Radiation field characterization of the NCT research facility at IEA-R1

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Abstract

An NCT (Neutron Capture Therapy) research facility was constructed at IEA-R1 reactor. The facility installed at beam-hole (BH) number 3 can be described to be consisted of 2 modules: - an inner BH module: with the filter, sample support and shielding arrangement sets and - an out of wall module: with biological shielding room surrounding the sample positioning/removing table. Neutron/gamma spectra can be modulated by a set of filters interposed between the reactor core and the sample position. The biological shielding at the end of the BH was designed and constructed to allow the extraction of the sample (and the inner shielding with it) even with the reactor on. This feature, together with a remote controlling sample positioning/removing system, enables controlling the sample exposure time (dose). Experiments with activation foils and thermo-luminescent dosimeters have been performed to characterize the field. Actual thermal neutron radiation conditions are 32.2 ± 0.1 Gy/h of dose rate with 25 % of gamma contamination for a 3.5 MW reactor operation power. As the sample irradiation region is inside BH, sample size is limited to a cylindrical enclosure of 30.0 cm height by 12.8 cm in diameter and therefore due to its size limit, the facility is not suited to carry any human treatment. Field modulation and time exposure control possibilities of this facility provide adequate radiation conditions to perform NCT research experiments.

Keywords: NCT, experimental facility, field modulation, TLD, activation foils

1. Introduction

IEA-R1 is a pool type multi-purpose nuclear research reactor. Its first criticality occurred in 1957 and set the origin of Energy and Nuclear Research Institute (IPEN). Since then it has been submitted to many improvements as did IPEN, which has also increased its activities, infrastructures and working power. Although IEA-R1 has not stood as the solely facility at IPEN, as many other facilities have been built, it still interprets a prominent role in the institution. The upgrade from 2 MW to 5 MW it was submitted in late nineties and the amount of work developed by many different researcher groups which use some of its beam-holes to perform their experiments can be set as examples of its importance to IPEN.

The NCT research group of IPEN starts its first feasibility studies in early nineties (Gaspar, 1994) but no experiments were carried out before the beginning of this decade. Since then the NCT group has been working in neutron beam modulation and characterization aiming to tailor it to the best conditions attainable to perform NCT experiments.

This work presents the results from simulations and experimental work done so far to fulfill this goal.

2. NCT Facility

The NCT research facility was constructed at IEA-R1 reactor and it is installed at beam-hole (BH) number 3. BH-3 is a 2.6 m long and 20.32 cm (8 inches) diameter tube which extends from one of the faces of the reactor core to the outside of the reactor pool wall.

The facility (Figure 1) can be described to be consisted of 2 modules:

- an inner BH module with the filters, sample and shielding arrangement sets. As these sets have eventually to be changed, they are settled into two movable structures. Sample irradiation cavity and shielding set lie on the most external structure

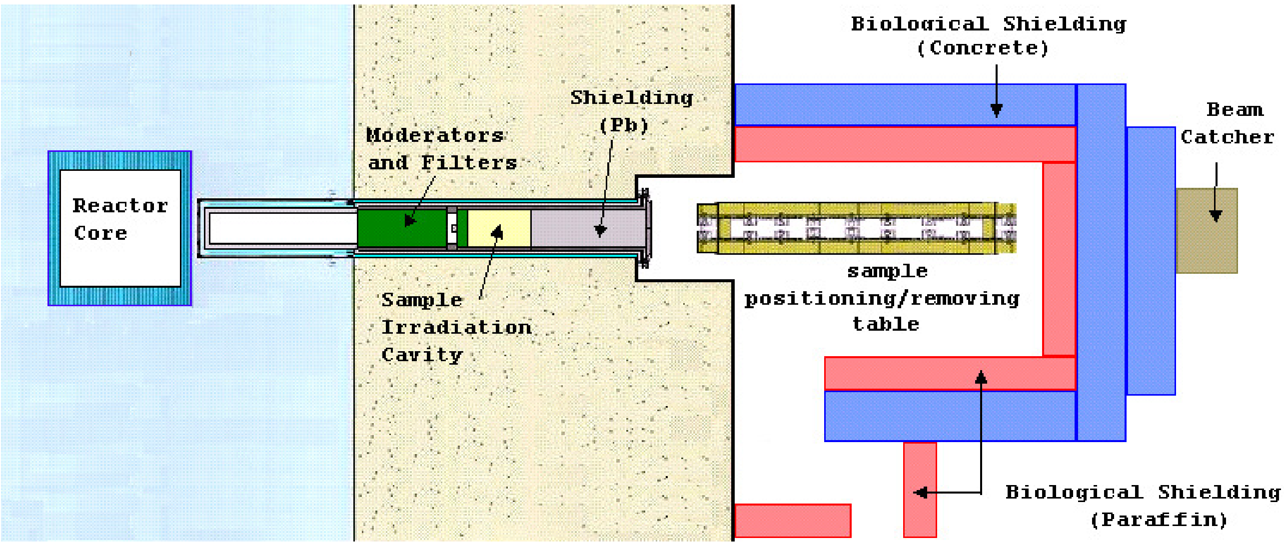

Fig. 1 – Schematic view of the NCT facility

inserted and withdrawn from the BH by a remote operating system. Although filter disks can also be placed in the mentioned structure, most part of the filters set lies on the most internal structure. It is removed from BH by manipulating a retrieving tool and is inserted back in the tube by pushing it through the forementioned remote operating system. Due to radiation safety procedures, this structure is rarely removed from its place. In order to withdraw this most internal structure, reactor core must be shutdown and moved to a different place in the pool so to attain proper radiation safety conditions.

- an out of wall module: with biological shielding room surrounding the sample positioning/removing table. Sample positioning/removing table is placed close to BH-3 exit so to stand as a support to the movable parts whenever they are outside the tube. It also performs the insertion and withdrawal of the inner BH module. The biological shielding is composed by paraffin/concrete walls and ceiling. It has been projected to attain adequate radiation conditions to allow the presence of individuals around its external vicinities even with the reactor on and with no shielding in the tube. This characteristic together with the sample changing device allows controlling sample exposure time. Sample changing device is a remote operating carriage system which grabs/carries/looses samples. Its only purpose is to place and retrieve samples from the high dose environment found in the biological shielding room.

The facility, so designed, allows the interposition of materials between the reactor and the sample irradiation cavity, providing the possibility to interfere with the radiation field the sample is subjected to. Exposure time can also be controlled by remote controlling sample positioning/removing system. Irradiation position has been projected to be inside the BH so as to get higher neutron flux. Sample irradiation cavity is a 12.8 cm diameter and 30 cm wide cylinder shaped region and therefore the NCT facility is not suited to perform any human treatment.

3. Simulations

Many sets of simulations have been carried out in order to select the best set of modulators and filters to achieve an adequate radiation field (high thermal neutron flux and low gamma contamination) to perform the NCT experiments. These simulations were the focus of previous works (Coelho, 2002; Gual, 2005).

MCNP (Brown, 1987) has been used to perform such simulations.

4. Experiments

Neutron flux has been determined through activation foils experiments.

Dose rates have been determined by thermo-luminescent dosimeters (TLD). In order to discriminate gamma and neutron contribution 3 different kinds of TLDs were used: TLD-400 (CaF_2:Mn), TLD-700 (^{7}LiF:Mg,Ti) for gamma dose measurements and TLD-600 (^{6}LiF:Mg,Ti) for neutron dose measurements. Selection of a group of TLDs with similar response functions was done for each kind before dose experiments were performed. Calibration curves were obtained up to 1,000 Gy (TLD-400 and TLD-700).

Actual thermal neutron radiation conditions are 32.2 ± 0.1 Gy/h of dose rate with 25 % of gamma contamination for a 3.5 MW reactor operation power and a set of filters constituted by approximately 22 cm of lead.

Thermal neutron flux has been quantified as 1.39 ± 0.12 × 10^8 n/cm^2. Epithermal neutron flux is 2 orders of magnitude lower but fast neutron flux is as high as thermal neutron flux. Neutron flux profile along sample irradiation cavity shows higher values closer to the BH external end. These unexpected responses - odd neutron profile and high fast neutron flux - have been regarded to neutron leakage between the tubes. Figure 2 shows a schematic perpendicular view at the filter disposition quota, which as the sample positioning quota, has a wider air gap in its upper part.

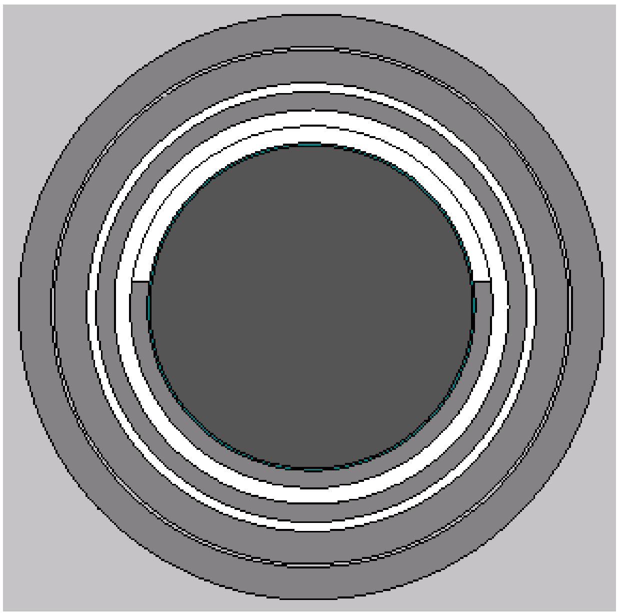

Fig. 2 – schematic perpendicular view of the NCT facility. White: air gaps; light grey: reactor pool wall; grey: tubes (BH, Liners and moveable structure); dark grey: filters (represented by the centered disk);

5.Conclusions

IEA-R1 is an old pool type multi-purpose research reactor whose utilization has changed along the years. Although it has not been projected to perform NCT, research in this area is under progress.

Simulations have been conducted as supporting tools to better select the set of filter to be used in order to improve radiation field.

Neutron flux and doses due to neutrons and gammas have been determined in the sample irradiation position of the NCT facility. Thermal neutron flux has been quantified as 1.39 ± 0.12 × 10^8 n/cm^2.s and dose due to gamma has been determined to correspond to 1/4 of that due to neutrons (32.2 ± 0.1 Gy/h). These values reveal the feasibility to perform research experiments on NCT in this facility. The observed high fast neutron flux have shown however the necessity to improve the facility.

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References

Coelho, P.R.P., et al. 2002. Neutron Flux Calculation in a BNCT Research Facility Implemented in IEA-R1 Reactor. In: Wolfgang S., Raymond M., Andrea W. (Eds.) Research and Development in Neutron Capture Therapy. Monduzzi, Bologna, pp.197 - 201.

Gaspar, P.F., 1994. *Considerações Sobre o Estudo da BNCT. Dissertação de mestrado* (Considerations in BNCT study, Master degree dissertation), IPEN.

Gual, M.R. et al. 2004, Study for neutron-DNA interaction at IPEN BNCT research facility, Braz. J. Phys., 34 (3A), 901-903.

Brown, F.B., 1987. MCNP – A general Monte Carlo N particle transport code, Report LA-UR-03-1987, Los Alamos, NM, Los Alamos National Laboratory.