THE CONVERSION AND POWER UPGRADING OF IEA-R1 EXPERIENCE AND PERSPECTIVE

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ABSTRACT

This paper describes the Brazilian national program related to the modernization of its main Research Reactor,IEA-R1.This program included the conversion to LEU, the changes necessary to upgrade the power from 2 to 5 MW, and the enhancement of its utilization. Finally the future plans concerning the fuel elements to be used (U_3Si_2-Al), the replacement of the Reflector (Be) and the continuous improvements, mainly those related with safety, utilization and operational performance are described.

INTRODUCTION

The IEA-R-1 is a pool type, light water cooled and moderated, graphite reflected Research Reactor. It was designed and built by Babcock&Wilcox Co. in accordance with specification furnished by the Brazilian Nuclear Energy Commission, and financed by the US Atoms for Peace Program.

The first start-up was in September 16, 1957, being the first criticality achieved in the Southern hemisphere[1]. The first core was a 5x6 arrangement with curved plate type, LEU fuel elements ,which later on were changed to HEU. Since its first start-up 202 core configurations had been installed.

Although , during its life the Reactor had been continuously modified was only in the beginning of 1995, that in view of a favorable budget from the Federal Government and the decision of partially nationalize the production of the imported radioisotopes, mainly ^{99}Mo, that the decision to modernize and upgrade the power of the IEA-R1 from 2 to 5 MW and to change its operational cycle from 8 hours a day to continuous operation was taken. Also the conversion to LEU, which had began in the eighties , was completed and in September 16, 1997, 40 years after its first criticality, the Reactor operated with 5 MW and with a core configuration of 25 Brazilian made LEU fuel elements .

This paper presents the modifications which were done to operate the reactor at 5 MW, mainly those related with safety and aging, as a passive spray system for emergency cooling, isolation valves of primary system, secondary reactor cooling system, fire system, ventilation system, electrical system, Instrumentation and Control, and Radiation Monitoring System. Besides these modification it was necessary to prepare a new Safety Analysis Report, a review of the Emergency, Radioprotection, and Security Plans, as well as a Quality Assurance Program in order to accomplish safety and regulation required by the licensing authority (Brazilian Nuclear Energy Commission). Also the paper will review fuel elements utilization during the Reactor life, mainly the effort made to convert the Reactor to LEU. Finally, the utilization of the reactor as well as the future plans will be presented.

FUEL UTILIZATION AND CONVERSION TO LEU

Although the conversion of IEA-R1 had already been presented in the 96 RERTR[2], here we wish to summarize it and to actualize this information to a complete conversion.

The first fuel load was with 19 curved plates, U-Al LEU produced by B&W(40 fuel elements including standard and control), and had been used for a short irradiation time, when fuel failure occurred (pit corrosion). Today these fuel are storage in dry tubes, waiting to be transfer to the USA accordingly with a contract signed between DOE and Brazilian Nuclear Energy Commission (CNEN). These fuel elements were replaced by the same type as the early one, but with improvements in the fabrication. The second load was with HEU ,U-Al flat fuel plates (18) from UNC (USA), and many of them were used in the core configurations until last year. Today they are stored in racks in the reactor pool also waiting to be returned to the USA .Also at this time the control mechanical concept was changed from oval type (B_4C) to fork type(Ag-In-Cd) to be inserted in control fuel elements fabricated by CERCA(4). Table 1, summarizes the characteristics of these fuel and control elements.

The conversion of the IEA-R1 initiated in the beginning of eighties with the restrictions by the international market to supply HEU fuel elements. In that time 5 fuel elements of UAl_x -Al dispersion type, LEU, 18 plates were bought from NUKEM(Germany), keeping the same amount of ^{235}U per plate as in the HEU fuel, as well as the physical dimensions. The characteristics of these fuel elements are also illustrated in table 1. With the international restriction in uranium supply to Brazil , the decision was to produce locally fuel elements, given the technical experience already developed by the Brazilians in front end of the fuel cycle and engineering .The decision was to produce fuel elements of U_3O_8-Al ,LEU, and geometrically identical to NUKEM fuel element. In 1985 two prototypes partial fuel elements, one with 2 fuel plates and other with 10, were introduced into the core for performance tests and qualification. These partial fuel element were kept in the core until the beginning of 90. With the good performance of the Brazilian fabricated LEU prototype, the first complete LEU fuel element was introduced in the core in 1988. As there are not facilities for post irradiation qualification in Brazil, as well as the budget and political restriction in that time to allow the qualification abroad (irradiation in a high flux reactor and post irradiation), the decision was to perform the qualification "in use". A paper to be presented in this meeting will describe the qualification [3]. Since then, an average of 2 new LEU fuel element were introduced per year in the core, including the control elements, converting gradually the HEU to LEU core, and finally at the same time when the reactor was ready to operate in 5 MW (Power upgrading), in September, 16 of 1997, the IEA-R1 operated with a core configuration of 5x5 Brazilian made LEU fuel elements. A paper to be presented in this meeting will give the core calculations for the LEU core operating with 5 MW[4] .

Table 1 - Fuel Element Assemblies of IEA-R1 Research Reactor

First Year in Reactor		1957	1958	1968	1972	1981	1985(*)/1988
F.A Id. Number		1 to 40	41 to 79	80 to 118	119 to 122	123 to 127	128 and so on
Number of F.A	Standard	34	33	33		5	16
	Control	5	4	6	4		4
	Partial	1	2				2
Original Enrichment		20%	20%	93%	93%	20%	20%
Manufacturer		B&W (USA)	B&W (USA)	UNC (USA)	CERCA (France)	NUKEM (Germany)	IPEN (Brazil)
Fuel Type		U-Al alloy	U-Al alloy	U-Al alloy	U-Al alloy	UAl_x-Al	U_3O_8-Al
Number of plates per F.A	Standard	19	19	18		18	18
	Control	9	9	9	12		12
	Partial	10	9 / 10				2 / 10
Type of Fuel Plate		curved	curved	flat	flat	flat	flat
Dimensions (mm)	plate th.	1.37	1.37	1.52	1.52	1.52	1.52
	meat th.	0.61	0.61	0.51	0.51	0.76	0.76
	cladding	0.38	0.38	0.505	0.505	0.38	0.38
	active w.	63.5	63.5	63.5	63.5	60.35(min)	60.35(min)
	active l.	597	597	597	597	590 (min)	590 (min)
Grams of ^{235}U per F.A	Standard	159	159	186		180	180/211
	Control	76	76	90	130		120/140
	Partial	87	76 / 84				20 / 100
F.A Max. Burnup (% ^{235}U)	Standard	0	~ 30	~ 50		~ 50	~ 30(**)
	Control	0	~ 40		~ 50		~ 20(**)
	Partial	0	~10	~ 43			~ 20

(*) - Partial Fuel Element Assembly (**) - Up to September 1996.

POWER UPGRADING OF IEA-R-1m

The IEA-R1 RR was originally designed to operate at 5 MW[5], however due several reasons, it had operated since the fifties at 2 MW, 8 hours per day. .Although the basic structures are almost the same as the original project, several improvements and changes in components , systems and structures had been made along Reactor life, being one of the most important the introduction of a steel liner in the pool walls. Several other modifications had been made along its life:

1.Substitution of the original control drive mechanism;

2.Changes in the pneumatic system in order to obtain a better homogenization of flux in the irradiation position, and the substitution of the aluminum by steel in the tubes;

3.Substitution of the original control console by a General Atomic fabricated one;

4.Instalation of fly wheel to hydraulic pump of the primary coolant systems allowing to increase the thermal capability of the system up to 5 MW;

5.Instalation of a decay tank for ^{16}N;

6.Construction of shielding in the resins and purification system.

All these modifications contributed to increase the safety and operational performance of the reactor, although having its utilization limited to due its power (fluxes) and operating cycle. Actually, during the last 40 years the reactor had been used mainly in basic and applied research, NAA, and produced some radioisotopes for medicine, industry, universities and research centers. It is worth to mention, that the IEA-R1 had produced ^{131}I since the early sixties and introduced the utilization of Nuclear Medicine in Brazil, and although at present time not being a commercial producer of radioisotopes, it has developed experimentally many pharmaceutics radioisotopes which are used by medical centers.

In the beginning of eighties, due the increase in the demand of Nuclear Medicine in Brazil, IPEN decided to distribute commercially pharmaceuticals radioisotopes, however due the operational limitation of IEA-R1 in that time, the decision was to import the primary radioisotopes (^{99}Mo), and distribute it after processing as pharmaceutical product (Generator of ^{99m}Tc). It is interesting to mention that in Brazil the commercialization of radioisotopes is by constitutional law monopoly of the Federal Government. Since that time, there were plans to increase the power of IEA-R1, and to operate continually. Also it was planned to produce ^{99}Mo by fission, however budget limitation and technical difficulties (fuel supply, huge amount of financial resources to construct hot cells, waste management) have impeded the success of these plans, although several and scientific progress had been achieved, mainly with the support of IAEA.

In 1995, in view of a favorable budget from the Federal Government, and the priorities given to the production of radioisotopes, the project to upgrade the power of IEA-R1 had been returned. Also, in view of the great need of financial resources to produce ^{99}Mo by fission, and the success recently obtained by countries like China in developing a generator of ^{99m}Tc (gel technique) which allows the use of ^{99}Mo by capture, had change our strategy, and are adapting this new technique which will be less costly, and under the new conditions of irradiation (Be irradiator in core, continuos operation, fluxes ≈ $5x10^{13}$ n/cm^{2}.s) will allow to produce ^{99}Mo to attend part of the demand of ^{99m}Tc generator in Brazil.Papers[6,7] to be presented in this meeting will discuss this subject in details. Besides, the new operational condition of IEA-R1 will provide the possibility to produce radioisotopes which were imported, such as ^{131}I, ^{32}P, ^{51}Cr etc, as well as new radioisotopes such as ^{153}Sm, ^{166}Ho, ^{165}Dy and ^{186}Re. In fact, just changing the operating cycle to operate 64 hours continuos per week at 2MW, which started in 96, allowed the commercial production of ^{153}Sm.

To achieve the goal of up grading (5 MW), and 5 days continuous operation to allow the commercial production of radioisotopes, the project was divided in three parts, improvements and increase of the fuel element production, adequacy of systems, structures and components of IEA-R1, and adequacy of the production of Radioisotopes. Here we are going just to describe the second part, since it had already being concluded, however related with fuel element production it is worth to mention that the consumption is going to increase to more than 10 fuel element per year which is demanding some adequacy in the fuel element production facilities, also since last year the U_3O_8-Al fuel had increase its uranium density from 1.9 gU/cm^3 to 2.3 gU/cm^3 and are already in the present core configuration.

To accomplish safety requirements demanded by the Brazilian Regulatory Body (CNEN) to up grade the power of IEA-R1, a set of actions were made which consist mainly with the adequacy of old systems and design of new ones, involving engineering, analysis, safety evaluation and licensing. The most representative adequacies are:

Reactor Core : The Core configuration was changed from mixed (HEU,LEU) 5x6 array to a LEU 5x5. The new core configuration provide thermal fluxes of magnitude $5x10^{13}$ n/cm^{2}.s. Also a Be irradiator was bought from CERCA and is going to be used to produce ^{99}Mo in the center of the core .

Primary Cooling System: Four isolation valves type ball and gate electrically actuated were installed at the inlet and outlet primary piping to isolate the reactor pool within one minute in a case of primary system piping break (LOCA). Pumps also had components changed due aging, and are monitored in operation by a new Vibrating Monitoring System.

Secondary Cooling System :The cooling towers were revised and all secondary piping completely changed .The new piping were installed on the ground to facilitate inspection. Also the pumps are monitored by a vibration monitoring system

Spent fuel wet storage: Two new Aluminum set of racks were installed to increase the spent fuel storage capacity .
Fire System: A new detection and extinguish fire system was installed covering all areas of risk, according evaluation previously performed.

Ventilation and Air Conditioning (VAC) :A new system had been installed with the separation of reactor building into two distinct and isolated areas (cold and hot). The cold area will be completely free of radioactivity contamination risk. A new set of filter batteries, shutoff dampers, fan coils, blowers, isolated air ducts and instruments were installed.

Electrical System : New power panels were provided to distribute power from main switch gear and emergency generators directly to set of consumers and motor control center. All wiring was checked, revised, and distributed into new cable trays, making possible the isolation of instrumentation and power cables for new systems .

Instrumentation and Control : Improvements were made in the reactor protection system and in safety related instrumentation. New interlocks were concepted into 2 out 3 logic, specially to drive primary circuit isolation and emergency core cooling system valves using pool level signals from new sensors as initializing events. An interlock to protect core against power excursion at lower power level was also installed. Also new panels were installed in the control room, and in the emergency room for the new systems and radiation protection systems .

Radiation Monitoring System :Old monitors were replaced and new gaseous effluent monitors. Also new panels in the control room were installed.

Emergency Core Cooling System(ECCS) :It is a fully passive system, employing two redundant trains with four automatic valves designed to work in fail safe concept, spraying water directly from reservoirs into uncovered reactor core, and avoiding fuel element melting. ECCS was designed to continuous operation during 26 hours after reactor shutdown. A paper to be present in this meeting describes in detail this system[8] .

Besides this systems small changes were done in the reactor infrastructure. Also a formal licensing process was realized with the regulatory branch of the Brazilian Nuclear Energy Commission, and a new version of the Safety Analysis Report was prepared[9]. The project started on July 1995, when a proposal was present and approved by the competent authority. The reactor operated at 5 MW in September, 1997, after a series of commissioning tests were made .The financial resources to realize the up grade of power was around US$ 2 Million, but without question the benefits of this up grading is much more than it cost.

FUTURE PLANS AND CONCLUDING REMARKS

The up grade and conversion of the Research Reactor IEA-R1 has open for this reactor new opportunities, as to become actually a radioisotope producer and to attend part of the demand for primary radioisotopes in Brazil, mainly ^{99}Mo. Besides the radioisotopes production the plans for the utilization of IEA-R1 includes the increase in scientific applications ,an experimental facility for BNCT, neutron radiography, gems irradiation, silicon doping, and materials and fuel irradiation. However to achieve these goals still a lot of work needs to be done.

In the side of fuel production, the future plans are to build a pilot factory with capacity to produce LEU fuel elements, oxide and silicide. In fact we had already bought U_3Si_2 powder from CERCA and are already fabricating fuel elements .

In the reactor side, the next step is the modernization of all instrumentation and control room, and changing of aged components. Also its planned to change the graphite reflector to beryllium, and a compact core configuration with 20 silicide fuel elements,in which will be possible to achieve neutron fluxes up to 1.0×10^{14} n/cm^2.s.

The radioisotopes pharmaceutical production facilities has already been modernized and being prepared to distribute their products from primary radioisotopes produced by reactor and also by a new cyclotron recently installed at IPEN.

As conclusion, the production of LEU fuel elements, the conversion and up grade of power of IEA-R1, and the production of radioisotopes gave to Brazil a new standard in the peaceful application of Nuclear Energy, as well contributed in the policy of non proliferation.

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