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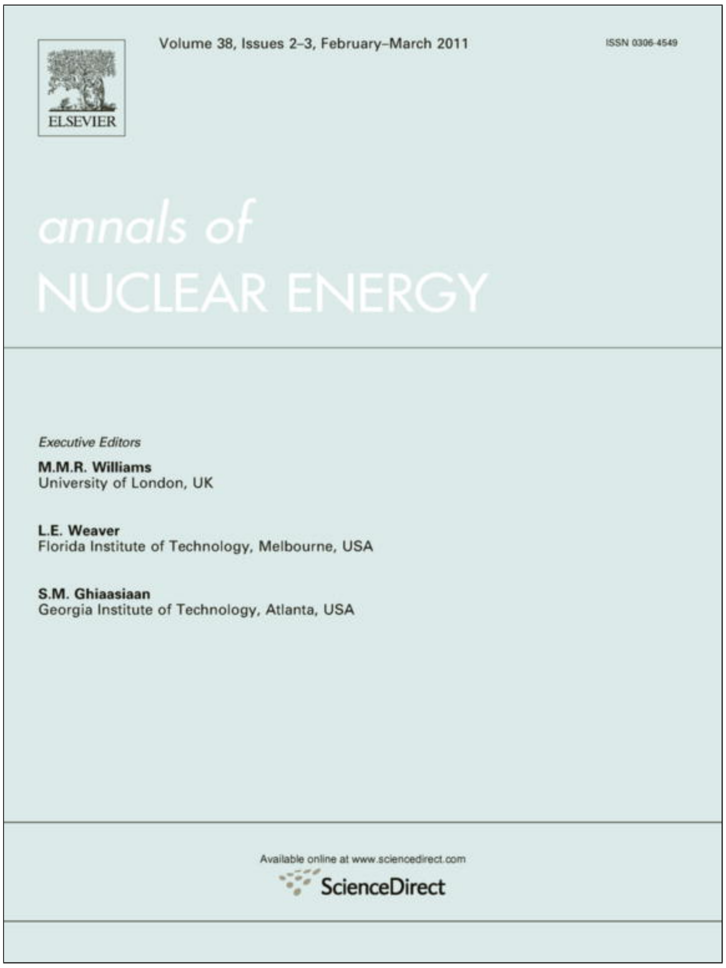
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Technical Note

New mechanical samples positioning system for irradiations on a radial channel at nuclear research reactor in a full-power continuous operation

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ABSTRACT

This paper describes a new mechanical samples positioning system that allows the safe placement and removal of biological samples for prolonged irradiation, in a nuclear reactor during full-power continuous operation. Also presented herein the materials of construction and operating principles. Additionally, this sample positioning system is compared with an existing pneumatic and automated transfer system, already available at the research reactors.

The system consists of a mechanical arm with a claw, which can deliver the samples for irradiations without reactor shutdown. It was installed in the IEA-R1 research reactor at Instituto de Pesquisas Energéticas e Nucleares (IPEN), Sao Paulo, Brazil, and for the past 5 years, the system has successfully operated and allowed the conducting of important experiments. As a result of its introduction, the facility has been in a position to positively respond to the increased demand in studies of biology, medicine, physics, engineering, detector/dosimeter calibrations, etc.

It is one example of the appropriated technologies that save energy and resources.

1. Introduction

The IEA-R1[1] is a pool-type research reactor, moderated and cooled by light water. It utilizes graphite and beryllium reflectors, and it is currently operated at a thermal power of 3.5 MW. The reactor is used in academic and applied research, as well as for education purposes and in the production of radioisotopes for medical and industrial application.

IEA-R1 is equipped with several external experimental facilities that include nine irradiation channels (eight radials and one tangential) extending to the reactor external wall where the nuclear physics experiments are carried out; a pneumatic transfer system; and thermal columns. The pneumatic transfer system available at the IEA-R1 reactor is limited to short-time irradiation.

The high demand of the beam hole #3 (BH#3) in the research reactor IEA-R1 utilization, to conduct "in vitro" and/or "in vivo" experiments on biological samples (Coelho et al., 1997), required innovative solutions that could bring improved reactor efficiency. As a result, the idea of a new sample positioning system was considered: a system to place/retrieve biological samples in/from the reactor without interrupting reactor operation. The following requirements were the premises followed during the conceptual design:

1. the placement and removal of biological samples to/from the irradiation channel would not require reactor shutdown;
2. the new system design would be capable of handling the required size and amount of biological samples undergoing testing during the different experiments being carried out;
3. it would be a simple system that does not require external sources of power;
4. it would be easy to maintain;
5. its introduction would require minimum capital investment;
6. it would not compromise the safety of personnel and equipment operations; and
7. it would allow safe observation of the irradiation process from the experiment room.

Most research reactors are equipped with a pneumatic sample transfer system (also known as the rabbit system), where small capsules can be inserted into the vertical channel of the reactor and retrieved during power operation (Jang et al., 2004; Chung et al., 2008; Burgette et al., 2009; Palmer, 2010). The other research reactors are equipped with automated transfer systems (Li et al.,

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[1] The acronym IEA refers to the old name of IPEN and R1 means the first reactor.

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2004; Ismail, 2010), but these systems are complex and expensive. As mentioned above, the existing pneumatic and automated transfer systems for nuclear research reactors were limited to short-time irradiation.

During the design of this new system, a pneumatic sample transfer system was considered. Unfortunately, it included the purchasing and installation of an air compressor system, including: a new air compressor and associated equipment (air filters, compressed air lines, air receiver, control system, etc.). The additional capital investment for a new compressed air system, together with its subsequent costs of operations and maintenance, were considered cost-prohibitive. Furthermore, the new safety aspects of utilizing compressed air, in radioactive operations, were deemed unnecessary.

The available sample positioning systems for irradiation in a thermal column at the research reactors are very simple (Esposito et al., 2007). It allows the positioning of the samples closer to the radiation source in front of the beam line. The samples are delivered to the irradiation zone in a small car that moves along a rail system.

Fig. 1 shows a diagram of the experimental facility with the reactor core. Also seen here, the surrounding water tank and shield wall, the beam line configuration, and how the new sample positioning system is oriented with respect to the pre-existing structure and irradiation location.

This paper presents a decision based on a:

1. It is a prototype.
2. It is used in a specific facility.
3. Need to reduce the cost of investment in research.

The novelty of the constructed system lies in its simplicity, which allows the irradiation of biological samples for a prolonged time, while complying with the safety requirements of a nuclear facility. Additionally, the irradiation of samples can be carried out in the radial channel during full-power continuous reactor operation. The system also accommodates specific design requirements of the reactor in question, but can be adapted to other reactors.

2. Materials and methods

BH#3 is a 2.6 m long by 20.32 cm diameter tube which extends from one of the faces of the reactor core to the outside of the reactor pool wall. The sample irradiation holder is shaped as a semi-cylinder measuring 12.8 cm in diameter by 30 cm long, and it is placed in moveable structure.

The strategy followed during the construction of the system responded to the following principles:

1. The design would accommodate for the required maneuverability when handling the samples for irradiation while safety of operations remains unaltered. It would also be of a simple design, fast and easy assembly, with low implementation and maintenance costs.
2. The manufacture and assembly of the system would be possible using means, technology and experience available in the national market.
3. All materials used in the construction of the new system must be radioactively and thermally stable, non-toxic, provide the required structural strength and corrosion resistance and be available in the national market.

Aluminum and stainless steel were selected as suitable materials of construction. In aluminum, their neutron activation product has a short life.

2.1. Description of the new system

Between the years 2002 and 2004, the irradiation of biological samples for research purposes, in the BH#3 of IEA-R1, would only allow the irradiation of one sample per week. Additionally, the insertion and removal of samples was only possible with the reactor shut down, and did not allow for change of the sample exposure time.

In response to the need for increased reactor availability and efficiency, without compromise to the safety of operations and while fulfilling research requirements, the idea of a new system that would allow the placement and removal of biological samples

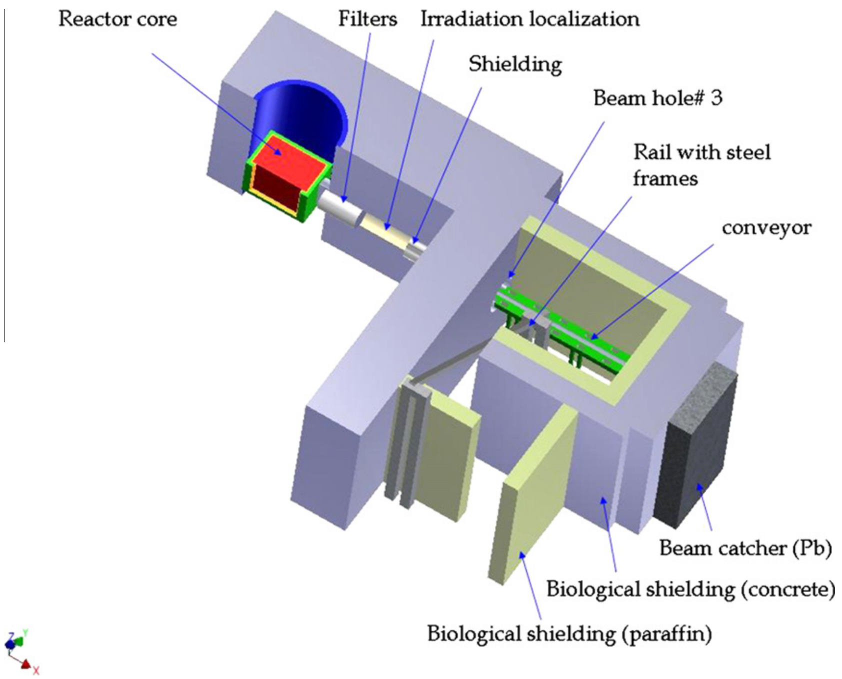

Fig. 1. Diagram of the experimental facility of beam hole #3 (BH#3) in the research reactor IEA-R1.

for irradiation, during full-power continuous reactor operation, was born.

The new system consists of three parts:

- sample positioning system,
- transporting system, and
- monitoring system.

The following provides a description of the systems listed above:

The sample positioning system consists of the sample holder; a mechanical arm with a claw; roller bearings; a pulley system; a sample carrier; an aluminum U-shaped track rail and a mechanical switch. The sample holder is a basket-like construction with a handle, entirely manufactured of acrylic. It has two plates forming a 20-degree angle, with an additional upper plate that has 13 drilled holes to carry the sample containers in an upright position. 0.5 mL Eppendorf tubes are used as sample containers. The base of the sample holder is designed for proper and exact positioning in the irradiation cell of the sample carrier (described hereafter). Normally, a 25 μL DNA sample contained in each Eppendorf tube to be delivered into the reactor for neutron irradiation (see Fig. 2). The mechanical arm with a claw slides along the rail by means of the roller bearings and delivers the sample holder to a sample carrier (semi-tube) secured to a conveyor in the reactor channel. The pulley system consists of one pulley and a steel cable secured to a 25-degree inclined 10 m long aluminum rail, supported of a steel frame. For safety purposes, mechanical stops were installed at each end of the aluminum rail. The sample carrier (semi-tube) is made of aluminum with a shield and allows the placement of the sample holder within its so-called irradiation cell (see also sample holder above) after the filters and aligns all the samples in the path of the reactor beam line. The mechanical switch consists of a frame, a handle, a flexible stainless steel cable and springs. The handle can slide up and down along the frame. When pulling the handle, the stainless steel cable connected in the middle, remotely operates the claw at the other end of the cable. The springs are responsible for returning the handle to its original position, therefore closing the claw. The sample delivery system is designed to transport the Eppendorf tubes containing the DNA samples to the irradiation zone in the reactor as an isothermic system, therefore avoiding the effects of temperature on plasmid DNA. The Eppendorf IsoTherm system consists of an IsoRack in an isolated box (IsoSafe) with two cooling pads (IsoPacks) that can effectively and consistently maintain the samples at low temperatures between −21 °C and 0 °C, over a period of several hours. It can be used as a sample transport and temperature stabilization device. It holds up to 24 tubes (Safe-Lock 0.5 mL/1.5 mL/2.0 mL).

The transport system consists of the reactor channel conveyor; two micro-switches; an electric motor and an electric control pad with two buttons that activate the reactor channel conveyor for entry/exit of the samples into/out of the reactor irradiation zone. When the "IN" bottom is pressed, the conveyor delivers the semi-tube with the samples into the reactor irradiation zone. When the "OUT" button is pressed, the conveyor operates in a reversed mode, allowing the exit of the semi-tube with the samples out of the reactor irradiation zone. The conveyor is located in front of the reactor beam hole.

The monitoring system has three small video cameras installed above the reactor channel. The camera is wired to a TV monitor located in a room behind the biological shield, making it possible to observe the placement and removal of samples in/out of the sample carrier (semi-tube). This video set-up provides real-time sample positioning viewing.

Fig. 2 shows the new engineering system for biological sample irradiations on a radial channel beam hole #3 (BH#3) at the IEA-R1 research reactor in Brazil. The biological shielding is made of paraffin containing concrete walls and ceiling. Also, the old beam

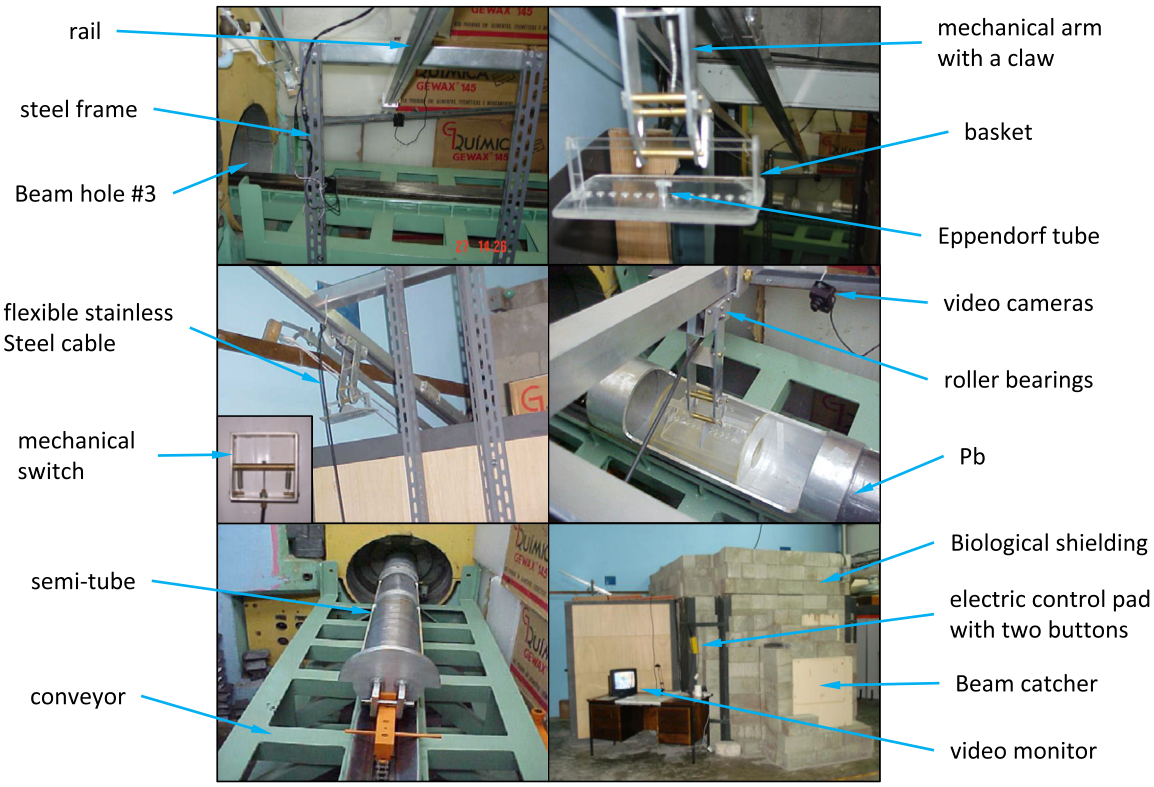

Fig. 2. New mechanical samples positioning system for irradiations on a radial channel at nuclear research reactor in a full-power continuous operation.

catcher standing along of the BH#3 axes outside the shielding is used. It comprises in a box of leaded walls with borate paraffin inside it. The biological shielding of the radiation room meets the standards of radiation safety for the personnel.

This new system was entirely manufactured and installed at the Instituto de Física de la Universidad de São Paulo (IF-USP).

2.2. System operation

The following steps and sequence describes the operation of this new system:

1. Insert the polypropylene tube(s) containing the sample(s) into the basket.
2. Grab the basket with the aid of the mechanical claw. Pull the handle on the mechanical switch to open the claw and catch the basket. Then, release the handle on the mechanical switch and the claw will close automatically, therefore securing in the basket.
3. Press the "OUT" button on the remote control system and the semi-tube will come out of the beam hole.
4. Using the pulley system, slide the mechanical arm with the claw along the rail until it reaches the sample carrier (semi-tube). Once the samples are just above the support bench inside the semi-tube, pull the handle on the mechanical switch. This will open the claw and release the basket.
5. Confirm that the basket has been dropped in the intended location within the semi-tube by checking on the video output. Readjust as necessary using the mechanical arm.
6. Pull on the cable on the pulley system to remove the mechanical arm with the claw out of the reactor channel.
7. Press the input button on the transport system so that the semi-tube is inserted back into the beam hole.
8. To remove the sample, the reverse operation is performed.

3. Results

The features of designed sample positioning system may be summarized as follows:

1. It is an original design.
2. It is a mechanical system.
3. Easy maneuverability and simplicity of design and operations.
4. Simple construction.
5. Low maintenance cost. The main components are replaceable in a relatively short time.
6. Minimal manufacturing cost, which did not exceed USD $ 1000, which is the exceptional advantage of the proposed design.
7. The sample can be irradiated for long periods of time (hours, days) when the reactor is operating at full power.
8. High productivity of samples irradiation.
9. It allows remote handling and safety.
10. It can irradiate about 500 g.
11. It is possible to have a full module replicated in stock in case it needs to be replaced for failure.

The constructed system was tested, determining the following parameters:

1. The neutron flux through activation foils experiments (Muniz, 2006).
2. Dose rates by thermo-luminescent dosimeters (TLD) (Nascimento and Coelho, 2006).
3. The effect caused by mixed radiation "thermal $n + \gamma$" in DNA plasmid with absence and presence of radical scavenger concentration, glycerol, pH 7 (Gual et al., 2006).

The impact of device application may be described as follows:

1. The irradiation channel BH#3 of IEA-R1 reactor was modified to direct irradiation of biological samples.
2. The developed technological system, that is remotely handled, can deliver samples for irradiations without interrupting reactor operation, which is used for radioisotope production.
3. Its application in research, taking place in that facility, in the field of radiobiology, dosimetry, and material testing is immediate.

In fact the new engineering design contributed to increase the research capabilities. Currently, many types of experiments have been conducted in the BH#3. Some examples include:

1. analysis of cell damage (in polymers),
2. experiments of characterization and improving the fluxes (Coelho et al., 2008), and
3. validation of gel dosimeters (Mangueira et al., 2010).

The practical value of this research is demonstrated, since for the first time it is achieved the result of using the radial channel #3 of the Brazilian research nuclear reactor for irradiation of biological samples.

The economic contribution of this research is given by:

1. Savings time and money for implementation.
2. Savings of electrical energy.
3. Saving time and money for quick and easy construction.

The social contribution is given since it opened new lines of research thanks to new possibilities of radiation in the reactor IEA-R1.

The device is very well suited, because for the first time the radial channel #3 of IEA-R1 Brazilian reactor for sample irradiation was used while the reactor is operating for long irradiations periods. This channel became a multipurpose channel.

4. Conclusions

The proposed solution of the sample positioning system for irradiation on a radial beam hole, it has no implication of the radiobiological protection of the personnel, since all the samples are remote handle behind of the biological shield of experimental facility and possibility to control an exposure time.

The good performance of the device is showed carrying out radiobiological and dosimetric experiments.

It was demonstrated that is viable to build this device in nuclear research reactors with the necessary requirements for biological samples irradiations for long time, during full-power continuous reactor operation and safety on a radial channel. The design is economic; also it is the most suitable for research reactors in developing countries.

It is shown that the device can be manufactured entirely with the available materials and technology experience in any conventional workshops due to the components employed are lighter and standards.

On the other hand, the results obtained show the successful applying of new mechanical device. The most important feature of this device is that it increased the development of new types of studies.

It is one example of the appropriated technologies that save energy and resources.

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