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THE HIGH FLUX REACTOR PETTEN, PRESENT STATUS AND PROSPECTS

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ABSTRACT

The High Flux Reactor (HFR) in Petten, The Netherlands, is a light water cooled and moderated multi-purpose research reactor of the closed-tank in pool type. It is operated with highly enriched Uranium fuel at a power of 45 MW. The reactor is owned by the European Communities and operated under contract by the Dutch ECN. The HFR programme is funded by The Netherlands and Germany, a smaller share comes from the specific programmes of the Joint Research Centre (JRC) and from third party contract work.

Since its first criticality in 1961 the reactor has been continuously upgraded by implementing developments in fuel element technology and increasing the power from 20 MW to the present 45 MW. In 1984 the reactor vessel was replaced by a new one with an improved accessibility for experiments. In the following years also other ageing equipment has been replaced (primary heat exchangers, pool heat exchanger, beryllium reflector elements, nuclear and process instrumentation, uninterruptable power supply). Control room upgrading is under preparation. A new safety analysis is near to completion and will form the basis for a renewed license.

The reactor is used for nuclear energy related research (structural materials and fuel irradiations for LWR's, HTR's and FBR's, fusion materials irradiations). The beam tubes are used for nuclear physics as well as solid state and materials sciences. Radioisotope production at large scale, processing of gemstones and silicon with neutrons, neutron radiography and activation analysis are actively pursued. A clinical facility for boron neutron capture therapy is being designed at one of the large cross section beam tubes.

It is foreseen to operate the reactor at least for a further decade. The exploitation pattern may undergo some changes depending on the requirements of the supporting countries and the JRC programmes.

1. INTRODUCTION

The High Flux Reactor (HFR) in Petten, The Netherlands, is a multi-purpose research reactor operated with highly enriched uranium as a fuel at a power of 45 MW.

The HFR is property of the European Communities. It is operated under contract by the "Netherlands Energy Research Foundation (ECN)". The programme is managed by the "HFR Division" of the "Institute for Advanced Materials", one of the nine institutes of the "Joint Research Centre (JRC)" of the European Communities. The HFR programme is executed in four year periods. The present programme period covers the years 1988 to 1991. The running programme is funded by a "Supplementary Programme" shared by the Netherlands and the Federal Republic of Germany, and by "Specific Programmes" of the JRC. In addition a target is set for third-party contract earnings. The programme resources are outlined in Table 1.

The programme objectives are defined by Dutch or German institutions under the supplementary programme, by JRC institutes for the specific programmes and by interested institutes or companies from inside and outside the European Communities under third-party contract research.

The irradiation capacity of the HFR is utilized to a high degree. The largest share is still related to materials technology for fission reactors (structural materials and fuel irradiations for LWR's, HTR's and FBR's) and future fusion machines. The beam tubes are used for nuclear physics, but with a larger share for solid state physics and materials sciences. Radioisotope production, processing of gemstones and doping of silicon with neutrons, neutron radiography and activation analysis are actively pursued and offered to commercial customers. Design of a clinical facility for boron neutron capture therapy and related research is in progress. The facility will be installed at one of the large cross section beam tubes.

2. CHARACTERISTICS OF THE HFR

The HFR has been designed according to the principles of the Oak Ridge Research Reactor (ORR). It is a classical multi-purpose research reactor. Its nuclear and thermal characteristics are compiled in Table 2. The reactor core is housed in a closed tank, which together with the circulation pumps and the heat exchangers forms the primary circuit. Light water is used as a coolant and moderator. The reactor tank is submerged into a deep water filled pool with thick concrete walls. The pool is lined with an aluminum liner. Presently the HFR is operated at 45 MW using highly enriched uranium as fuel. The core lattice is a 9 x 9 array containing 33 fuel assemblies, 6 control members, 19 experiment positions and 23 beryllium reflector elements. The row at the east side of the core lattice, normally loaded with 9 beryllium reflector elements, is arranged outside the core box of the reactor vessel.

The fuel assemblies contain 23 fuel plates with an active length of 600 mm. The uranium is about 93 % enriched in U-235. The fresh fuel uranium content per assembly is presently increased from 420 g to 450 g U-235. The two side- plates of each fuel assembly contain together 1000 mg B-10 in fresh condition. The control elements consist of a cadmium section on top of a fuel section. The fuel section contains 19 fuel plates with a total fresh mass of 290 g U-235. Their drive mechanism is situated below the reactor vessel.

The new reactor vessel installed in 1984 has advanced characteristics with respect to accessibility for experimental equipment as compared to the original ORR-design. The vessel is shown in Fig. 1. It is an aluminium construction consisting of a lower cylindrical part embedded in the concrete floor of the pool and an upper part arranged in the reactor pool. Those parts are flanged and bolted together at the pool bottom level. The upper or pool part of the vessel is an all-welded construction and has apart from the support structure a rectangular cross section, which provides an easier access to the pool side facilities than the circular cross section of the older design. Direct vertical experiment access to the reactor core positions is through the holes of the central reactor top lid, which also supports the experimental tubes.

Adjacent to the reactor pool there are two smaller pools for storage and handling purposes. On top of one of these two pools a hot cell for the dismantling of irradiated capsules is placed. A simplified sketch of the installation is given in Fig. 2.

The arrangement of the irradiation possibilities at the HFR is shown in Fig. 3. There are 9 in-core positions in the fuel region of the core and 10 boundary and reflector positions. The 12 positions in the large pool side facility are highly valuable, mainly for transient tests and fuel rods, whereas the new small, low fluence rate pool side facility suffers from interference with some of the beam tubes. From the 12 horizontal beam tubes, two, namely HB11 and HB12, have been installed together with the new vessel, replacing the old thermal column. They have a very large cross section and advantageous characteristic for future use for boron neutron capture therapy. The vertical beam tubes and a pneumatic rabbit system are mentioned for completeness.

A detailed description of the operational characteristics of the reactor and the experimental facilities is given in Ref. [1].

3. MAJOR UPGRADING AND MODERNIZATION ACTIVITIES

Design of the HFR commenced in 1958 and first criticality was reached in November 1961. The major milestones of HFR's history are summarized in Table 3. Power increases and performance improvements with respect to the provision of more and higher flux density in-core positions was rendered possible mainly by fuel technology development which was characterized by increasing the mass of U-235 in the assembly from 120 g in 1961 to 450 g in 1990, and by the introduction of B-10 as a burnable poison.

In the mid seventies it was realized that embrittlement of the vessel material would become a licensing problem in the future. So it was decided to install a new vessel. The vessel replacement was carefully planned and prepared until action of removing the old vessel and replacing it by a new one took place in a shut-down period not longer than 15 months [2]. As mentioned above the new design incorporated major improvements with respect to experimental utilization. In addition provisions were made for an optional further power increase to 60 MW.

After the vessel replacement the process of upgrading and replacement of ageing equipment was accelerated, always under the consideration to keep the option open on further increase of operating power to 60 MW.

The old primary heat exchangers, being designed for 20 MW operation, gave some problems during summer conditions in heat removal capacity at 45 MW and made further power increase impossible. In addition the necessary increased flow at the secondary side, beyond design conditions, for a considerable period of time, led to degradation and increased vibrations at the penetrations of the baffle plates for the numerous pipes. As the available limited space in the bunkers did not allow to introduce tube/shell heat exchangers of the enlarged capacity, a new plate type heat exchanger with titanium plate was chosen. The number of maintenance and cleaning actions could be reduced considerably as a result of daily application of the built-in backflash option.

Also the pool heat exchanger was replaced to care for larger heat removal capacity. An additional reason for this replacement by a plate type was the need to be able to clean the primary side of the exchanger. This became necessary to avoid the growth of algae in the exchanger, which deteriorate heat removal capacity.

The original beryllium reflector elements are still in use with all indications of their extended use and handling damage after nearly 30 years of utilization. Embrittlement and dimensional changes caused by the high received neutron fluence as well as indications of reactivity loss after reactor shutdown due to the ingrowth of He-3 and Li-6 became a matter of concern. New elements were ordered with updated technical specifications, and after their recent delivery they will be inserted into the core in the near future.

In order to promote diversification and redundancy for the flux protection system, an extra set of three nuclear safety channels of different design will be introduced, which in the case of overpower will directly act on the magnet circuits of the control rods in the sub-pile room. The location will be completely outside the reactor control room to decrease the risk of common mode failures in case of fire.

Increased failure rates, and unavailability of spare parts led to the replacement of the major part of the nuclear channels. Also the uninterruptable power supply was replaced to avoid increasingly costly repairs of outdated equipment, and also to introduce redundancy and to relocate for diversity in cabling routes in search for additional fire protection measures and prevention of common mode failures. A complete upgrading of the control room is now under preparation. Outdated components have to be replaced, and the new design will incorporate modern ergonomic principles.

On request of the Dutch licensing authorities a complete reappraisal of the safety analysis is in progress which will replace the old HFR hazard report written more than 30 years ago. This safety analysis will be the basis for a renewal of the present HFR operating license. In parallel the set-up of a comprehensive quality assurance system is in progress which comprises a systematization and documentation of all the existing practices and procedures for reactor operation proper and all the activities connected to the exploitation of the reactor.

4. EXPLOITATION OF THE HFR PETTEN

The current programme of the HFR addresses a broad scope of applications of neutrons to science and technology which are briefly addressed in the following section [3].

LWR fuel rod behaviour is investigated under steady state and transient conditions. Both BWR and PWR operating conditions can be simulated. For transient scenarios in a wide range of power ramp rates, the pool side facility provides particularly favourable possibilities.

HTGR structural and reflector graphite is irradiated with emphasis on the behaviour under specified load conditions in the temperature range between 300 and 1200°C. HTGR fuel irradiations address mainly the fission product release behaviour in a wide temperature domain (600°C to 1500°C).

The HFR Petten is also participating in international R&D programmes on LMFBR fuel. Mixed oxide fuel as well as advanced concepts - carbide and nitride fuel - are tested under start-up and in-situ operational transients. FBR structural materials are irradiated to high fluences in order to assess mechanical properties, including creep and fatigue under irradiation.

Materials research for fusion has increased largely in recent years. The present tests in the HFR are embraced by the European Fusion Technology Programme. They mainly concern creep, fatigue and crack growth in austenitic stainless steel together with research on vanadium alloys and on structural ceramics as well as testing of ceramic and liquid metal candidate blanket breeder material with on-line tritium release measurements.

Present utilization of the horizontal beam tubes is shown in Fig. 4. The programme comprises crystal and magnetic structures, ordering in liquid and amorphous alloys, spin density distributions, phonons, spinwaves and residual stress measurements by diffraction and inelastic scattering of neutrons, further the study of inhomogeneities in technical materials by means of small angle neutron scattering, for which purpose a new facility has been brought into operation in 1989. One of the beam tubes is in permanent use for neutron radiography, methodology development as well as applications, mainly in the space and aircraft industry. At the large cross section beam tube 11 a filtered beam facility for boron neutron capture therapy with epithermal neutrons is being designed. This facility will be the principal research tool for BNCT research in Europe.

In view of decreasing irradiation capacity and in view of increasing demand for radioisotopes for medical and industrial purposes the radioisotope production services at the HFR are being upgraded presently. In the field of activation analysis the HFR offers several facilities over a wide range of irradiation times and sample volumes. Facilities for silicon doping and gemstone colouring are also in operation.

Efficient utilization of a research reactor is only possible, when it is embedded into the infrastructure of a large nuclear research centre. In this respect the close and fruitful co-operation between JRC and ECN is noteworthy. The HFR programme makes ample use of neutron metrology and reactor physics services and also of the well equipped ECN hot laboratories.

5. SUMMARY AND CONCLUSIONS

The High Flux Reactor Petten is operated as a multi-purpose research reactor and serves as a principal tool for a wide variety of applications. The programme is mainly sponsored by The Netherlands and Germany and by the European Communities, but the reactor is also offered to institutions and companies from Europe and abroad.

Being continuously upgraded and modernized since its first criticality in 1961, the reactor can be regarded as a modern and up-to-date research tool even after nearly 30 years of operation. Experience has developed and equipment is available for addressing the full scope of materials testing for nuclear energy deployment as well as for efficient utilization of the beam tubes for fundamental and applied research.

6. REFERENCES

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(Revised edition 1986/1987, CEC, Luxembourg) (1986)

[2] Chrysochoides, N.G., Cundy, M.R., Von der Hardt, P., Husmann, K.,
Replacement of the Reactor Vessel and Connected Components.
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Report EUR 12271 EN (1989).

Table 1 :

PROGRAMME RESOURCES 1988 - 1991

Supplementary Programme

a) exploitation of the reactor	
- Federal Republic of Germany	32.5 MECU
- The Netherlands	32.5 MECU
b) preparation of experiments	
- Federal Republic of Germany	6.5 MECU
- The Netherlands	p.m. *
JRC specific programmes	7.0 MECU
Third party contract earnings	5.0 MECU

Total	83.5 MECU +p.m. *

* work to be carried out directly by the Netherlands, valued by the Commission at 6.5 MECU

Table 2 : Summary of nuclear and thermal properties of the HFR

Reactor power	45 MW	
Specific power (averaged over fuel positions)	310 MW/m^3	
Number of fuel assemblies	33	
Number of control members	6	
Number of in-core irradiation positions	9	
Number of reflector irradiation positions	8	
Number of horizontal beam tubes	12	
Number of pool side facility positions	22	
Fuel charge of fresh fuel assemblies	420 g ^{235}U	
fresh fuel loading of the fissile control members followers : 290 g		
Boron charge in side plates of fresh fuel assemblies	1000 mg ^{10}B	
Total fuel charge	11 kg ^{235}U	
Volume of core	0.2 m^3	
Average thermal flux density in inner fuel position	1.0×10^{18} m^{-2}s^{-1}	
Maximum thermal flux density in inner fuel position	1.6×10^{18}m^{-2}s^{-1}	
Maximum fast flux density in in-core exp. position	2.8×10^{18}m^{-2}s^{-1}	}
Maximum fast fluence rate in pool side facility I .	3.8×10^{17}m^{-2}s^{-1}	} equivalent fission fluence rate
Maximum fast fluence rate in pool side facility II	1.6×10^{16}m^{-2}s^{-1}	}
Maximum thermal fluence rate in in-core exp. pos.	1.5×10^{18}m^{-2}s^{-1}	
Maximum thermal fluence rate in pool side facility I	2.7×10^{18}m^{-2}s^{-1}	
Maximum thermal fluence rate in pool side facility II*	3.2×10^{17}m^{-2}s^{-1}	
Radiation heating graphite : in-core positions	6 to 12 W/g	}
reflector positions	2 to 6 W/g	} maxima in axial direction
pool side facility	<3 W/g	}
Flow rate of primary coolant through core	1.14 m^3/s (4100 m^3/h)	
Coolant speed in fuel assembly	7 m/s	
Coolant speed in filler element	0.2 to 7 m/s	
Inlet temperature of coolant	318 K (45°C)	

Table 2 (continued)

Outlet temperature of coolant	328 K (55° C)
Temperature difference across the reactor core	10 K
Average heat flux density in mid position	1.00 MW/m^2 (100 W/cm^2)
Maximum heat flux density in mid position	1.60 MW/cm^2 (160 W/cm^2)
Absolute pressure above reactor core	340 kN/m^2 (3.4 bar)
Pressure difference over the reactor core	110 kN/m^2 (1.1 bar)

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* PSF 22 and PSF 27 only

Table 3 : HFR Petten, History

1958 - 1961	Design and construction
1961	First criticality of HFR (November 9) Maximum power 20 MW
1962	Transfer from RCN to EURATOM (October 31)
1966	Power increase to 30 MW (May 8)
1970	Power increase to 45 MW (February 20)
Mid 1972	Introduction of burnable poison
1974 - 1977	Feasibility study for replacement of reactor vessel
1978	Decision to replace reactor vessel
1980 - 1981	Design of new reactor vessel
Nov.'83 - Feb.'85	Period of shut-down for reactor vessel replacement
Jan. 1985	First criticality after vessel replacement
1987	Replacement of primary heat exchangers
1988/1989	Replacement of beryllium reflector elements
1989	Replacement of pool heat exchangers

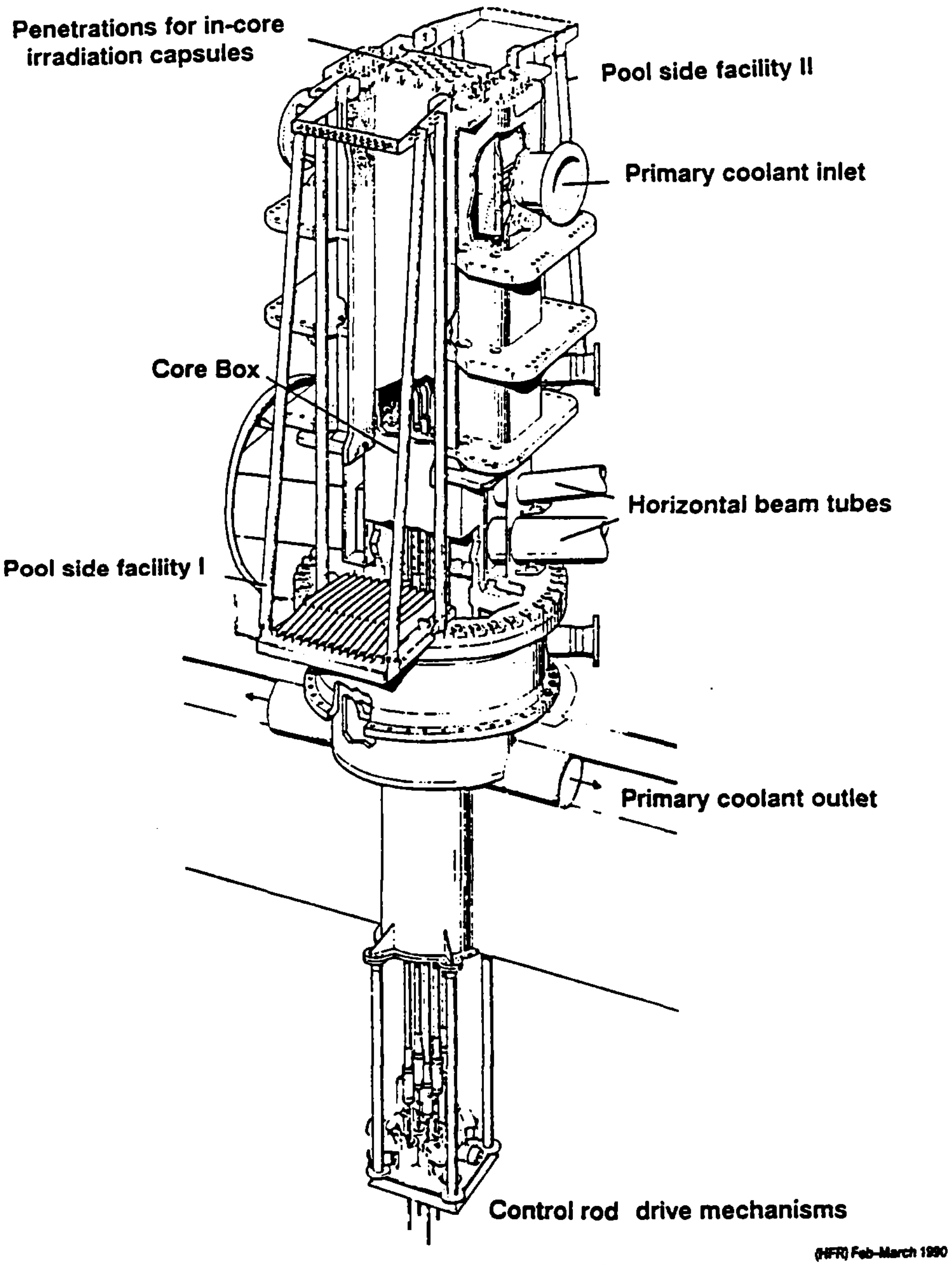


Fig. 1. New reactor vessel of HFR

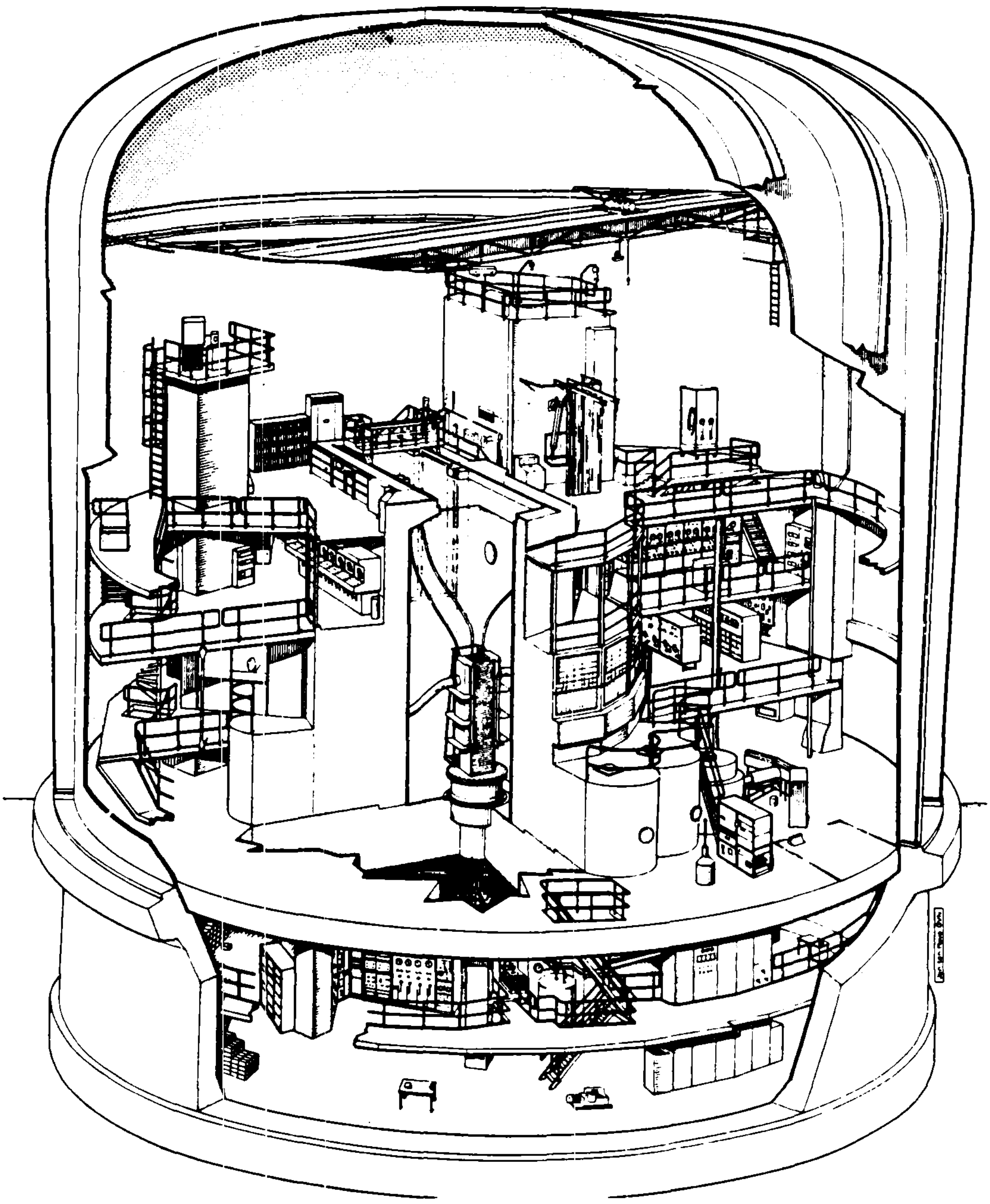
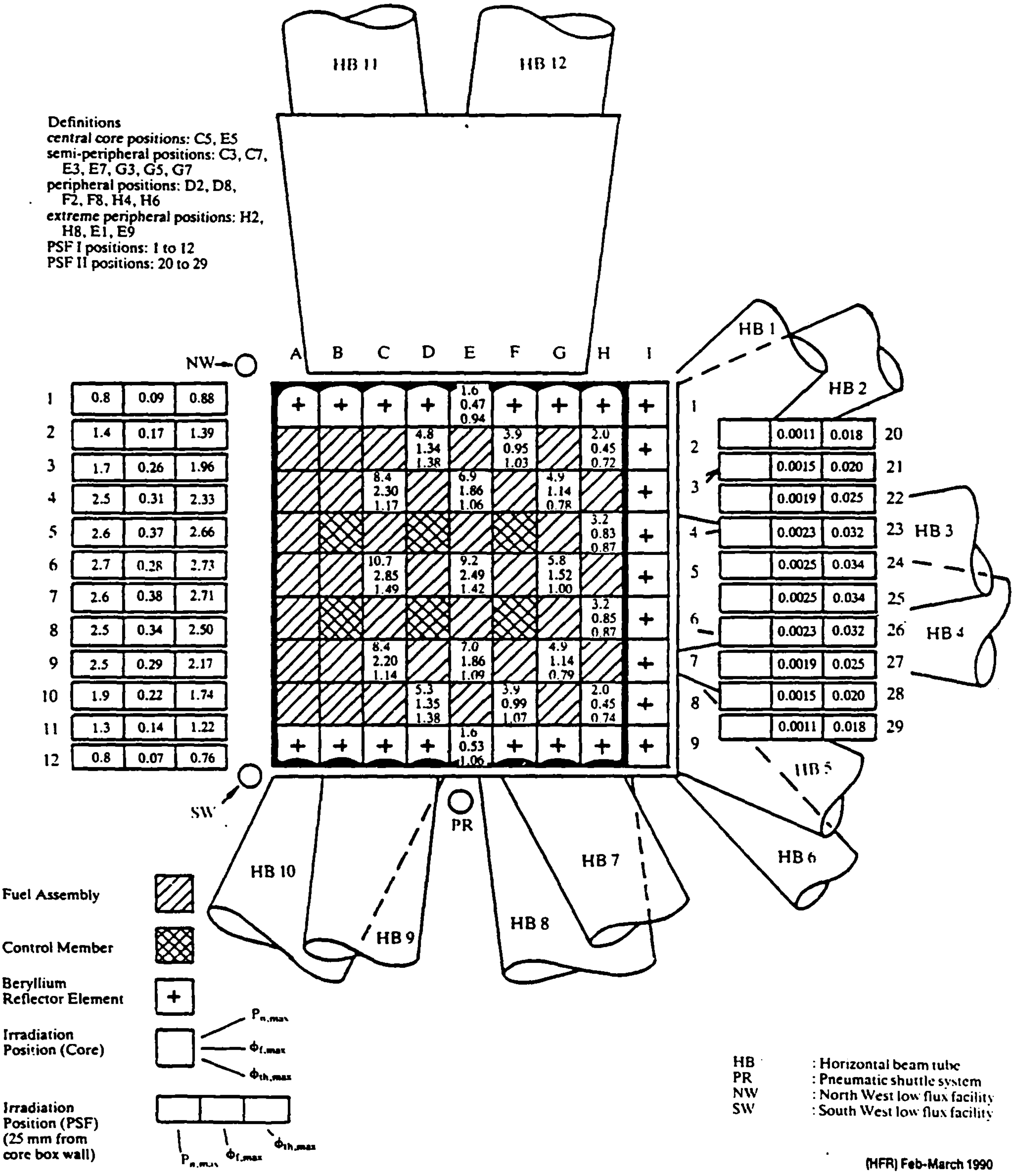


Fig. 2. Isometric drawing of the reactor building



Definitions
central core positions: C5, E5
semi-peripheral positions: C3, C7, E3, E7, G3, G5, G7
peripheral positions: D2, D8, F2, F8, H4, H6
extreme peripheral positions: H2, H8, E1, E9
PSF I positions: 1 to 12
PSF II positions: 20 to 29

	A	B	C	D	E	F	G	H	I
1	+	+	+	+	1.6 0.47 0.94	+	+	+	+
2	▨	▨	▨	4.8 1.34 1.38	▨	3.9 0.95 1.03	▨	2.0 0.45 0.72	+
3	▨	▨	8.4 2.30 1.17	▨	6.9 1.86 1.06	▨	4.9 1.14 0.78	▨	+
4	▨	▦	▨	▦	▨	▦	▨	3.2 0.83 0.87	+
5	▨	▨	10.7 2.85 1.49	▨	9.2 2.49 1.42	▨	5.8 1.52 1.00	▨	+
6	▨	▦	▨	▦	▨	▦	▨	3.2 0.85 0.87	+
7	▨	▨	8.4 2.20 1.14	▨	7.0 1.86 1.09	▨	4.9 1.14 0.79	▨	+
8	▨	▨	▨	5.3 1.35 1.38	▨	3.9 0.99 1.07	▨	2.0 0.45 0.74	+
9	+	+	+	+	1.6 0.53 1.06	+	+	+	+

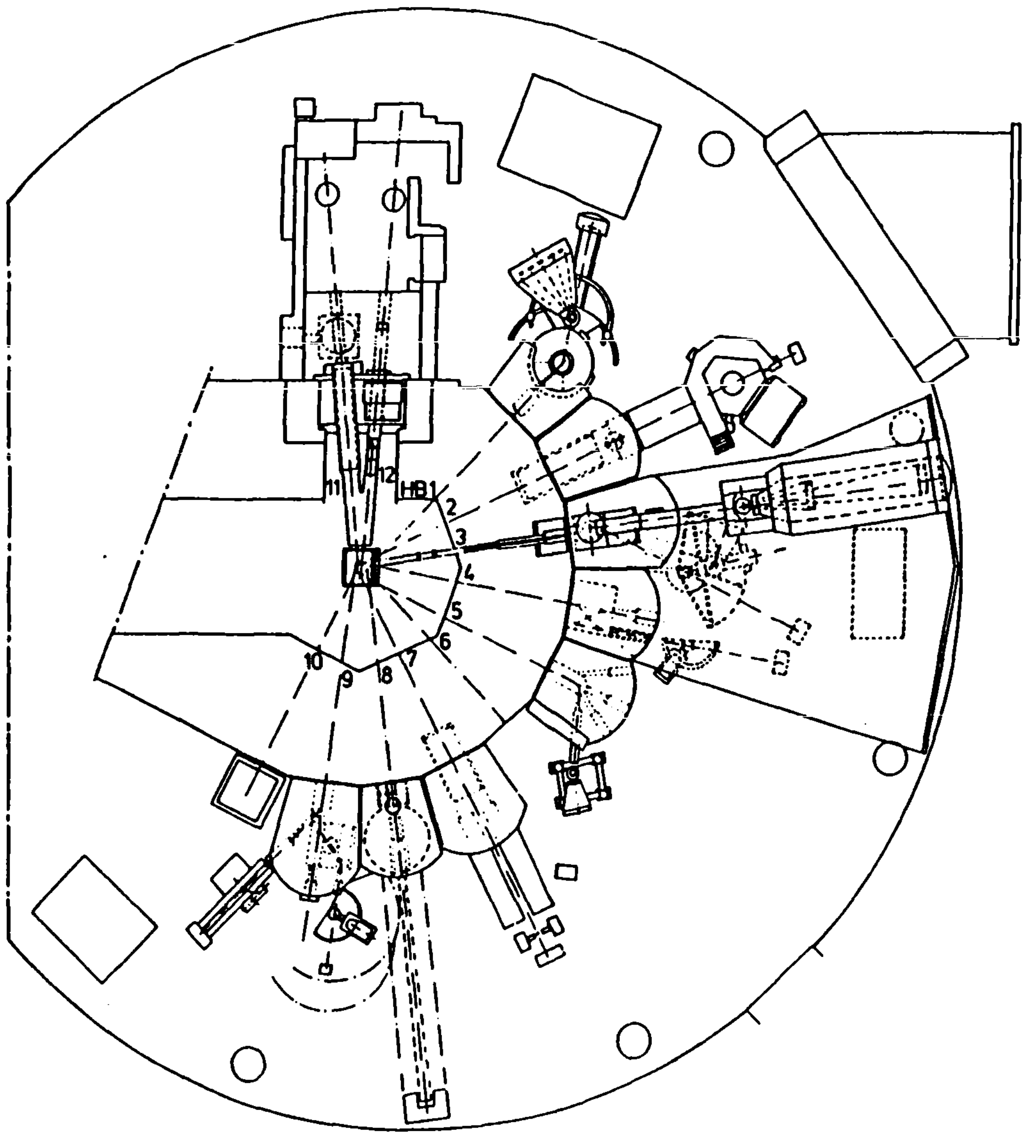
1	0.8	0.09	0.88
2	1.4	0.17	1.39
3	1.7	0.26	1.96
4	2.5	0.31	2.33
5	2.6	0.37	2.66
6	2.7	0.28	2.73
7	2.6	0.38	2.71
8	2.5	0.34	2.50
9	2.5	0.29	2.17
10	1.9	0.22	1.74
11	1.3	0.14	1.22
12	0.8	0.07	0.76

	0.0011	0.018	20
	0.0015	0.020	21
	0.0019	0.025	22
	0.0023	0.032	23
	0.0025	0.034	24
	0.0025	0.034	25
	0.0023	0.032	26
	0.0019	0.025	27
	0.0015	0.020	28
	0.0011	0.018	29

HB	: Horizontal beam tube
PR	: Pneumatic shuttle system
NW	: North West low flux facility
SW	: South West low flux facility

(HFR) Feb-March 1990

Fig. 3. Standard core configuration with nuclear values and permanently installed experimental reactor facilities



HB1 diffuse scattering/triple axis spectrometer

2 nuclear polarization set-up

3 A. triple-axis spectrometer
B. small angle neutron scattering facility (sans)

4 diffractometer for stress analysis

5 double-axis diffractometer

6

7 polarized neutron capture set-up

8 thermal/sub-thermal radiography

9 A. single-crystal diffractometer
B. activation analysis set-up

10 fasy

11 neutron capture set-up

12 filtered beam facility/(proton polarization set-up)

(HFR) Feb-March 1990

Fig. 4. Horizontal beam-hole neutron experiments