MULTI-BEAM NEUTRON GUIDE SYSTEM AT IRI, DELFT

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1. Introduction

One of the main facilities of the Interfaculty Reactor Institute (IRI) at the Delft University of Technology is the swimming-pool type research reactor HOR. In 1963 it was critical for the first time. The power raised from 100 kW in 1963 to 500 kW in 1965. In 1968, forced cooling was introduced. From that time on, the reactor is operated at 2 MW, 5 days per week. The reactor comprises a variety of irradiation facilities, used among others for radioisotope production and neutron activation analysis. It is equipped with six horizontal radial beam tubes, originally used for neutron-scattering experiments. Throughout the years, the research activities have grown steadily, both in the development of new techniques and in applying these techniques in new research areas [1]. In the last decade of the 20th century, the utilisation of the beam tubes is extended to include neutron activation analysis [2] and production of positron beams [3]. Moreover, the role of IRI has been reinforced as centre of neutron beam research in the Netherlands and as home base for neutron research, carried out at large international facilities, such as ISIS, Didcot, UK and ILL, Grenoble, France. This led to further developments. One of the beam tubes was equipped with a new type of neutron guide system, to produce two 'clean' neutron beams, i.e. with optimal thermal neutron intensity, combined with very low fast-neutron and gamma contamination [4]. Existing polarised neutron beam instruments were improved [5], and new neutron-beam instruments were developed (the neutron reflectometer ROG [6] and a prototype spin-echo small-angle neutron scattering instrument, SESANS [7]). To facilitate further extension of beam application, an experiment hall, adjacent to the reactor hall was built (see Fig.1).

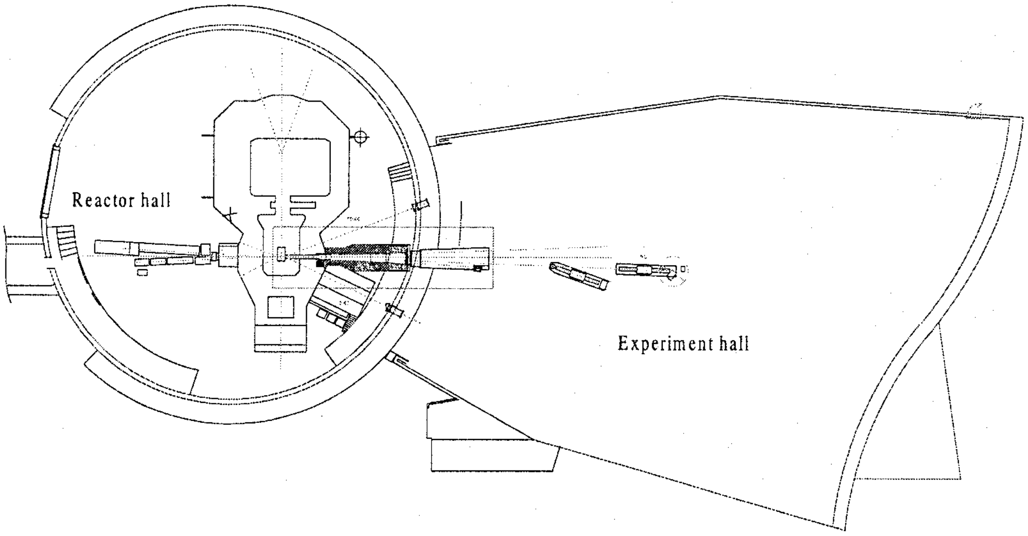
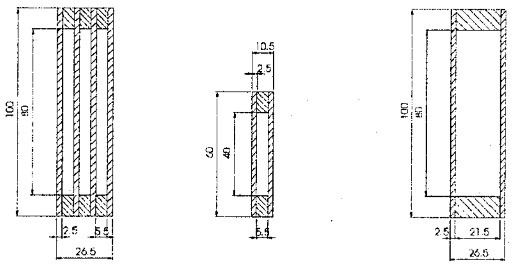


Figure 1. Reactor hall (diameter 25 m) and experiment hall of IRI, Delft. Neutron-guide system discussed here is indicated by dashed rectangle.

Two beam tubes are fed into this experiment hall. One is used for positron-beam application. The other one, the subject of this paper, is to be used for a variety of neutron-beam applications. At the moment the following applications are foreseen: two new neutron-scattering instruments, a new facility for neutron depth profiling and a prompt-gamma activation analysis facility. The objective for the design of the neutron guide system was to produce four thermal-neutron beams with high signal-to-noise ratio, using the existing 217-mm-diameter neutron beam tube.



Curved section guides B, C and D Guide A Straight section guides B, C and D

Figure 2. Cross section of the neutron guides.

2. Description

The four neutron guides consist of two sections, a 7-m-long curved section followed by a straight section of 4.2 or 5.2 m (see for the dimensions Table I and Fig. 2). The curved section of three guides (denoted B, C, and D) consist of three stacked microchannels. The glass walls separating the microchannels attenuate the fast neutrons and gamma rays, making the neutron-guide system act as an efficient filter [4]. The fourth guide (A) consists of only one microchannel. The straight sections of guides B, C, and D are single channels, yielding a more homogeneous intensity distribution. The curved sections consist of two parts. System I is the in-pile part of the guides, starting at a distance of 1 m from the nose of the beam tube. The guides are kept in an aluminium plug (Fig. 3), placed in a vacuum container. This container is designed in such a way as to facilitate, in a later stage, the incorporation of a cold-neutron source.

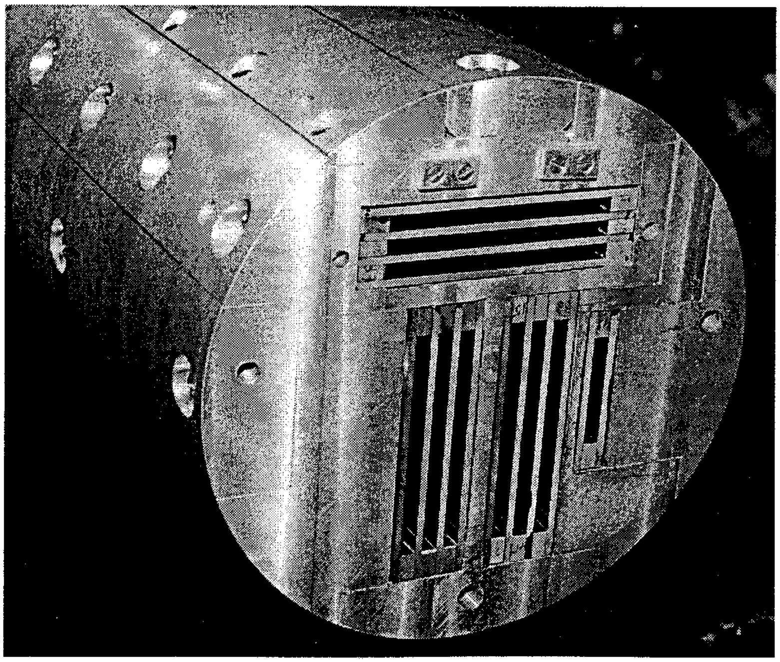


Figure 3. Photograph of the start of the neutron-guide system at 1 m from the core. Top: guide C; bottom (from left to right): guides D, B, and A. Behind the plates on top, two thermocouples are attached.

System II is the out-of-pile part of the curved guides, starting at the end of the biological shielding of the reactor and ending at the wall of the reactor hall. At this position four beam, shutters of $^6Li_2CO_3$ are situated. At the position of the guides, the containment wall of the reactor has 1-mm-thick aluminium windows. The straight sections, system III, guide the neutrons into the experiment hall. The system had to fit into the existing 217-mm-diameter beam tube, leading to the optimum packing of the guides at the core side as shown in Fig. 3. At the end of the straight guides, the separation of the guides A, B, C, and D are 25, 42, and 42 cm, respectively. Both the horizontal and vertical internal surfaces of the guides are coated with so-called m=2 supermirror coating [8], i.e. the critical angle for reflection for neutrons is twice that of nickel. A typical reflection curve is shown in Fig. 4.

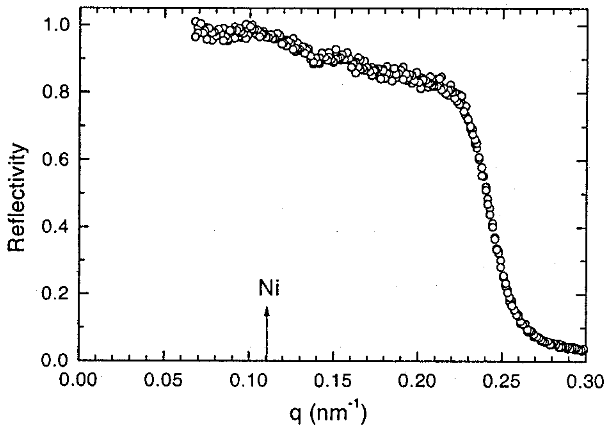


Figure 4. Typical reflectivity curve of the supermirror coating used [8], as a function of $q = 2\pi\ \theta/\lambda$, with θ the glancing angle and λ the neutron wavelength. The arrow indicates the critical q-value for natural nickel.

Since the bent stacked neutron guides act as filters, they can be considered as a secondary radiation source. We calculated the strength of this source, resulting in a line-source strength of approximately 10^9 fast neutrons $m^{-1}s^{-1}$ and 10^{10} gammas $m^{-1}s^{-1}$ from 1 to 4 m form the start of the guides. At 4.2 m (being the direct line of sight) it drops several orders of magnitude. From this point onwards the main contribution to the source strength originates from the imperfect reflection of thermal neutrons, producing capture gammas. Using this calculated source strength, the shielding was designed. The main part consists of a layered shielding of 60% Fe, 35% polyethylene, and 5% boron plastic, with a radial thickness decreasing from 80 cm at 1.5 from the start of the guides to 40 cm at 5 m.

The neutron guides (incl. coating), the aluminium plug, the vacuum containers and the main part of the shielding were supplied by Petersburg Nuclear Physics Institute, Gatchina, Russia. Fabrication and installation were carried out and controlled within a well-defined Quality Assurance regime.

TABLE I: Dimensions of the four neutron guides A-D.
The bent multi-channel sections, situated in the reactor hall (system I refers to in-pile section, system II to out of pile section), are followed by straight sections (system III), guiding the thermal neutrons into the new experiment hall (see also Figs. 1 and 2).

System number		I, II	I, II	III	III
Neutron-guide		A	B, C, D	A	B, C, D
Width microchannel	[mm]	5.5	5.5	5.5	21.5
Height microchannel	[mm]	40	80	40	80
Number of microchannels		1	3	1	1
Glass wall thickness	[mm]	2.5	2.5	2.5	2.5
Guide length	[m]	7	7	4.2	5.2
Bending radius	[m]	400	400	∞	∞
Direct line of sight	[m]	4.195	4.195	-	-

3. Performance

Shielding
Measurements at 2 MW showed that the shielding around the neutron guide system was adequate. The dose equivalent rates, measured at the surface of the shielding blocks are smaller than 10 μSv/h.

Temperature
At 2 MW reactor power, the temperature measured at the nose of system I (see Fig. 3), reaches after approximately 2 days of operation an asymptotic value of 329 K.

Transmitted thermal neutrons
We simulated the transmission of thermal neutrons by means of the Monte-Carlo technique. For ideal geometry, and using the real reflection properties of the coating (Fig. 4), the integrated thermal neutron fluxes are given in Table II. As the source we used a Maxwellian spectrum for a moderator temperature of 329 K, and a isotropic neutron flux of 1.4×10^{13} neutrons $cm^{-2}s^{-1}$ at the entrance of the beam tube. The calculated spectrum, displayed in Fig.5, has a maximum at λ=0.16 nm. Neutron fluxes were measured by means of Au-foil and Cu-foil activation. In the 2-cm-wide water gap between the core and the nose of the beam tube, the measured flux decreases from 1.15 to 0.9×10^{13} $cm^{-2}s^{-1}$. The values at the exit of system II and III are given in Table II.

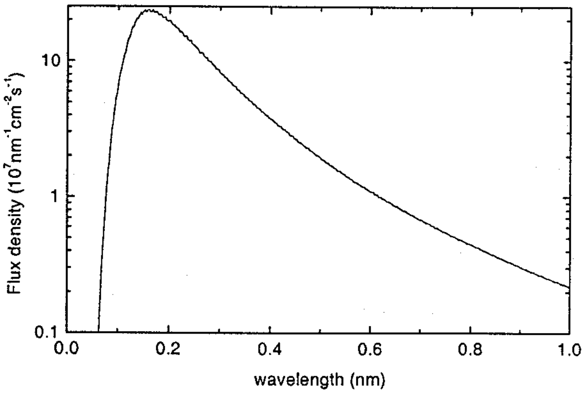


Figure 5. Thermal-neutron spectrum at the exit of the neutron guide, calculated by means of Monte-Carlo technique for an ideal geometry. In the simulations, realistic reflection curves were used.

Table II: The calculated values of the transmitted intensity after system II and III for an ideal geometry assuming an isotropic incoming neutron flux $\Phi_o = 1.4 \times 10^{13}$ cm^{-2}s^{-1} and moderator temperature $T_n = 329$ K (see text).

	thermal neutron flux (10^7 cm^{-2}s^{-1})			
	exit system II		exit system III	
guide	calculated	measured	calculated	measured
A	8.35	5.08	7.63	3.31
B	7.50	5.07	6.49	3.64
C	7.50	4.34	6.49	3.09
D	7.50	4.92	6.49	3.55

4. Discussion

A new neutron guide system with high signal-to-noise ratio was designed, built and installed. Starting in one existing beam tube, four neutron guides feed thermal neutrons into the recently built experiment hall. Provisions are made to include, in a later stage, a cold neutron source in the nose of the beam tube. At the exit of the 12-m-long guides, the thermal neutron flux is 3 - 4 × 10^7 cm^{-2}s^{-1}, which is an excellent result for a 2 MW reactor. The quantitative assessment of the quality of the system, i.e. comparing the measured and the calculated values, is not trivial. In the calculations discussed here, we assumed an isotropic neutron flux at the entrance of the guide. In practice, this is not the case. More sophisticated Monte-Carlo calculations, simulating the real geometry, are well underway and will be published elsewhere [9].

5. References

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