The RMB Project - Development Status and Lessons Learned.

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Abstract. Brazilian research reactors and related facilities have a limited capacity for radioisotope production, leading to a high dependence on external supply for radioisotopes used in nuclear medicine. In order to overcome this condition and due to the very old age of the main research reactors in the country, the Brazilian Nuclear Energy Commission (CNEN) decided to start a new research reactor project, named RMB (Brazilian Multipurpose Reactor). This reactor will be part of a new nuclear research center, on a site about 110 kilometers from São Paulo city, in the southeast part of Brazil. The new nuclear research center will have a 30 MW open pool type research reactor using low enriched uranium fuel, and several associated facilities and laboratories. The research reactor main functions are to produce radioisotopes for medical and industrial applications, to use thermal and cold neutron beams in scientific and technological research, to perform neutron activation analysis, and to perform materials and fuel irradiation tests. This article presents updated information on technical matters, the overall development status of the RMB project, and some lessons learned in relation to the complexity of the project management.

Key Words: Research Reactor Project; Research Reactor Utilization

1. Introduction

Brazil has four research reactors (RR) in operation: IEA-R1, a 5 MW pool type RR; IPR-R1, a 100 kW TRIGA type RR; ARGONAUTA, a 500 W Argonaut type RR, and IPEN/MB-01, a 100 W critical facility. The first three, constructed in the end of the 1950's and in the beginning of the 1960's for teaching, training and nuclear research, have been the basic infrastructure for the Brazilian nuclear developing program. The last built reactor, IPEN/MB-01, is the result of a national project developed specifically as a laboratory for qualification of reactor physics analysis. Considering the relative low power of Brazilian research reactors, with exception of IEA-R1, none of the other reactors is appropriate for regular radioisotope production, and even IEA-R1 has a limited capacity. Therefore, the total amount of ^{99}Mo needed to attend the Brazilian nuclear medicine demand has been imported. Due to the complete dependence on external supply, the 2008/2009 international ^{99}Mo supply crisis affected significantly the Brazilian nuclear medicine services, and this vulnerable condition supported, in 2010, the decision of the Brazilian Nuclear Energy Commission to build a new research reactor [1, 2]. The new reactor named RMB (Brazilian Multipurpose Reactor) will be a 30 MW open pool type reactor, using low enriched uranium fuel. The reactor facility will be the main installation of a new nuclear research institute. In addition to produce radioisotopes for medical application, the complex will have several facilities as a neutron (cold and thermal) beam laboratory for research; a radioisotopes processing facility; a neutron activation analysis laboratory; and a post-irradiation laboratory for analysis of materials and fuels specimens irradiated in the reactor. The neutron beam laboratory will work as a national laboratory in complement to the Brazilian Synchrotron Light Laboratory. The reactor building has the capability of storing the spent fuel elements for the plant lifetime [3]. The project also previews in the site a facility to process and store medium and low-level waste.

2. The RMB nuclear center

RMB is the new CNEN´s nuclear research and production center. The new site is located in Iperó, 110 kilometers west from São Paulo city, in the southeast part of Brazil. The RMB Center site has an area of about 2 millions square meters. The new site infrastructure shall consider in its design and construction not only the needs of the reactor and its complementary laboratories, but also the needs of future facilities and laboratories. As a new nuclear center, it is necessary to have all the environmental and nuclear site licenses issued by the competent authorities adding more time and effort for the project development.

The center will have three main nucleus: one for research and production, one administrative and one for infrastructure (*see FIG. 1.)*.The administrative nucleus will have a library, an administration building, a hotel, a restaurant, an ambulatory, and a training center. The infrastructure nucleus will have a water treatment plant, a warehouse, a workshop, a building for the fire brigade, a garage, a sewage treatment station, a chemical waste treatment station, a meteorological station, the main gate, and the electric substation.

FIG. 1. Artistic view of RMB nuclear research center.

The research and production nucleus (RPN) is the main reason of the project and comprises the nuclear and radioactive facilities of the RMB project. The research reactor is the main installation that includes the reactor building itself and the spent fuel storage building. Coupled to it, the radioisotope production facility and three laboratories: one for scientific and technological research utilizing neutron beams, one for neutron activation analysis and the third one for post irradiation analysis of irradiated materials and nuclear fuels specimens.

The radioisotope production facility will have two lines of hot cells: the first one for production of the radioisotopes ^{99}Mo and ^{131}I through the processing of irradiated LEU targets; and the second one for processing “sealed sources”, like ^{192}Ir and ^{125}I, for industrial and medical applications. According to the established requirement, this radioisotope facility coupled to the reactor characteristics will have the capacity to produce radioisotopes and sealed sources to attend the national needs beyond 2020.

The neutron beams laboratory will have lines of thermal and cold neutrons for experiments involving different neutron beam techniques like diffraction, small angle scattering, and reflection, as well as other methods like neutron imaging and prompt gamma activation analysis.

The neutron activation analysis laboratory will have two pneumatic connections to the reactor to receive long life irradiated samples, and five pneumatic tubes connected directly to the reflector vessel for cyclic irradiations of short life products and delayed neutron activation analysis.

The post irradiation laboratory is the facility that, together with irradiation capsules and rigs in the reactor, allows tests of materials and fuels specimens focused in the needs of the Brazilian nuclear program for power reactors.
Seven more facilities complement the research and production nucleus: the reactor auxiliary building, the cooling towers, the electrical supply and distribution building, a radioactive waste management facility, a workshop, an operator's support building, and a researcher's building (*see FIG. 2.*).

1 – RPN Entrance
2 – Researchers Bld.
3 – Workshop Bld.
4 – Waste Processing and Storage Bld.
5 – Electrical Supply Bld.
6 – Cooling Towers
7 – Reactor Auxiliary Bld.
8 – Reactor Bld.
9 – Spent Fuel Bld.
10 – Post Irradiation Lab.
11 – Radioisotope Processing Bld.
12 – Radiochemistry Lab.
13 – Operator Support Bld.
14 – Neutron Beam Lab.

FIG. 2. Artistic view of RMB research and production nucleus.

3. The RMB research reactor design

In 2010, CNEN and CNEA took the decision to adopt, for the new research reactors of Brazil (RMB) and Argentina (RA10), the conceptual model of the OPAL research reactor based on INVAP´s design. For the Brazilian RMB research reactor, in addition to radioisotope production and neutron beam utilization, CNEN established two other design requirements. The first one was the capability to test fuels and materials for the Brazilian nuclear power program, and the second was the requirement to have the necessary infrastructure to allow the interim storage, for at least 100 years, of all spent nuclear fuel used in the reactor. References [3,4,5,6] present the RMB reactor in a detailed manner.

RMB is a MTR open pool type reactor that uses beryllium and heavy water as reflector, and light water as moderator and cooling fluid. The power of the reactor is 30 MW, and its main requirements were established by CNEN technicians during the feasibility study and the conceptual design. The reactor core is a 5 X 5 matrix, containing 23 plate type fuel elements, and leaving 2 positions available for materials irradiation tests. Each fuel element has 21 fuel plates made of low enriched (19.75 wt%) uranium silicide-aluminum dispersion fuel (U_3Si_2-Al) with aluminum cladding. Three sides of the core are surrounded by a reflector vessel, filled with heavy water that acts as reflector for the neutrons produced in the core. The reflection on the fourth side is done with the utilization of removable beryllium blocks inside a box of regular water. The core is designed to have a cycle length of 28 days.

The reflector vessel is made of zircaloy, and it is installed in the bottom of the reactor pool, about 10.5 meters below water surface level. Filled with heavy water, it has an internal diameter equal to 2.6 meters and an internal height equal to 1.0 meter. It has 5 positions for silicon neutron transmutation doping; 14 positions for pneumatic irradiation; 20 positions for bulk irradiation; one cold neutron source; 2 cold neutron beam tubes; 2 thermal beam tubes, 1 thermal neutron beam tube for neutron imaging and one position for fuel irradiation testing, where up to 2 rigs can be installed simultaneously. At least 10 of the bulk irradiation positions in the reflector vessel can be used to irradiate rigs with low enriched fuel targets to produce Mo-99.

The reactor pool is a 5.1 meters diameter, 14 meters high cylindrical tank made of stainless steel, filled with water up to the 12.6 meters level. It houses the reflector vessel, a small spent fuel storage rack with capacity to store up to 32 fuel elements, the bundles of tubes used for pneumatic irradiation, the internal piping that form the inlet and outlet of the primary and pool cooling systems, the nuclear and process instrumentation, auxiliary support and mechanical structures, and the water inventory required for the cooling systems to perform their functions. Adjacent to the reactor pool there is the service pool, connected to the reactor pool by a transfer channel, a 9.0 meters high rectangular stainless steel structure, with maximum water level equal to 7.6 meters. The service pool houses a spent fuel storage rack with capacity for up to 600 spent fuel elements (enough for 10 years of operation); and many other devices needed for normal operation of the facility.

To comply with the requirement to allow the interim storage, for at least 100 years, of all spent nuclear fuel used in the reactor, a building named “Spent Fuel Storage Building” was designed adjacent to the reactor building. This building, which can be accessed directly from the reactor building, will have two pools: one for temporary wet storage of the spent fuel used in the reactor, and the other for handling and storage of rigs used for material and fuel irradiation tests. This building has also a dry store zone for shielded casks with spent fuels inside.

The two pools of the spent fuel storage building plus the reactor pool and the service pool, these latter two located in the reactor building, form a stainless steel structure embedded in a concrete block. Three hot cells located in the reactor building and one hot cell in the spent fuel storage building complement the concrete block.

In the RMB, the thermal and the cold neutron beams will be generated inside the reflector vessel by the neutrons thermalized by the heavy water (D_2O) at room temperature and a cold neutron source composed by a cryogenic cylinder of approximately 17 liters, containing liquefied D_2 at a temperature of 19°K, respectively. The thermalized neutrons will be extracted by three thermal neutron beam tubes and two cold neutron beam tubes (*see FIG. 3.*). Inside each beam tube, it will be possible to install three neutron guides with an angular separation of 3 degrees between each other. These neutron guides extend to an experimental hall of instruments named Neutron Guide Hall (NGH) where several neutron scattering instruments can be installed. In the initial stage, the intent is to implement only two neutron guides for thermal neutrons and another two for cold neutrons. Based on user's community demand and studies still in progress, it was suggested to install, in this first stage, two diffractometers (one high-resolution and one high-intensity), a small-angle neutron scattering (SANS) and a neutron-imaging instrument in the specific thermal beam tube at reactor face.

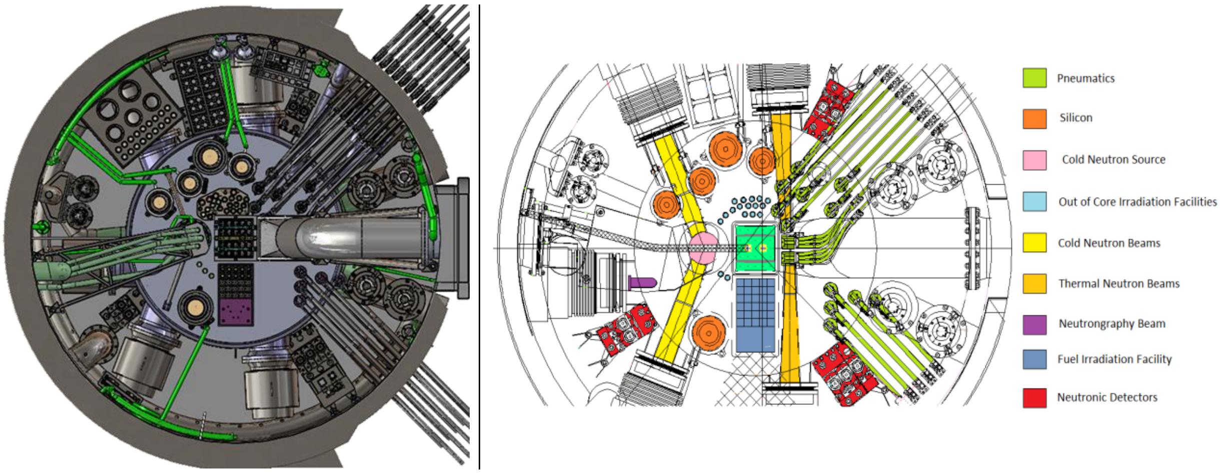

FIG. 3. RMB Reactor tank scheme

4. Project development status

The IAEA publication "Specific Considerations and Milestones for a Research Reactor Project" [7] presents a diagram with three main phases and milestones for the infrastructure development program and for the research reactor project. These phases are: phase 1- pre-project; phase 2- project formulation; and phase 3- implementation. The associated milestone are: ready to make a knowledgeable commitment to a research reactor project; ready to invite bids for a research reactor; and ready to commission and operate the research reactor. It is possible to do a parallel of the RMB project status to the phases and milestones presented in reference [7].

For phase 1, one can correlate the several feasibility studies and plans developed by RMB Project, where reference [1] is an example, taking into account that Brazil had already four research reactors in operation and a nuclear infrastructure well established. One key document developed was the Report to the Ministry (Department) of Planning (MPOG) presenting the RMB project and analyzing its economic, social and institutional feasibility. The MPOG discussed and approved the RMB Report, leading to the RMB project inclusion in the Multiannual Budgetary Plan (in the beginning for cycle 2012-2015 and now for cycle 2016-2019) of the Government.

The RMB project management organization set the life cycle into three phases: phase 1- Implementation; phase 2- operation; and phase 3- decommissioning. The phase 1 of RMB project organization overlaps phases 2 and 3 of IAEA reference [7]. The implementation phase of RMB project has the following steps: (i) site setup; (ii) conceptual design; (iii) basic (or preliminary) engineering design; (iv) detailed (or executive) engineering design; (v) procurement and contracts; (vi) construction; (vii) fuel assembly development and manufacture; (viii) nuclear and environmental licensing; and (ix) commissioning. For each step, there are management plans and resources allocated. There is also a strong interaction among the engineering steps and the licensing needs. *FIG. 4.* shows the overlapping of the project steps and the documents for formal licenses submission.

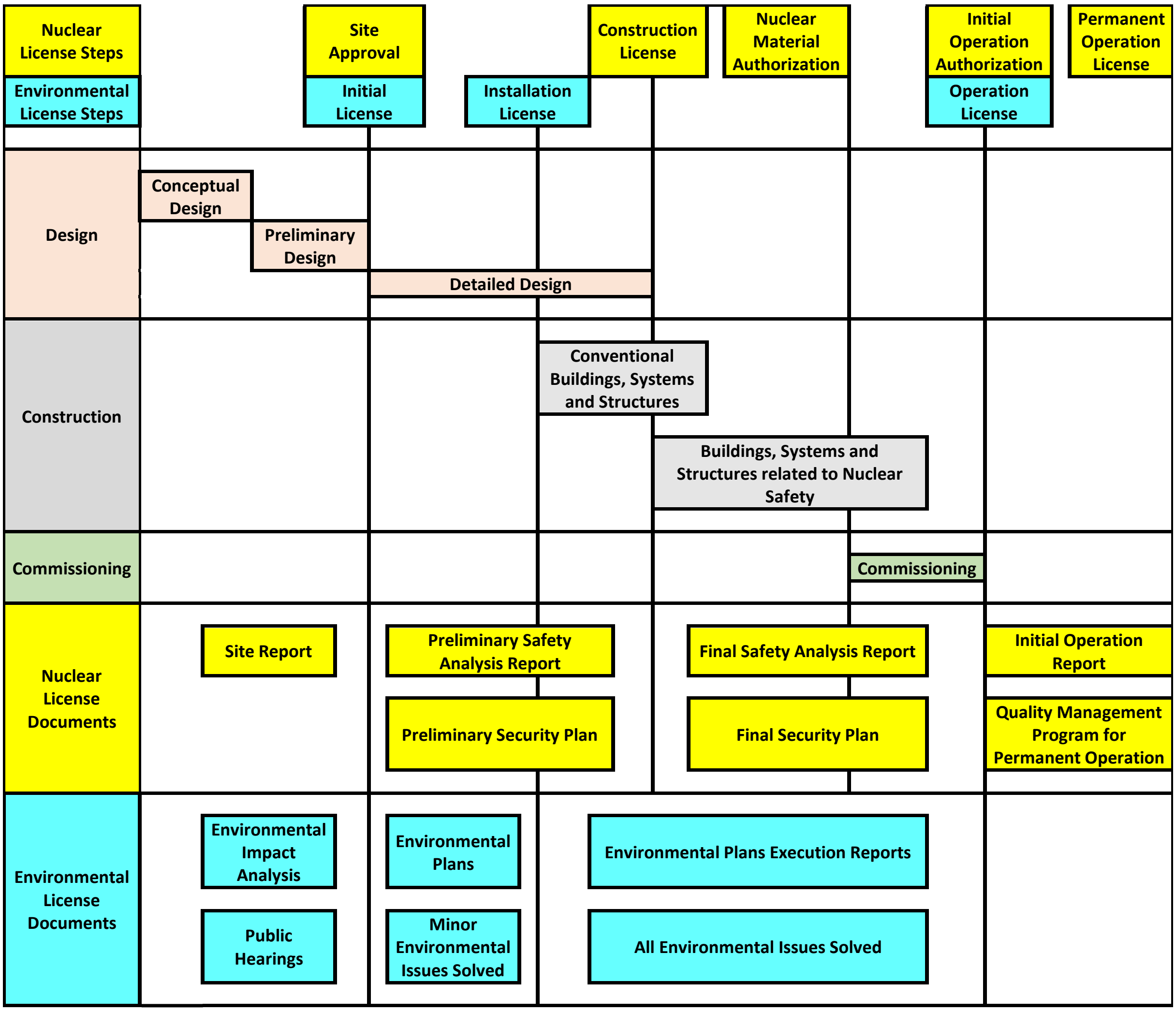

FIG. 4. Overview of implementation steps for nuclear and environmental licensing.

A resume of the status of the project development is:

a) Site setup – site is defined, topography and ground survey done, meteorological tower installed and pre-operational radiological environment monitoring plan is under regular execution.
b) Conceptual design – done. CNEN Institutes technicians developed the conceptual engineering design of the research reactor, laboratories, main facilities and infrastructure.
c) Basic engineering design – done. The Ministry of Science, Technology and Innovation (MCTI) granted CNEN with financial resources for the basic engineering design of the RMB project. It allowed, in 2012, the signature of a contract with INTERTECHNE, a Brazilian company, to develop the engineering work for the preliminary design phase of all buildings, facilities and infrastructure of the new center. In 2013, CNEN signed a contract with INVAP for the work related to the basic engineering of the reactor and connected systems. Both contracts ended in November 2014. Almost seven thousand engineering documents were produced up to this point of implementation.
d) Detailed engineering design - The MCTI granted CNEN with financial resources for the detailed engineering design of the RMB research reactor. A term of reference for the work was already done and its contract is under negotiation.

e) Fuel assembly development and fabrication - The MCTI granted CNEN with financial resources for the fuel assembly development and improvement of the existing fabrication infrastructure. This package includes the production of a plate type entire core for the IPEN/MB-01 critical facility. This will be the reactor physics laboratory for the RMB reactor.
f) Environmental license - Environmental licensing process started. MRS, a Brazilian Company, prepared the Environmental Impact Analysis (EIA) for the RMB center. IBAMA (Environment Regulatory Authority) analyzed and approved the RMB EIA. CNEN sponsored three public hearings in two cities near the RMB site (Iperó and Sorocaba), and in Sao Paulo city. IBAMA has granted RMB Project with the first environmental license (Initial License) in May 2015. CNEN has already started the actions to prepare the environmental plans for the IBAMA installation license authorization. With this license, it will be possible to initiate the field infrastructure actions for the construction step. RMB Project got also the license for using the water from a river located near the site for the center operational needs, and water from the underground for human use.
g) Nuclear license - Nuclear licensing process started. CNEN Institutes technicians elaborated the Site Evaluation Report (SER). The Nuclear License Authority (DRS/CNEN - Directorate of Radioprotection and Safety of CNEN) analyzed the SER and approved it. The DRS/CNEN granted RMB Project with the Site License in January 2015. CNEN Institutes technicians are now elaborating the Preliminary Safety Analysis Report (PSAR) of the RMB research reactor.

Regarding this resume of the RMB status, one can infer that RMB project has already concluded phase 2 and has already initiated phase 3 pointed out by the IAEA reference [7].

5. Some remarks on lessons learned

A new research reactor project, together with the infrastructure development of a new research center, gives important challenge to the researchers and technicians in charge of them due to the complexity of matters and issues involved. We list below some remarks tagged as lessons learned or experiences gained on dealing with the project development.

a) The Government has approved the RMB Project and the budgetary process has developed in a natural way inside the bureaucratic departments. Nevertheless, due to economical and governmental matters, the financial resource given to the project did not reflect the budgetary approval, in other words, the money to the project has not come as planned. This imposed restrictions to the management of the project, and it was only possible to develop some steps (work packages) at once instead of an integral work, as an EPC process.
b) The nuclear and environmental licensing process is complex. Although being a research reactor project, the licensing authorities and the public opinion apply a graded approach taking the nuclear power plants as the case of comparison. The Fukushima accident, which happened in the beginning of the RMB project development, enlarged this remark. During the RMB project public hearings it was evident the fear, from the public side, to any new nuclear installation. One very good action taken by the project management team was to give speeches in the chamber of councilors of the cities near the RMB site and to bring people to visit the IPEN/CNEN-SP nuclear research institute where there are two research reactors and laboratories that produce most of the radiopharmaceuticals used in the nuclear medicine centers of Brazil. After these visits, most of the people became in favor of the project understanding its importance to the society as a hole.

c) One important action on the project management is to have as partner Brazilian technical groups that can become, somehow, stakeholders of the project. The Physics Society, the Nuclear Medicine Society and the Nuclear Energy Association are examples of these technical groups. The partnership with the academy (universities) has also brought good results, as the speeches and technical meetings done on subjects related to RMB laboratories and their future utilization. This is a key point to develop the RMB utilization community.
d) Important objectives of the project are to be structuring, technology developer and motivator for human resources formation for the nuclear area in Brazil. Areas as nuclear engineering, radioisotope utilization, fuel development and fabrication, neutron beam utilization are so far good examples on the achievement of these objectives.

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