THE REACTOR
AND
THE NEUTRON SOURCES

THE REACTOR

ORPHEE is a swimming pool type reactor with a thermal power of 14 MW and a neutron flux of 3.10^{14} neutrons $cm^{-2}s^{-1}$. The main components of the reactor are shown in figure 1.

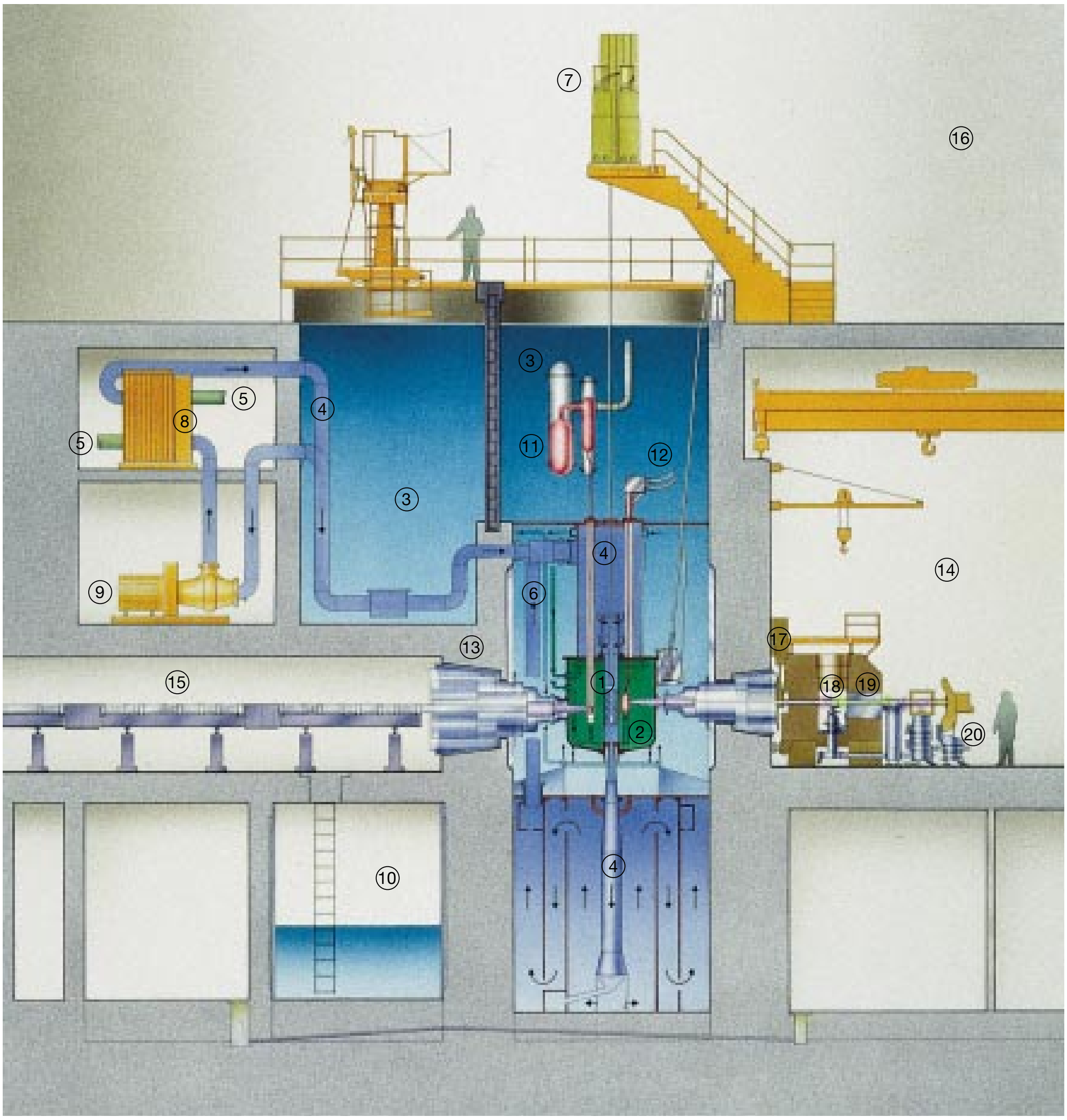


Figure 1: vertical cut of the reactor and its cooling circuit.

1. Core
2. Heavy water reflector
3. Pool and transfer channel
4. Primary circuit
5. Secondary circuit
6. Heavy water circuit
7. Command mechanism of the control rods
8. Exchanger
9. Pump
10. Drainage tank for the pool
11. Cold source
12. Hot source
13. Tangential tubes
14. Experimental hall
15. Neutron guide
16. Hall for access to reactor pool
17. Fixed primary protection
18. Monochromator
19. Protection of the monochromator
20. Spectrometer

THE CORE

The core is very compact. It is housed in a zircaloy parallelepipedic enclosure with a square section (25 x 25 cm^2) and an active height of 90 cm.

It consists of 8 assemblies of parellel plates (fuel elements) made from a fissile material (an aluminium - uranium alloy, the latter enriched in ^{235}U) which are arranged around a central beryllium reflector.

The division of the fuel elements into thin plates (1.27 mm) separated by narrow channels of water (2.1 mm) produces a very large surface for thermal exchange per unit volume (on the order of 0.6 m^2 per dm^3), yielding an elevated specific power. This is the main condition for the production of a significant neutron flux.

The total mass of uranium 235 of the core is less than 6 kg.

The core is renewed every 100 days.

The control of the reactivity is accomplished by means of vertically moving control rods consisting of neutron absorbing plates (Hafnium).

The core is placed in a reflector of heavy water circulating from bottom to top in a stainless steel vat. The biological protection is ensured by light water, contained in a pool measuring 15 m high and 4.5 m diameter. The pool is surrounded by a 1.50 m thick concrete wall. The total diameter of the reactor block is 7.50 m.

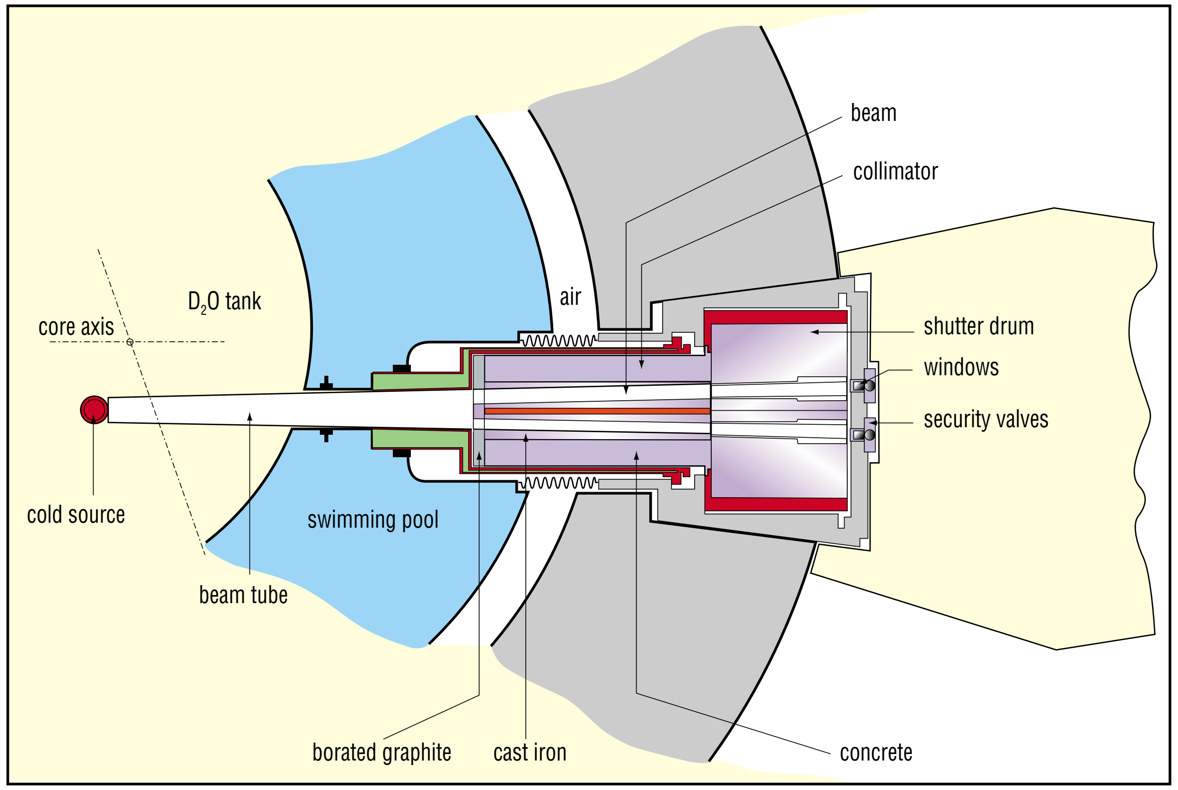


Figure 2: horizontal cut of a beam hole.

THE BEAM TUBES

The reactor is equipped with 9 horizontal tubes, tangential to the core, allowing the use of 20 neutron beams. The "nose" of these tubes is situated in the moderator near the core, where the flux of thermalized neutrons is maximum. Three tubes are viewing the two "cold sources", two other tubes a "hot source".
It is thus possible to select the spectrum of neutrons that is best adapted to the desired use.

Six cold beams are extracted to an adjoining hall (neutron guide hall) by "neutron guides" emerging from the reactor building.

Nine vertical tubes are used to irradiate different samples for activation analysis. The samples are sent by a pneumatic connection to the Pierre Süe Laboratory, a joint facility of the CEA and the CNRS.

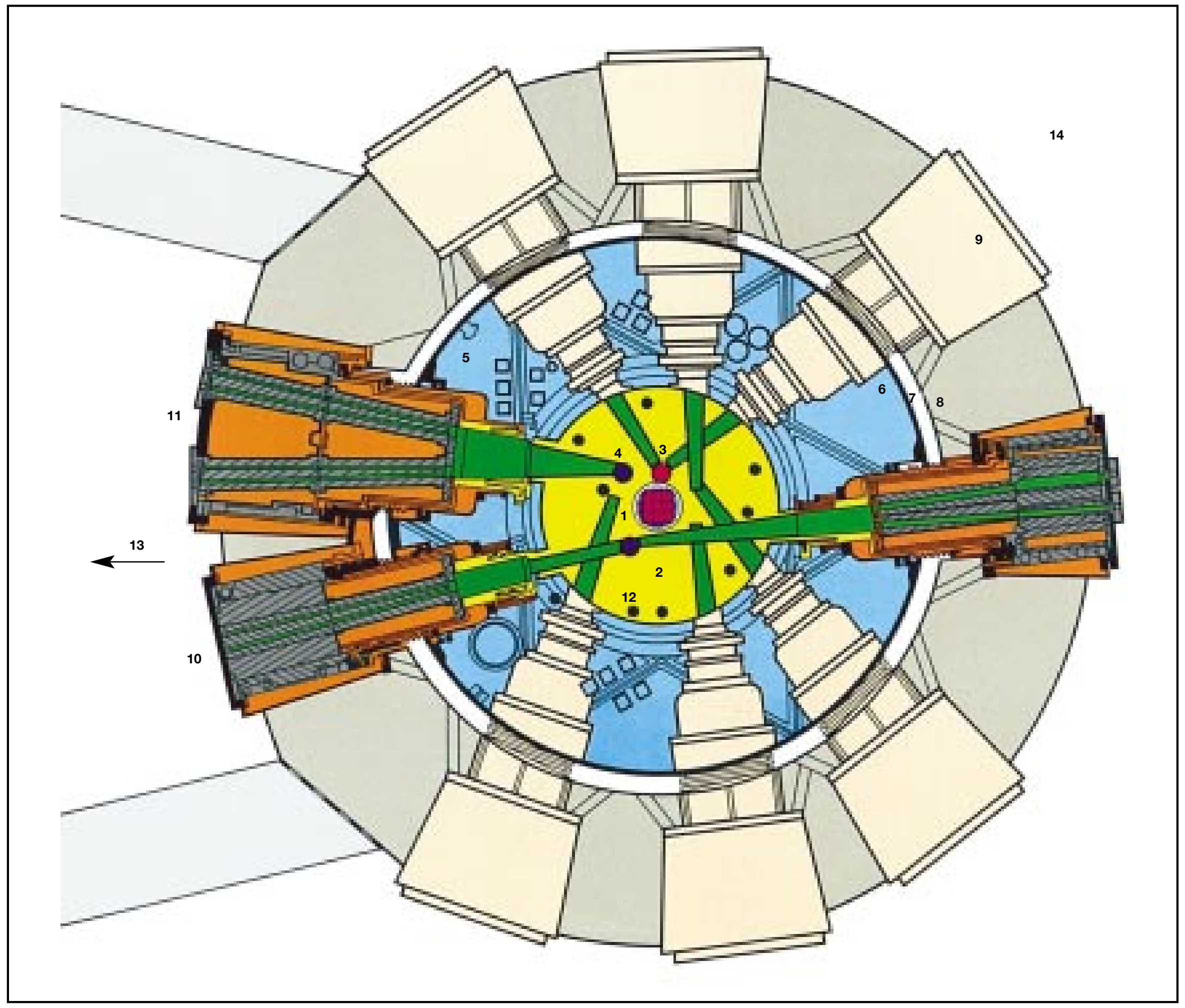


Figure 3: horizontal cut of the reacteur block at the beam hole level.

1. Core
2. Heavy water reflector
3. Hot source
4. Cold source
5. Pool
6. Pool inner wall
7. Annular space
8. Pool outer wall
9. Single tube
10. Single tube
11. Double tube
12. Vertical tube
13. Neutron guide hall
14. Experimental hall

THERMALISATION OF NEUTRONS

ORPHEE has been designed to produce a high thermal neutron flux at neutron energies ~25 meV. Nevertheless, many experiments need higher (~ 100 meV) or lower (~ 5 meV) neutron energies. They may be obtained from secondary moderators, placed inside the principal moderator where they create local conditions which modify the average energy.

1 - The principal moderator :

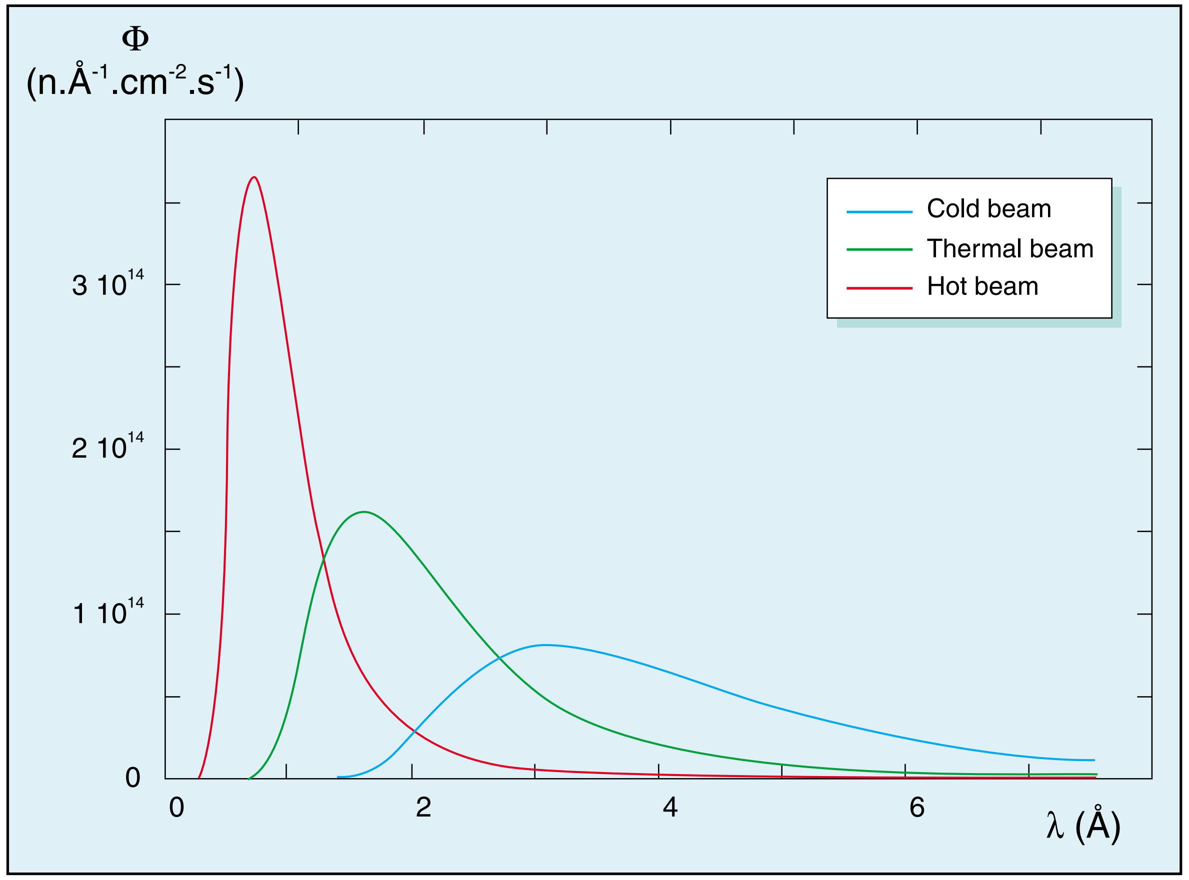
It is a cylindrical heavy water tank, 2 meters high and 2 meters diameter. The mean temperature of the water is kept around 50°C. With such a moderator, the localisation of the maximum of the thermal flux is sufficiently far enough from the core to prevent any overheating of the "nose" of the beam tubes. Also, many beam tubes can be inserted since there is a large volume over which the neutron flux varies only slightly. The distance from the nose of the thermal beam to the core axis is 360 mm.

2 - The cold sources :

The moderator is liquid hydrogen. The hydrogen is entirely confined in a close-loop. In the upper part, the gas is condensed by thermal contact with liquid helium. Thermosiphon phenomena ensure the circulation of the liquid to provide in fresh liquid the hydrogen cell.
Inside the heavy water tank we have two cold sources SF1 and SF2 with closely related geometry : the liquid occupies the volume between two cylinders of 100 and 130 mm diameter. The total height of the internal volume is 200 mm (SF1) and 300 mm (SF2) respectively.

3 The hot source :

It is a cylinder made of graphite, 122 mm diameter and 208 mm high. It is only heated by the γ ray flux produced by the reactor. Thermal isolation is obtained from several thermal screens (of graphite), the whole device being enclosed in a double wall container (in zircaloy). The operating temperature is 1400 K.



Differential flux (per Å) given by local moderators.

		TYPE	FLUX (10^9 n.cm^{-2}.s^{-1})_
CHANEL	BEAM		
1T	1	Thermal	3.93
4F	2	Cold	17.5
7C	2	Hot	7.52
8F	G1	Cold	0.99
	G 1bis	Cold	0,71
	G2	Cold	1.26
	G3	Cold	1.61
	G 3bis	Cold	1,5
	G4	Cold	0.91
9F	G5	Cold	1.88
	G 5bis	Cold	1.22
	G6	Cold	2.07

****The measurement has been made by activation of a gold foil.
The flux is measured at the monochromator position for 1T, 4F and 7C and at the end of guide position for the 8F and 9F tubes.***

THE NEUTRON GUIDES :

The propagation characteristics of the wave associated with a neutron involves the refractive index "n" of the medium, which depends on its chemical composition. At an interface, the passage from a medium with index "n_1" to a medium with index "n_2" will involve a change in the direction of propagation and, under certain conditions ($n_2<n_1$; incident angle < critical angle), the wave will not be able to pass through : it will undergo total reflection. The critical angle depends on the difference (n_2-n_1) and on the wavelength of the neutron. This phenomenon, well known for electromagnetic waves (optical fibers), is used to transport neutrons without loss over distances covering several tens of meters. The guide is a hollow tube made of thick glass whose internal walls are polished and covered with a layer of nickel. However, the index of this material, although one of the best, is only slightly different from the vacuum index and the critical angle of total reflection is small : $\theta_c = 6 \times \lambda$ (Å) arc min.

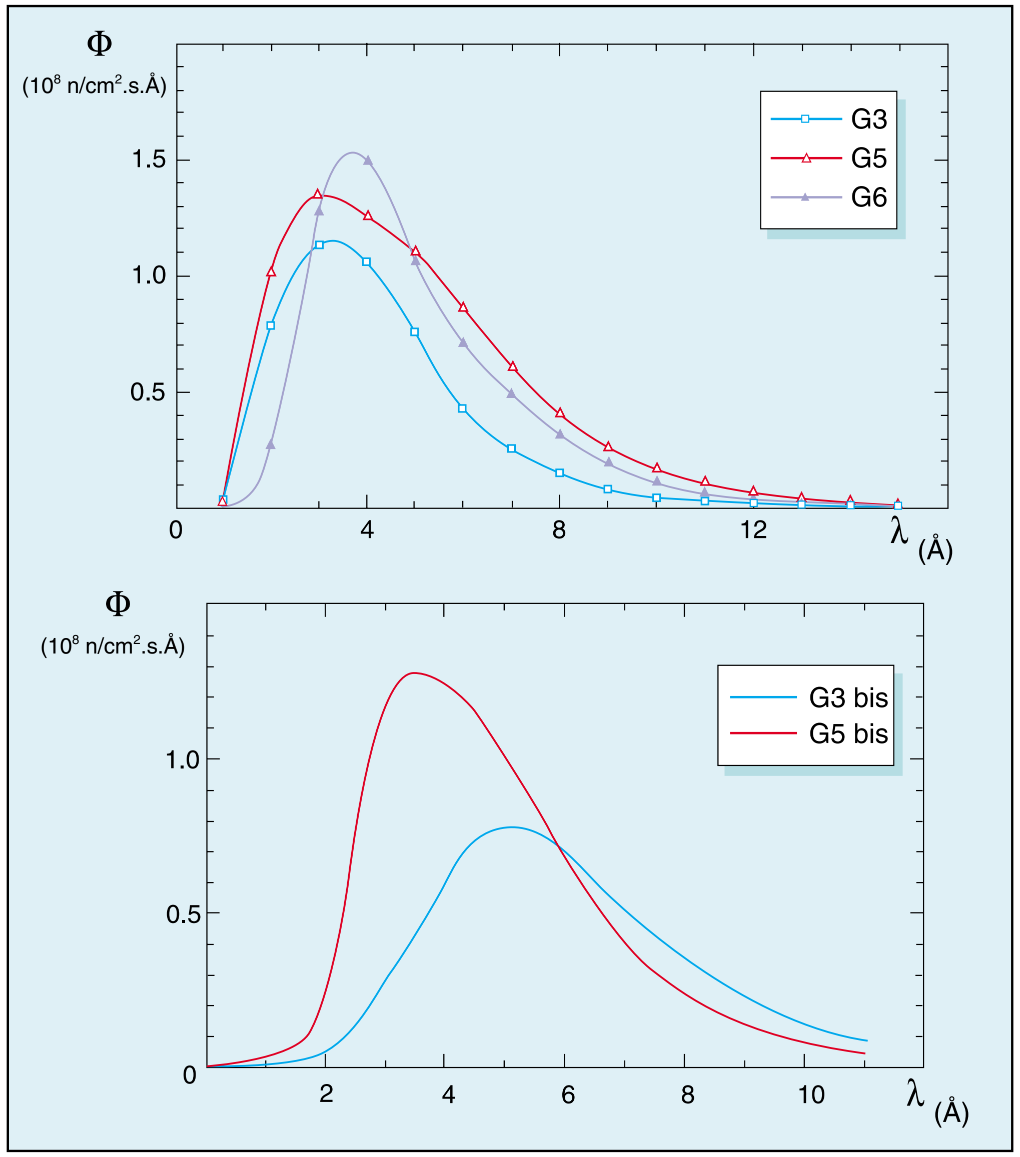


Figure 4: Flux versus wavelength at the end guide position.

In order to increase the performance, one can use constructive interference between the waves reflected by alternating layers of controlled thickness, which creates a succession of diffraction peaks beyond the critical angle. Present day technology allows the deposition of multilayers of nickel-titanium giving guides with an effective critical angle 2 at 3 times that of a simple total reflection guide.

Another possibility given by the neutron guide is to suppress all fast neutrons in the beam. Indeed, with a curved guide (length L, width e, radius of curvature R_c, critical angle of the coating $k\theta_c$(Ni)) only neutrons with wavelength greater than λ_c(Å)=(1146/k) $\sqrt{e/R_c}$ will propagate.

Along each guide, several spectrometers are installed. Each uses only the narrow wavelength band given by a monochromator placed inside a short interruption of the guide. As it is only at the end position of a guide that one can get a broad band or a polychromatic neutron beam, this potential is enhanced with 3 neutron beam deviators.
The following table gives the main characteristics of each guide and deviator. The flux transmited, as a function of wavelength, is shown in figure 4.

One can note that since the previous edition of this book, 2 guides (G1 and G2) have been equipped with supermirrors $2\theta_c$, which increase considerably the available flux at short wavelengths.

MAIN CHARACTERISTICS OF GUIDES

GUIDE	COATING	RADIUS OF CURVATURE (m)	WAVELENGTH CUT-OFF (Å)	WAVELENGTH AT MAXIMUM FLUX (Å)	TOTAL LENGTH (m)	NUMBER OF SPECTROMETERS
G1	Supermirror $2\theta_c$	463	3	4	33,3	1
G2	Supermirror $2\theta_c$	1042	2	3	39,3	2
G3	^{58}Ni	4167	2	4	39,6	1
G4	ordinary Ni	4167	2	4	63,2	5
G5	ordinary Ni	∞	1,7	2,7	56,3	5
G6	ordinary Ni	1042	4	4	39,7	2
DEVIATORS						
G1 bis	Polarizing Supermirror $3\theta_c$	46	4,4	6,2	8,6	1
G3 bis	Supermirror	50	2,3	3,3	9	1
G5 bis	Supermirror	155	3,4	5,3	9,5	1