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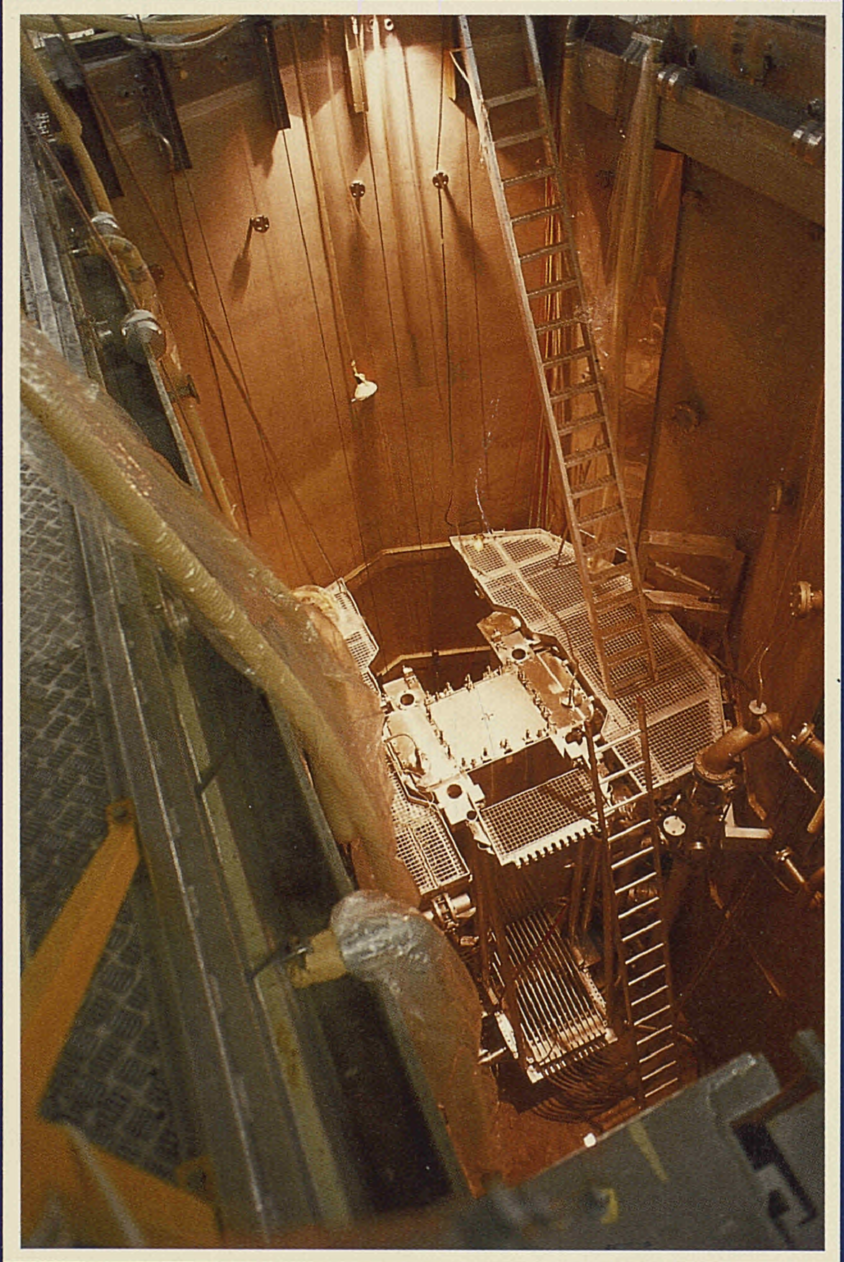
COMMISSION OF THE EUROPEAN COMMUNITIES

Multiannual programme
of the Joint Research Centre
1984-1987

ANNUAL REPORT 1984

OPERATION OF THE HIGH FLUX REACTOR



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OPERATION OF THE HIGH FLUX REACTOR

ABSTRACT

The programme resources in 1984 were largely devoted to the replacement of the old reactor vessel and its peripheral equipment.

The original vessel had been in operation for more than 20 years and doubts had arisen about the condition of the aluminium tank after so long an exposure to neutrons.

The operation, which had never been attempted before on a reactor of that size and complexity was planned and prepared over a number of years to take advantage of the occasion to provide a much improved vessel, incorporating the latest design features.

The plant was shut down at the end of November 1983 and the 14 months operation began with a short cooling-off period for decay of short lived radioactivity followed by removal of the old tank and its dissection into pieces convenient for consolidation and storage as radioactive waste.

After decontamination of the shielding pool, the new vessel and neutron beam tubes were installed and the reactor was recommissioned.

Routine 45 MW operation was resumed on 14 February 1985 and has been uneventful since then.

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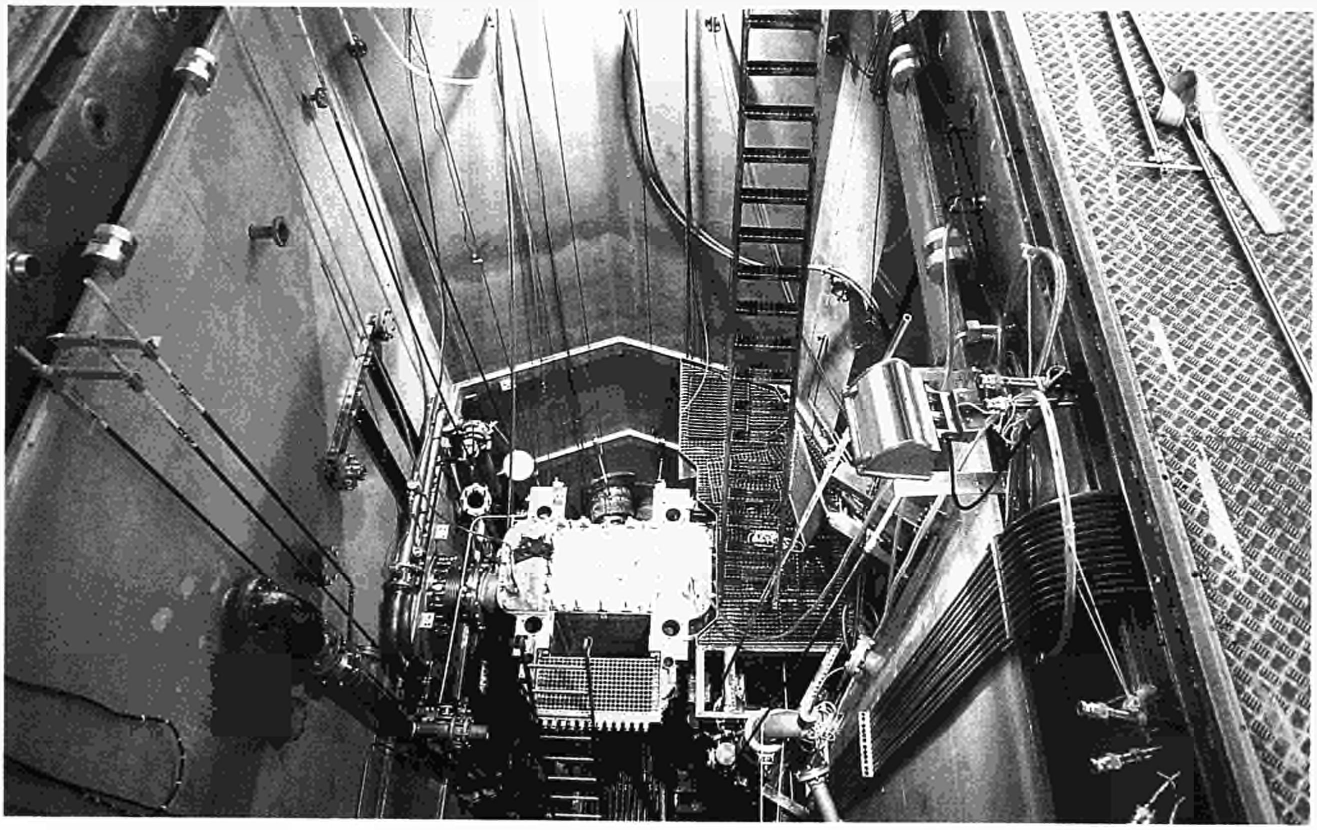


HFR Petten
Two views (one on the front page) of the new reactor vessel after installation (October, 1984)

High Flux Materials Testing Reactor HFR Petten, 1984 Annual Report

Research Staff	**41 persons**
1984 Budget (commitment credits)	
Programme funding, incl. vessel replacement expenses	**17.3 Mio ECU**
Support by other JRC programmes	
Use by commercial clients	**1.7 Mio ECU**
Total	**19.0 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, four projects have been defined for the 1984 work:

1. **HFR Maintenance**
2. **Reactor Vessel Replacement**
3. **Reactor Utilization**
4. **General Activities**

On a lower level of subdivision, the term "project" is used for activities under one of the four 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 thermonuclear 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 in a position to handle a large experimental work volume on schedule.

2. OBJECTIVES

The 1984 programme objectives have been

1. to replace the reactor vessel during an extended plant shutdown,
2. to cooperate with different research teams for the scientific, technical, and administrative definition of reactor utilization projects,
3. to direct and manage such projects and to evaluate the results obtained,
4. to develop new methods and equipment for future tasks,
5. to maintain international contacts and coordination through meetings, symposia and publications.

HFR Petten

Upgrading and development 1966-1982

- **Power increases 20 to 30, 30 to 45 MW**
- **Introduction of burnable poison fuel**
- **Several core configuration changes**
- **Complete replacement of reactor and general purpose experimental instrumentation**
- **New in-tank experiment penetrations**
- **Several improvements on major plant systems**
- **In-house computer code developments**
- **New reactor and experiment data loggers**
- **New dismantling cell transfer system**
- **Second (beam tube) neutron radiography facility**
- **Modification of the reactor building entrance/exit area**
- **Enlarged computing facilities**

1984 major upgrading

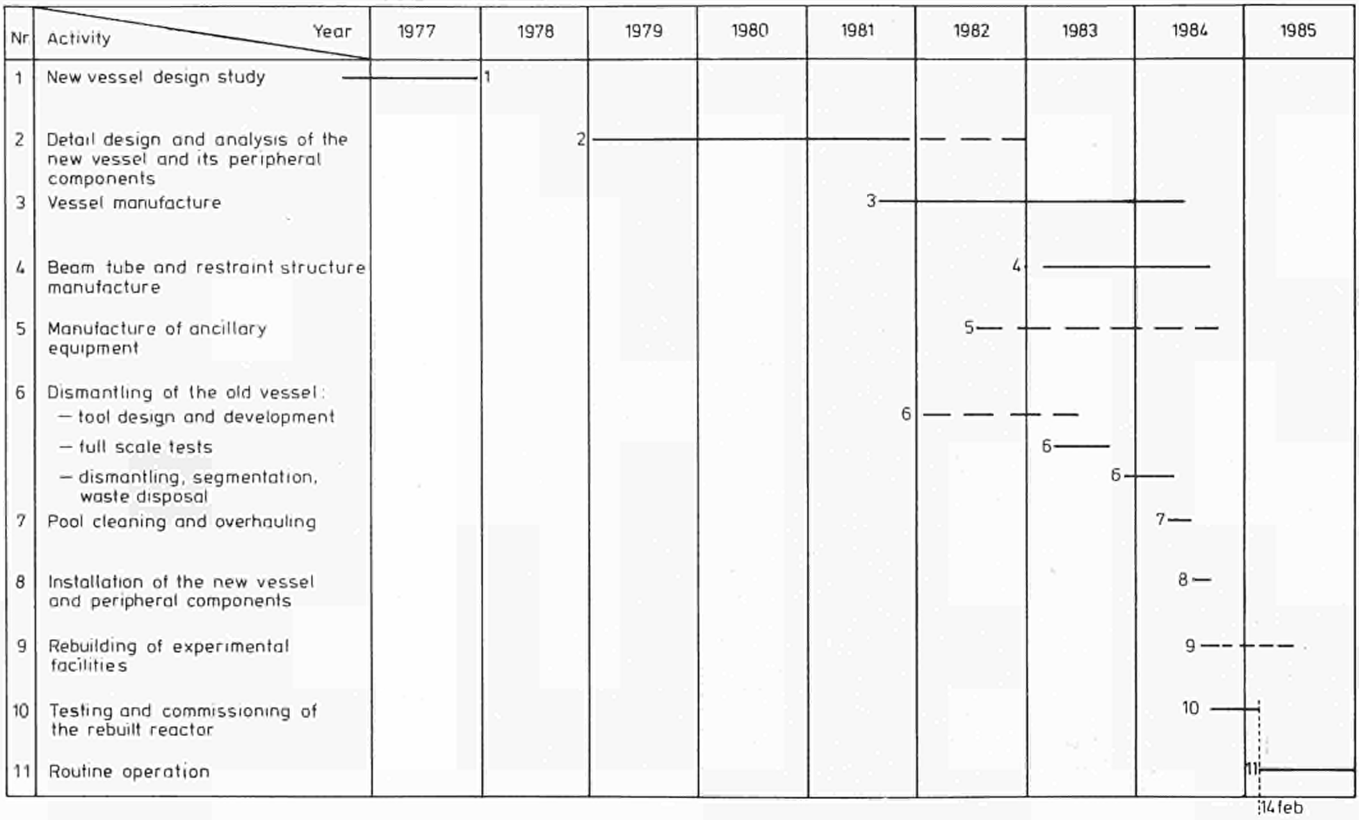
- **Replacement of the reactor vessel and of its peripheral installations**

Future developments

- **Building extensions for low activity component storage**
- **Replacement of primary and pool cooling heat exchangers**
- **Medium activity laboratory concept studies**
- **Neutron beam quality improvements**
- **Neutron radiography image analyser system**
- **Studies on complete reactor instrumentation and control room replacement**
- **Studies for a power increase to 60 MW and for a core conversion to reduced enrichment fuel**

HFR VESSEL REPLACEMENT

A. Historical Review



3. RESULTS

3.1. Facilities and Services

3.1.1. Reactor: The Vessel Replacement

a) HISTORY

Phase I (Design Study), 1974/78

Earliest considerations about the replacement vessel had been triggered in 1974 by results of the vessel material surveillance programme which suggested increasing embrittlement of the material and a limited lifetime of the existing tank. Based on preliminary ideas, a working group elaborated a design study in 1976/77 which contains the fundamental layout and specifications of the replacement vessel. Agreement from main users of HFR, specifications for the detailed design, and a definition for ancillary activities were obtained during the first half of 1978. The Design Contract was then awarded at the end of 1978.

Phase II (Detail Design), 1979/81

The two years required for the detail design have been characterized by

- a large volume of additional information prepared and transmitted to the Contractor,
- regular meetings reviewing progress of the work, deciding on key questions (e.g. application of the ASME Boiler and Pressure Vessel Code, material of the future tank, in-service inspection principles, ...)

  From February 1980, representatives of Dutch licensing bodies have participated in these meetings and in the decision making process,
- a number of ancillary contracts, and amendments to the main contract, covering the design of new beam tubes, the vessel restraint structure, hydraulic studies, the pool cooling system, and safety oriented analyses.

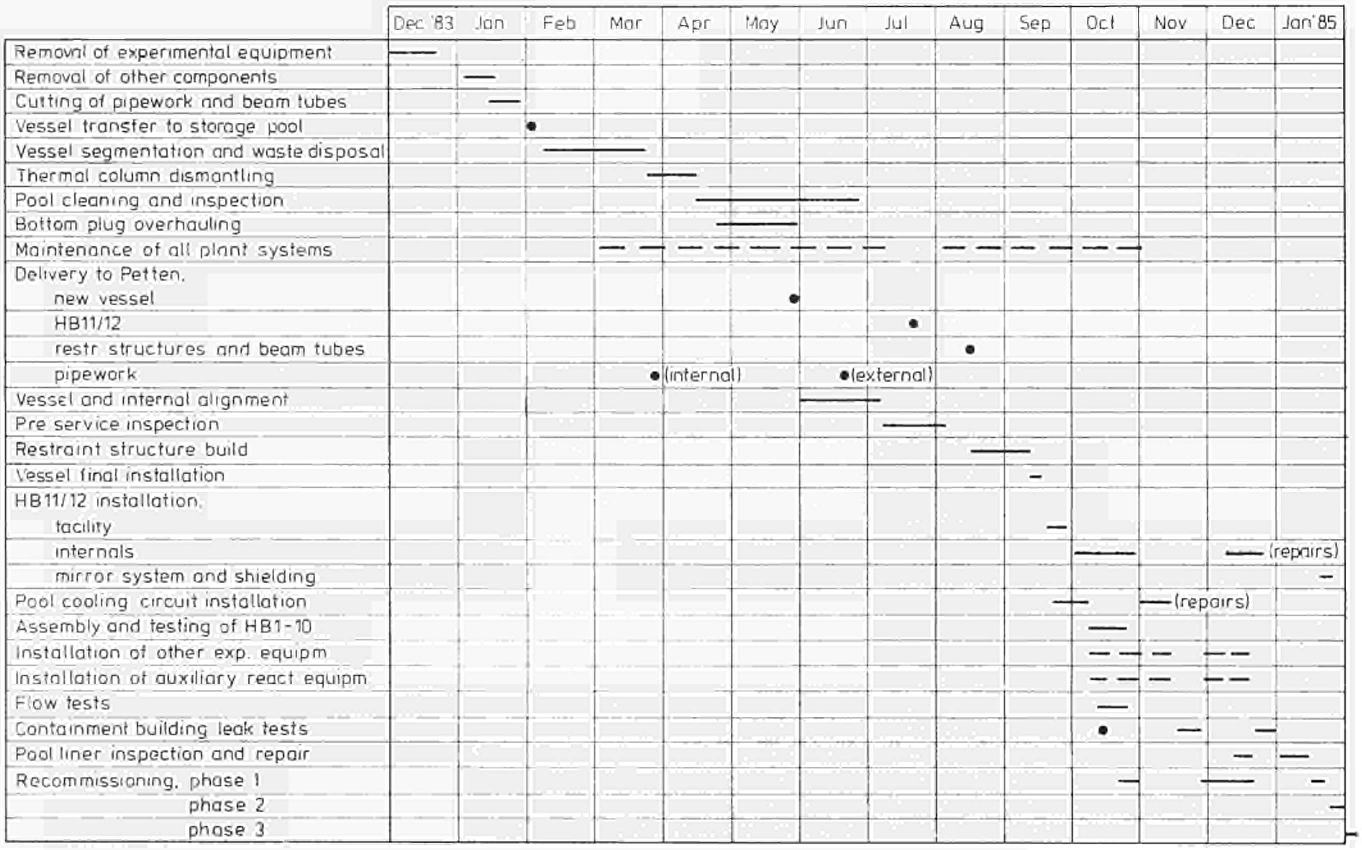
Several parallel actions had been defined and started:

a) the development of a scenario for the replacement operation including considerations on methods, tools, and on constraints for the disassembly of the present vessel and its associated equipment,
b) studies on new reactor control instrumentation,
c) studies on new pool side facilities and their irradiation capsules,
d) design of a new twin-beam facility to replace the obsolete thermal column,
e) literature search and inquiries with a large number of research reactor operators on the neutron embrittlement of aluminium and on possible ongoing or planned surveillance irradiation programmes,
f) contract specifications for the services of an industrial architect, for a quality assurance organisation, and other ancillary services.

Mk II Design

An alternative design approach, starting with the idea of a straight cyclindrical vessel, has been pursued by a working group in 1979/80. A report issued in July 1980 concluded that the

HFR PETTEN
SURVEY OF THE 1984 VESSEL REPLACEMENT ACTIVITIES



simplicity of the design and manufacture of the cylindrical concept would override the disadvantages (new core configuration and geometry), provided that reduced neutron fluxes could be compensated by a reactor power increase. A comparative study "Mk I vs Mk II" has been compiled and made available in July 1981.

The MkII concept was not examined beyond that study.

Prospective Studies

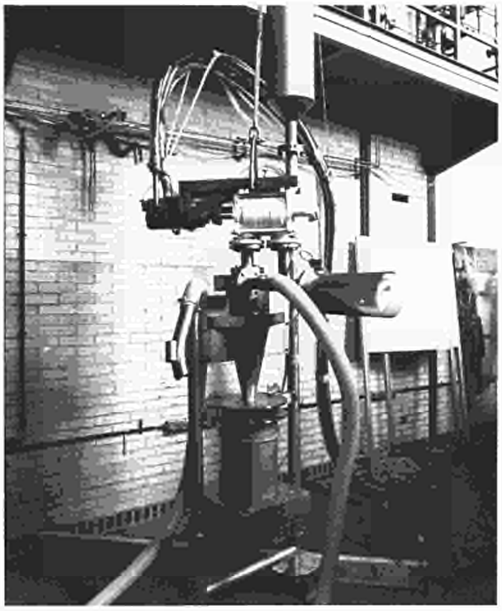
A study contract was awarded to an independent organisation in March 1978 in order to formulate an unbiassed assessment of irradiation needs after 1981 in Europe and in the United States, and to come up with suggestions for the appropriate experimental equipment of the reactor after replacement of the vessel.

Another assessment of the irradiation markets in North-America and in Japan has been carried out in 1981/82.

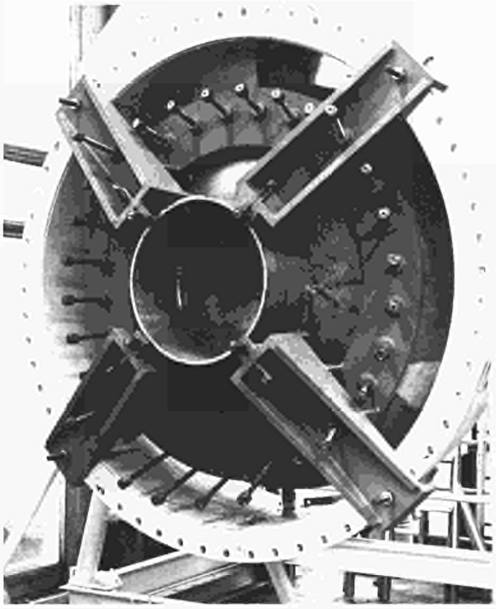
Manufacture

Manufacture of the required new components was split up into the following main groups:

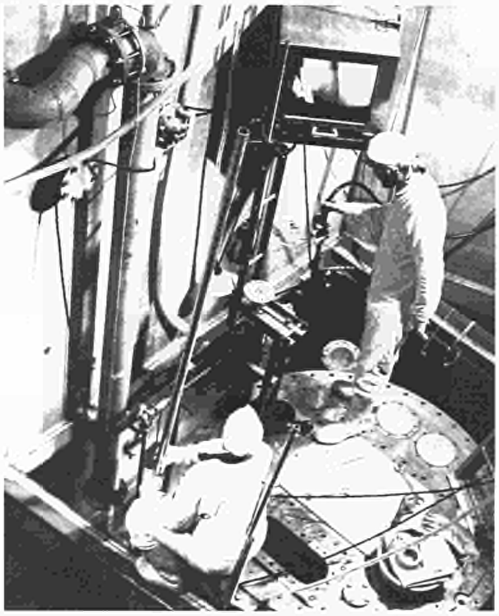
a) the vessel proper, together with its internal fixtures and closures, and a spare (training) vessel, ordered in August 1981,



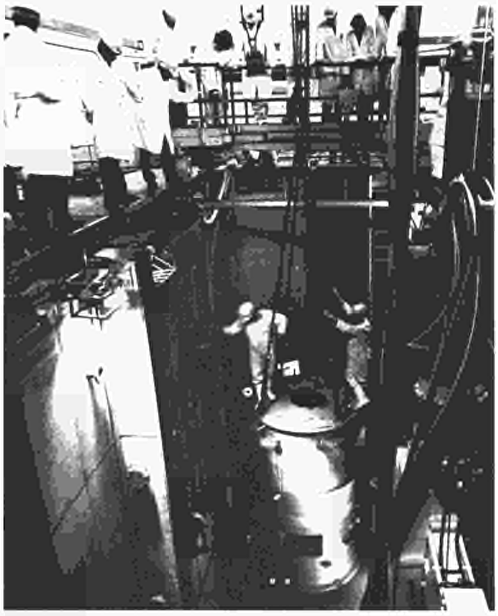
Cyclone for the removal of suspended matter during under water dissection



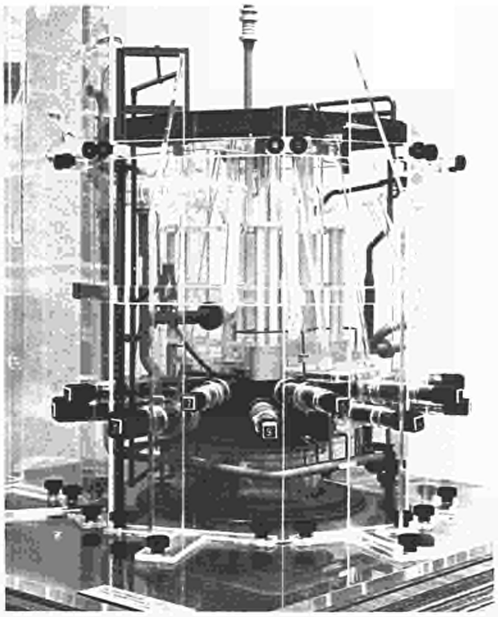
Specially designed machine for the removal of the thermal column front piece



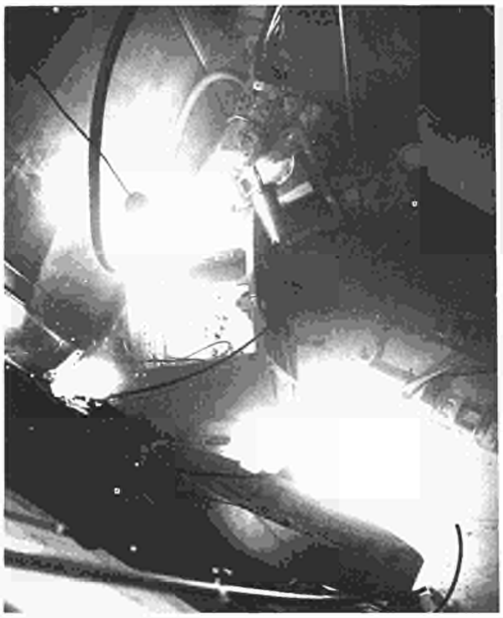
Underwater closed circuit TV used during disassembly of the old reactor installation



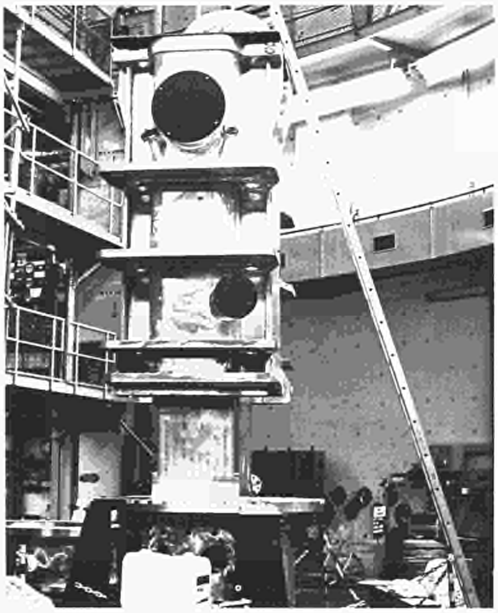
Transfer of the old reactor vessel to the storage pool (February 1984)



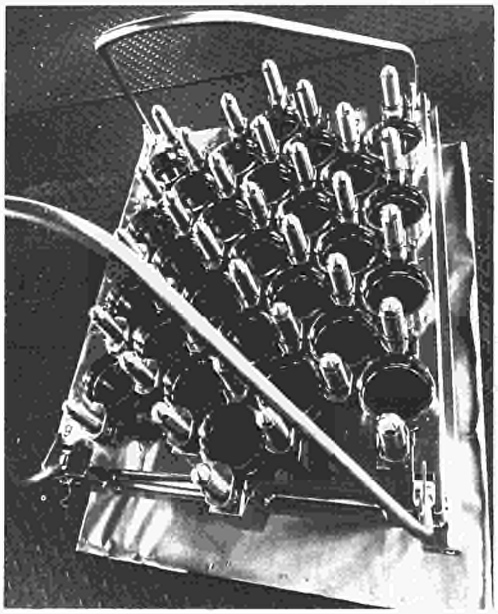
Perspex model of the new plant



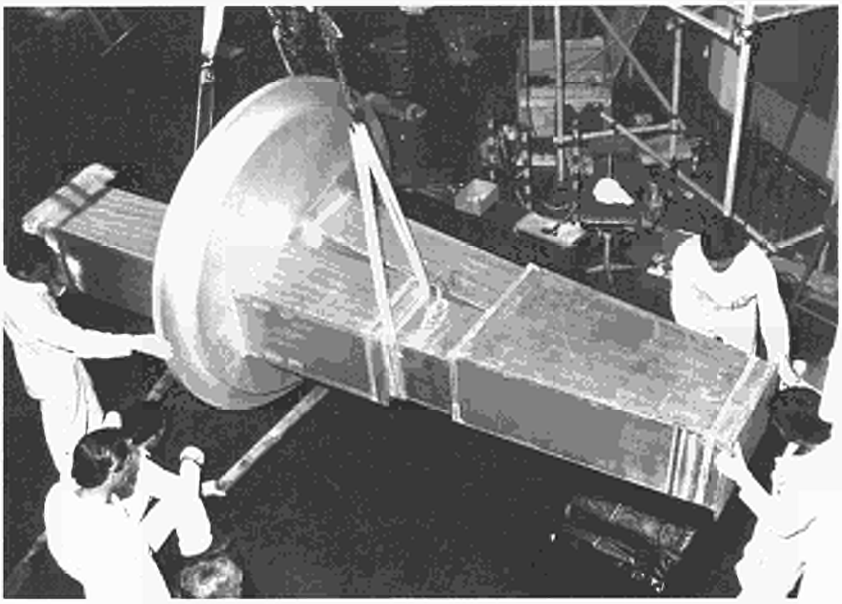
Core box of the old vessel prior to final dissection



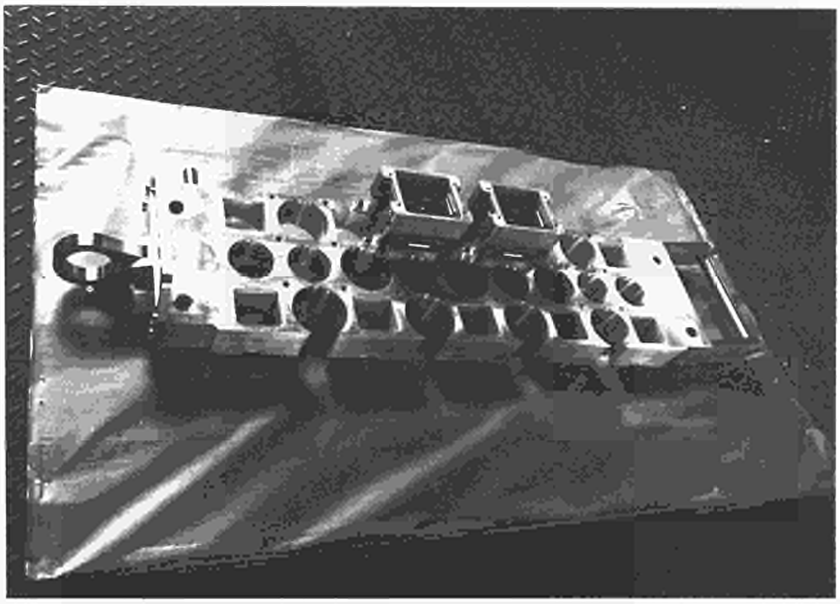
New vessel during alignment and fitting of its components in the reactor building



New top cover



New twin-beam HB 11/12 facility replacing the obsolete thermal column



New core hold-down device ("grid-bar")

b) beam tubes, pool cooling system, and vessel restraint structures, ordered in April 1983,

c) two pool side facility support tables, ordered in December 1982,

d) rabbit systems, nuclear instrumentation guide tubes, standard isotope and activation analysis facilities, beam tube collimators and shielding plates, pool neutron radiography camera, pool cooling system external pipework and instrumentation, walkways on vessel top cover level, auxiliary tools and jigs, etc. have been ordered in the period of 1981 to 1984, as specifications and designs became available.

b) CHRONOLOGY OF THE REPLACEMENT PROPER

Dismantling of the old installation

Possible dismantling scenarios and potential problem areas had been analyzed by a working group from the middle of 1980. One year later the necessary operations and their preparation were sufficiently well known to structure them into projects and sub-projects and to assign the required resources. The preparation phase 1981/83 essentially consisted in setting up of a detailed disassembly, segmentation, and disposal procedures; development, design, manufacture and testing of specialized tools; a full-scale segmentation test on a dummy vessel in the Technology Hall pool (July/August 1983).

Dismantling proper then took place between January and March 1984, followed by cleaning, inspection, and overhauling of the reactor and storage pools (April/May 1984).

Installation of new equiment

Late deliveries of the new vessel and of several peripheral components caused about 2.5 months delay in 1984. Full scale work started in August and terminated in October, 1984.

Recommissioning

Testing and commissioning of the new reactor followed a three-phase scheme (unfuelled tests, low power runs, full power operation). Several adjustments and repairs were necessary. In its important functional behaviour, however, the installation gave full satisfaction. First criticality could therefore be reached on 25 January. Routine operation was resumed on 14 February, 1985, and has since then been uneventful.

3.1.2. Other Facilities

a) Reactor complex

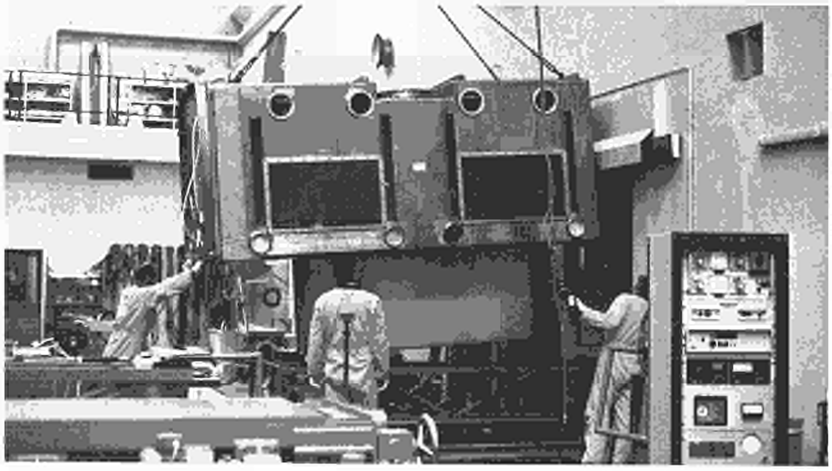
Advantage was taken of the extended plant shut-down for a complete and thorough inspection and overhauling of all systems and circuits. An entire revision of the drawing file has been initiated.

A large number of the experimental facilities had to be removed during the replacement period. Most were scrapped and replaced, others renewed and refurbished.

The Dismantling Cell in the reactor containment building played an essential role for conditioning and packaging of radioactive waste resulting from the dismantling of the old reactor. About 4 tons of low and medium activity debris were removed to waste disposal during 177 transports. - The cell has also been used for the inspection of reflector beryllium elements.

b) Outside the reactor complex

A facility for the remote encapsulation of pre-irradiated fast breeder fuel pins and of other highly active samples into sodium filled irradiation capsules has been completed in 1984. The so-called EUROS cell was transferred into its gamma shielding inside the hot cell complex where the final tests started.



Remote encapsulation facility EUROS
Arrival of the equipped alpha box in the hot cell complex

3.1.3. Neutron Metrology

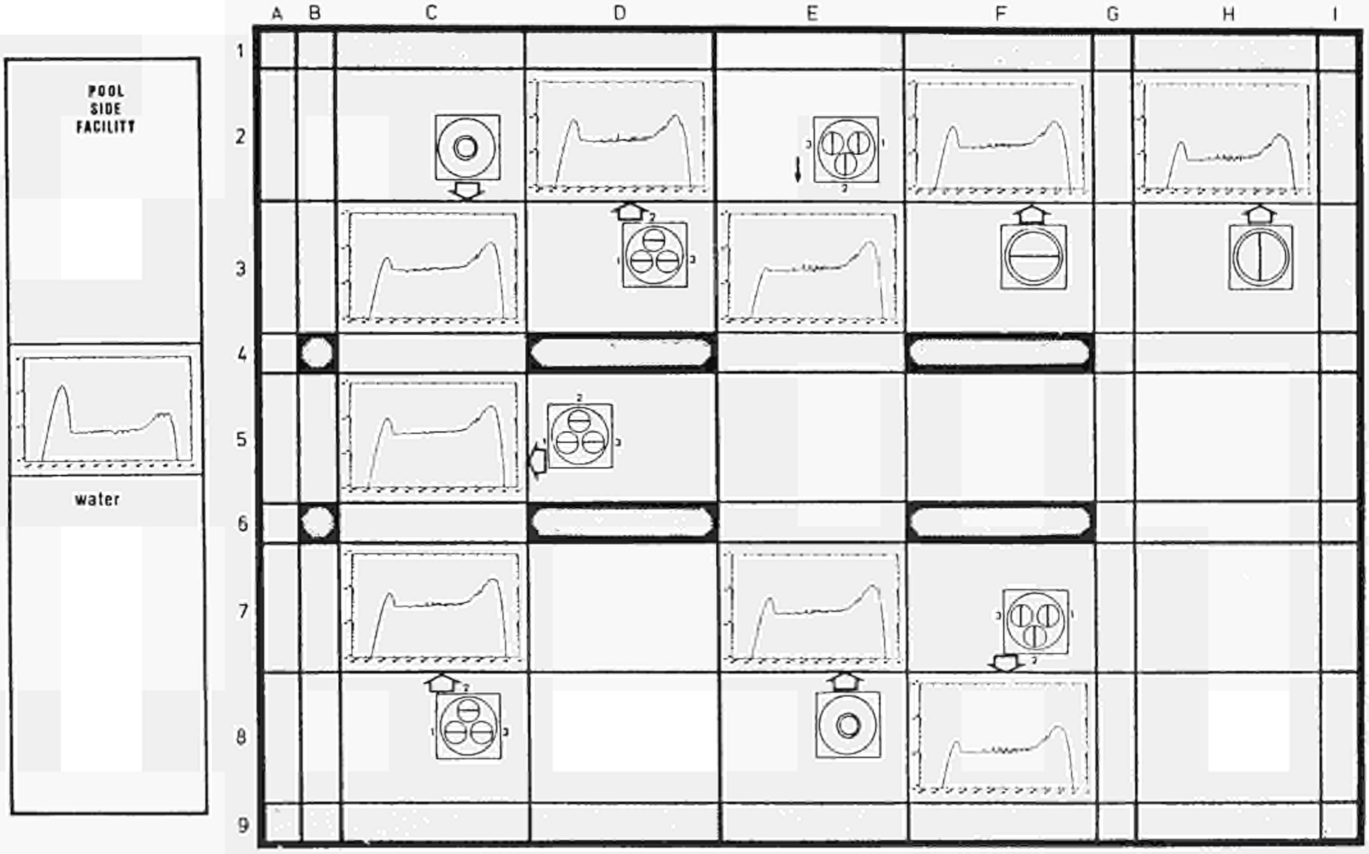
The accurate kwowledge of neutron density and energy at the site of each irradiation specimen, and of the relevant reaction cross sections, are essential for the correct interpretation of experimental data.
Two 1984 examples of neutron metrology work are given below.

Radiation damage in stainless steel (AISI 316L)

Calculations have been performed in support to fusion materials tests on the gas production level (amounts of hydrogen and helium per atom) and the number of displacements (dpa) in austenitic steel. The calculations have been carried out with improved input data viz.:

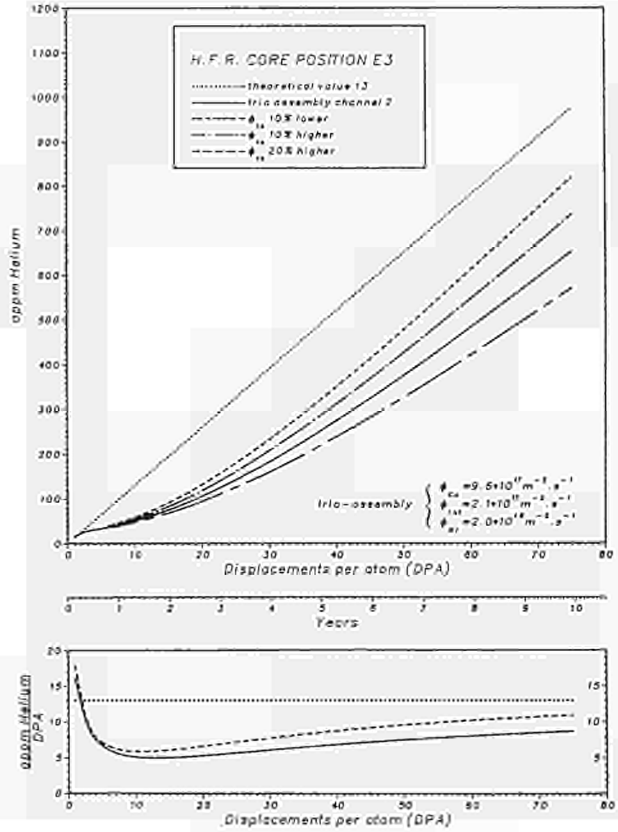
- experimentally determined neutron spectrum information from mock-up steel and graphite experiments (TRIO and REFA geometry) and an aluminium reference device,
- updated gas production cross section data based on the ENDF/B-V library.

Neutron fluence rate spectra in several mock-up assemblies of the HFR



Horizontal axis: energy in MeV; Vertical axis: fluence rate per unit lethargy in $m^{-2}.s^{-1}$.

The diagrams refer to the experiment geometry ⊖=graphite ⦶=steel ◎=standard assembly.



Neutron metrology
He production vs number of displacements in AISI-316L steel, for channel 2 of the TRIO assembly in H.F.R. position E3 at the height of the maximum fluence rate

Special attention has been given to the influence of intermediate energy neutrons on gas production, an item neglected in the past. Sensitivities were calculated in order to determine the influence on the helium production by varying the thermal fluence rate. The time interval in which a certain helium/dpa ratio is reached depends strongly on the local neutron environment. Important changes in the thermal fluence rate values will be required to obtain this ratio (see paragr. 3.2.3).

Uncertainties in damage calculations

Radiation damage estimates are of limited use unless accompanied by realistic estimates of the inaccuracy. The results of the REAL-80 international interlaboratory exercise have shown that discrepancies in prediction of radiation damage parameters and unrealistic values for the uncertainties of these data, partly orginate from using incomplete and/or unrealistic input data and partly from incorrect (or not optimized) processing of the available data by the relevant adjustment codes. Experience has been aquired with linear and nonlinear least squares adjustment using different input covariance information. Computer programs have been developed which produce uncertainty information (covariances) for input data such as reaction rates and activation and damage cross-section data in multigroup structure.

3.2. Irradiation Projects

3.2.1. Scope

The experimental work carried out in HFR Petten originates from close collaboration with teams from different research areas

- nuclear fission energy, especially under safety aspects,
- thermonuclear fusion and blanket breeder materials,
- environment,
- neutron beam utilization for fundamental and technological materials research,
- radioisotope production for scientific, industrial, medical, and agricultural applications.

1984, the "year without neutrons", has been used for post-irradiation examination and reporting on finished irradiation tests and for the design and manufacture of new equipment.

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.

As a contribution to HTR core structural material irradiation testing, a large number of graphite samples has been irradiated since 1962. 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, up to extreme neutron fluences.
In terms of number of irradiated samples and neutron fluences this is the most significant graphite research work in the world.

Six new graphite capsules have been designed and manufactured for irradiation in 1985, two of which for the Japan Atomic Energy Research Institute (JAERI). For fuel elements of the HTGR four new tests have been prepared.

One will contain specimens from the U.S. GA Technologies company. Overall, the planning of the HTGR-related experiments at HFR Petten reaches into the year 1988.

Light water reactors (LWR)

A large part of the experiments carried 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 features 20 to 25 experiments per year, including their non-destructive tests before and after irradiation.

In 1984, a large back-log of data evaluation could be processed. Design, development, and laboratory-model testing of an iodine release experiment have been pursued. The in-pile tests which will be carried out in 1986/87 are conceived to supply accurate information about release and transfer of the most hazardous radioactive species under a severe light water reactor accident.

Liquid metal cooled fast breeder reactors (LMFBR)

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

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

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 occured 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. Nearly 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.
During the year 1984, five new structural material irradiation rigs, and seven fuel pin transient condition devices, have been assembled.
A number of fuel pins pre-irradiated in a fast breeder reactor have been received at site for re-encapsulation by means of the EUROS facility (see paragr. 3.1.2).

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 commerical 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.

The first irradiations have been started in 1982 and their number increased considerably in 1983. In 1984 six new irradiation devices for structural materials radiation damage have been assembled. A novel high-dose facility with tailoring of the helium production ratio (Steel Irradiation Enhanced Neutron Assembly, SIENA) has been developed.

Work has been pursued on a blanket breeder test facility with tritium transport and analysis option.

Supporting studies on neutronic aspects of fusion material irradiations in HFR and on the required metrology (dosimetry) have been pursued (see 3.1.3).

Survey of fusion materials irradiation tests in HFR Petten

HFR proj. number	Project name	Specimen material	Test type	Status, end 1984
R 139	SINAS	Austenitic stainless steel	Post-irradiation tensile and creep tests Post-irradiation crack growth experiment	First tests finished Follow-up under design
E 198	FRUST 10		Post-irradiation tensile	Irradiation to be continued
	FRUST 01-03 11-13	Austenitic stainless steel, incl. AMCR	Post-irradiation tensile	Finished
	04-06 07-09			Assembly finished. Irradiation in 1985/86
	SIENA 14		(High fluence)	Under design. Irradiation in 1985/90
E 157	CRISP	Austenitic stainless steel	In-pile creep measurements continuous	Under assembly. Irradiation in 1985/87
E 167	TRIESTE		intermittent	Irradiation to be continued
E 199	LOCFIRE		In-pile fatigue	Under development. Irradiations in 1985/87
E 200	FATMAC		In-pile crack growth	
R 207	INFANTE			
D 202	SUPRA	V_3Si	Fundamental research in radiation damage in superconducting materials	Several irradiations finished
R 204	VABONA	V-5Ti	Radiation damage studies	First irradiation finished. Second rig under design
R 212	EXOTIC	Ceramic breeder compounds e.g. Li_2O $LiAlO_2$, Li_2SiO_3 etc.	Irradiation testing with parameter variation and studies of T-release and property changes T-recovery with in-pile loop	Under assembly. Irradiation in 1985/87
E 224	LIBRETTO	Liquid breeder Li17Pb83	In-pile T breeding and permeation testing. Post-irradiation T-recovery	Under development Design started
D 217	CERAM	Insulator and first wall ceramics. Might include graphite	Radiation damage studies	Under development. Irradiation in 1985/87. Design available

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 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.

In 1984 the computer program which governs the fast rabbit system FASY has been translated into FORTRAN-IV which results in an appreciably faster procedure. After reinstalment in HB-10 the system was found to work satisfactorily.

The results obtained with FASY during 1983 have been evaluated. A publication on the determination of selenium in dry biological materials, sea and rain water, foodstuffs and hair was prepared [1].

[1] Woittiez, J.R.W. and Nieuwendijk, B.J.T. Analysis of selenium in environmental and biological samples by neutron activation analysis. Paper prepared for the J. of Microprobe and Trace Analysis. November 1984. A communication of this work will be presented at the forthcoming Conference on Radioanalytical Chemistry at the Trace Centre of Dalhousie University, Halifax N.S., Canada, in June 1985.

The programme for off-line treatment of gamma-spectra of samples, activated in the PROF or PIF in the HFR has been renewed by the ENR [2].

[2] Balder, J.R. Spectrum Analyse Systeem voor Activeringsanalyse SANSA. ENR Report - 184. December 1984.

The procedure for the analytical application of prompt capture gamma-ray measurements has been developed.

The variation of the background with the sample mass and composition due to neutron scattering can be accounted for by internal standardization on the (spurious) spectral lines of germanium which stem from the Ge(Li)-detector.

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.

- **Solid State Physics**

The major activities with respect to the five experimental facilities for neutron scattering research have been concerned with the dismantling and recommissioning of these facilities. The reactor vessel replacement offered the opportunity for revisions, modifications and upgrading of the beam tube facilities.

Instrumental

The collimator plugs of all beam tubes in use by Solid State Physics i.e. HB1, HB3, HB5 and HB9A/B, have been replaced by newly designed ones. These plugs, meant for tailoring geometrically the neutron beams, have been optimized for each instrument at its particular beam tube. Generally, this means that the monochromator crystals of the instruments face a larger part of the core box, which results in higher beam intensities without paying the penalty of serious losses of resolution or increasing background radiation. The split beam collimator plug of HB9, which serves two instruments, has been improved in such a way that the double crystal monochromator of the one instrument does not suffer any longer from shadow effects from the polarizing monochromating unit of the other one.
For the powder diffractometer at HB5 a combined beam shutter and slit exchanger has been installed. For the other beam tubes the old beam shutters have been combined with heavy concrete shields into single units, which fit almost exactly in the entrance cubicles of the beam tubes; marginal space is left for adjustment to the beam position. By the end of the year the neutron diffractometers were not yet completely recommissioned. However, all preparations had been finished, which e.g. means that the instrument at HB1 is ready to be provided with a new dedicated process computer. Similar computers are available for the instruments at HB3 and HB9. These will shortly replace the online control by the old computer.
The different geometry of the new reactor vessel with the beryllium reflector outside the core box offers possibilities for relatively easy changes in this geometry.

In the interest of increasing the thermal flux in the beam tubes, experiments have been carried out with a mock-up of variable reflectors at the R2-0 reactor at Studsvik. These experiments indicate that replacement of some beryllium by D_2O may give rise to considerable gain factors for the thermal flux in near-by beam tubes. These gain factors, however, ought to be taken with great care as far as applicability to a real reflector configuration of the HFR is concerned. Although very promising, this result has first to be confirmed by sophisticated reactor calculations for real configurations, before definite conclusions can be drawn.

Research

Being without neutrons in the actual research field considerable effort was put into data analysis and reporting on earlier experiments. The subjects dealt with cover several topics in crystallography, chemistry, solid state physics and metal physics. This research program is carried out in close cooperation wiht several dutch universities and industrial research laboratories and in lesser extent with foreign research institutes or laboratories. It has resulted in the dissemination of over twenty external publications, among which one Ph.-D-thesis, completely based on work carried out with the HFR beam tubes.

• Nuclear Physics

The replacement of the vessel has offered a unique possibility to upgrade the neutron beam facilities, and to increase the number of beams for nuclear physics from four to five.
The major improvement by the reactor reconstruction consists of the conversion of the former thermal column into a twin-beam arrangement. Due to the large dimensions of the thermal column containment it has been possible to construct two new beam channels of large openings. In this way the target position at each beam will be illuminated from the entire surface of one side of the reactor core box. Com-

pared to a conventional beam tube the increase of solid angle will result in a gain of about a factor 15. One of the twin channels (HB12), is provided with an iron filter transmitting a beam of 24 keV neutrons. It is expected that the flux density will reach approximately the same value as obtained at the enriched iron filter installation of Brookhaven National Laboratory. For such high flux densities neutron polarization becomes meaningful and it is therefore the intention to construct a portable polarized proton polarizer. Furthermore, the filter set-up has been constructed to exchange filters during reactor shut-down.

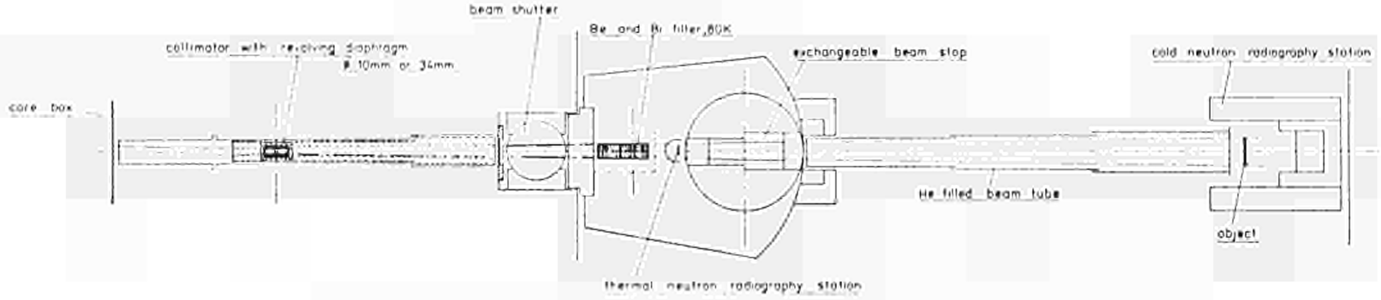
At the other channel (HB11) a system of focussing Ni mirrors has been installed. This mirror system was in operation before the vessel replacement but, in the new set-up the thermal flux density will be increased with a factor 4 by reducing the thickness of the water layer between the beam tube and the reactor core.

The upgrading of the beam facilities also included the out-pile installations. At the facility for capture of polarized thermal neutrons by polarized target nuclei the crystal neutron polarizer has been replaced by a polarizing mirror system. In this way the neutron flux density is improved considerably. Furthermore, the magnetic field of the nuclear polarization installation will be increased to 8 tesla resulting in a higher degree of nuclear polarization. For the other polarized neutron facility, which provides polarized thermal neutrons for capture experiments with unpolarized target nuclei the old polarizing mirror system will be replaced by a similar system with better parameters.

In addition to the iron filter in HB12, a second iron filter has been installed at the nuclear polarization set-up (HB2). In combination with the mirror system and polarized proton polarizer mentioned above this facility offers the following options:

i) experiments with polarized 24 keV neutrons and polarized target nuclei (filter and proton polarizer in position, mirror system open),
ii) experiments with polarized thermal neutron and polarized target nuclei (filter and proton polarizer out, mirror system closed).

Finally, it is considered to install a boron filter at HB 5 for nuclear physics.



Sketch of the envisaged facility for radiography with thermal or cold neutrons at HB8

3.2.6. Radioisotopes

Radioisotopes are produced in HFR Petten in a variety of multi-purpose or dedicated facilities.

In the scope of the vessel replacement, all facilities have been scrapped and replaced by new ones. Several significant design improvements could be introduced. Among the novel production devices designed and assembled in 1984, one notes two new ^{60}Co facilities. The demand for medium to high specific activity cobalt largely exceeds the HFR production capacity.

3.2.7. Miscellaneous

Development of proliferation - proof research and test reactor fuel (Project "LOUISE")

One of the recommendations of Working Group 8C of the International Nuclear Fuel Cycle Evaluation (INFCE) concerns the fuel of research and test reactors: wherever technically and economically feasible these reactors should be converted from the presently used highly enriched uranium to proliferation - proof reduced enriched material.

Studies on such novel fuel elements have been carried out a HFR Petten since 1977. Test irradiation and post-irradiation examination of four elements took place in 1982/84.

The neutronic and thermohydraulic design of high density uranium silicide conversion elements has been pursued in 1984. Although not yet finalized the studies confirmed the necessity of a reactor power increase to compensate losses of neutron flux, hence an upgrading of the primary heat removal system.

4. CONCLUSIONS

1984 was characterized by an extended reactor shut-down for the replacement of the vessel and its peripheral components. Many experimental facilities were replaced during the process.

By largely assigning own staff, the overall project could be carried out within the normal HFR Programme funding.

The total radiation exposure remained at about 30% of the estimated values.

For decommissioning of similar installations the swift and uneventful dismantling of the 22 years old reactor set an interesting example.

The new HFR Petten features increased and improved experimental facilities. Among others the obsolete thermal column has been replaced by two high flux beam tubes. Moreover the new plant has been designed for future increases of reactor power and neutron fluxes.

For the next three to four years the reactor has to cope with a large irradiation programme, claiming its capacity to nearly 100%.

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