BUDAPEST RESEARCH REACTOR

Atomic Energy Research Institute (KFKI-AEKI), Budapest

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DESCRIPTION OF THE BUDAPEST RESEARCH REACTOR

The research reactor in Budapest was first put into operation in 1959. A *full scale reconstruction* and upgrading project started in 1986, aiming at the substitution of aged components, the enhancement of reactor safety, and the increase of reactor power to 10 MW. Regular operation was resumed on 25 November 1993.

The reactor serves for basic and applied research (condensed matter, radiochemistry, biological irradiation, and reactor technology), technological and commercial applications (production of radioisotopes, neutron radiography, activation analysis, and pressure vessel surveillance), education and training: (undergraduates, PhD students, IAEA training courses, etc.).

The Budapest Research Reactor is a tank type reactor, moderated and cooled by light water. The fuel of the research reactor is made of an alloy of aluminium and uranium-aluminium eutectic with aluminium cladding. Fuel enrichment is 36 %, the fuel elements are hexagonal. The equilibrium core consists of 229 fuel elements, with a lattice pitch of 35 mm. The core is surrounded radially by a solid beryllium reflector.

Some technical data:

- thermal power: 10 MW
- approx. max. thermal flux density: 2.2 x 10^{14} n/cm^{2}s
- approx. max. fast flux density: 1.0 x 10^{14} n/cm^{2}s

The reactor has 10 horizontal beam tubes (8 radial and 2 tangential). At one of the horizontal beam tubes a *cold neutron source* (CNS) is installed. Three neutron guides lead the cold neutrons into the guide hall, adjacent to the reactor hall, where the experiments can be carried out. The neutron guides can also be used to provide thermal neutrons when the cooling system is not switched on.

At the other horizontal channels fast and/or thermal neutron beams are available for experiments. Special filtering systems are built in to enhance the required energy range.

Irradiation may also be carried out by inserting samples into the 51 special vertical channels. In one of these channels a pneumatic rabbit system is operated, serving for neutron activation analysis.

Dosimetry and flux measurements are carried out routinely in addition to beam monitoring.

The reactor is operated in cycles of different continuous periods of 114, 270 and 450 hours.

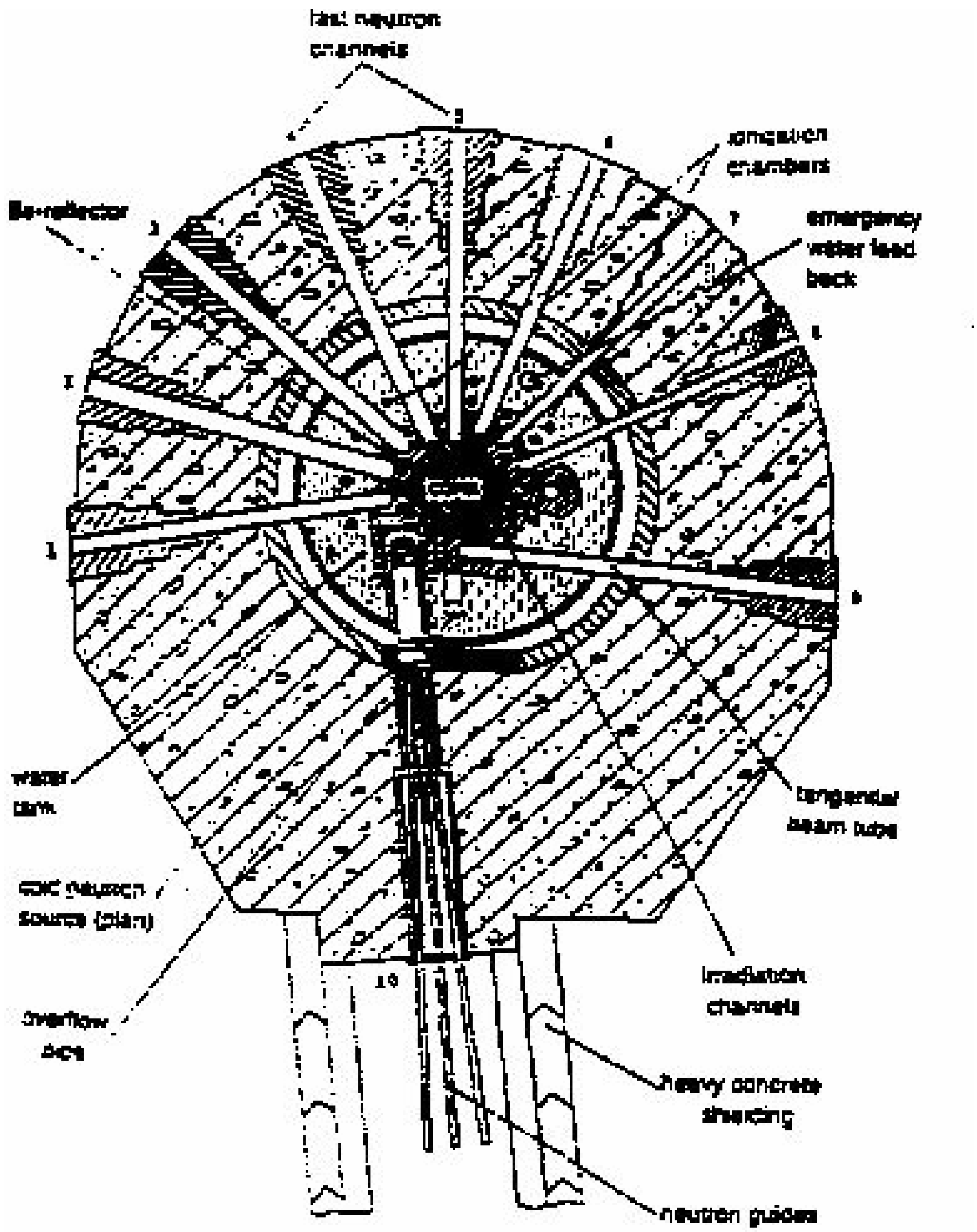
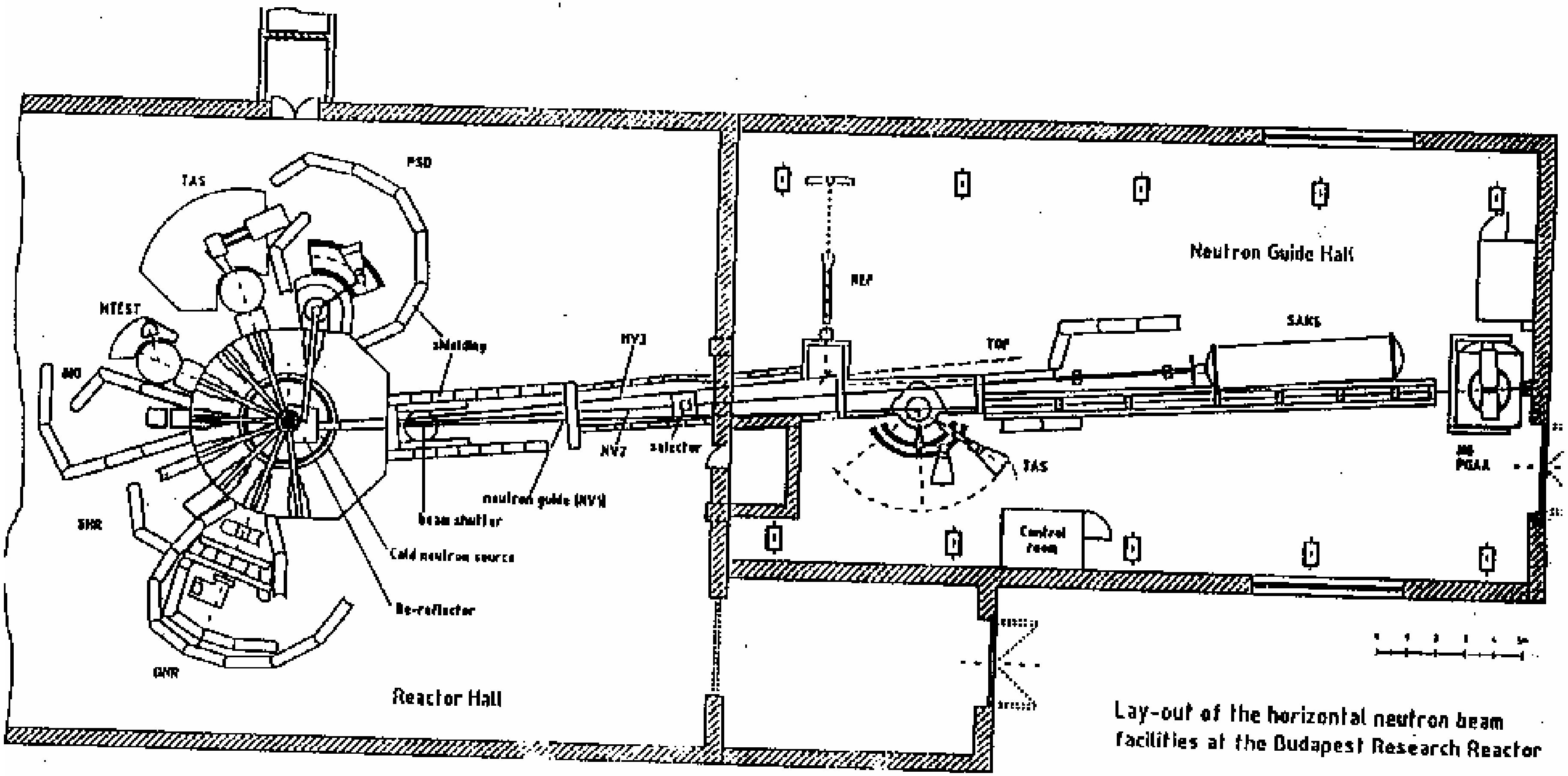


Fig. 4a. Scheme of the irradiation facilities at the Budapest Research Reactor



Lay-out of the horizontal neutron beam facilities at the Budapest Research Reactor

Fig. 4b.

BIOLOGICAL IRRADIATION FACILITY

Description

An irradiation facility existed at the BRR from 1968 for 18 years. During the reconstruction of the reactor a new system for biology and dosimetry research was designed and completed in 1995. The final tests and the investigation of the beam quality were performed in early 1996. Since that time the system is in continuous operation and improvement.

The channel lock consists of 3 steel and heavy-concrete segments turnable by an excentrical axis to open and close the channel. There is an internal rateable filter holder at a distance of 262 cm from the core which has six windows with the following materials: four Bi disks of 5, 10, 15 and 20 cm thick and one Pb disk of 20 cm, the 6^{th} one is an open hole. At the orifice of the beam tube two cylindrical tanks were constructed of aluminum to serve as a water shutter and its emergency water storage, respectively. The water can be pumped up from and released to a larger buffer tank located outside of the reactor shielding block by pressurized air. A microprocessor controlled electronic unit connected to a PC operates the two shutters and the internal filter systems. The construction materials inside the beam tube work as internal, not removable filters with total thickness of 18 mm Pb and 15 mm Al.

The irradiation cavity is situated outside of the shielding block of the reactor in a distance of 1400 mm; thus its surface-to-reactor core distance is 3100 mm including the exchangeable core window (65 mm) made either of beryllium (rolling as the fast neutron reflector, too) or of aluminum. This window can be changed only during the maintenance or refueling period. The use of the aluminum window results in a hard neutron spectrum (See Fig. 5). Between the reactor shielding surface and the cavity there is a borated water shielded collimator with a useful diameter of 10 cm. It is possible to use this collimator as a holder for outer filters of about 800 mm length. Presently, filters of Lucite, polyethylene, iron, aluminum and lead are available to decrease the gamma and neutron intensity or to modify the neutron spectrum and the neutron-to-gamma ratio. There are two changeable filter disks of boron carbide working as thermal and epithermal absorbers. The collimator is movable on a rail. The samples to be irradiated can be rotated to achieve a uniform, homogeneous irradiation. Cadmium or Boron carbide filters are used, if required, for decreasing the thermal neutron contribution. A large variety of irradiation geometry can be configured inside or outside of the collimator depending on the state, shape, weight of the material to be exposed.

The cavity is surrounded by a borated water shield, which can be moved on a rail, as well. The whole construction is covered and surrounded by shielding elements, like a bunker, made of borated water and paraffin wax, heavy concrete and lead.

Three levels of the dosimetry system were developed: real time, active beam monitors, passive activation, track etch and TL detectors and computer codes for spectrum and dose calculations. Some typical dose and flux values are presented in Table 1 and the schematic view of the system are presented in Figure 6 and 7.

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Table 1. Presently existing minimum and maximum dose and flux values variable by internal and external filters.

Quantity	Energy	Unit	Min.	Max.
neutron dose rate	E>0.5 eV	mGy/s	0.023	14
γ dose rate	-	μ Gy/s	1.5	2570
Flux	E>0.5 eV	$cm^{-2}s^{-1}$	$2*10^6$	$2*10^9$
Thermal flux	E<0.5 eV	$cm^{-2}s^{-1}$	$5*10^4$	$3*10^8$
Intermediate flux	0.5 eV<E<100 keV	$cm^{-2}s^{-1}$ per unit lethargy	$8*10^3$	$2*10^6$

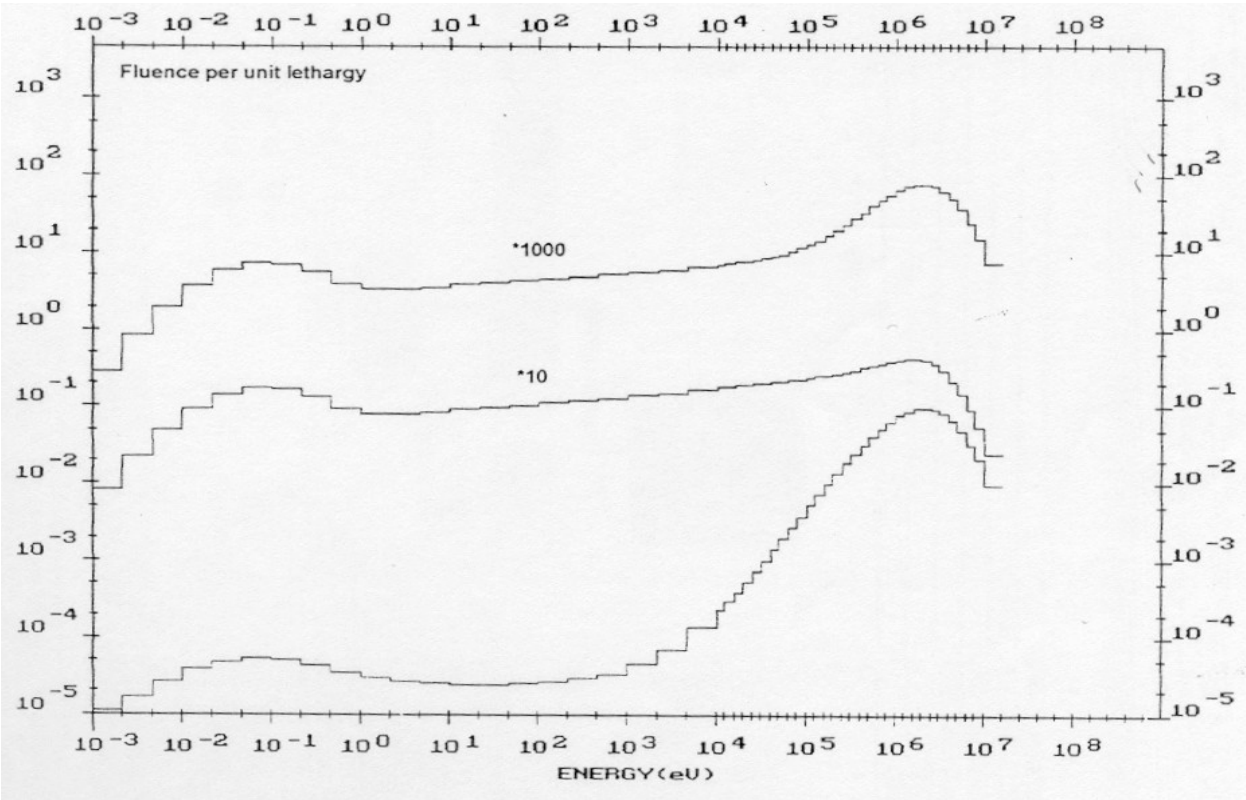

Fig. 5. Typical **neutron spectra** in the irradiation cavity. The beam-coupling window is Be, the internal filter is Bi, 100 mm thick. *Lower curve:* no external filter. On the middle: 200 mm polyethylene and 45 mm Pb external filters. *Upper curve:* 45 mm Pb + 30 mm Fe external filters. The spectra are normalized to 1 and shifted by the factors indicated to avoid overlapping.

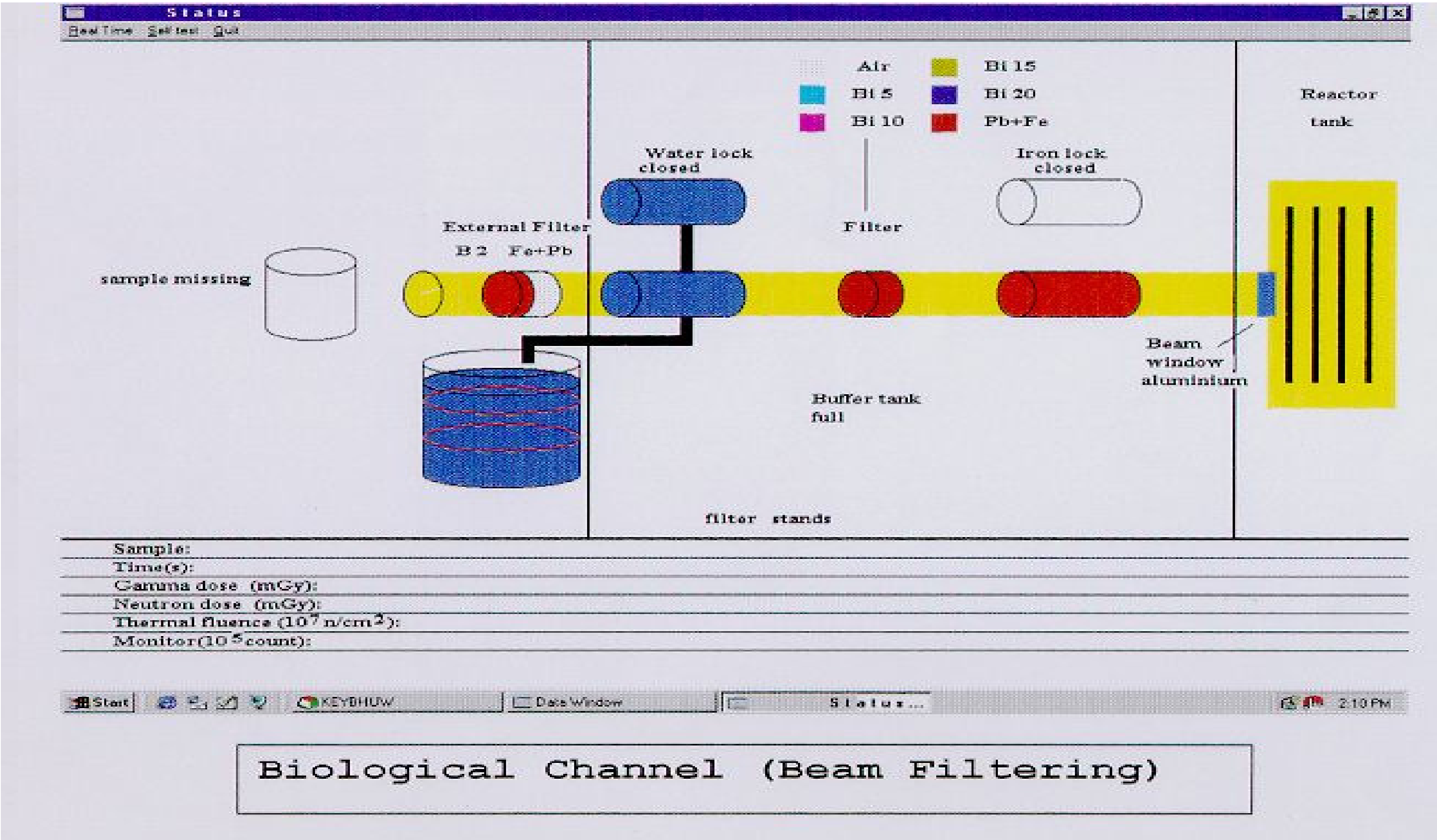
Status
Real Time Self test Quit
Air
Bi 5
Bi 10
Bi 15
Bi 20
Pb+Fe
Reactor
tank
Water lock
closed
Iron lock
closed
External Filter
B 2 Fe+Pb
Filter
sample missing
Beam
window
aluminium
Buffer tank
full
filter stands
Sample:
Time(s):
Gamma dose (mGy):
Neutron dose (mGy):
Thermal fluence (10 7 n/cm 2):
Monitor(10 5 count):
Start
KEYBHUW
Data Window
Status...
2:10 PM
Biological Channel (Beam Filtering)

Fig. 6.

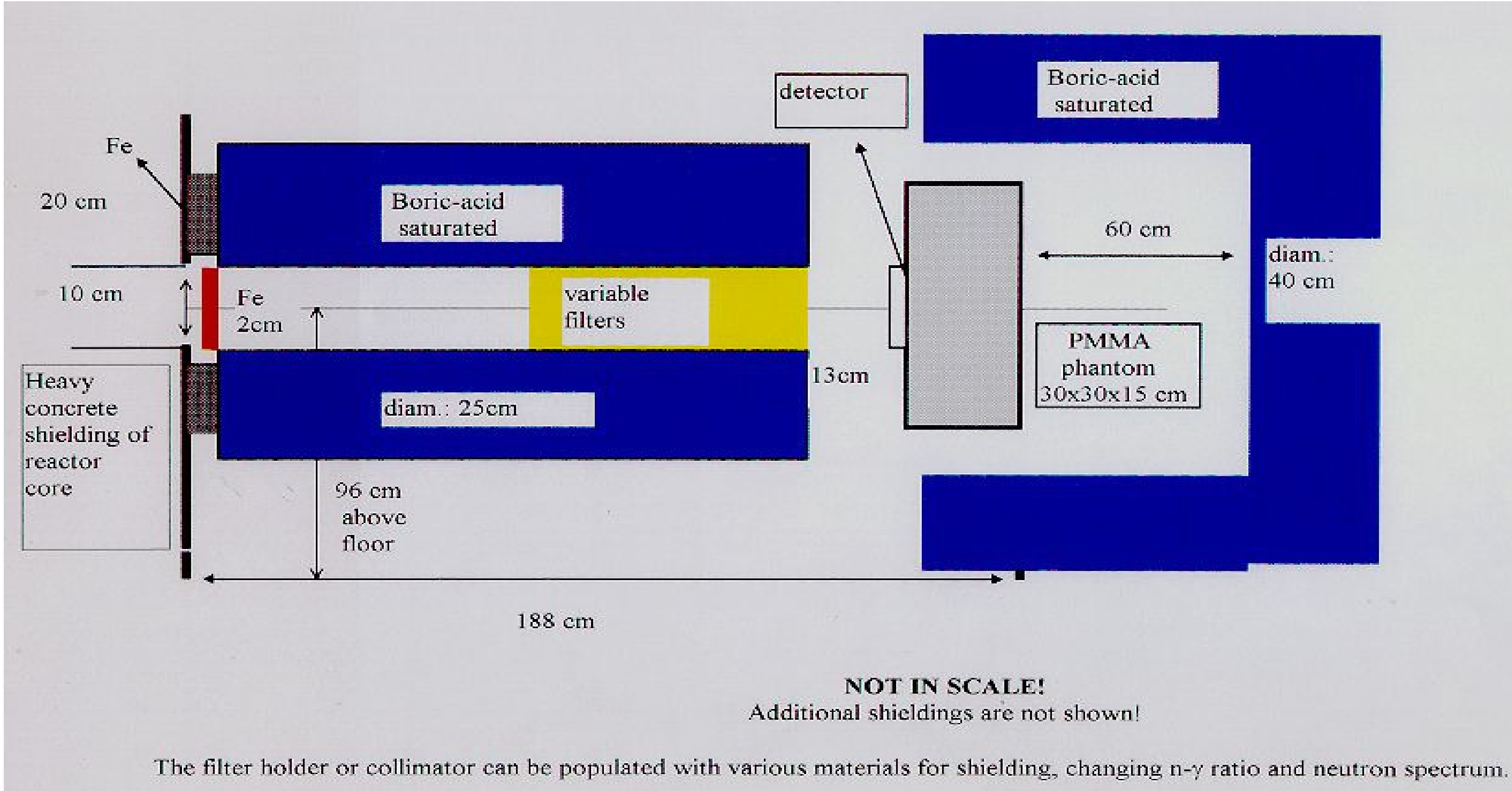

Fig. 7. Irradiation Facility at BRR Channel
Target Area

(a)

(b)

Photo 5ab. Biological Channel

a. PMMA filter in the tube with monitors (GM tube for gamma, Th-232 fission chamber for fast and U-235 fission chamber for thermal neutrons)

b. Rotating container in the tube

BIOLOGICAL IRRADIATIONS

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Introduction

During the last two years the Biological Irradiation Facility was further improved in order to enlarge the activity on the field of radiation biology:

– the irradiation cavity was modified to avoid the mechanical shock of the experimental animals and to decrease the total irradiation time for a given dose without changing the quality of the radiation;

– also the control system was upgraded to be able to measure low neutron dose with higher accuracy;

– a new set of external filters were manufactured to produce softer neutron spectra for BNCT and to increase the neutron-to-gamma dose ratio up to ~70 in order to study the biological effects of low neutron dose only, without significant gamma contamination: it was also our aim to construct such spectra which can be considered as so called "realistic neutron spectra", may be found in work places, to be used for dosimetry purposes.

For illustration, in Fig. 8 two filtered, "realistic spectra" are presented, used for testing the averaged responses of semiconductor detectors under development for personal dosimetry and for low dose experiments.

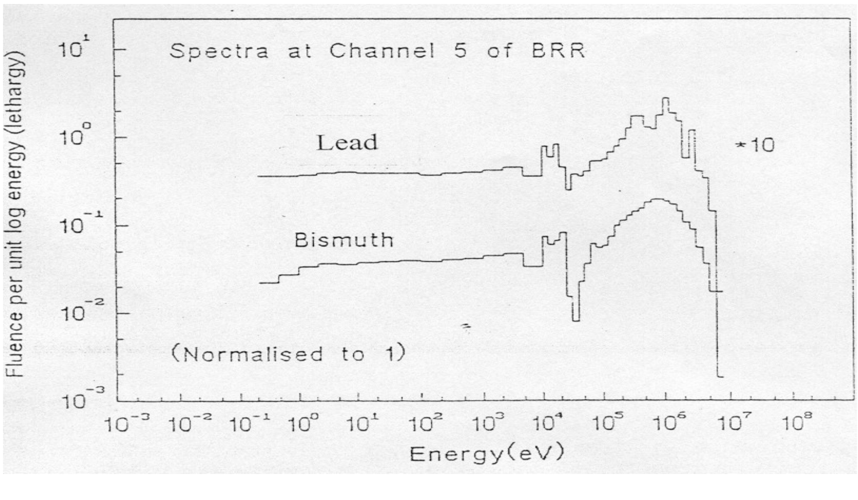

Fig. 8. Spectra at the Biological Irradiation Facility of BRR with the following filter combinations:

a.) Lead 200, Al 93, Fe 20, Pb 63, H_2O 480 mm,

b.) Bismuth 200, Al 85, Fe 30, Pb 63, H_2O 480 mm.

The spectra were calculated by the MCNP 4A code, using as input the leakage spectrum from the core calculated earlier. The spectra were normalized to 1 neutron.cm^{-2}.s^{-1} and presented as flux per unit lethargy (logarithmical energy).
Thermal neutrons were not calculated but measured to spare run time and have statistics good enough. It is observable that the intermediate (1/E) part extends up to ~10 keV, the fast section has a peak at about 1 MeV for both spectra. These spectra can be considered as quite hard ones with low dose and flux as shown in Table 2.

Table 2. Flux and dose values calculated and measured (see Fig. 8.)

	Lead filter		**Bismuth filter**
Intermed. flux ratio, %	40.8		39.5
Fast flux ratio, %	59.2		60.5
Measured thermal flux	520*	1180	1050
Measured intermed. flux	5700		14000
Fitted fast flux	8200		21000
Total flax	14420*	15080	36050
H^* conversion factor**		167	171
Hp conversion factor**		175	179

Fluxes are given in neutron.cm^{-2}.s^{-1}
*additional 8 mm Al and 10 mm B_4C filter combination
**in pSv.cm^2

Intermediate neutron water kerma and flux measured between
1999. Okt. – 2000. Febr.

No	Date	Filter mm	Circumstances	Dose rate $mGy.s^{-1}$	Inc. Flux $n.cm^{-2}.s^{-1}$	Refl. Flux $n.cm^{-2}.s^{-1}$	Monitor cps
1	X.18.	0 Bi 45Pb+10B_4C	10 cm far from B_4C filter	0.087	1.75^*10^5	–	17400
2	X.19.	0 Bi 45Pb+10B_4C	Between B_4C filter and 3 cm water	0.30	2.98^*10^5	2.95^*10^5	16900
3	X.19.	0 Bi 45Pb	On B_4C filter	0.87	1.76^*10^6	–	–
4	X.25.	150 Bi 45Pb+10B_4C	Between B_4C filter and 2 cm water	0.007	9.57^*10^3	5.18^*10^3	2360
5	X.26.	0 Bi 100 plexi	On B_4C filter	0.233	4.39^*10^5	6.34^*10^4	12400
6	X.26.	0 Bi 45Pb+100plexi	On B_4C filter	0.134	2.61^*10^5	8.64^*10^3	9600
7	XI.15.	50Bi 45Pb+10B_4C	On B_4C filter	0.045	6.20^*10^5	2.93^*10^4	9000

Notes:
Flux is given per unit lethargy, 1/E spectrum considered below 100 keV.
Dose: 0.5 eV – 100 keV, incident + reflected together.

Gamma dose measured between
1999. okt. – 2000. Febr.

No	Date	Filter mm	Circumstances	Dose rate $mGy.s^{-1}$	n/gamma	Monitor Cps
1	X.18.	0 Bi 45Pb+10B_4C	10 cm far from B_4C filter	0.087	5.31	17400
2	X.19.	0 Bi 45Pb+10B_4C	Between B_4C filter and 3 cm water	0.30	–	16900
3	X.19.	0 Bi 45Pb	On B_4C filter	0.87	–	–
7	XI.15.	200 Pb+20Fe 45Pb+10B_4C	On B_4C filter	0.045	16.1	600

Fast* neutron water kerma and flux measured between
1999. Okt. – 2000. Febr.

No	Date	Filter# mm	Circumstances	Dose rate $mGy.s^{-1}$	Flux $n.cm^{-2}.s^{-1}$	Monitor Cps
1	X.18.	0 Bi 45Pb+10B_4C	On B_4C filter	4.36	4.05^*10^8	17400
2	X.25.	50 Bi 10B_4C	On B_4C filter	2.81	2.60^*10^8	9600
3	X.25.	150 Bi 45Pb+10B_4C	On B_4C filter	0.172	1.62^*10^7	2360
4	X.26.	0 Bi 100 plexi	On B_4C filter	2.99	2.77^*10^8	12400
5	X.27.	200 Pb+20Fe 45Pb+10 B_4C	On B_4C filter	0.0233	2.17^*10^6	600
6	I.17.	50 Bi 45Pb+10B_4C	On B_4C filter	1.32	1.20^*10^8	9000

In the first line the internal, in the second line the external filters are given in mm.
* Neutron energy > than 100 keV.

Thermal neutron water kerma and flux measured between
1999. Okt. – 2000. Febr.

No	Date	Filter mm	Circumstances	Dose rate $mGy.s^{-1}$	Inc. Flux $n.cm^{-2}.s^{-1}$	Refl. Flux $n.cm^{-2}.s^{-1}$	Monitor cps
1	X.18.	0 Bi 45Pb+10B_4C	10 cm far from B_4C filter	0.004	1.75^*10^5	–	17400
2	X.19.	0 Bi 45Pb+10B_4C	Between B_4C filter and 3 cm water	0.006	2.98^*10^5	2.95^*10^5	16900
3	X.19.	0 Bi 45Pb	On B_4C filter	0.176	1.76^*10^6	–	–
4	X.25.	150 Bi 45Pb+10B_4C	Between B_4C filter and 2 cm water	0.0004	9.57^*10^3	5.18^*10^3	2360
5	X.26.	0 Bi 100 plexi	On B_4C filter	0.016	4.39^*10^5	6.34^*10^4	12400
6	X.26.	0 Bi 45Pb+100plexi	On B_4C filter	0.014	2.61^*10^5	8.64^*10^3	9600
7	XI.15.	50Bi 45Pb+10B_4C	On B_4C filter	0.0017	6.20^*10^5	2.93^*10^4	9000

Note:
Dose: incident + reflected together.

COLD NEUTRON CHANNEL

Used for Prompt Gamma Activation Analysis

*A **neutron capture gamma-ray facility** has been built in the guide hall of the Budapest Research Reactor for PGAA and (n,g) spectroscopy. An existing evacuated **neutron guide** has been extended by a 17 m long section, the last 12 meters of which are made of borosilicate glass with natural Ni coating. The guide is curved and it guides the neutrons 30 m away from the reactor, providing excellent background conditions for (n,g) experiments.*

*A 25% **HPGe detector**, guarded by an eight-segment BGO annulus and a back-catcher crystal serves as the basic gamma-ray detection system. It is completed with appropriate NIM electronics, including 16k ADCs and coincidence logic, and can be operated in **Compton-suppression** and **annihilation-pair spectrometer** modes. The data acquisition system is based on PC boards interfaced to the ADCs by a ten-input digital multiplexer. The PC is connected to the ethernet LAN which, in turn, is connected to the Internet*

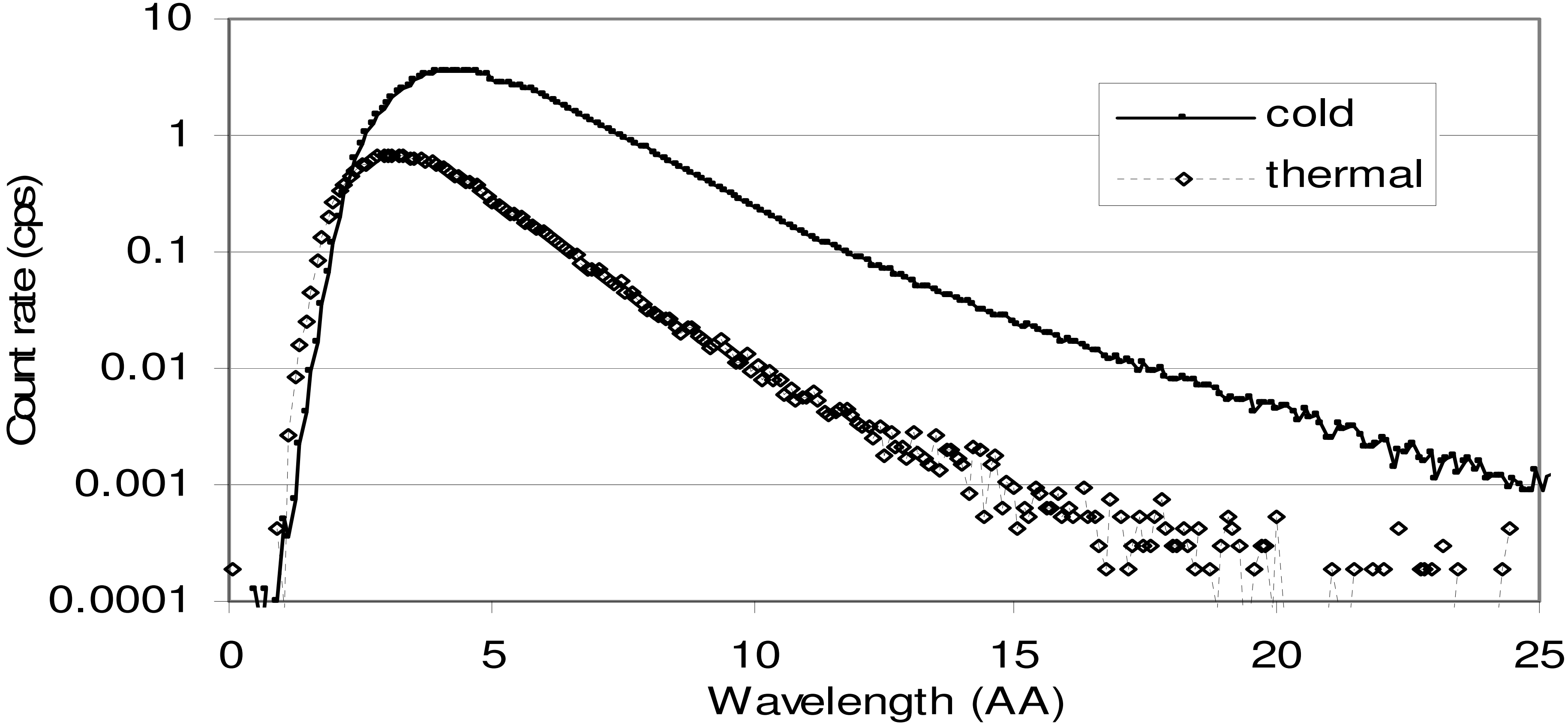

Fig.9. Measured Cold and Thermal Neutron Spectrum

Photo 6. Cold Neutron Channel

PROMPT GAMMA ACTIVATION ANALYSIS FACILITY

This facility serves for non-destructive analysis of elemental composition by observing neutron-capture prompt gamma rays. Hence the name prompt gamma activation analysis, PGAA in short. It has been described in detail in refs. 1,2.

The instrument is located at the end position of *neutron guide NV1*. The experimental area is a $3\times 5\ m^2$ place, backed by the rear wall of the guide hall. The *pneumatic beam shutter* at the end of the guide lets the neutrons enter the 3 m long evacuated aluminium tube extending across the experimental area, down to the beam stop at the rear wall. The targets are positioned on a thin aluminium frame, placed in a small chamber, which can be evacuated.

The basic gamma-spectroscopic instrument consists of an n-type high-purity germanium (HPGe) main detector with closed-end coaxial geometry and a BGO scintillator guard detector annulus, surrounded by a 10 cm thick lead shielding. The whole system is positioned on *a table, which can be moved in either direction*. A second (15%) HPGe detector is also available for γ -γ coincidence measurements, facilitated by a multiparameter data acquisition system.

Main specifications

Neutron guide cross section:	**$2.5\times 10\cdot\ cm^2$**
Thermal-equivalent flux at target:	**$3\times 10^{7\cdot}\ cm^{-2}s^{-1}$**
Vacuum in target chamber (optional):	≈ 1 mbar
Target chamber Al-window thickness	0.5 mm
Form of target at room temperature:	Solid, powder, liquid, gas in pressure container
Target packing at atmospheric pressure:	sealed FEP Teflon bag or vial
Largest target dimensions:	**$3\times 3\times 12\cdot\ cm^3$**
γ -ray detector	n-type coax. HPGe, with BGO shield
Distance from target to detector window:	23.5 cm
HPGe window:	Al, 0.5 mm
Relative efficiency:	25% at 1332 keV (^{60}Co)
FWHM:	1.8 keV at 1332 keV (^{60}Co)
Compton suppression enhancement:	≈ 5 (1332 keV) to ≈ 40 (7000 keV)

Responsible: T. Belgya, Institute of Isotopes, Budapest

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2. T. Belgya et al., in: "9th International Symp. On Capture Gamma-Ray Spectroscopy and Related Topics", Budapest 8-12 Oct. 1996, (Eds. G. Molnár, T. Belgya, Zs. Révay, Springer-Verlag Budapest, 1997) pp 826
3. see Annexes