREASE OF MONOCHROMATIC BEAM INTENSITY

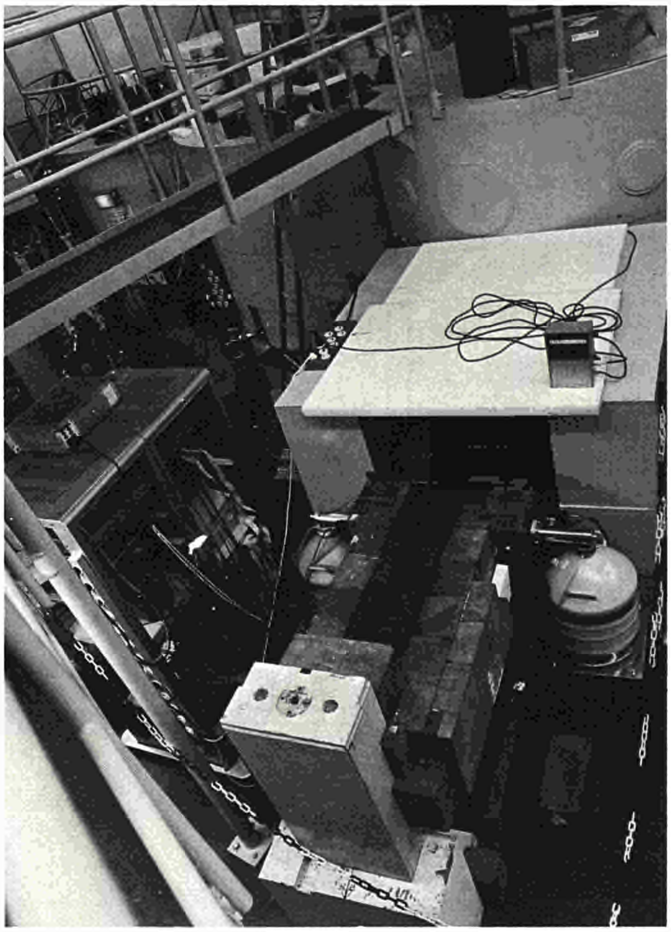


HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR PETTEN
HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR PETTEN

**HB2: Nuclear polarization set-up**

At this set-up experiments are conducted for the study of capture of polarized thermal neutrons by polarized target nuclei. The old neutron polarizer, a Heussler crystal, has been replaced by the polarizing mirror system formerly installed at the polarized neutron capture set-up, HB7. In this way the flux density of polarized thermal neutrons has been increased from $10^6$ $cm^{-2}s^{-1}$ to about 2 x $10^7$ $cm^{-2}s^{-1}$.
For this purpose the center block of the old shielding units has been replaced by two smaller blocks allowing space for the mirror system and a new beam shutter.
Furthermore the cryogenic equipment has been reinstalled, for the time being without the superconducting magnet which is under revision at the manufacturer.
In order to provide space for the electronics, without conflicting with the neighbouring beam experiments, a platform has been placed above the beam path extending the top floor of the upper shielding block.





NUCLEAR PHYSICS
Nuclear polarization facility at HB2
Polarized neutron capture set-up at HB7
(overall views from the reactor-hall)

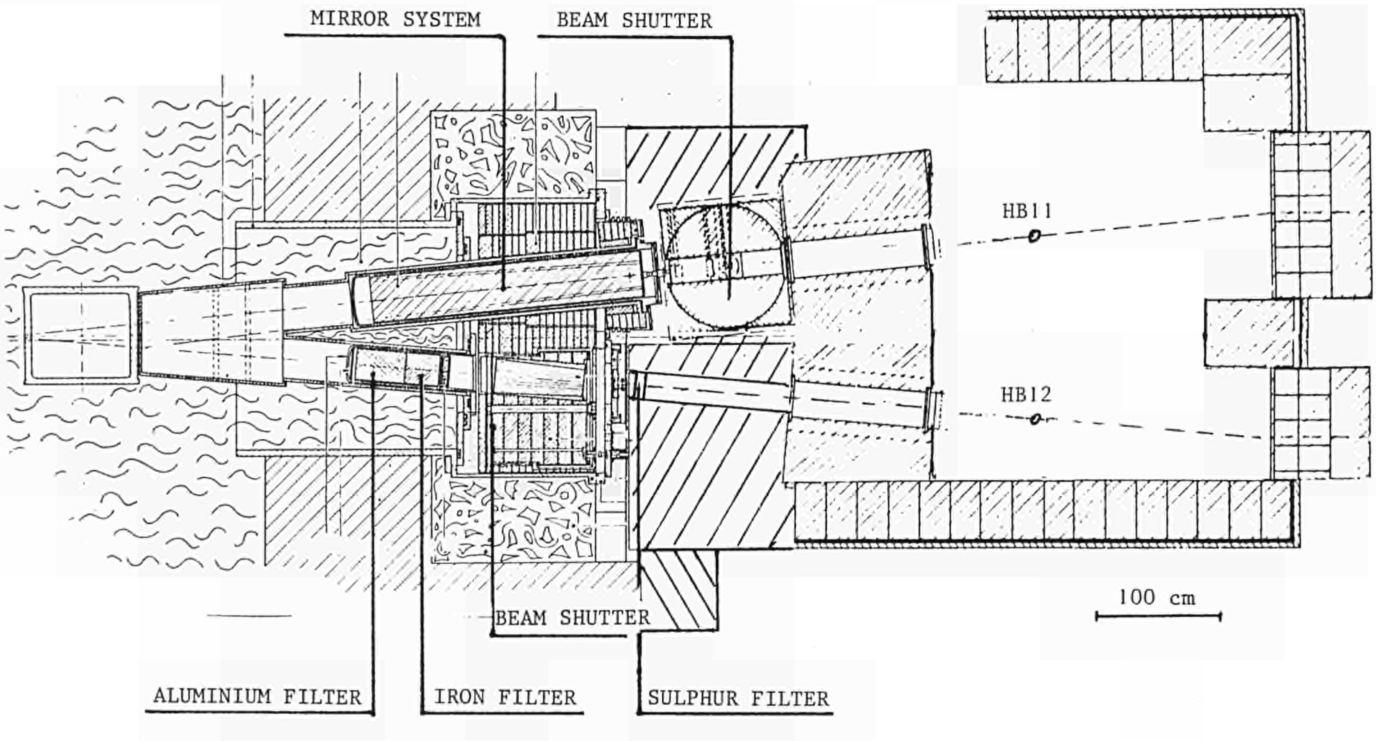
**HB7: Polarized neutron capture set-up**

This set-up is a facility for capture of polarized thermal neutrons by unpolarized target nuclei. The old neutron polarizer, a focussing mirror system, has been replaced by a similar system obtained from the Karlsruhe Nuclear Research Center. The new system has the same geometry as the old one, but the individual mirrors have a higher reflectivity and the magnetization is performed by permanent magnets. To facilitate the installation of this system the shielding has been reconstructed. From HB2 the old center block has been modified and placed as top shielding. This arrangement has considerably decreased the level of the background radiation around the exit of the mirror system with respect to the situation before the vessel replacement.

**HB11: Neutron capture set-up**

An intense beam of unpolarized thermal neutrons for capture experiments is extracted at this facility. The high flux density is resulting from the large dimensions of the beam tube (40 x 40 $cm^2$ cross section), which allows transmission of neutrons from the entire surface of one side of the reactor core through a focussing mirror system, previously installed in the thermal column (HB0). The unwanted epithermal neutrons are filtered out by the mirror system, producing a clean beam of thermal neutrons. Based on the experience from HB0 the shielding has been reconstructed. Extensive use of borated polythene as shielding component has resulted in a decrease of the background level on the platform above HB11/12 as compared to the HB0 situation.

Schematic situation of the new HB11/HB12 twin beam facility at the end of 1985



**HB12: Filtered beam facility**

In the same way as HB11, this facility is provided with a large beam tube through which the target position is illuminated from the whole surface of one side of the reactor core. In this beam tube an iron filter, consisting of 24 cm iron, 36 cm aluminium and 6 cm sulphur, has been installed. By transmission through the filter a quasi-monoenergetic neutron beam of 24 keV neutron energy is extracted.
The 24 keV neutrons are used for capture gamma experiments, and for astrophysically relevant cross section measurement. Some experiments will need a polarized 24 keV beam.
For this purpose a neutron polarizer is under construction consisting of a polarized proton scatterer (protons polarized by a high magnetic field at low temperature), which will polarize the neutrons by transmission.

- **Solid State Physics**

The major activities with respect to the five experimental facilities for neutron scattering research have been concerned with the installation and recommissioning of these facilities. The reactor vessel replacement offered the opportunity for revisions, modifications, and upgrading.
Although no fundamental changes have been made, much effort was put into improving geometrical conditions and partly or completely renewing electronics and/or computer control. The ultimate performance of the setups with respect to available neutron flux at the sample positions is somewhat disappointing. It was anticipated that because of the new beam in-pile collimators the flux would generally increase by as m uch as 60%. This now seems to be counter-balanced by effects due to the new vessel geometry, such as thicker walls, different water layers between beam tubes and reactor core, etc. Although the general trend is clear, different behaviour is observerd for the individual beam tubes which might be due to variations in reactor core loadings.
The study on possibilities for flux improvements by replacing part of the beryllium reflector by a heavy water reflector is considerably delayed with respect to its final report, which should include advanced reactor physics calculations.
Plans have been worked out for the design and construction of a small-angle neutron scattering facility at one of the beam tubes in use by the Solid State Physics group. This instrument is meant for the study of inhomogeneities in condensed matter of characteristic lengths between 1-100 nm, both in the field of fundamental science as well as in that of materials science.

During the second half of 1985 all five instruments of the Solid State Physics group were in use again for carrying out its regular research programme. It concerns different topics in crystallography, chemistry, solid state physics and metal physics, often carried out in close cooperation with several Dutch universities and in lesser extent with foreign research institutes or laboratories. There is an increasing interest from the industrial laboratories.
Besides the publication of a number of scientific papers, this beam research also led to three PhD promotions through theses based on work carried out at the HFR.

# 3.2.6. Radioisotopes

The demand for radioisotopes has been constantly increasing during recent years. Among the reasons for this development are

- new and intensified applications in medical diagnosis and therapy, and in industry,
- progressive legalization of foodstuff sterilizing by gamma irradiation.

A number of simple reloadable devices are available and are currently used at HFR for the activation of various targets "à la carte". Special facilities have been developed for the production of iridium-192 (cancer treatment, industrial radiography), molybdenum-99 (various diagnostic and therapeutic applications) and cobalt-60 (gamma sterilization).
All facilities were rebuilt after the vessel replacement, and the production lines resumed after start-up.
As a new development, silicon crystals are now "doped" with accurately dosed impurities, through the $^{30}Si(n,\gamma)\ ^{31}Si \xrightarrow{\beta^-} {}^{31}P$ reactions for the semi-conductor industry.
Two new long-term irradiation rigs for cobalt-60 production were taken into oper ation. 102 fissile samples were irradiated, and shipped for extraction of $^{99}Mo$.

Number of irradiations carried out in 1985:

| Facility | | Number of capsules |
|---|---|---|
| High flux pool side isotope facility | HFPIF | 25 |
| Reloadable isotope facility | RIF | 100 |
| Pool side rotating facility | PROF | 75 |
| Pneumatic rabbit system | PRS | 203 |
| | Si irradiation facility | 20 |
| Gamma irradiation facility | GIF (in the storage pool) | 7 |

# 3.2.7. Miscellaneous

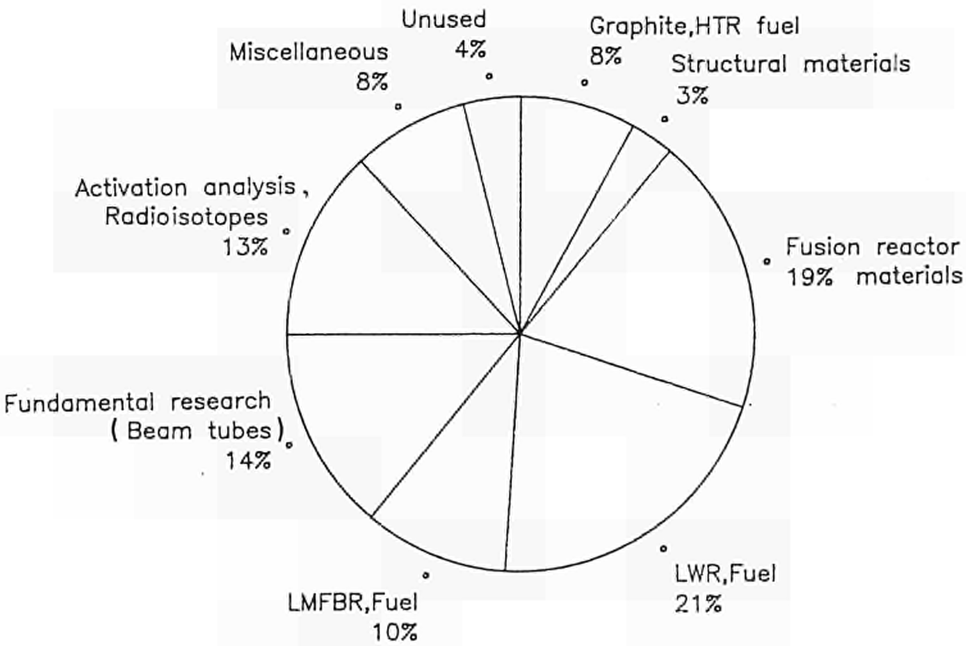
Neutron-induced embrittlement of the new reactor vessel's aluminium alloy will be monitored at four to five years' intervals by mechanical testing of alloy specimens irradiated in two special rigs. These "surveillance" irradiations started early in 1985 and will be pursued virtually throughout the new reactor's lifetime.

The post-irradiation analyses of low-enriched research reactor test elements, irradiated in the HFR in 1982-1983, were concluded. Specifications and drawings for a new series of high density test elements have been prepared. The in-pile testing is planned for 1987/1988.

HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR PETTEN
HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR HIGH FLUX MATERIALS TESTING REACTOR PETTEN

# 4. CONCLUSIONS

1985 was the first year of operation of an entirely rebuilt reactor. Its performance turned out to be uneventful and trouble-free.
Rebuilding of the experimental facilities lagged somewhat behind. This accounts for the overall reactor utilization percentage of 57% during cycles 85.02 through 85.11 as compared to an average of 78% during the four years preceeding the vessel replacement.
Previsions for 1986–87 indicate a gradual further increase towards the 75–80% level.




THEORETICAL HFR OCCUPATION IN % BASED ON TARIFF FOR THE PERIOD 1986–1990

# 5. 1985 PUBLICATIONS OF THE HFR PROGRAMME

1. P. von der Hardt (ed.)
Programme Progress Report "Operation of the High Flux Reactor",
July-December 1984. Communication No. 4181

2. P. von der Hardt (ed.)
Annual Report 1984 "Operation of the High Flux Reactor"
EUR 9811 EN

3. P. Kennedy, A. J. Flipot, R. Conrad and H. Kwast
Annual Progress Report 1984: EXOTIC
ECN-167 (June 1985)

4. M. R. Cundy and P. von der Hardt
"HFR vessel replacement at Petten"
Nuclear Europe 5/1985 page 39-42

5. N. G. Chrysochoïdes, M. R. Cundy, P. von der Hardt, K. Husmann,
R. J. Swanenburg de Veye and A. Tas
"High Flux Testing Reactor Petten. Replacement of the reactor vessel and
connected components. Overall report"
EUR 10194 EN (September 1985)

6. H. Hausen
"Critical survey of the neutron-induced creep behaviour of steel alloys for the
Fusion Reactor Materials Programme"
EUR 9924 EN

7. J. P. Genthon and H. Röttger (eds.)
Proceedings of the Fifth ASTM-EURATOM Symposium on Reactor Dosimetry,
GKSS Research Centre Geesthacht, September 24-28, 1984
EUR 9869 (Part I and Part II)

8. E. J. Bleeker, U. Dahlborg, K. Sköld and W. B. Yelon
"Upgrading thermal neutron beams of light water moderated research reactors
by reflector optimization"
Int. Conferenced on Neutron Scattering in the 90's.
Jülich (FRG) 14-18 Jan. 1985

9. A. Korko, J. Markgraf and D. Perry
"Under-water inspection equipment for eddy current and diameter scanning
of LWR fuel rods at HFR Petten",
7th Int. Conf. on NDE in the Nuclear Industry, Grenoble, France, January 1985

10. R. L. Moss and P. May
"Comparative and predictive study of the annual fuel cycle costs for HEU and LEU
fuels in the High Flux Reactor, Petten, 1985–1993"
International Meeting on Reduced Enrichment for Research and
Test Reactors (RERTR), Petten, 14-16 October 1985

11. J. R. Deen and J. L. Snelgrove
"Reduced-reactivity-swing LEU fuel cycle analyses for HFR Petten"
ibid.

12. P. von der Hardt, R. Conrad, J. Markgraf and P. Zeisser
"Irradiation testing of fuel elements for different nuclear reactor lines at the HFR Petten"
KTG-Fachtagung "Performance of Fuel and Cladding Material under Reactor Operating Conditions", Karlsruhe, 28-29 November 1985

13. H. Kwast, R. Conrad and J. d. Elen
"EXOTIC. An experimental programme on the development of ceramic tritium breeding materials"
J. Nucl. Mat. 133 & 134 (1985), 246-250

14. J. Konrad
"Irradiation of uranium 235 in the HFR Petten for the production of Mo-99, I-131, and Xe-133 radioisotopes"
Revue IRE, Vol. 9, No. 3 (September 1985)

15. J. Markgraf, D. Perry and J. Oudaert
"LWR fuel rod testing facilities in High Flux Reactor (HFR) Petten for investigation of power cycling and ramping behaviour"
Res Mechanica *13* (1985) 187-210

16. W. Vogl, I. Ruyter and J. Markgraf
"The Petten ramp test programme of KWU/KFA during the years 1976 to 1981"
Res Mechanica *14* (1985) 171-195

17. P. von der Hardt
"European test facilities for light water reactor fuel pins"
Res Mechanica *14* (1985) 261-270

18. I. Ruyter, G. Pott, J. Markgraf and F. Sontheimer
"Steady state irradiation and ramp testing of highly instrumented fuel rods"
Res Mechanica *16* (1985) 117-134

19. J. Konrad
"Radioisotope production facilities at the HFR Petten"
Seminar on Applied Research and Service Activities for Research Reactor Operation, IAEA Vienna, Copenhagen, September 9-13, 1985

20. G. Tsotridis and B. Steriopoulos
"An analytical model of flow and heat transfer inside a porous medium"
2nd Nat. Conf. in Alternative Sources of Energy, Thessaloniki, Greece, November 6-8, 1985

21. P. von der Hardt and R. J. Swanenburg de Veye
"De Pettense Hoge Flux Reactor in een nieuwe levensfase"
Energiespectrum 9, nr. 12 (December 1985)

# ANNEX

**1985 Visitors to the HFR Programme**

Not counting commercial visitors, working groups or conference participants, scientific/technical visitors in 1985 were distributed over the following countries:

| | | | |
|---|---|---|---|
| Belgium | 3 | Canada | 4 |
| Denmark | 5 | Japan | 12 |
| F.R. of Germany | 20 | U.S.A. | 6 |
| France | 7 | Others | 3 |
| Netherlands | 15 | | 25 |
| United Kingdom | 4 | | |
| Other EEC countries | 3 | | |
| | 57 | | |
| | | Total | 82 |

There were eight working group meetings with participants from all EEC countries, and ten individual visitors from other parts of the Commission's services.

**European Communities – Commission**
EUR 10498 – Operation of the High Flux Reactor

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## ABSTRACT

This year was characterized by the end of a major rebuilding of the installation during which the reactor vessel and its peripheral components were replaced by new and redesigned equipment. Both operational safety and experimental use were largely improved by the replacement. The reactor went back to routine operation on February 14, 1985, and has been operating without problem since then. All performance parameters were met.
Other upgrading actions started during the year concerned new heat exchangers and improvements to the reactor building complex.
The experimental load of the High Flux Reactor reached a satisfactory level with an average of 57%. New developments aimed at future safety related irradiation tests and at novel applications of neutrons from the horizontal beam tubes. A unique remote encapsulation hot cell facility became available adding new possibilities for fast breeder fuel testing and for intermediate specimen examination.
The HFR Programme hosted an international meeting on development and use of reduced enrichment fuel for research reactors. All aspects of core physics, manufacture technology, and licensing of novel, proliferation-free, research reactor fuel were debated.

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