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LAMI – A PLANNED BRAZILIAN FACILITY TO INVESTIGATE THE MECHANICAL AND PHYSICAL PROPERTIES OF STRUCTURAL MATERIALS UNDER IRRADIATION

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ABSTRACT

The LAMI (Laboratorio de Materiais Irradiados) is a hot laboratory designed to the characterization of irradiated structural material and will constitute one of the main installations of the Brazilian Multipurpose Reactor (RMB). The strong points of LAMI are: to contribute, through theoretical and experimental investigations, to the development of knowledge in materials science in order to be able to predict the evolution of the physical and mechanical material properties under service conditions (irradiation, thermomechanical solicitation, influence of the environment, etc); to characterize the properties of the materials used in the nuclear industry in order to determine their performance and to be able to predict their life expectancy; to establish, maintain and make use of the database generated by these data and to provide expertise on industrial components, in particular to investigate strain or rupture mechanisms. The test materials can be irradiated or not, and originate from surveillance programs, experimental neutron irradiations or simulated irradiation with charged particles. The main line of LAMI will have 10 shielded hot cells. The building also will have an area dedicated to micro and nanostructural materials analysis. The mechanical characterization to be carried out within LAMI includes mechanical tests on irradiated materials, comprehension of behavior and damage processes and the incorporation of the test data results in a data bank for capitalization of test results. Planned materials to be tested are going to be metallic alloys used in industrial and experimental reactor: pressure vessel steels, internal stainless steels, austeno-ferritic steels, zirconium alloys and aluminum alloys.

1. INTRODUCTION

The so-called "hot labs" are facilities specialized in handling and testing of radioactive and/or irradiated materials. These facilities are designed and constructed to shield radiation (alpha, beta or gamma) from the handled material. Generally, the building materials used in these facilities are concrete, lead and steel. The handling of materials in analysis is performed remotely with the help of remote handling devices and if necessary direct visualization of the operation; this can be done with the aid of a plumbiferous glass base window [1,2].

The materials for analysis in hot laboratories can be classified according to their level of activity in radioactive materials and irradiated materials. Radioactive materials are those with a high level of activity and therefore require a radiation shield capable of retaining the alpha, beta and gamma types of radiation. In general, the building materials used are concrete and lead. The irradiated materials have lower levels of radiation than the radioactive ones and are not emitting alpha particles. Conventional contention for these materials is built with steel (usually stainless steel) and lead.

The materials irradiated in a PWR type nuclear reactor are those that form the structure of the pressure vessel and its internals, except for the ceramic fuel. Radiation, especially neutron, which causes damage to these materials, as well as change their mechanical and physical properties, are crucial for its service life. The neutron irradiation may, for example, increase the mechanical strength of steel, reducing its ductility and weaken the structure they belong. Therefore, it is important to monitor these changes in the material of the pressure vessel throughout the service life thereof, which is the goal of the so-called surveillance program

Specialized laboratories in the analysis of irradiated materials (and/or radioactive) exist in some countries of the world and its activities are focused on the periodic analysis of samples of material from their nuclear reactors or from other countries that do not have this facility. A periodic analysis of samples from reactor's environments is intended to ensure safety and determine the lifetime of its components. Have a lab that makes analyses within the international standards, determined and regulated by rules of the IAEA (International Atomic Energy Agency), will allow the country be independent of other facilities and also autonomous to supervision and decision making of their own nuclear facilities.

2. BRAZILIAN MULTIPURPOSE REACTOR (RMB)

The RMB enterprise aims to provide the country with a scientific facility that meets the technological needs of different sectors of Brazilian society, among them one can cite the health sector through the production of radiopharmaceuticals for diagnosis and treatment of various diseases, the science and technology sector that will have a powerful experimental tool for both basic studies on the effect of radiation damage in organic and inorganic materials as for agricultural and industrial applications, as well as serving as a support for the development of parts and components for defense systems, such as for example, in the manufacture of nuclear reactor for naval propulsion. Today, the RMB is the project with largest financial support from CNPq, the brazilian agency for research development.

2.1. Design of RMB

RMB is designed to be an open pool multipurpose research reactor, with a primary cooling system through the core. Its planned power is 30 MWe. The reactor core will be compact, using MTR fuel assembly type, with planar plates, U_3Si_2-Al dispersion fuel with 4,8 gU/cm^3 density and 20 % ^{235}U enrichment. The reactor core will be cooled and moderated by light water, using light water or beryllium as reflector. Heavy water may be used as reflector at the position of the beam holes. Neutron flux (thermal and fast) should be higher than 2.10^{14} n/cm$^{2\cdot}$. Figure 1 shows the design of the RMB core in a preliminary study.

This core design will allow the irradiation of structural materials for nuclear application and the production of various radiopharmaceuticals for application in health care because the reactor core has specific positions for these purposes.

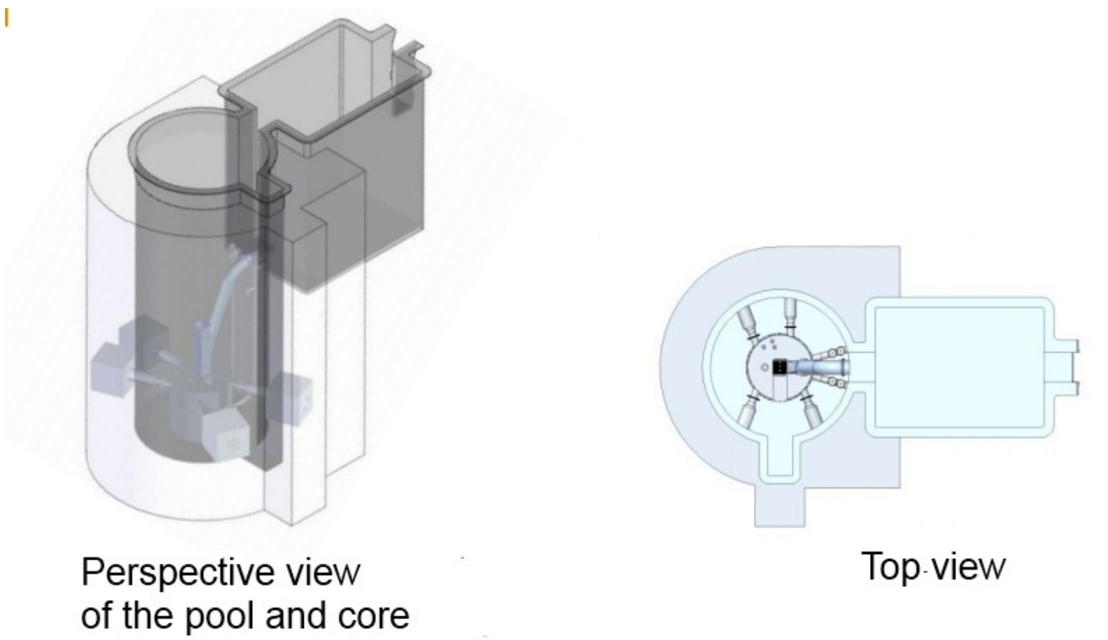


Figure 1. Preliminary design of RMB core.

3. IRRADIATED MATERIALS TESTING LABORATORY (LAMI)

The LAMI (Laboratorio de Materiais Irradiados) is a hot laboratory designed to the characterization of irradiated structural materials and will constitute one of the installations of the Brazilian Multipurpose Reactor (RMB). The basic guide applied to the laboratory is CNEN-NE-1.04, which deals with the licensing of nuclear facilities [3].

The strong points of LAMI are: to contribute, through theoretical and experimental investigations, to the development of knowledge in materials science in order to be able to predict the evolution of the physical and mechanical material properties under service conditions (irradiation, thermomechanical solicitation, influence of the environment, etc); to characterize the properties of the materials used in the nuclear industry in order to determine their performance and to be able to predict their life expectancy; to establish, maintain and make use of the database generated by these data and to provide expertise on industrial components, in particular to investigate strain or rupture mechanisms. Special attention is given to the program of monitoring radiation damage in pressure vessels and structural materials analysis of fuel elements and control rods.

The building of LAMI in a preliminary design, with an estimated area of 70 x 30 m^2 (Figure 2), will hold two parallel series of hot cells, one to be built initially, will have ten cells and is aimed at thermomechanical testing of irradiated materials. The other line will be used in the future for analysis of materials associated with nuclear fuel. In addition to these two lines, the building will also have laboratories for preparation and observation of micro-and nanostructural materials of nuclear interest.

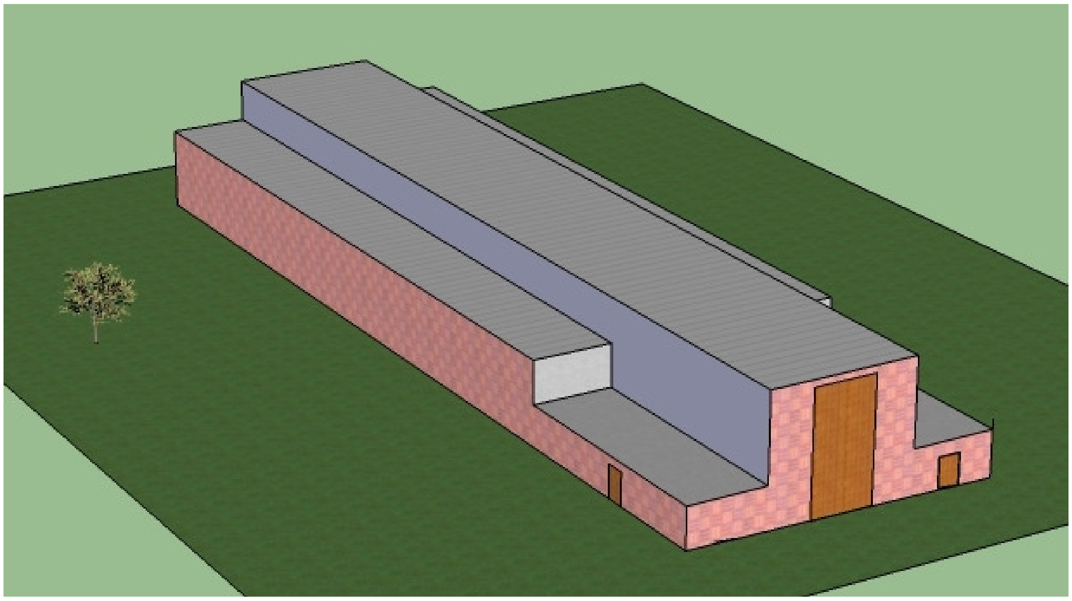
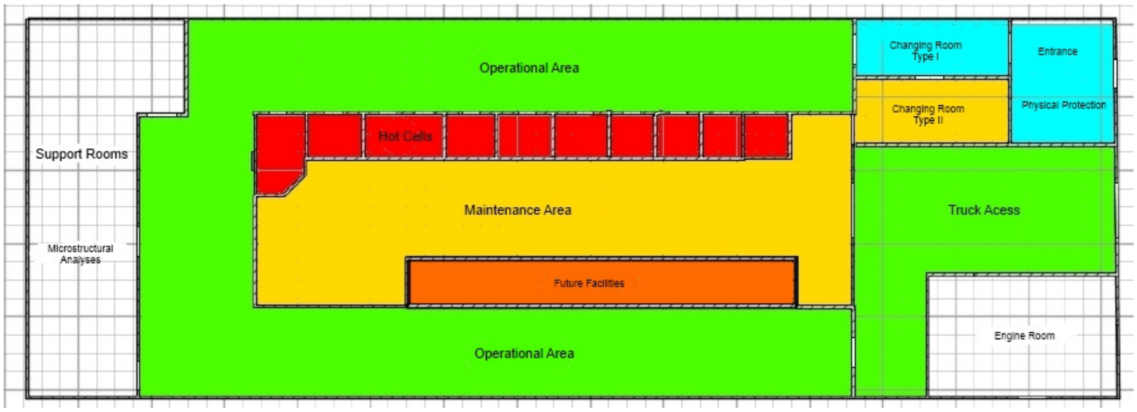


Figure 2. Artistic Concept of LAMI future installation.

Each cell consists of a stainless steel gasproof case (containment), lined with lead panels (shield) with approximate total size of the cell 3.0 x3, 0x4, 0 m^3. A leaded glass window allows internal viewing and remote handling devices will be used to perform the manipulation of materials and equipment inside. Although the cells are independent of each other, there are channels of communication between them for the handling of samples throughout the cell line. Access for maintenance is carried out at the back and at some points in the line will be available coupling nozzles for insertion of samples from shielded containers [4].

Service areas in the laboratory are divided and classified, the level of radiation, according to the Safety Series 30 [5], into four zones: zone I (blue), where there is no effect of radiation or contamination; zone II (green) where there is no effect of radiation or radiation beyond the limits for doses of operators; zone III (yellow), where there is a possibility of higher doses and effects of contamination than in zone II, and zone IV (red), which is characterized as containing handled radioactive material. Figure 3 shows the future layout of the hot cell units of the first test line of irradiated materials of LAMI.

The maximum allowed activity within hot cells will be in general near 10^{13} Bq in term of equivalent ^{60}Co for most of the hot cells in the main line of LAMI. LAMI will have its shielding, containment, ventilation & air filtration and radiological protection systems, sized to beta and gamma radiation, from the materials and components analyzed.



(a)

(b)

Figure 3. (a) LAMI preliminary floor plan; (b) Diagram of LAMI first line of hot cells.

3.1. Materials, Tests and Equipaments

The materials analyzed at LAMI will generally be those used in structural components of the reactor core, the pressure vessel and its internals and other critical equipment such as steam generator and pressurizer. In addition, materials and components in other stages of the fuel cycle (eg the enrichment step) may also be tested. Examples of typical materials are: zirconium alloys, nickel alloys, aluminum and its alloys, stainless steels and low alloy steels, polymer matrix composites reinforced with ceramic and others.

The first line of hot cells to be implanted will be dedicated to analysis and mechanical testing of irradiated structural materials. The main mechanical tests to be performed include tensile, creep and fatigue tests, and Charpy impact and fracture type tests. A description of the arrangement of the various tests in the cells is given in Table 1. The second line of cells will be deployed later with a cell designed to study stress corrosion cracking under slow deformation conditions in a water environment of the primary circuit, typical of a PWR.

Table 1. Distribution of tests and analysis at the LAMI first line of hot cells

Cell Number	Function
01	Microstructural Analysis (in the vicinity of the lines)
02	Receiving, Visual Inspection, Dimensional Analysis and Hardness
03	Tensile and Uniaxial Compression Tests
04	Fatigue Tests
05	Uniaxial Creep and Stress Relaxation Tests
06	Biaxial Creep and Tube Pressurization Tests
07	Cutting, Grinding, Polishing and Welding
08	Storage
09	Fracture Toughness Testing
10	Charpy Impact Tests

4. CONCLUSIONS

LAMI is a project that aims to provide the nation with conditions of analysis and testing of irradiated materials that will contribute to the design, development and maintenance of other nuclear facilities, giving independence to the country in this area of vital importance to the scientific and technological development, health and defense areas.

The LAMI project includes the installation of the laboratory in two phases. The first one will consist of a line of 10 hot cells dedicated to analysis and mechanical testing of irradiated materials. A future expansion will also cover tests on radioactive materials.

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