STUDIES FOR A MULTIPURPOSE RESEARCH REACTOR FOR THE CRCN/CNEN-PE

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ABSTRACT

This paper presents a conceptual proposal for the design and construction of an irradiation research facility at the CRCN (Regional Center of Nuclear Sciences) site, in cooperation with an international partner. The planned irradiation facility is based on a multipurpose research reactor with an innovative design feature, which is a core with two sub-critical parts coupled by a heavy water tank for enhancing and flatten the thermal fluxes, improving safety, and improving beam applications.

INTRODUCTION

The multipurpose reactor, named CRCN/RPM-1, proposed for the CRCN (Regional Center of Nuclear Sciences), is planned to be a pool type reactor with 20 MWth, cooled by light water and, in principle, reflected by Beryllium elements. Reactor design, licensing and operation will be based on regulations from CNEN (National Nuclear Energy Commission) and, where applicable, standards and criteria from the IAEA. Aspects related to environmental impacts will be addressed during the licensing procedures, supported by the preliminary and final safety analysis reports (PSAR and FSAR), and by the environmental impact analysis reports.

The technological experience and industrial capabilities available in the Country assure the feasibility of such a project. This capability associated in a cooperative project with an international partner can produce an innovative and modern reactor which will the principal facility of CRCN.

Design data presented in this paper came from the first concept proposal [1,2], which considers plate type (MTR) fuel elements and a beryllium reflector. To broaden the international cooperation possibilities, some concept variations without beryllium and with pin type fuel are being studied. The basic requirement is that all variations should have similar performance outputs.

CNEN is the organization responsible for Licensing, Control, Regulation, Research and Development (R&D) in the nuclear field. R&D is coordinated by the Directorate for Research and Development (DPD) and carried out by three research institutes: IPEN – Instituto de Pesquisas Energéticas e Nucleares, in São Paulo; IEN – Instituto de Engenharia Nuclear, in Rio de Janeiro; and CDTN – Centro de Desenvolvimento de Tecnologia Nuclear, in Belo Horizonte. In addition to R&D in nuclear and related areas, the activities of these institutes include: large scale radioisotope production; small scale production of special materials and equipments; engineering and consulting services; and a variety of cooperation projects with local, state and federal institutions.

The CRCN (Regional Center of Nuclear Sciences) is a new CNEN unit located in Pernambuco, a Northeast State of Brazil, that is being constructed in accordance with the policy which aims at decentralizing, from the southeast region, the nuclear activities in Brazil. The CRCN will be located in the city of Recife in the state of Pernambuco. This center is planned to have laboratories for ionizing radiation metrology, radioprotection, dosimetry, radiopharmacy, trace and ultra-trace analytical chemistry and hydrology; a food irradiation facility; a cyclotron; and a multipurpose reactor.

THE CRCN/RPM-1 MULTIPURPOSE RESEARCH REACTOR

The CRCN/RPM-1 reactor is proposed to be a 20 MWth pool reactor, cooled by light water, moderated and reflected by a combination of a D_2O tank and beryllium elements. Its important characteristic is to have a core divided into two halves coupled by a central heavy water tank. This tank provides a large region with high thermal neutron flux and furnishes an additional safety feature, which is to shut the reactor down when it is quickly emptied. This additional shutdown capability has a different engineering principle from that of standard safety and control rods and, therefore, enhances the overall reactor safety.

The D_2O tank has a region with thermal neutron flux magnitude of $4x10^{14}$ n/cm^{2}s, which is very appropriate for producing radioisotopes, obtaining neutron spectra for boron neutron capture therapy (BNCT), obtaining neutron spectra for cold neutron experiments and many other applications. The beryllium reflector improves the fuel utilization and yields neutron fluxes adequate for materials and fuel irradiation.

The reactor core has 30 plate type (MTR) fuel elements, divided into two halves coupled with a 40 cm heavy water tank, and surrounded by beryllium reflector elements. Figure 1 shows the main core characteristics. Each one of the core halves is subcritical but the coupled system (the two half-cores plus the D_2O tank) has an excess reactivity sufficient for a 25 day operation cycle. This core configuration can provide thermal and epithermal neutron fluxes for a great variety of applications. Inside the core, in the heavy water tank and in the reflector elements can be positioned irradiation samples for irradiating different types of materials.

The material transfer to the hot cells is done through tunnels connected to the superior part of the reactor pool. Small cars, using rails, inside the tunnels allow the transfer of materials from the pools to the interior of the hot cells. The control rod banks driving mechanisms are located in a room under the reactor pool. The D_2O water system is formed by the D_2O reservoir, a circulating system and the coupling tank between the two half-cores.

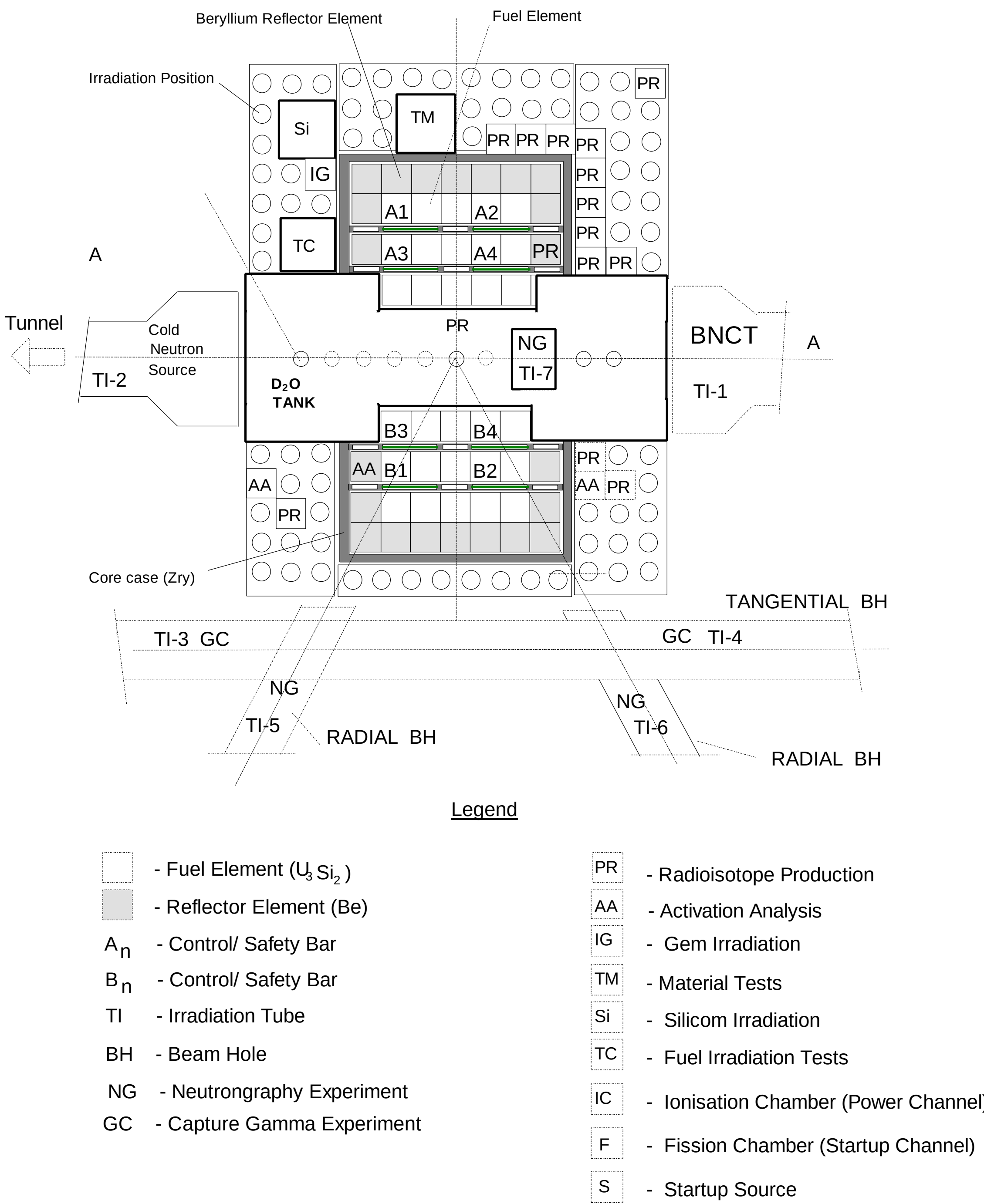

Figure 1 - The Reactor Core

The reactor core is contained in a rectangular baffle made of zircaloy which supports the chimney. From this baffle come out six beam tubes. There are four radial tubes, TI-1, TI-2, TI-5 and TI-6, one parallel tube with access from its both ends, TI-3 and TI-4, and one vertical tube, TI-7. The beam tubes TI-1 and TI-2 obtain neutrons directly from the D_2O tank and should be used for BNCT and cold neutron experiments. The beam tubes TI-5 and TI-6, which take neutrons from the beryllium reflector, and TI-7 are intended for neutrongraphy applications. The parallel beam tube, TI-3 and TI-6 should carry gamma capture type of applications.

The fuel material is U_3Si_2 dispersed in an aluminum matrix, cladded with aluminum. Each fuel element holds 19 plates with active length of 70 cm and transversal dimensions of 8 cm. The fuel thickness is 0.7 mm, the cladding thickness is 0.4 mm and the coolant channel thickness is 2.7 mm. The fuel enrichment and density are 20 % in weight and 4.8 gU/cm^3, respectively. For the first fuel load, it is planned to use fuel with 2 gU/cm^3 in order to decrease the excess reactivity of the fresh core. The fuel element is designed to withstand the transients typical from research reactors.

The control and safety elements are used for reactivity control during normal operation and to interrupt the chain reaction, shutting the reactor down in case of accident. They consists of plates located in between the fuel elements. The absorbing material is Ag-In-Cd. There are 8 control elements clustered in banks in order to provide a symmetric and flatter power distribution during the reactor operation. The reactor may be shutdown by pulling the control rods into the core or by emptying the D_2O tank.

REACTOR PHYSICS PARAMETERS

The power per element in the reactor is seen in Figure 2 to have a flat behavior due to the D_2O tank which allows a better fuel utilization. The values are presented normalized to a unit average power per element for the reactor.

0,727	0,859	0,929	0,859	0,727
0,859	1,018	1,112	1,018	0,859
1,083	1,253	1,353	1,253	1,083

1,084	1,254	1,354	1,254	1,084
0,860	1,019	1,113	1,019	0,860
0,729	0,861	0,930	0,861	0,729

Figure 2- Normalized power per element in the core

The D_2O tank and the beryllium reflector produces high neutron fluxes in several locations. The reactor yields neutron fluxes of different spectra for several applications. In the beryllium reflector the thermal neutron flux levels are about 10^{14} n/cm^{2}s. Coming out from the beam holes there are total currents of 10^{13} to 10^{14} n/s. There are also high flux levels in other positions and in the water surrounding the reactor. With these high neutron flux levels the reactor can produce several types of radioisotopes. The main reactor physics parameters for the proposed core are shown in Table 1.

Table 1. Reactor physics parameters for the first reactor core at BOL.

Parameter	
Shutdown margin	*59 %*
Reactivity inserted by emptying the D_2O tank	*-7880 pcm*
k_{eff} for the complete core without control rods – BOL	*1.1072*
k_{eff} for the complete core without control rods - end of first cycle	*1,0677*
k_{eff} for the complete core with all control rods fully inserted	*0.8871*
k_{eff} for the half core, without control rods and with a 20 cm D_2O tank	*1,0651*
k_{eff} for the half core without control rods and without the D_2O tank	*0,9535*
Moderator temperature coefficient of reactivity (40 – 80 oC)	*-9.5 pcm/^{o}C*
Fuel temperature coefficient of reactivity (40 - 80 oC)	*-1.7 pcm/^{o}C*
Void coefficient of reactivity	*-134 pcm/% void*
Effective delayed neutron fraction	*0.0076*
Prompt generation time	*112 ms*

THE COUPLED CORE BEHAVIOR

The interaction between the cores can be evaluated through some relative indexes such as the coupling reactivity and the interaction time between the cores. The coupling reactivity is here defined as the difference between the core excess reactivity due to the two cores together (with the D_2O tank) and the core excess reactivity due to one half core. As the reactivity increases the coupling becomes stronger. For the proposed reactor, with a 40 cm width D_2O tank, the coupling reactivity is 6360 pcm.

The interaction time is defined as the time necessary for a neutron to travel from one core to the other through the D_2O tank. In this way as the interaction time is reduced, the cores become strongly coupled. Similarly, for a D_2O tank with 40 cm width the interaction time is 133 s, just slightly larger than the mean generation time of the reactor (112 s), which is reasonable for coupling. On the other hand, a 120 cm wide tank yields an interaction time of 400 s resulting in loosely coupled half-cores.

An analysis for the reactor stability due to strong spatial dependent reactivity insertions was also carried out for the proposed CRCN-RMP/01 reactor. To illustrate the core stability, consider a case in which the control rods are inserted in half-core A, displacing the power distribution towards the half-core B. A spatial xenon oscillation may start due to xenon build-up in half-core B and its subsequent decay and burnup. Our calculations indicated that up to 54.2 cm of tank width no oscillations were observed. The Figure 3 illustrates the different behaviors for a core with 54.2 cm (black and red lines) and 200 cm (green and blue lines) wide tanks.

Two dimensional kinetics calculations are being performed to evaluate core behavior under typical design transients, the first results have been satisfactory so far.

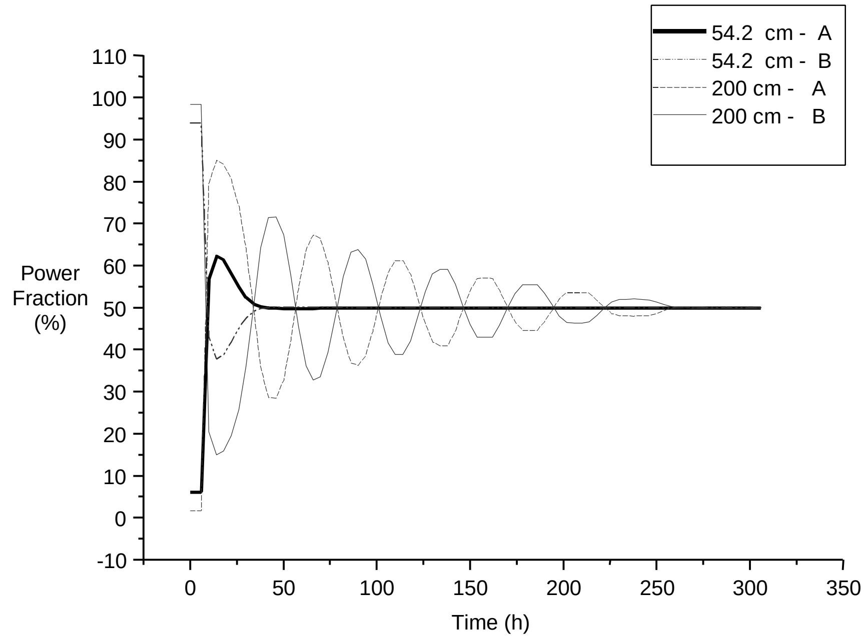

Figure 3 –Power in the coupled cores for spatial-xenon-oscillation transients. The analysis involved two different cores with 54,2 cm and 200 cm width. It is seen that the 54,2 cm core does not oscillate and goes directly to the final stable state, and the 200 cm core oscillates before reaching its final stable state.

PRIMARY COOLING SYSTEM

The CRCN-RMP/01 core is cooled by up ward flowing light water in forced convection regime. The total flow through the core is 2000 m3/h and the outlet temperature is around 48.5 C. In normal conditions each circuit operates with one pump removing half of the total heat power generated at the reactor core. To increase the reactor availability, one stand-by pump is available in each circuit.

The coolant coming out of the reactor core is sucked away by two exit nozzles at the side walls of the chimney. Some coolant also flows from the top of the chimney to the nozzles in order to confine the activated core coolant. This fraction is estimated as 10% of the total flow. The two flow patterns, from the core and from the chimney, are mixed at the hot legs and cooled at the heat exchangers.

The coolant is homogenized at the inlet plenum and the fraction of the total flow corresponding to the chimney pattern returns to the pool by an unidirectional valve. The remaining coolant is distributed between the fuel elements and other irradiation devices.

The chimney is about 3.2 m height in aluminum and supports the devices to access the core. On the top of the chimney, there is a removable grid, which has two purposes: to control of the downward flow; to avoid that objects falling into the pool to reach the reactor core.

REACTOR INSTRUMENTATION AND CONTROL

The instrumentation, control and protection systems will be designed according to the most advanced standards. Its configuration will be based on intelligent units for voting and protective logic. The reactor is to be operated with a highly automated supervision and control system. Its design should sought high reliability, availability, compactness and robustness. The protection and control systems will be independent from one another. The operator interface for controlling the reactor will have a digital visual displays.

The control and safety banks are defined in Table 2. The variation of power is accomplished by moving the control banks symmetrically. BC1 control bank is formed by the control elements A1 and A2; BC2 bank by the control elements A2 and B2, and BC3 bank by the control elements A3 and B3. The safety bank BS is formed by the control elements A4 and B4 and is always kept out of the core while the reactor is operating.

Table 2 – The control and safety banks

Control and Safety Bank	Control Elements
BC1 – Control Bank 1	A1 + B1
BC2 – Control Bank 2	A2 + B2
BC3 – Control Bank 3	A3 + B3
BS1 – Safety Bank	A4 + B4

Besides power maneuvers, the control banks are used to compensate for reactivity effects (burnup, xenon, temperature defect, etc...). Detailed burnup calculations will be performed to enable an “optimum” strategy to compensate for such effects, taking into account their respective time constants. The objective of this approach is to optimize fluxes at the relevant irradiation positions. Also the reactor should have an automatic control of power, that complies with this strategy.

To shutdown the reactor the protection system triggers all banks to fall into the core in a fail safe way. A second shutdown system is based on the fast emptying of the D_2O coupling tank.

All channels should actuate symmetrically in both cores. It is indicated 2 symmetric start up channels (fission chambers), 4 symmetric power channels (ionization chambers) and 2 start up sources.

PLANT COST EVALUATION

A preliminary cost estimation based on information compiled during conceptual studies are presented in Table 3. A more precise evaluation will be done early at basic engineering and final safety systems classification.

Engineering, equipment and construction costs were estimated based on juries practised in Brazil. R & D costs were not include since those activities would be developed at CNEN’s institutes.

Table 3- Preliminary Cost Estimation

Cost Breakdown Structure	Associated System / Main Components or Services	Preliminary Costs Millions US$
Reactor cooling	Primary; secondary; Cooling Towers; and pool cooling.	17
Heavy water coupling	Storage, treatment purification and emptying (Engineered Safety Feature – ESF)	5
Auxiliaries	Water treatment and purification, water processing, beam holes cooling, int. sump, coolant makeup, etc	9
HVAC – Heating, Ventilation and Air Conditioning	Engineered safety ventilation system, buildings HVAC, air intake and purification	5
Buildings	Containment, Storage pools, reactor pool, substation, laboratories, offices, workshops and associated buildings	20
Electrical	Normal and class 1E, including diesel generators, inverters and batteries	7
Instrumentation and control	Nuclear instrumentation, control and protection, radiation monitoring, control room and process instruments	8
Fire protection system	Fire monitoring, gas and water extinguishers	2
Reactor	Fuel elements, reflectors, control and safety rods, core support structure, chimney	7
Engineering and management	Design, analysis, procurement, construction, licensing and commissioning	10
	Overall Cost Estimation	**90**

CONCLUSIONS

The preliminary studies presented here and in Refs. 1 and 2 show that the proposed multipurpose reactor has interesting characteristics, namely, high thermal neutron fluxes in the D_2O tank and beryllium reflector elements, flatter power distribution in the core yielding better fuel utilization, larger excess reactivity with the less fuel due to the beryllium reflector properties, and, most importantly, an additional safety system through emptying the D_2O tank which has a different engineering principle from the control rods shutdown system.

The technological experience and industrial capabilities available in Brazil assure the feasibility of this project. These capabilities, associated in a cooperative project with an international partner, can produce an innovative and modern irradiation research facility which will the principal one at the CRCN.

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