THE RMB PROJECT – FUEL CYCLE MANAGEMENT

J.A. Perrotta[1], E.F.U. Carvalho[1], M. Durazzo[1], L.R. dos Santos[1], J.A. Baptista[1], J.E. Rosa da Silva[1], F.C. Junqueira[1], A.dos Santos[1], A.M.V. de Araujo[2], I. Tomazelli[2]
[1]Comissão Nacional de Energia Nuclear (CNEN), São Paulo, Brazil
[2]Centro Tecnológico da Marinha em São Paulo (CTMSP), São Paulo, Brazil
E-mail contact of main author: perrotta@ipen.br

Abstract. The Brazilian Nuclear Energy Commission (CNEN) decided to construct a new research reactor, named RMB (Brazilian Multipurpose Reactor). It is a 30 MW open pool-type research reactor using low enriched uranium fuel, and several associated facilities and laboratories. To establish an infrastructure for producing fuel assemblies for RMB operation and uranium targets for Mo-99 production, the RMB technical secretary has developed a coordinated project for the fuel cycle management system, putting together the fuel technology actors in Brazil. The goals of this coordinated project were: (i) to have a centrifuge cascade enriching uranium up to 20 wt% with the capacity to supply RMB yearly needs; (ii) to upgraded the CNEN existing infrastructure to produce nuclear fuel assemblies and uranium targets for the RMB yearly needs; (iii) to produce a set of fuel assemblies for a real RMB mockup core at the IPEN/MB-01 Critical Facility of CNEN. The RMB project design incorporates structures, systems and components (SSC) for interim storage of spent fuels for the hole plant lifetime. This paper presents details of the coordinated project that gives support and sustainability to the RMB fuel cycle supply and the spent fuel SSC designed.

Key Words: RR fuel assembly, RR fuel cycle management, Mo-99 uranium target.

1. INTRODUCTION

The Brazilian Nuclear Energy Commission (CNEN) decided to construct a new research reactor, named RMB (Brazilian Multipurpose Reactor). This reactor will be part of a new nuclear research center, to be built on a site about 100 kilometers from São Paulo city, in the southeast part of Brazil. It is a 30 MW open pool-type research reactor using low enriched uranium fuel, and several associated facilities and laboratories in order to produce radioisotopes for medical and industrial use; 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 project started in September 2008 and is nowadays at the designing stage before construction. Due to the necessity to produce radioisotopes for medical use and to give flexibility to researchers, the RMB reactor is designed to operate 24 hours per day, and an availability of more than 80% yearly. This operation profile leads to a need, per year, of more than 50 fuel assemblies for the reactor operation and more than 1000 uranium targets for Mo-99 production. The RMB design take in consideration that more than 3 thousand spent fuel assemblies will be generated along the 50 years of RMB lifetime, so concerning to this matter, two pools for wet storage and a hall for dry storage using shielded casks are designed in the RMB project for the interim spent fuel storage.

Brazil has the technology for uranium enrichment by ultracentrifuge method and has the technology for producing fuel for research and power reactors. The RMB fuel cycle management system has developed a coordinated project[1] to establish an infrastructure for producing fuel assemblies for the reactor operation and uranium targets for Mo-99 production. The goals of this coordinated project were: (i) to have a centrifuge cascade enriching uranium up to 20 wt% with the capacity to supply RMB yearly needs; (ii) to upgrade the CNEN existing infrastructure to produce nuclear fuel assemblies and uranium targets for the RMB yearly needs; (iii) to produce a set of fuel assemblies for a RMB mockup core at the IPEN/MB-01 Critical Facility of CNEN. As a result of this coordinated project, the

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[1] Project granted by the National Fund for Scientific and Technological Development (FNDCT/FINEP) from the Ministry of Science Technology and Innovation.

following actions were done: (i) The Navy Technological Center in Sao Paulo (CTMSP) upgraded a uranium centrifuge cascade, at its Isotope Enrichment Laboratory, for working exclusively to support RMB RR. This cascade is already commissioned and can yearly produce the 20% enriched uranium (UF_6) in the quantities as needed by RMB; (ii) The Nuclear Fuel Center (CCN) of the Energy and Nuclear Research Center (IPEN) of the CNEN, in Sao Paulo, has upgraded its infrastructure to attend RMB needs exclusively. The CCN upgraded all systems related to UF_6 conversion to metallic uranium, the production of uranium alloys, the preparation of powders and briquettes, plates rolling and fuel assembly, and quality control laboratories. As results of this upgrading, many innovative processes were developed and some patents generated; (iii) The CCN produced 19 fuel assemblies of U_3Si_2-Al dispersion fuel, with the same design of RMB project. The fuel design incorporates discrete burnable poison as needed by RMB design. These fuel assemblies were loaded at the IPEN/MB-01, Critical Facility of IPEN/CNEN-SP, for simulating the RMB core. Some of these fuel assemblies can be dismantling for modifying internal devices to benchmarking reactor physics analysis.

2. RMB PROJECT CHARACTERISTICS

RMB is an MTR open pool-type reactor that uses heavy water and beryllium as the reflector, and light water as moderator and cooling fluid. The power of the reactor is 30 MW, and its main applications are: radioisotope production to attend Brazilian demand; production of thermal and cold neutron beams for research and application in several technical areas; development of materials and nuclear fuels; neutron activation analysis; and silicon transmutation doping.

The reactor core is a 5 X 5 matrix, containing 23 MTR type fuel assemblies, and leaving 2 positions available for materials irradiation tests. Each fuel element has 21 plates made of low enriched (19.75%) uranium silicide - aluminum dispersion fuel (U_3Si_2-Al) clad with aluminum. Three sides of the core are surrounded by a vessel, filled with heavy water that acts as the reflector for the neutrons produced in the core. The neutron 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 26 to 28 days and 10 to 11 cycles per year.

The reflector vessel is made of zircaloy, and it is installed at 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 meters. 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 neutrongraphy 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; nuclear and process instrumentation; auxiliary support and mechanical structures, and the water inventory, required for the pool cooling system to perform its functions. *(See Fig.1)*

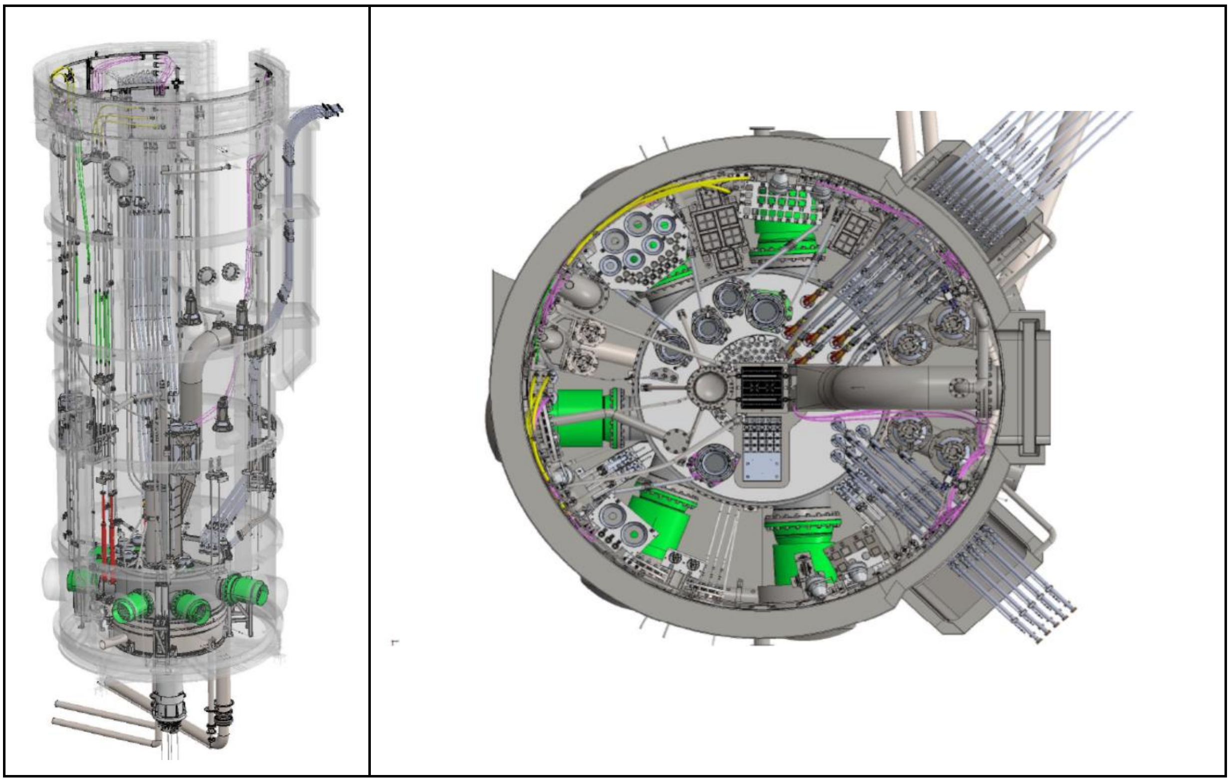


Fig.1. Reactor tank scheme (axial and radial)

Adjacent to the reactor pool there is the service pool, 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. The service pool is connected to the reactor pool by a transfer channel.

To comply with the requirement to allow the interim storage, for all spent nuclear fuel used in the reactor; a building, named “Spent Fuel Storage Building” (SFSB), was designed adjacent to the reactor building. This building, which can be accessed directly from the reactor building, will have two additional pools, one for temporary wet storage of the spent fuel used in the reactor, and the other for handling and dismantling rigs that were used for material and fuel irradiation tests. In the basement of the SFSB, there is room for dry storage of spent fuels using shielded flasks. The SFSB is designed for 100 years of life compared to 50 years life of the reactor.

The two pools of the SFSB 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. *(See Fig.2)*

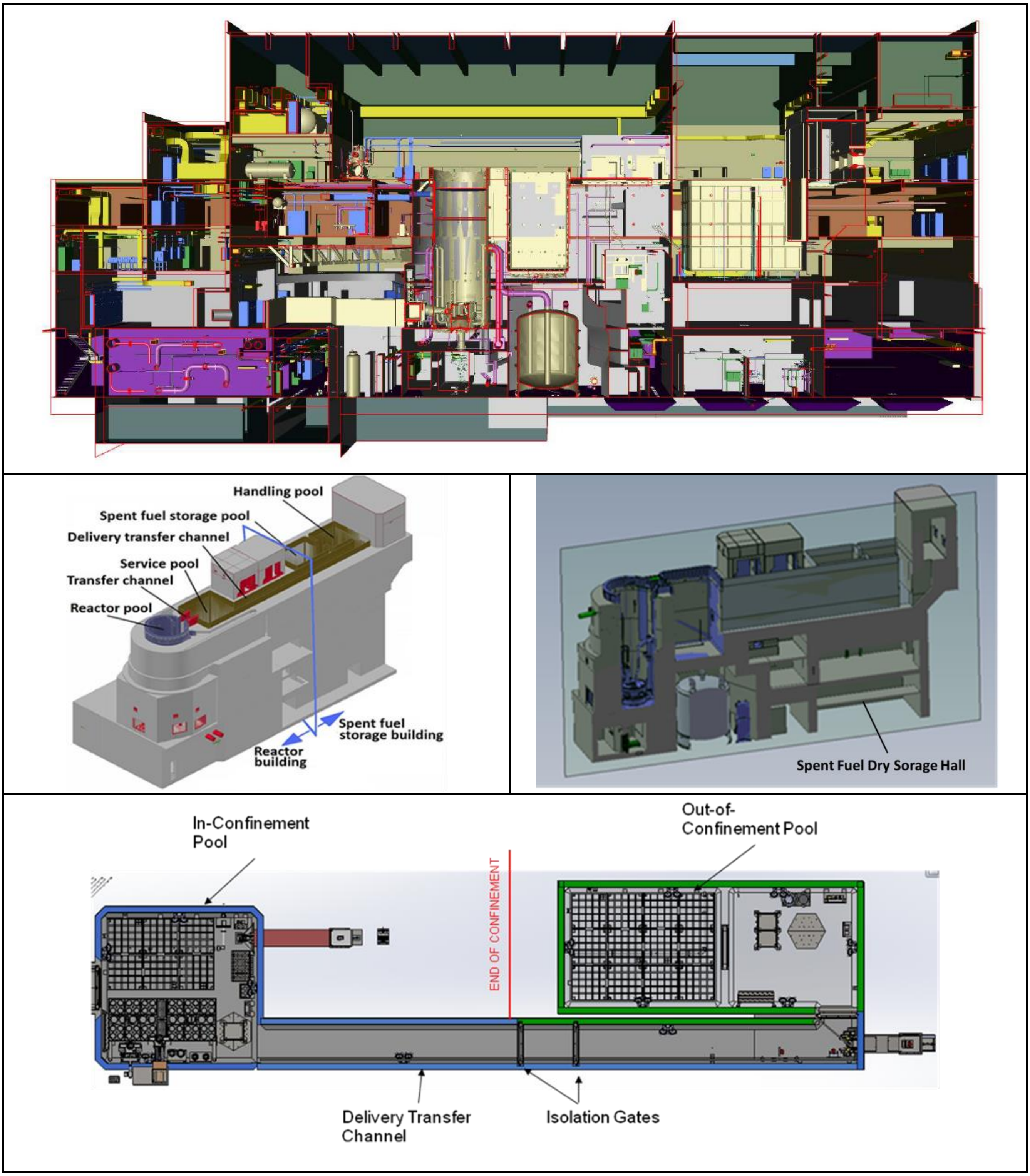


Fig.2. Spent Fuel Storage scheme (building, concrete block, pools)

2.1. Fuel Assembly

The fuel assembly has 21 fuel plates made of low enriched uranium (19.75%). The meat is composed of silicide-aluminum dispersion fuel (U_3Si_2-Al) clad with aluminum alloy. The uranium density can vary up to 4.8 gU/cm^3. *(See Fig.3)*

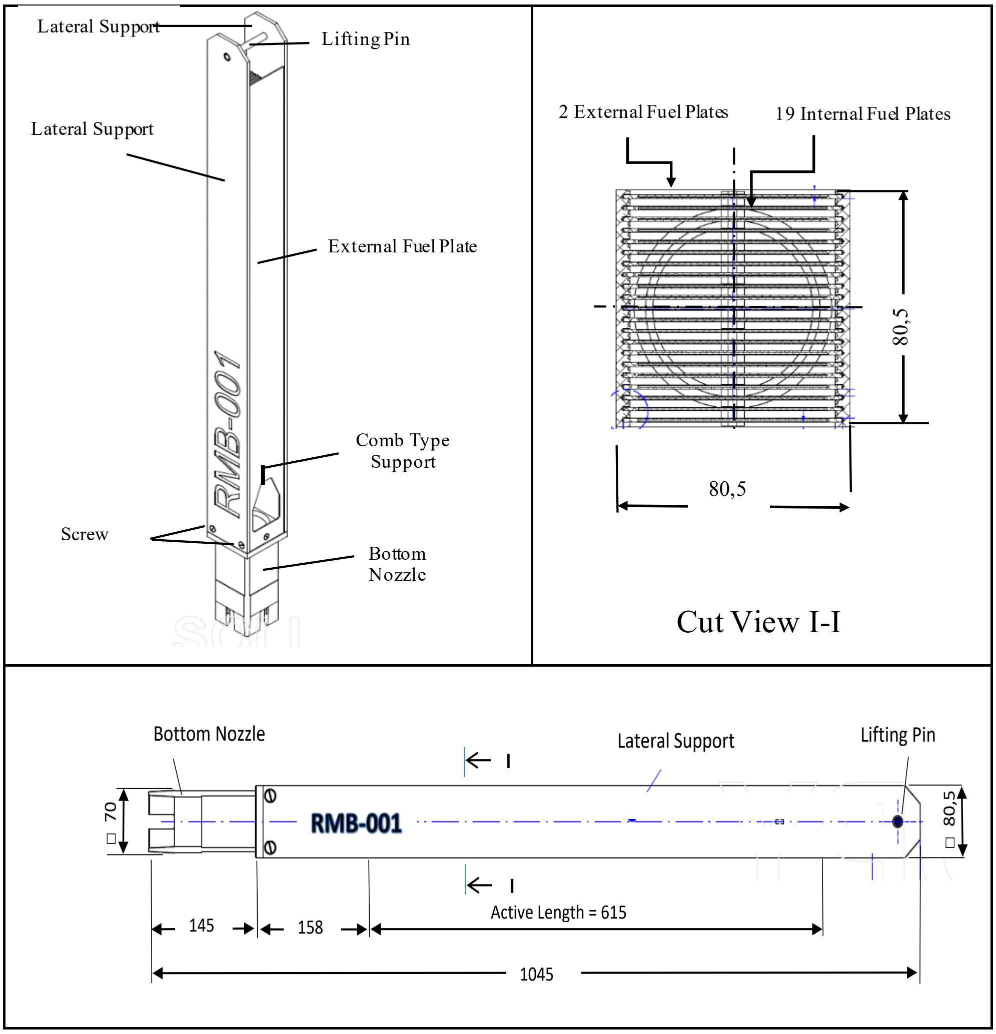


Fig.3. Fuel assembly scheme

3. URANIUM ENRICHMENT ACTIVITIES

The Navy Technology Center in Sao Paulo (CTMSP) has a uranium Isotopic Enrichment Laboratory (LEI) at its site in Ipero, Sao Paulo. This laboratory had a centrifuge cascade that could enrich uranium up to 20 wt%. This installation is under international safeguards inspection both from IAEA and ABACC agencies. The RMB coordinated project for fuel management asked the LEI to build a new exclusive cascade with the capacity for providing enriched uranium (UF_6) for the yearly needs of RMB operation. The UF_6 quantities include the needs for fuel assemblies for the reactor operation and uranium targets for Mo-99 production.

The LEI developed all the engineering, construction and testing of this new cascade using autonomous centrifuge technology. This cascade is already constructed and commissioned and gave the first batch to RMB fuel development. The new cascade attends the RMB's needs for a continuous operation.

4. FUEL FABRICATION ACTIVITIES

The Nuclear Fuel Center (CCN) of the Nuclear and Energy Research Institute (IPEN) of the Brazilian Nuclear Energy Commission (CNEN) has been working in the nuclear fuel cycle technology for more than 60 years and, particularly, in the development and production of fuel elements for research reactors. CCN has in its production history fuel elements as i) UO_2 fuel pins for the IPEN/MB-01 Research Reactor; ii) fuel elements for the Argonaut Research

Reactor of the Nuclear Engineering Institute in Rio de Janeiro; iii) more than 100 fuel assemblies produced for the IEA-R1 Research Reactor of IPEN (5 MW) with burnup higher dan 50 atoms% with safe and good performance.

In the area of RR fuel technology, CCN has developed dispersion fuels as U_3O_8-Al, U_3Si_2-Al, UMo-Al, and targets with alloys of UAl_x and metallic uranium for Mo-99 production.

The technology developed by CCN comprises all the steps for transforming the enriched UF_6 gas to the fuel assembly ready to the reactor use, including all the quality assurance and management activities. The RMB technical coordination recognizes this CCN capacity as a key factor for the sustainability of RMB operation.

The coordinated project was set up for bringing the CCN capacity to a level that would be able to provide all the fuel assemblies and uranium targets needs for the RMB continuous operation. In an overall view, the CCN laboratories producing capacity had to increase from a level of 12 fuel assemblies per year to a capacity 6 to 7 times more effective. CCN had small dispersed installations for development and production, but, with the coordinated project proposed, the infrastructure was centralized and increased. New equipment was put on operation to improve productivity and quality for the manufacturing process. The main improvements were:

a) A new room and equipment for transforming UF_6 into UF_4;

b) A new room and equipment for producing raw metallic uranium;

c) Modifications to systems and equipment in the uranium alloy producing sector (U_3Si_2, UAL_x, UMo, metallic uranium)

d) Modifications to systems and equipment for producing powders and compacts for the aluminum dispersion fuels;

e) Modifications to systems and equipment for preparing fuel plates and their finishing;

f) Modifications and new equipment for quality control and physical qualification of fuel plates;

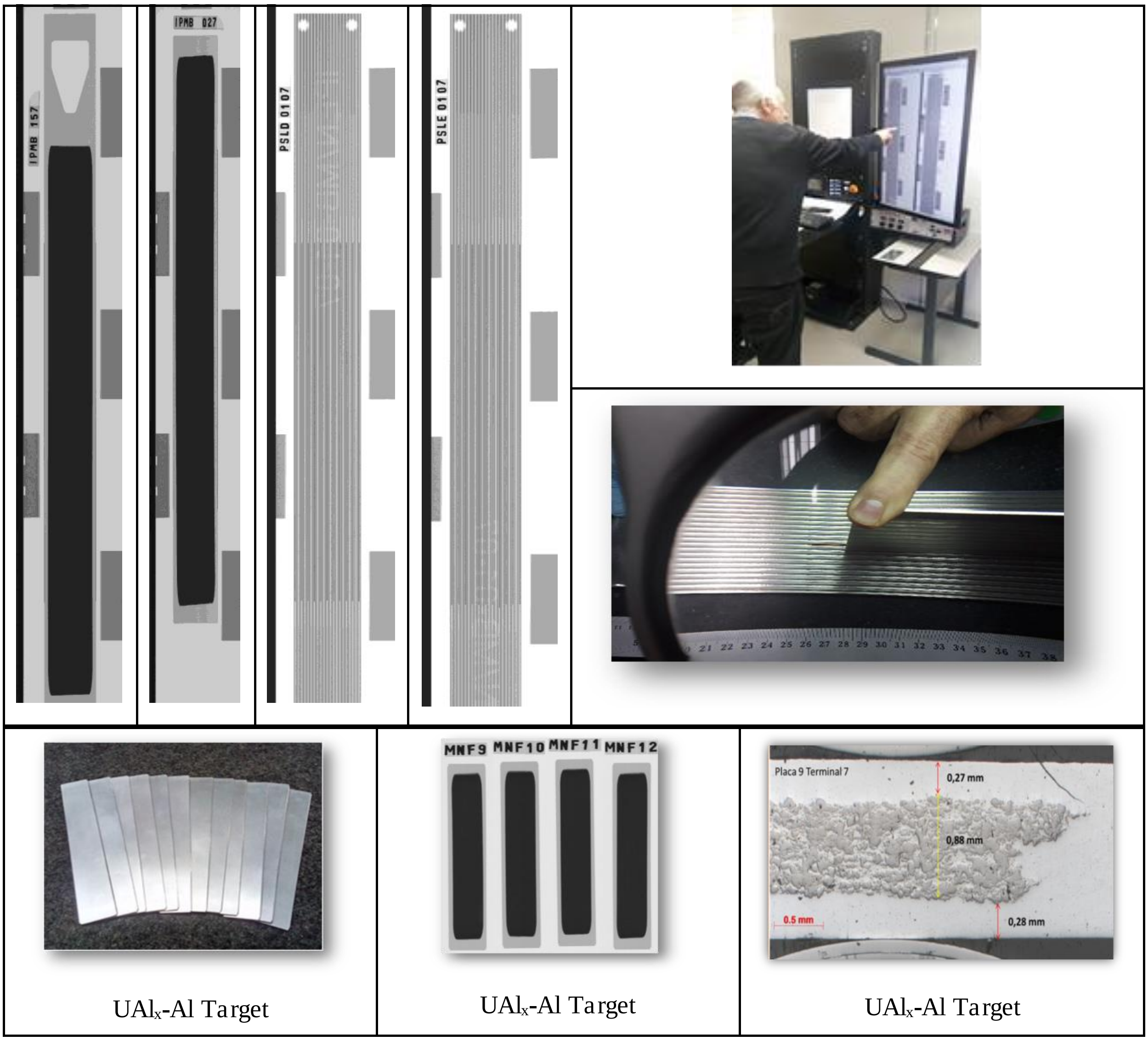
g) New equipment for fuel assembling and its quality control;

h) New laboratories and equipment for chemical, physical, destructive and non-destructive testing for in-process analysis and quality control;

i) New vault for fuel assembly safe storage.

Some innovative processes were developed in CCN for achieving the goals of the project. New equipment was installed to enable automatization resulting in less time required for the processes. Some patents were obtained related to innovative processes, is one example of this the simultaneous rolling process for multiple targets for Mo-99 production.

With the new CCN infrastructure, the fuel assemblies and the uranium targets are warranted for RMB continuous operation. *(See Fig.4)*



UAl_x-Al Target UAl_x-Al Target UAl_x-Al Target

Fig.4. Fuel assembly and U target fabrication infrastructure example

5. CRITICAL FACILITY NEW CORE ACTIVITIES

The IPEN/MB-01 research reactor is a critical facility designed and constructed by IPEN and in operation since 1988. In this facility, it is possible to build many different core configurations, because versatility and flexibility were both taken into account during the initial design. A new core was designed for attending reactor physics experiments for the RMB project. The new core has a 4x5 configuration having 19 fuel assemblies consisting of fuel plates of U_3Si_2-Al dispersion fuel with 2.8 gU/cm^3 and 19,75% wt% in U-235 enrichment plus one aluminum block. The fuel assemblies, designed identical to RMB fuel assemblies, use cadmium wires as burnable poison. The CCN produced these 19 fuel assemblies. Four fuel assemblies from these 19 are dismantlable type fuel assemblies allowing to load and unload each fuel plate and cadmium wire individually, which gives very good flexibility for the experimental routines and to the research in neutronic performance for mechanical and materials improvements to the fuel design. The production of the 19 fuel assemblies by CCN showed the conformity of the new installation and equipment for producing, routinely, fuel assemblies to RMB project.

6. CONCLUSION

The RMB Project, having a 30 MW research reactor, has developed a design and a coordinated action to give sustainability to the fuel management system. The reactor infrastructure has spent fuel pools and a spent fuel dry storage area enough for the interim storage along the plant operation lifetime. The fuel assembly production was solved through the construction of a dedicated enrichment cascade and a fuel assembly producing installation upgrade. This infrastructure is ready and able to produce all the needs for RMB continuous operation. As an exercise of this development, a batch of 19 fuel assemblies of the RMB type were produced and loaded in the IPEN critical facility for RMB reactor physics experiments. With these arrangements, the sustainability of RMB operation related to the fuel cycle management is warranted.