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Part 1 of 4

COMMISSION OF THE EUROPEAN COMMUNITIES

HFR INFORMATIONS FOR USERS

HFR Information on HFR facilities

by

J.J.M. SNEPVANGERS and W.L. ZIJP

1972

Joint Nuclear Research Centre
Petten Establishment - Netherlands

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Special attention is focussed on the devices recently developed in the field of direct in-pile measurements, in particular for the study of the mechanical properties of various nuclear materials exposed to high neutron flux densities.

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ABSTRACT

The present report gives a brief survey of the high flux reactor at the Petten establishment of the joint research establisment, its principal facilities and corresponding irradiation devices available for nuclear materials testing experiments.

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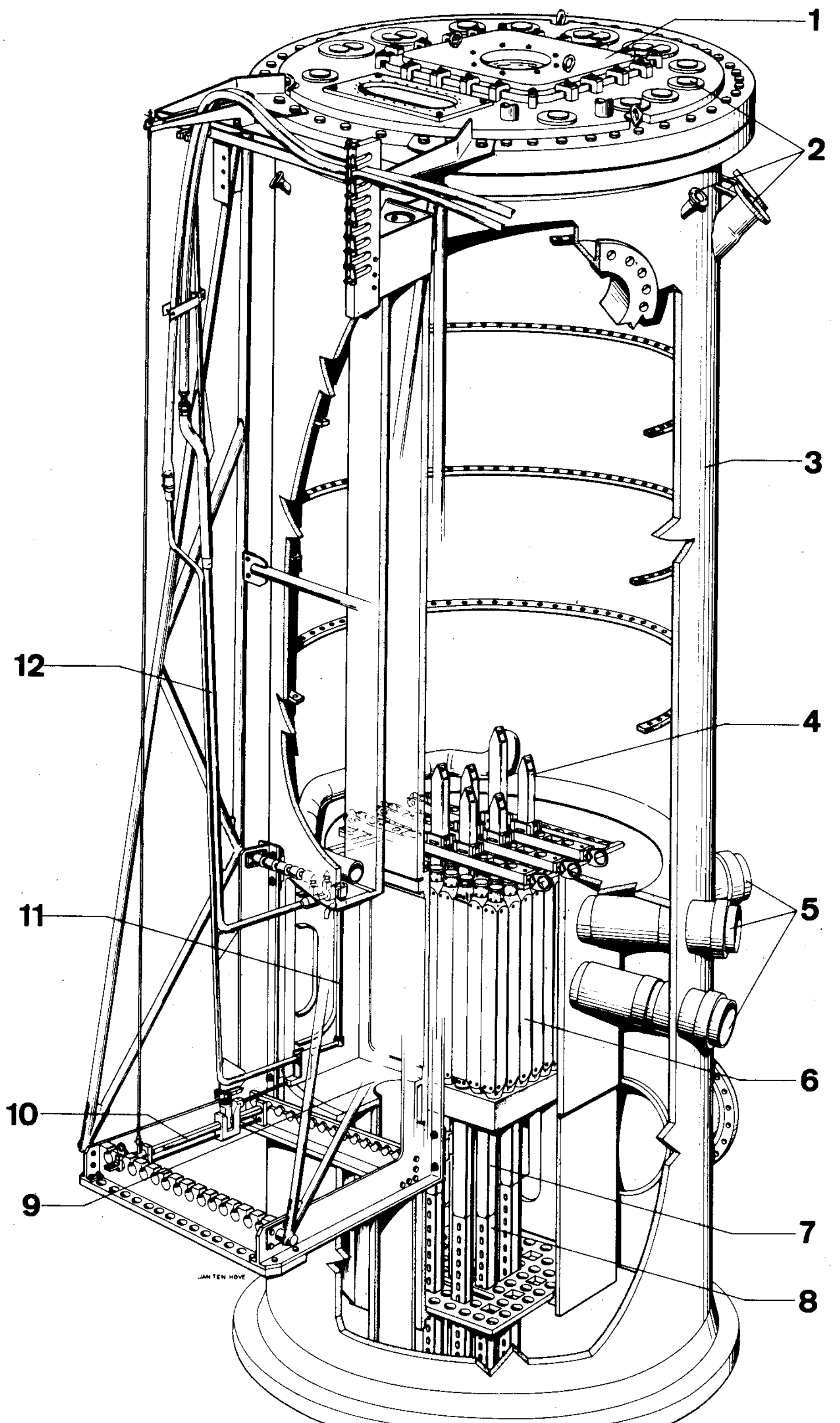
KEYWORD

HFR
IRRADIATION DEVICES
CAPSULES
IRRADIATION PROCEDURES
MATERIALS TESTING
MEASURING METHODS

Contents:



1. Cover
2. Penetrations
3. Reactor vessel
4. Control member absorber section
5. Horizontal beam-ports
6. Reactor core with fuel and reflector elements
7. Control member fuel section
8. Control member connection to drive mechanism
9. Poolside facility
10. Feed mechanism for a rig
11. Rig in position
12. Extension tube with power supply lines

Fig. 1. H.F.R. AND POOLSIDE FACILITY WITH A RIG IN THE POOLSIDE FACILITY.

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1. DESCRIPTION OF THE H.F.R.

The H.F.R. (High Flux Reactor) at the nuclear research centre at Petten is a materials testing reactor very similar to the Oak Ridge Research Reactor, and contains water as coolant and moderator (see figure 1). The normal operating power is 45 MW.

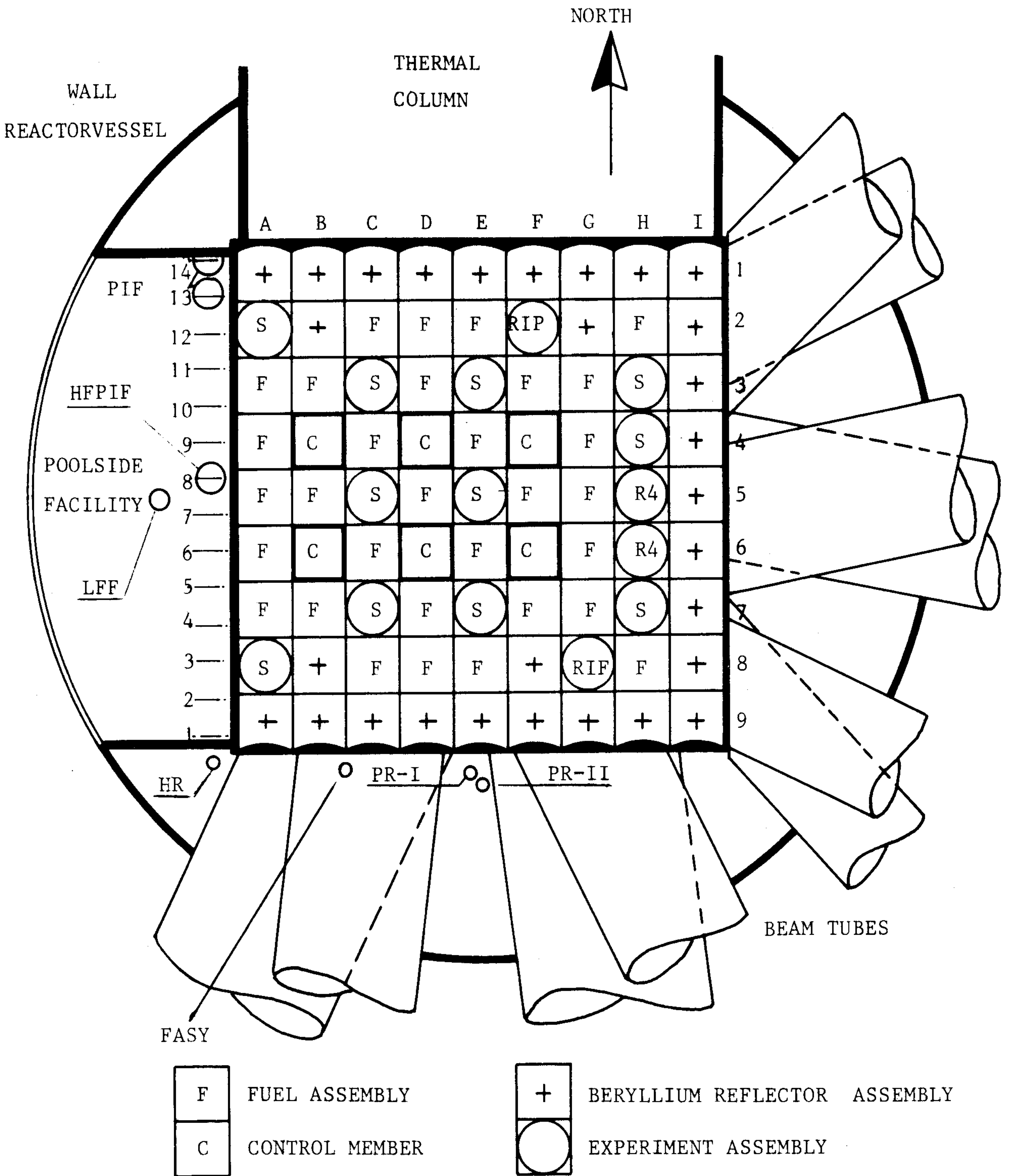
The fuel assemblies (horizontal cross section 81 mm x 77 mm, height 924 mm) are similar to the MTR fuel assemblies and contain 23 vertically arranged parallel curved fuel plates with a height of 625 mm. Each plate consists of a layer Al-U alloy meat with a thickness of 0.5 mm, clad with aluminium of 0.4 mm thickness. The length of the fuel inside the plate is 600 mm. The uranium consists of about 90% ^{235}U. The uranium content of the fresh assemblies is now 240 g ^{235}U.

The lattice is a 9x9 array (729 mm x 693 mm) with the fuel assemblies, similarly shaped beryllium reflector elements, and experimental assemblies (rigs or capsules). (See fig. 2).

There are six control members, each member containing a cadmium section on top of a fuel section. The drive mechanism is situated below the reactor. The control members are moved in a vertical direction. When a control member is moved upwards, the fuel section moves into the core displacing the cadmium section.

The reactor vessel is a welded aluminium tank, 1.60 m in diameter and 5.4 m high. Its wall thickness is 24 mm. It is designed to withstand an inside overpressure of 260 kN/m^2 (= 2.6 atm.). Reactor cooling is effected by recirculating demineralized water in a closed circuit, consisting of the reactor vessel, a decay tank, ion exchangers, three main circulation pumps, and the shell-side of three water-to-water heat exchangers. The water flows downward through the reactor core. The speed past the fuel plates is 4.7 m/s. The total flow rate is 4300 m^3/h. Water inlet temperature is usually kept around 30^o C; the corresponding outlet temperature is 40^o C. More data are given in table 1.

In the heat exchangers the reactor power is dissipated to the secondary coolant, which is taken from the North-Holland canal and which, after passing through the heat exchanger tubes, is discarded to the North Sea.



S = standard mock-up
R4 = high pressure fuel irradiation loop
RIF = reloadable isotope facility
RIP = reflector isotope plug
PIF = poolside isotope facility
HFPIF = high flux (density) poolside isotope facility
LFF = low flux (density) facility
HR, PRI and PRII: hydraulic pneumatic rabbit systems

Fig. 2. CONFIGURATION 45 MW CORE.

The flow rate varies between 1000 and 2500 m^3/h, depending upon conditions. The water level in the reactor pool is usually 8.70 m, so that above the reactor vessel there is still a water column of 4.30 m. This water layer serves as a shield also during handling of fuel assemblies and irradiation devices during shut-down.
Adjacent to the reactor pool there are two smaller pools for storage and handling purposes.

2. OPERATION CYCLE.

The operating pattern of the H.F.R. consists of a 24-day operation period, interrupted by one short core reloading stop, followed, alternatively, by 2-day or 4-day shutdown periods. These shutdown periods are again used for reloading of the reactor core, but also for removal, installation and reloading of irradiation rigs, maintenance to the reactor and experimental facilities and, preceding each new cycle, neutron flux density measurements in the new reactor core.
The actual core life of approximately 12 days is based upon a core loading policy, which is based on a 6-zone fuel core, each zone containing fuel elements of approximately equal uranium content. By moving the fuel elements stepwise (each 12 days) from zone to zone a relatively constant flux and power distribution can be maintained during each operating period, guarantying both proper reactivity control of the reactor core and stable irradiation conditions (flux and nuclear heating) for the experimental rigs.
Under the present refueling policy fresh fuel elements are first loaded in the outer zone and gradually moved inwards, until, following their fifth 12-day irradiation period, they have reached their maximum burn-up of approximately 100 g ^{235}U, leaving them to be reprocessed with a final fuel content of 140 g. Various alternative fueling schemes, one of which is based upon the application of burnable poisons and would consequently permit longer operating periods, are presently under consideration.
The H.F.R. is operated at 45 MW for approximately 270 days per yeat. Two extended shutdown periods, of a 2-week period for maintenance and modification at the beginning of the year, and a 4-week period for holidays during the summer season, interrupt the reactor operation during each year.

	A	B	C	D	E	F	G	H	I
1									
2	0.70 0.50						1.00 0.70		
3			2.60 1.80		2.85 2.00			1.00 0.70	
4								1.20 0.80	
5			2.85 1.90		3.15 2.10			1.25 0.90	
6								1.20 0.80	
7			2.60 1.80		2.85 2.00			1.00 0.70	
8	0.70 0.50						RIF		
9									

PSF 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Fig. 3. FAST FLUX DENSITY VALUES IN STANDARD MOCK-UP ASSEMBLIES.

Values refer to equivalent fission neutron flux densities and are expressed in units of $10^{18} m^{-2} s^{-1}$.
Upper value: maximum value (just below reactor midplane).
Lower value: average value (taken over 600 mm).

	A	B	C	D	E	F	G	H	I
1									
2	1.20 0.90						1.65 1.25		
3			1.90 1.30		2.25 1.60			1.25 0.90	
4								1.35 1.00	
5			2.15 1.45		2.40 1.65			1.25 0.90	
6								1.25 0.90	
7			1.90 1.30		2.25 1.60			1.25 0.90	
8	1.20 0.90						RIF		
9									

PSF 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Fig. 4. THERMAL FLUX DENSITY VALUES IN STANDARD MOCK-UP ASSEMBLIES.

Values are expressed in units of $10^{18} m^{-2} s^{-1}$.
Upper value: maximum value (just below reactor midplane).
Lower value: average value (taken over 600 mm).

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3. FACILITIES FOR EXPERIMENTS.

General.

The most important locations to instal irradiation capsules or rigs are:

1. the 6 inner positions in the fuel region
2. the positions between fuel region and reflector region
3. the positions in the poolside facility

For neutron and nuclear physics work there are available 10 horizontal beam tubes, of which one is used for the fast shuttle system (see 8.5). For the irradiation of small and separate samples several isotope irradiation facilities and conveyor systems (pneumatically or hydraulically operated) are available.
The reactor has also a thermal column, but this facility has not been of much interest.
Material irradiation experiments are carried out in the in-core positions and the poolside facility. Radiation damage experiments on non-fissile materials are mainly installed in core positions where a large fast neutron flux density is available, while fuel irradiation tests are often performed in the poolside facility or in the loop which is positioned in H5 and H6. For both type of experiments controlled conditions (e.g. temperature) are usually required.

4. IN-CORE FACILITIES.

Inside the reactor vessel the irradiation devices may be installed in both fuel assembly and reflector positions. In principle, all lattice positions can be used. In practice, a certain standard pattern of fuel and experiment assemblies is adopted. The present core configuration is shown in figure 2. The beryllium reflector elements have a longitudinal bore of 52.35 mm in which the irradiation devices can be installed. Those containing no irradiation devices are plugged with cylindrical beryllium inserts. The reflector elements may be replaced by aluminium filler elements. These filler elements have similar external dimensions to those of the irradiation device adopted to a maximum diameter of 70 mm. There are penetrations in both the reactor vessel cover plate and the pool wall for cables and tubes to the out-of-core instrumental equipment.
Irradiation devices installed in the reactor vessel can only be inserted or removed when the reactor is shutdown.

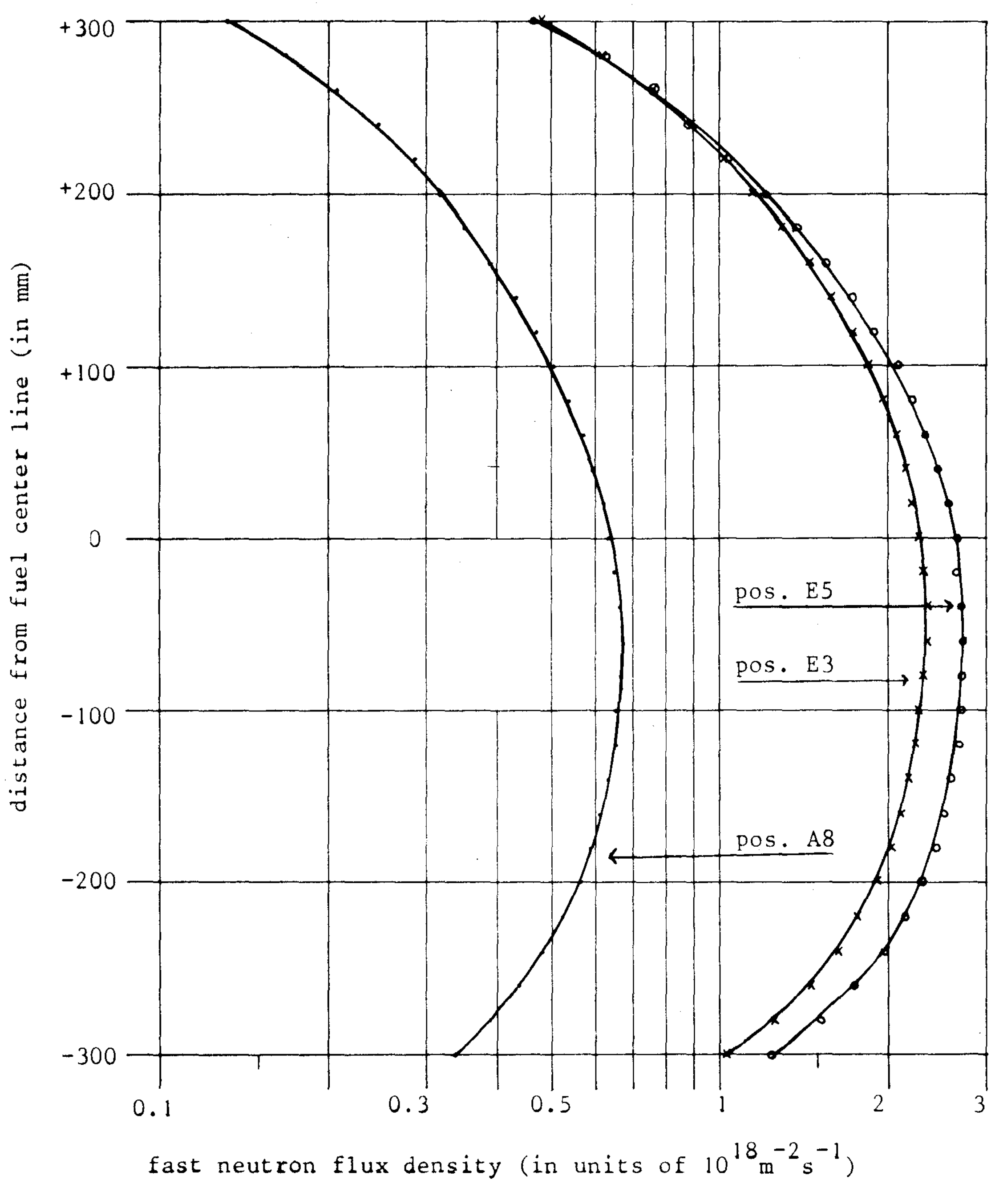

Fig. 5. CYCLE-AVERAGED VERTICAL DISTRIBUTION FOR THE FAST NEUTRON FLUX DENSITY IN STANDARD MOCK-UP ASSEMBLIES.

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Flux density measurements in experiment positions have been determined inside so-called standard mock-up assemblies (S-assemblies). These assemblies consist of an aluminium inner plug with a diameter of 46 mm covered with a lining of 2 mm stainless steel, placed in a hole with a diameter of 52.4 mm in an aluminium outer assembly.
Values for the flux densities of thermal and fast neutrons are shown in figures 3 and 4. Values for flux densities of neutrons with energies above 1 MeV and 0.1 MeV respectively are presented in table 2.
The Westcott r-factor (epithermal index) ranges from 0.080 to 0.120, except for the RIP-2 facility where an average value of 0.065 was measured.
Typical cycle-averaged vertical neutron flux density distributions are shown in figure 5. The maximum of this distribution, which is situated about 7 5 mm below the reactor midplane, is a factor 1.36 higher than the average value of this distribution over a total length of 600 mm.
Available data on nuclear heating for the experiment positions are presented in table 3.

5. POOLSIDE FACILITY.

The poolside facility gives access from the pool to the west face of the core box. The reactor vessel wall is interrupted at this point, to yield a compartment rectangular in shape, the height and width of which are identical to those of the core face. Experiments can be installed via a vertical flattened tube of 500 x 200 mm cross section, or, as is mostly done, in a horizontal direction from the pool. In order to facilitate access from the pool a support structure has been erected in front of the facility on which the irradiation devices can be placed. The experiments rest on a rail construction; they can be moved to or from the core box wall, even during reactor operation. Installation or withdrawal of experimental devices is in many cases also possible during operation of the reactor.
As the support structure makes it possible to adjust the distance from the core box wall, the facility is particularly suited for the irradiation of fuel material at a constant local fission rate density and for simulating the thermal load fluctuations of fuel elements. At a distance of 40 mm from the core box wall the unperturbed thermal flux density amounts to 2.5 x $10^{18}m^{-2}s^{-1}$ (the average value in vertical direction over a distance of 400 mm being 2 x $10^{18}m^{-2}s^{-1}$). Some flux density distributions are shown in fig. 6. The epithermal index as defined in the Westcott convention is about 0.02.

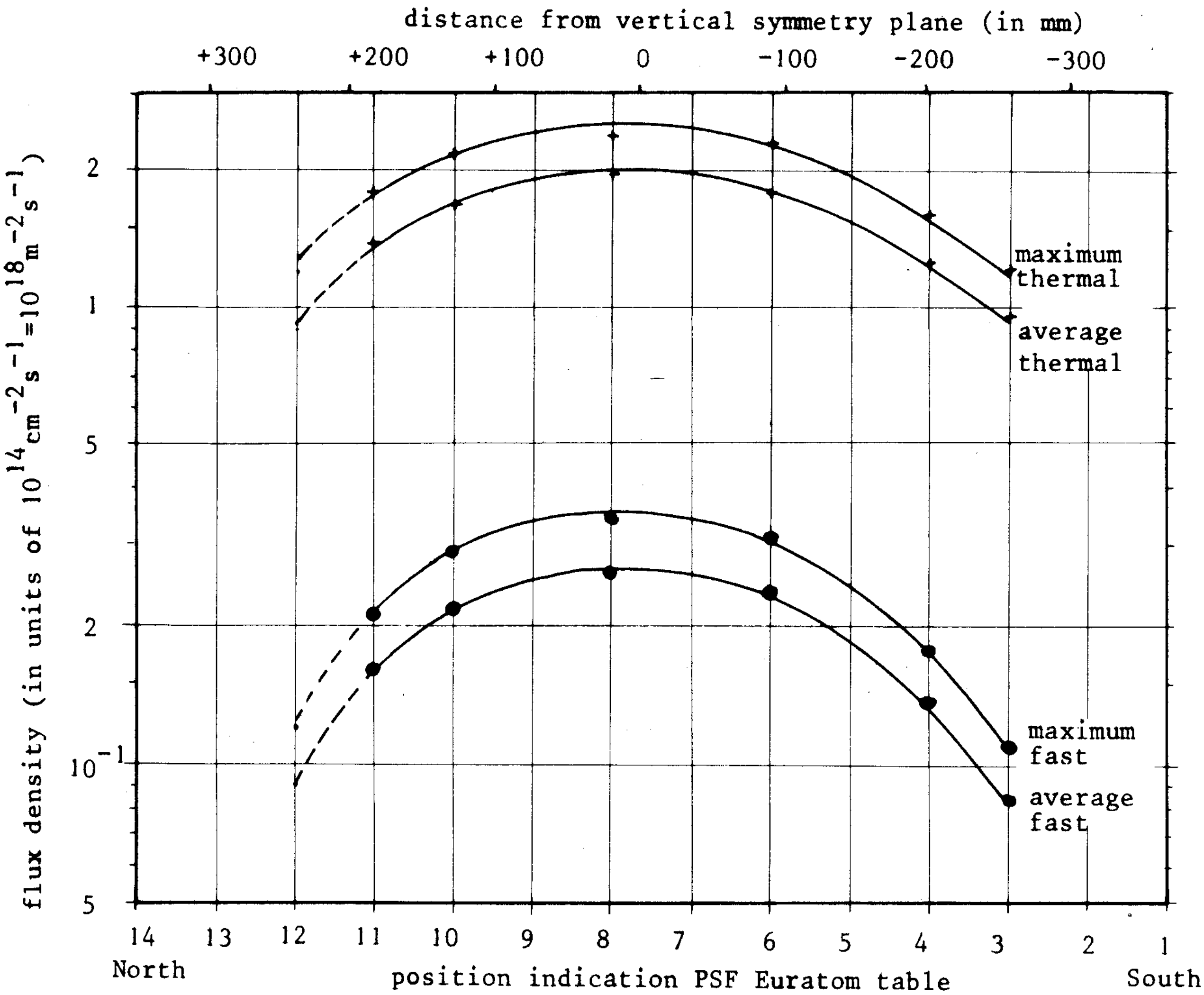

Fig. 6. HORIZONTAL NORTH-SOUTH FLUX DENSITY DISTRIBUTION IN THE POOLSIDE FACILITY.

The distance to the outside of the core box wall is 40 mm. The average values refer to the range from 200 mm above to 200 mm below the horizontal reactor midplane.

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6. BEAM TUBES.

The reactor has been equipped with 10 horizontal beam tubes. They are particularly suited for neutron and nuclear physics experiments in neutron beams. One beam tube is used for a fast shuttle system (see 8.5). The beam tubes extend from the core box wall, either slightly above or slightly below the reactor horizontal midplane, through the pool to the outside of the concrete shield, where they terminate in cubicles. Eight of them have a diameter of 175 mm and two a diameter of 250 mm. At the outer wall of the pool lead shutters have been provided; two tubes have been equipped with an internal shutter. Aluminium plugs, filled with concrete, provide the necessary shielding when the tube is not used. For experiments standard collimators may be inserted in the tubes. Usually extensive shielding provisions are then built-up on the main floor around the cubicles.
The equipment of the experiment may be connected to central cooling provisions (water, helium or carbon dioxide) and to a vacuum system.

7. LARGE HORIZONTAL FACILITY.

On the northern side of the reactor vessel a 630 mm diameter tube has been welded to the core face. An aluminium tube (so-called nose weldment) is inserted in the vessel tube. On the outside it is flanged to a large size facility (1.65 m inner diameter and 1.83 m length) which is provided in the pool concrete shielding structure.
The facility is especially designed for large engineering experiments. At present a graphite thermal column has been installed in the irradiation space. It is a self-contained unit, which can be completely removed from the irradiation space. It is at irregular intervals only used for the irradiation of standard isotope capsule in a thermal neutron flux density. The policy is to leave the thermal column in, until projects for engineering experiments come up.

8. IRRADIATION FACILITIES FOR SEPARATE CAPSULES.

At present four devices are available for the irradiation of small separate capsules. Two devices are installed in the reflector region inside the reactor vessel, and two devices are positioned in the poolside facility. One new device is planned to be ready for operation by July 1971; it is a semi-automatic fast shuttle system.

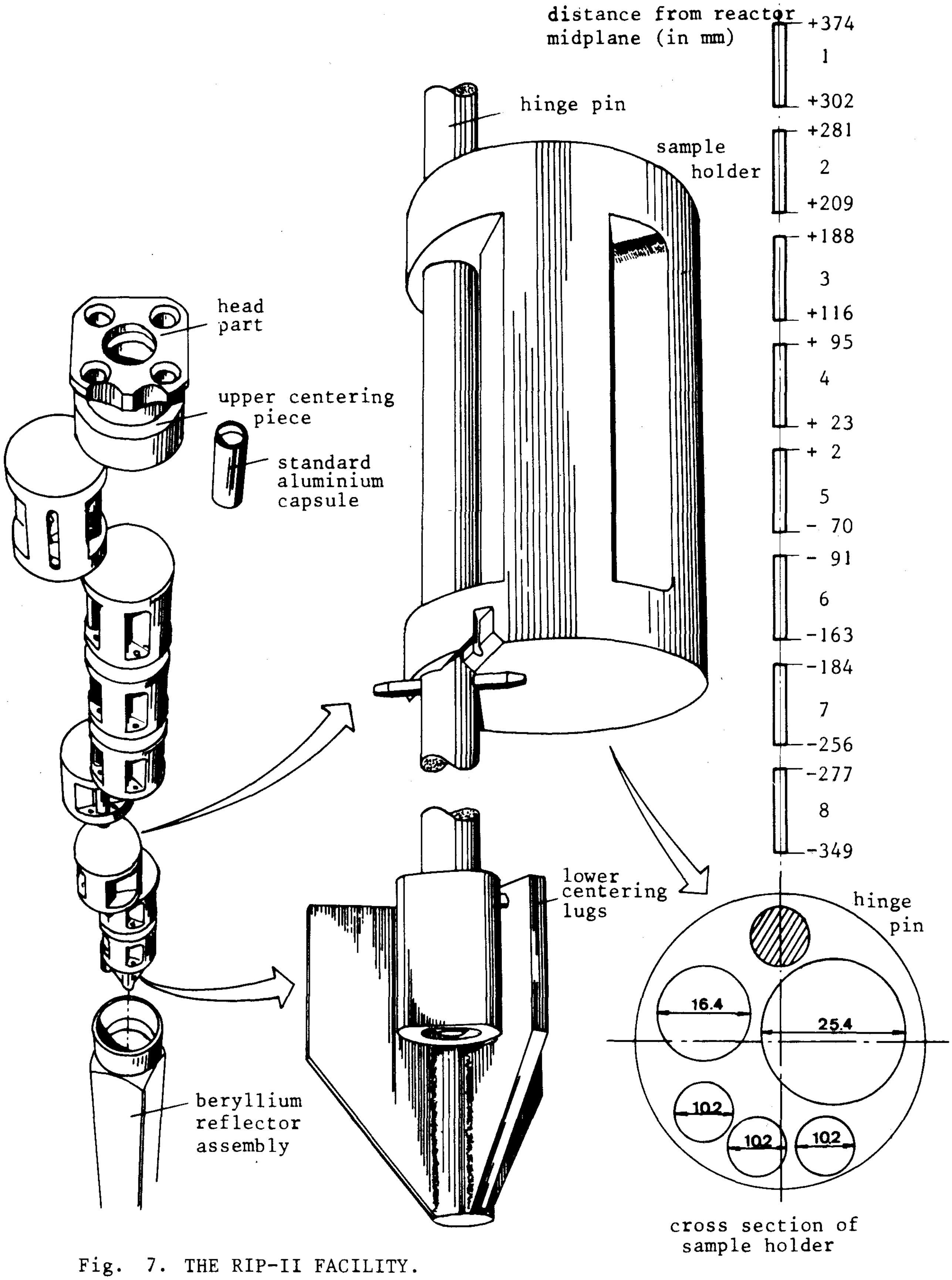

Fig. 7. THE RIP-II FACILITY.

In all these cases standard aluminium capsules are used, the cover of which must be welded to the capsules.

8.1. The RIP-II facility.

The RIP-II device (see fig.7) consists of 8 trays, connected to an aluminium rod. Each tray is designed to hold one 25 mm ø capsule, one 16 mm ø capsule and three 10 mm ø capsules.

The outside height is 80 mm; the useful internal height is 72 mm. The RIP-II can be placed in the central hole of any beryllium reflector assembly. Its location in the reactor lattice may depend on the fuel and rig loading of the core, but as its normal location the core position F2 is foreseen. Loading and unloading can only be performed during reactor shutdown. Thermal flux densities are in the range from 0.7 to $3.2 \times 10^{18}\ m^{-2}s^{-1}$, depending on tray position.

8.2. The Reloadable Isotope Facility.

This facility, abbreviated as RIF, is a simple capsule holder made of aluminium with 4 vertical cylindrical holes, three for receiving small capsules with 10 mm diameter and one for receiving capsules with 16 mm diameter. The normal capsule length will be 50 mm, although other lengths may also be acceptable. This facility provides irradiation positions over a length of 200 mm near the reactor midplane, in a relative flat part of the vertical facility. The normal position for the RIF will be G8. The RIF is shown in figure 16. The thermal and fast flux density values are about 2.8×10^{18} and $0.7 \times 10^{18} m^{-2}s^{-1}$ respectively. The irradiation time is a multiple of 24 hours.

8.3. The Poolside Isotope Facility.

This facility, abbreviated as PIF, is installed in the northern corner of the poolside facility (position indicated with PSF 13, 14). The aluminium frame work offers 30 irradiation positions, arranged in two parallel vertical columns (designated as North column and South column), which are suited for the irradiation of 25 mm diameter standard aluminium capsules (height 80 mm).

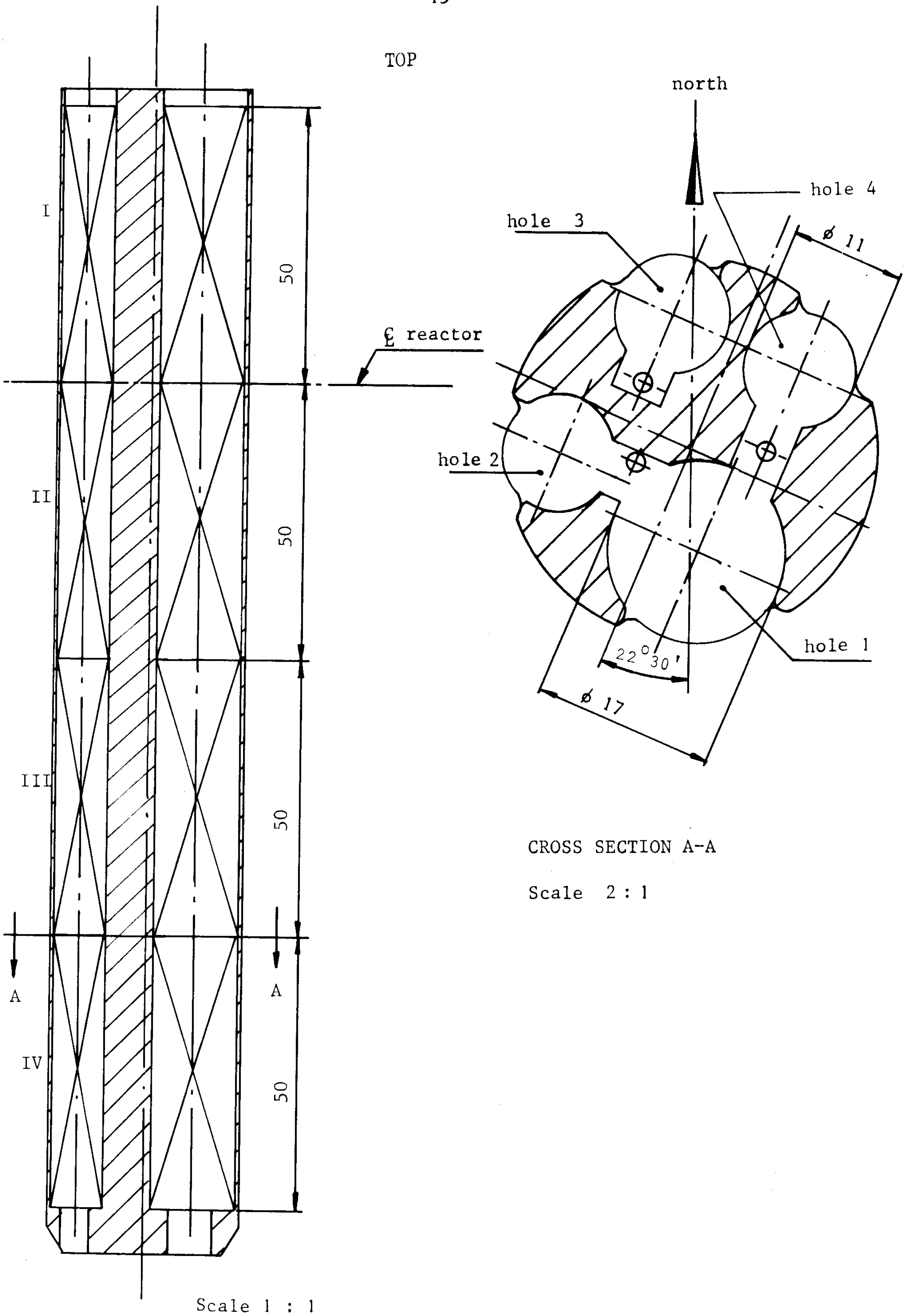

Fig. 8 . CAPSULE HOLDER RIF, POSITION G8.

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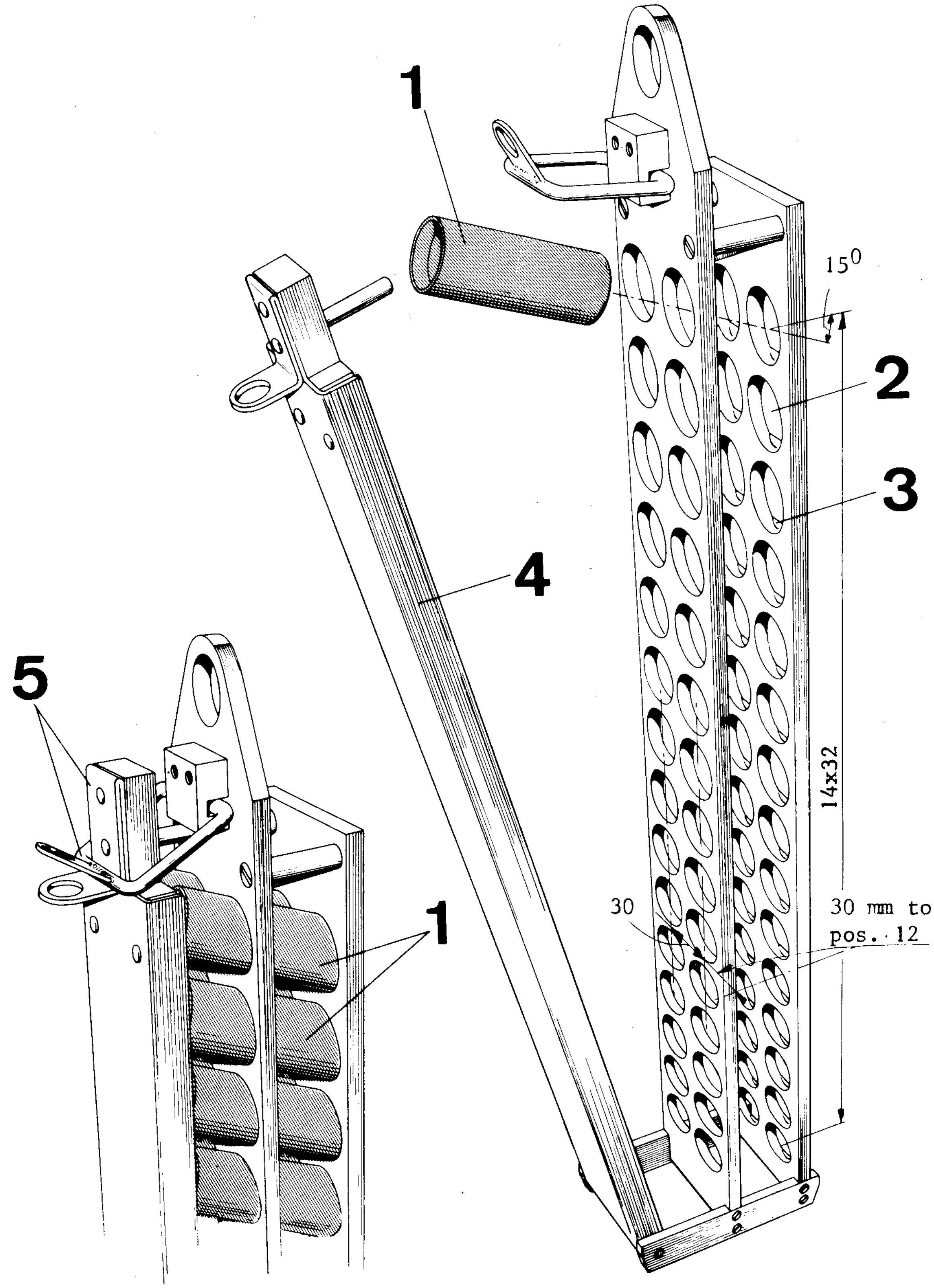

Fig. 9. P.I.F. (POOLSIDE ISOTOPE FACILITY).

1. Standard aluminium capsule
2. Hole for holding the capsule
3. Rear capsule support
4. Locking bar
5. Locking mechanism

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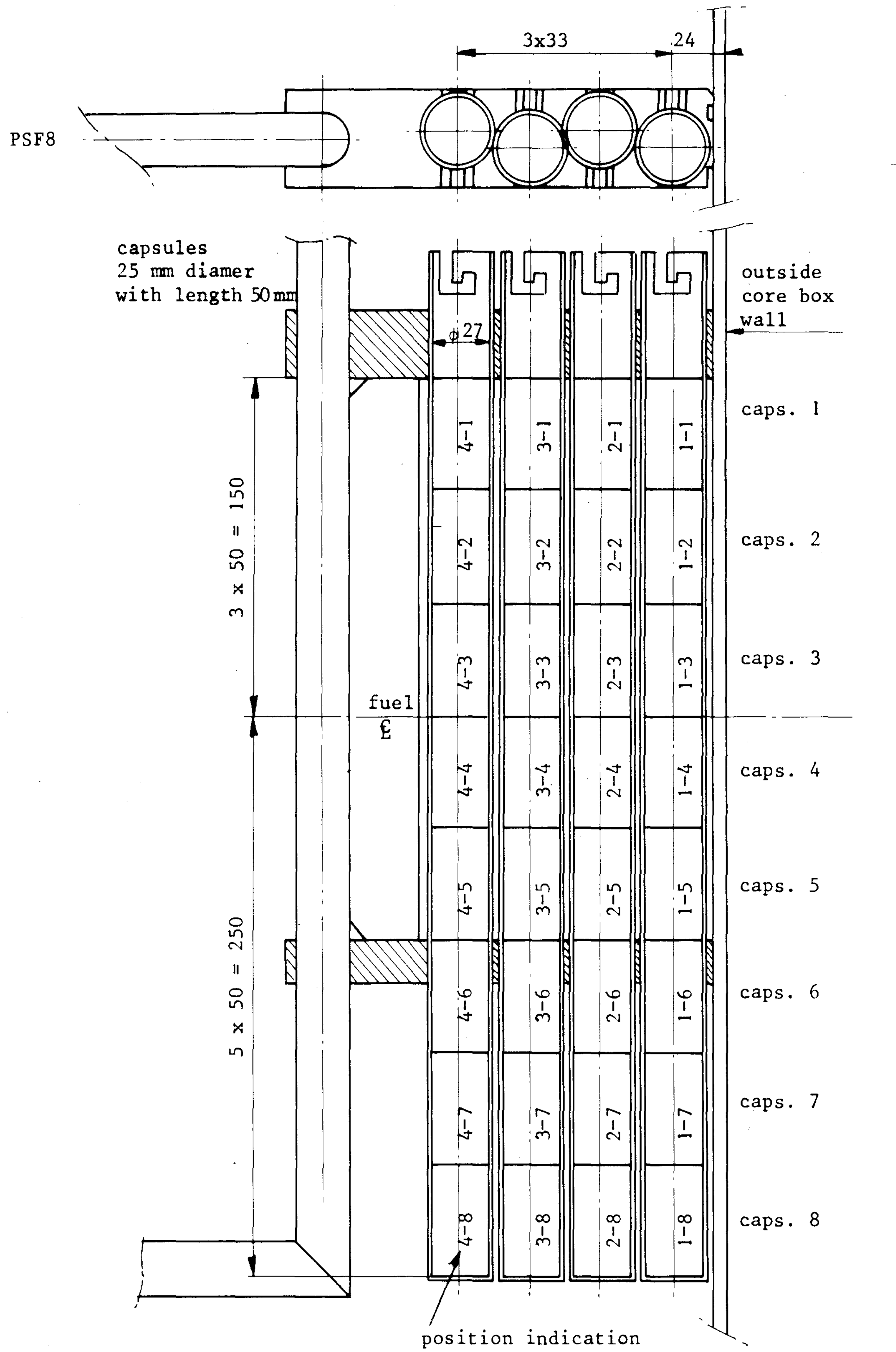

Fig. 10. HIGH FLUX POOLSIDE ISOTOPE FACILITY

RMG 2193

The capsules are placed under an angle of 75° with the vertical axis in order to facilitate handling operations. A locking device keeps the capsules in position. The PIF is shown in figure 9. The facility can be moved towards or from the core during reactor operation. The minimum time between loading and unloading is usually one day.
The thermal flux density ranges from 0.3 to 0.9 x $10^{18} m^{-2} s^{-1}$. The fast flux density is a factor 10 smaller.

8.4. The high flux poolside isotope facility.

This facility is abbreviated as HFPIF; it can be installed on a standard trolley mechanism of the poolside support structure. The position PSF 8 has often been used for this device. Four tubes can be placed behind each other, in which aluminium sample irradiation capsules of 23 mm inner diameter and a length between 42 and 192 mm can be placed.
The device can be installed and removed during reactor operation. Normally reloading takes place once a day. The position scheme of the capsules is shown in figure 9.
Maximum values for thermal and fast flux densities are about $2.5 \times 10^{18} m^{-2} s^{-1}$ and $0.5 \times 10^{18} m^{-2} s^{-1}$ respectively.

8.5. Semi-automatic fast rabbit system.

This system, called FASY, will be in operation mid 1971. It is designed for the irradiation and measuring of short-lived radionuclides. The irradiation position is in beam tube 10 against the outside of the core box wall and is surrounded by a cooled piece of lead to reduce the gamma dose rate.
The irradiations are performed in polyethylene shuttles and irradiation intervals range from a few seconds to a maximum of fifteen minutes. The internal dimensions of the shuttles are ϕ 10 mm and 19 mm long.
After irradiation the samples can be sent within one second to the counting positions where the counting can take place with the sample inside or outside the shuttle. The expected thermal neutron flux density value is ca $\geq 2.10^{17} m^{-2} s^{-1}$.

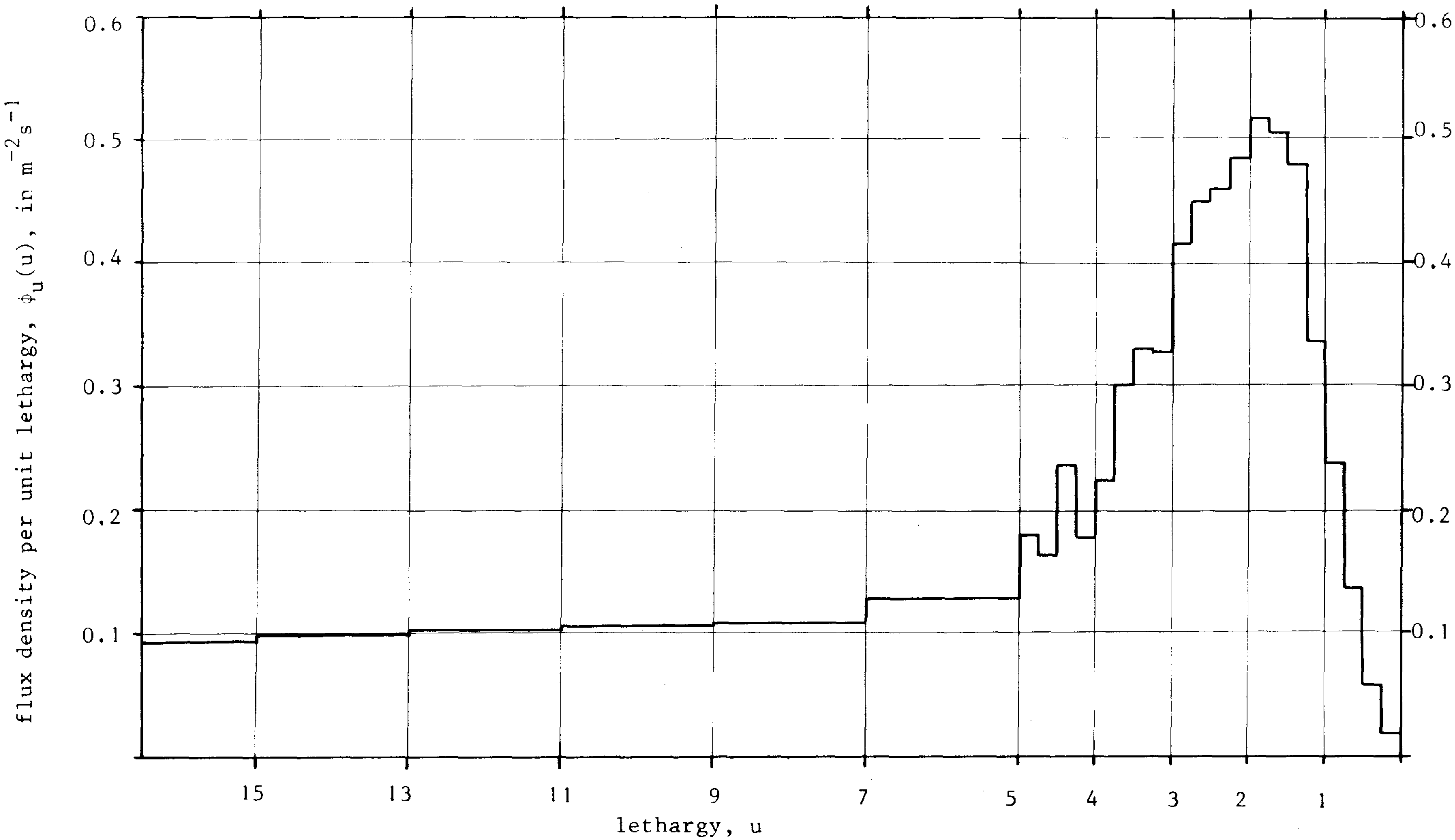

Fig. 11. TEDDI-M SPECTRA FOR S-ASSEMBLIES IN C3, C7, E3 AND E7.

The lethargy u is defined by the relation $u = \ln (E_o/E)$, where E_o = 1.602 pJ = 10 MeV.

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9. CONVEYOR FACILITIES FOR SINGLE CAPSULES.

Two pneumatic and one hydraulic operated conveyor or post systems are available for individual irradiations of small size samples in standard shuttles. For the irradiation of larger samples a mechanical operated system exists.

The irradiation terminals of the first three systems are located inside the reactor vessel, outside the core box between the upper and lower bulkhead

The first pneumatic rabbit system (PR-1) is automatically operated. The shuttle has internal dimensions of 22 mm ∅ x 100 mm. The irradiation time can be selected between 0.5 second and approximately one day. The radiation damage in the polyethylene shuttle sets a limit for the irradiation time.

Recently a special construction with lead shields has been made to minimize nuclear heating. Samples can be transferred and handled in a small lead cell. They may be transported to the chemistry laboratory by means of a separate pneumatic conveyor system.

In the second pneumatic rabbit system (PR-II) a small size shuttle with internal dimensions of 13.5 mm ∅ x 70 mm, can be irradiated for time intervals ranging from minutes to several hours. The facility is operated manually.

In the hydraulic rabbit facility (HR) a shuttle with an internal diameter of 15 mm and an internal length of 55 mm, can be irradiated during periods ranging between 15 minutes and one day.

A fourth facility, the Low Flux Facility (LFF) is located in the poolside facility. It has been constructed for the irradiation of solid and liquid samples, using standard polythene bottles of 200 cm^3.

Neutron flux density values for these four facilities are given in table 4.

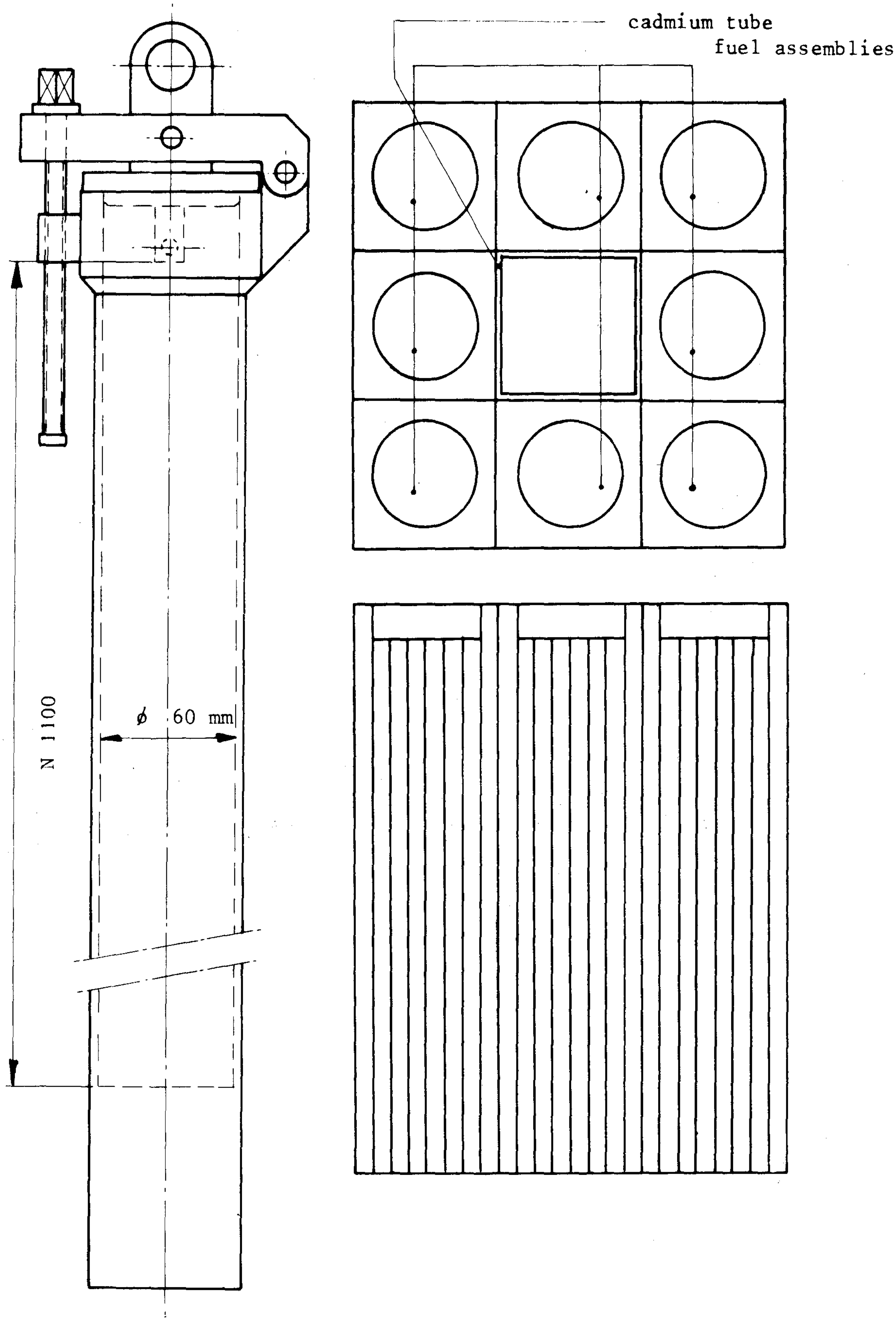

Fig. 12. THE GAMMA IRRADIATION FACILITY (GIF) WITH THE CAPSULE.

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10. NEUTRON SPECTRUM.

The neutron spectrum as calculated by the TEDDI-M program, a two dimensional 27 group diffusion theory code, is shown in figure 11. The fast flux density quoted in this report is, unless otherwise specified, an "equivalent fission neutron flux density", i.e. the flux density which would be measured with a nickel activation detector, if the neutron spectrum were a pure fission neutron spectrum. The contribution to a fission neutron spectrum by neutrons with energies greater than 0.1 MeV or greater than 1 MeV is 98.6 or 69.0 per cent respectively. For the experiment positions inside the fuel region it follows from the TEDDI-M calculations, that the flux density of neutrons with energies above 0.1 MeV resp. 1 MeV is 1.58 resp. 0.722 times the measured equivalent fission flux density.

From the calculated spectrum data obtained up till now it follows that there are no significant differences in spectra for similar assemblies in positions which are comparable with respect to the type and location of adjacent assemblies. Moreover it turns out that for a given position the neutron spectrum is hardly influenced by the usually occurring differences in the fuel charges of the adjacent assemblies.

11. THE GAMMA IRRADIATION FACILITY.

For the irradiation of samples in a gamma ray field a facility is available in the reactor pool.

Eight spent H.F.R. fuel assemblies are placed in a grid around a square cadmium tube, so that there is a hole of about 75 mm in the centre. The GIF is shown in figure 12.

The samples can be mounted in an aluminium capsule with an internal diameter of 60 mm and an internal height of about 950 mm. The capsule is filled with air and a gamma dose rate of 4 to 8 Mrad/h can be expected.

Table 1. Summary of nuclear and thermal properties of the H.F.R.*)

reactor power	45 MW
number of fuel assemblies	31
number of control members	6
number of inner experiment positions	6
fuel charge of fresh fuel assemblies	240 g ^{235}U
average fuel charge of fuel assemblies	190 g ^{235}U
total fuel charge	7 kg ^{235}U
volume of core	0.2 m^3
average thermal flux density in inner fuel pos.	$1.9 \times 10^{18} m^{-2} s^{-1}$
maximum thermal flux density in inner fuel pos.	$3.2 \times 10^{18} m^{-2} s^{-1}$
flow rate of coolant	4300 m^3/h
coolant speed in fuel assembly	4.7 m/s
coolant speed in filler element	0.2 to 5 m/s
inlet temperature of coolant	303 K
outlet temperature of coolant	313 K
temperature difference	10 K
average heat flux density in mid position	0.90 MW/m^2
maximum heat flux density in mid position	1.40 MW/m^2
nuclear heating in graphite in mid position	11 to 14 kW/kg
nuclear heating in graphite in reflector region	4 to 5 kW/kg
absolute pressure above reactor core	340 kN/m^2
pressure difference over the reactor core	60 kN/m^2

*) All units correspond to the recommendations for application of the international system of units.

Table 2. Average flux density values in standard mock-up assemblies.

The values refer to a range from 300 mm above to 300 mm below the midplane of the fuel and are expressed in units of $10^{18} m^{-2} s^{-1}$. The maximum values are a factor 1.36 larger than the average values.

core position	thermal flux density	equivalent fission neutron flux density	fast neutron flux density for:	
			E > 1 MeV	E > 0.1 MeV
A2 and A8	0.88	0.50	0.35	0.80
C3 and C7	1.30	1.80	1.30	2.85
C5	1.43	1.90	1.35	3.00
E3 and E7	1.62	1.80	1.30	2.85
E5	1.67	2.00	1.40	3.15
G2	1.24	0.72	0.50	1.15
H3 and H7	0.90	0.72	0.50	1.15
H4	1.00	0.80	0.55	1.25

Table 3. Nuclear heating in graphite samples.

Values refer to a typical graphite drum inside a steel container in an aluminium filler element. The overall accuracy is about 20%.

region	position	nuclear heating (in kW/kg) (maximum of axial distribution)
in-core	C3 and C7	11
	C5	13
	E5	14
	E3 and E7	12
reflector	A2 and A8	4
	G2 and G8	5
	H3 and H7	5
	H4	5
poolside facility	PSF 4, 10 mm	2.5
	100 mm	1.5
	FSF 8, 10 mm	4.5
	100 mm	2

Table 4. Flux density values in conveyor facilities.

All values are expressed in units of $10^{15} m^{-2} s^{-1}$.

	thermal flux density	fast flux density
PR-I	570	50
PR-II	10	1.15
HR	100	15
LFF	25	4

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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