DESIGN AND QUALIFICATION OF THE RA-6 REACTOR BNCT FACILITY

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ABSTRACT

The RA-6 is an open pool MTR type reactor with 500 Kw nominal power, using fuel elements enriched to 90 %. It was designed and constructed fully in Argentina and is owned and operated by the C.N.E.A. at the Bariloche Atomic Center.
A design of the epithermal device was performed, analyzing different and relative sizes of the materials conforming the neutron filter to optimize the neutron spectrum and the absolute value of the epithermal flux at the beam port.[1] This design was used also to make preliminary studies regarding the nuclear safety and solve potential licensing problems.
A complete design of the internal filter was presented to the Regulatory Authority and after some feedback the filter was constructed and mounted. During this stage a very simple (without any geometry complexity) external port was used to test the free beam facility and to get a complete on phantom dosimetry [2].
Using the previous results the new beam port was designed, built and mounted by november 1998. The final characterization of the facility was performed, obtaining a good agreement between calculated and measured values
The irradiation room was designed and is being constructed to adequate the facility to irradiate patients.

1. INTRODUCTION

The RA-6 reactor located at Bariloche Atomic Center, is a pool type one with 500 kW of nominal power and U 90 % enriched fuel owned and operated by C.N.E.A.. It is mainly devoted to research, development and teaching activities. It has five neutron irradiation beam channels and a thermal column (removed).

Due to its small power and a suitable operation schedule (usually one single experience each time) the alternative selected for getting an epithermal irradiation facility was to approach, as close as possible, to the reactor core by removing the external thermal column; instead of using one of the irradiation tubes.

In order to fulfill these criteria no shutter system was considered in the design. The reactor shutdown is used as the shutter.

Because only small modifications were required, the first stage was the arrangement of a thermal beam to test and validate our calculation methods and to gain expertise in the different experimental techniques to design and characterize the epithermal facility.

The epithermal beam facility was then designed [1] and built replacing the old thermal column (internal and external). Figure 1 shows a plant view of the complete facility including the material composition of the neutron filter, the port and the external shield.

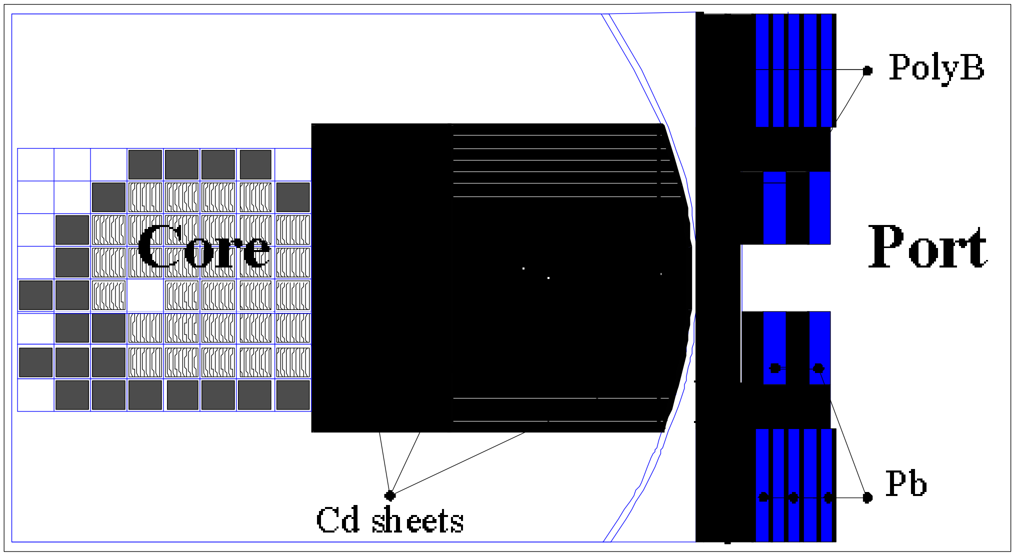

FIG. 1. Plant view of the epithermal facility

2. BEAM OPTIMIZATION AND CHARACTERIZATION

During November 1998 the cylindrical port was replaced by a new one as showed in Figure 2.

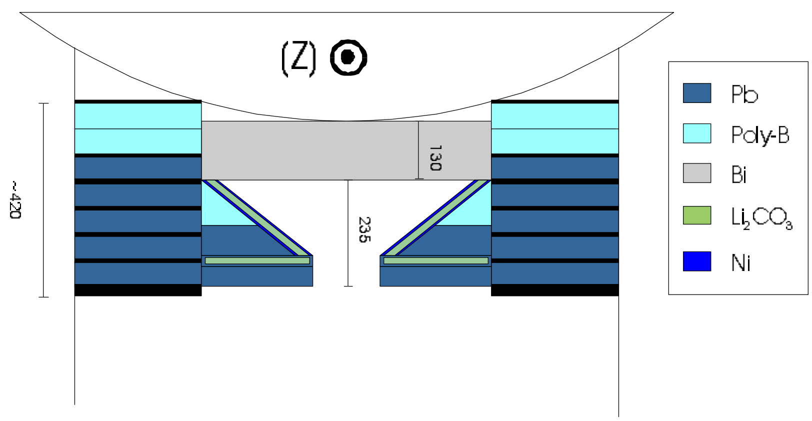

FIG. 2. Plant view of the conical port

3. FREE BEAM MEASUREMENTS AND SPECTRUM ASSESSMENT

3.1. MONTE CARLO SIMULATION

The main features of the calculation process were:

- Coupled neutron-gamma calculation with MCNP4B [3] and cross sections based on ENDFB6 data library.

- Cell tallies at the beam center and at several positions near the external shielding (for neutrons and photons).

- A detailed neutron and photon source in the core was obtained through a KCODE calculation.

- Neutron spectrum in 47 energy groups (BUGLE-96 structure) was calculated at the beam center.

- Photon and neutron doses rate were calculated by using Attix [4] flux-to-dose rate conversion factors. The calculated photon doses rate at the beam center agree within 20 % with the measured ones.

3.2. NEUTRON AND GAMMA CHARACTERIZATION

Multiple activation detectors with different energy response, were irradiated at the beam center, and the induced activities were measured by gamma spectroscopy for neutron energy characterization. Diluted, 0.1 mm, Cd covered foils of Mn, Au, Cu and In were used; together with pure, 0.127 mm, Cd covered foils of Sc and In.

The gamma and neutron dose rate were measured at the beam center, with Graphite and Tissue equivalent paired ionization chambers.

3.3. SPECTRUM ASSESMENT

Calculated reaction rates were evaluated from the 47 groups calculated free beam spectrum and the IRDF90 cross section library. Groups cross sections were condensed by expanding the calculated spectrum to the 640 groups structure of the IRDF90 library.

Calculated to measured reaction rates ratio (C/M) are showed in Table I for the different reactions.

REACTIONS	C/M
$In^{115}(n,g)In^{116m}$	1.25
$Mn^{55}(n,g)Mn^{56}$	0.87
$Cu^{63}(n,g)Cu^{64}$	1.03
$Au^{197}(n,g)Au^{198}$	1.07
$Sc^{45}(n,g)Sc^{46}$	0.89
$In^{115}(n,n')In^{115m}$	1.02

TABLE I: C/M REACTION RATES VALUES

3.4. FREE BEAM PARAMETERS

The free beam measured parameters are compared to the calculated ones from the calculated spectrum and group calculated kerma factors in the Table II; showing a very good agreement.

PARAMETERS	MEASURED	CALCULATED
Epithermal flux (0.5 eV – 10 keV) [n/ cm^2 seg]	$1.1 * 10^9$	$1.0*10^9$
Fast neutron dose (> 10 keV)/ n_{epi} [cGy/ n cm^2]	$7.5 * 10^{-11}$	$7.1 * 10^{-11}$
Photon dose / n_{epi} [cGy/ n cm^2]	$3.0 * 10^{-11}$	$3.2 * 10^{-11}$

TABLE II: FREE BEAM PARAMETERS

4. IN PHANTOM MEASUREMENTS

These measurements were performed in a 17.3 cm diameter and 20.5 cm length, 1 cm thickness, cylindrical PMMA phantom filled with water.

The gamma and the fast neutron dose rates inside the phantom were evaluated using the paired ionization chambers method [5]. The thermal neutron flux was measured using bare and Cd covered gold wires. The N^{14} and B^{10} dose rates were calculated through the measured thermal neutron flux (0-0.5 eV) and the corresponding kerma factor. Figure 3 shows the absorbed dose in the center axis of the phantom.

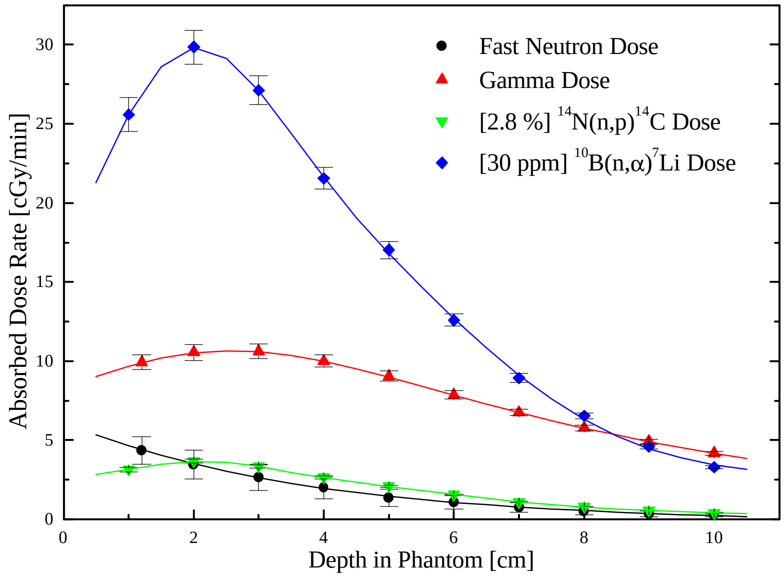

FIG. 3. In phantom doses rate measurements

Due to the associated increase in the thermal flux within the phantom, fast neutron dosimetry is, in this new configuration, strongly affected by the thermal response of the TE ionization chamber. Figure 3 shows relative change in gamma and neutron dose rate due to relative change in thermal response of the TE chamber (K_T) and the Graphite chamber (K_C); considered as independent parameters, for a thermal flux of 1.0E9 n/cm^{2}s.

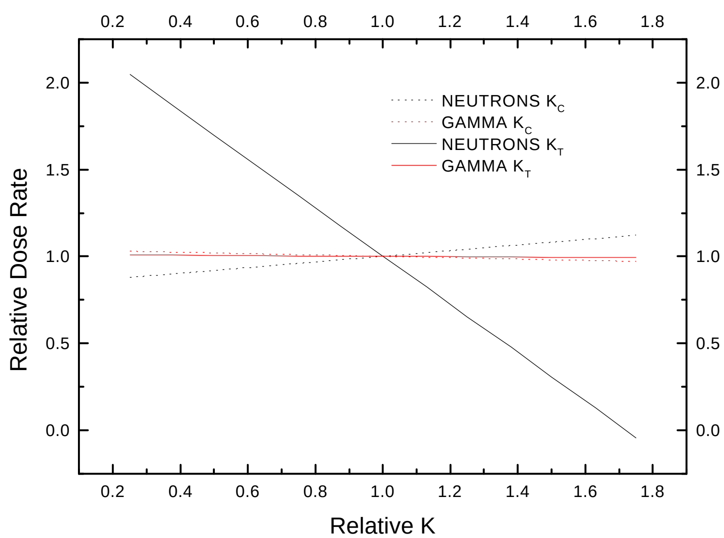

FIG. 3. Relative dose rate vs relative change in the thermal neutron sensitivity for both chambers at a thermal flux of 1.0 E9 n/cm^{2}s

K_C has nearly negligible influence on both dose rates; but neutrons dose rate changes approximately 75% due to a 50% change in K_{TE}. In these measurements, a theoretical value of 7.2 C n/min cm^{2}s was used; and K_C was assumed to be negligible.

Estimated percentage contribution of the different error sources to the measured neutron and gamma dose uncertainties are showed in Table III for the 1 cm in-phantom-depth position.

ERROR SOURCE	MAGNITUDE	FAST NEUTRON DOSE [%]	GAMMA DOSE [%]
Reactor Power	1%	1.5	1.0
Positioning	1mm	2.6	1.2
Thermal Flux	6%	2.2	<0.1
Chamber Current	1% (each)	4.0	1.1
Tissue equivalent gamma sensitivity	2%	8.0	<0.1
Tissue equivalent relative neutron to gamma sensitivity	2.5%	2.6	<0.1
Graphite gamma sensitivity	2%	5.0	2.0
Graphite relative neutron to gamma sensitivity	100%	3.5	1.4
Tissue equivalent thermal neutron sensitivity	25%	10.5	0.1
Graphite thermal neutron sensitivity	100%	9.4	3.9
TOTAL		17.8	5.0

TABLE III: DOSES RATE UNCERTAINTIES ANALYSIS

5. IN PHANTOM THERMAL FLUX COMPARISON

Measured to calculated thermal flux ratio along the phantom central axis are showed in Figure 6.

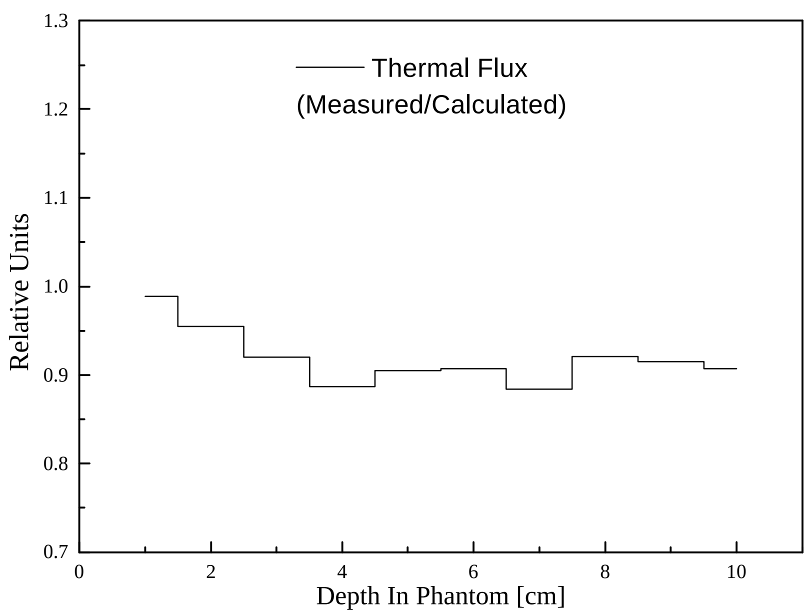

Figure 6: Measured to calculated thermal flux ratio

6. IRRADIATION ROOM

Irradiation room plant is showed in Figure 7.

An internal borated polyethylene shielding of 10 cm thickness was choosed, together with an external shielding of 50 cm thickness of concrete.

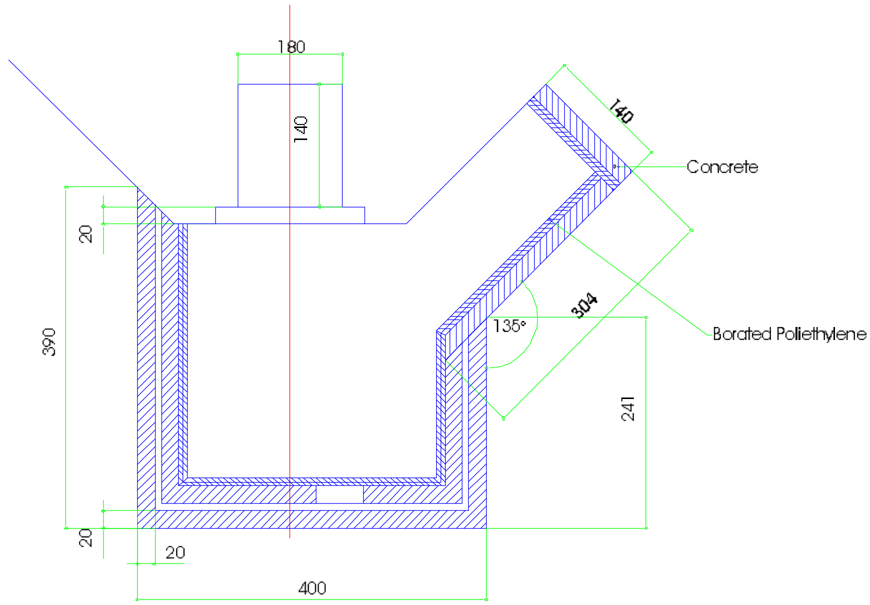

FIG. 7. Irradiation Room

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