PROGRAM OF CONVERTING IEA-R1 BRAZILIAN RESEARCH REACTOR FROM HEU TO LEU

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ABSTRACT

IEA-R1 is a pool type research reactor that operates since 1957 at IPEN-CNEN/SP in São Paulo, Brazil. Although designed to operate at 5 MW it has been operating, since the beginning, at 2 MW and has been used for radioisotope production and research. The earlier cores used LEU MTR fuels but in the late 60's it was changed to HEU MTR fuels. Since the 80's up to now the reactor has been changing its core from HEU to LEU fuels. IPEN has been producing and qualifying its own LEU MTR fuels, made with U_3O_8-Al dispersion fuel plates with 1.9 gU/cm^3. Two thirds of the IEA-R1 core are already occupied with IPEN fuels. IPEN is now producing U_3O_8-Al dispersion fuel plates with 2.3 gU/cm^3 and will also produce U_3Si_2-Al dispersion fuel plates with 3.0 gU/cm^3 as a planned optimization of IEA-R1 core and upgrade of the reactor power from 2 to 5 MW in order to increase the radioisotope production. In 1997 IEA-R1 is planned to have only LEU fuels in the core.

REVIEW OF IEA-R1 CORES

The IEA-R1 is a pool type, light water moderated, and graphite reflected research reactor. It was designed and built by Babcok & Wilcox Co. in accordance with specification furnished by the Brazilian Nuclear Energy Commission, and financed by the US Atoms for Peace Program.

The first criticality occurred on September 16th, 1957, being the first criticality achieved in South America. [1,2]. Although designed to operate at 5 MW, IEA-R1 has been operating at 2 MW since its beginning. In these 39 years of operation IEA-R1 has been used to perform research in nuclear and solid state physics, radiochemistry and radiobiology, production of some radioisotopes and to give irradiation services to the scientific community and also industry.

Since startup to present time (September 1996), 181 core configurations have been installed and around 150 fuel element assemblies used. The reactor operated 40 hours per week (8 hours/day) in most of its life time, but since the beginning of this year is operating in one continuous cycle of 64 hours per week.

Concerning fuel utilization it is possible to analyze the reactor history in four cycles.

The first cycle corresponds to the first core of the reactor. It was composed of U-Al alloy fuel with 20wt% enrichment, having 19 curved fuel plates produced by B&W. These fuel assemblies failed at the earlier stages of the reactor operation, due to pit corrosion caused by brazing flux used to fix the fuel plates to the support plates. These fuels were replaced, in 1958, by new ones, also produced by B&W. They were identical to the earlier ones (U-Al alloy, 20wt% enrichment, 19 curved fuel plates) but brazing was not used for assembling. The fuel plates were fixed mechanically to the support plates. These fuels operated with good performance up to the discharge burnup used at that time.

The second cycle corresponds to a complete substitution of the core. Fuel made with U-Al alloy, 93 wt% enrichment , having 18 flat fuel plates were bought from UNC (USA). At this time the core was converted from LEU to HEU. Some of these fuels are still operating in the core. In the middle of this cycle the control rod mechanical concept was also changed from rod type to fork type (plate type). The control fuel element assemblies were fabricated by CERCA (France), using U-Al alloy, 93 wt% enrichment, and flat plates.

The third cycle is characterized by the restriction of HEU fuel supply. IPEN bought, from NUKEM (Germany), 5 fuel element assemblies of UAl_x-Al dispersion type, with 20wt% enrichment and having 18 flat fuel plates per fuel element assembly. The amount of ^{235}U in the LEU fuel plate was almost the same as the HEU fuel plate and the geometry of the fuel element assembly was the same. With this partial LEU core load, the HEU fuels, that stayed in core, began to have higher burnup and the numbers of fuel element assemblies used in the reactor core had to be increased due to reactivity needs.

The fourth cycle has began with IPEN decision of fabricating its own fuel and to replace, gradually, the high burnup HEU fuels in the core. IPEN had already, at that time, good knowledge and experience in core engineering, fuel engineering and fuel fabrication, so the decision to produce MTR fuels to the IEA-R1 was a natural way to maintain the reactor in operation. The IPEN fuels are of U_3O_8-Al dispersion type, with 20wt% enrichment and geometrically identical to LEU fuel from the third cycle.

Table 1 summarizes the different fuel element assemblies used in IEA-R1 core. Figure 1 shows the present core configuration and Figure 2 and Figure 3 show, respectively, the burnup profile of fuels at the beginning of the fourth cycle and the present situation.

FUEL ELEMENT DEVELOPMENT

During the 80's IPEN had already accumulated experience in reactor engineering (neutronics, thermo-hydraulics, safety analysis) and references [3,4,5,6,7] are examples of activities concerning research reactor analysis and HEU to LEU conversion.

The area of fuel engineering was also developed at the 80's in IPEN, where the design and construction of a Zero Power Reactor took place, achieving experience in areas of mechanical design, material specification, fuel performance analysis and fuel qualification.

IPEN had also experience in fuel fabrication and process development since the middle 60's when development of U_3O_8-Al dispersion fuel was already being conducted to produce the core of ARGONAUTA Reactor at IEN in Rio de Janeiro [8 to 11]. Besides, a fine group of researchers in material science and metallurgy had been working in IPEN giving support to the fuel materials and fabrication processes development [12 to 17].

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

Characteristics		First Cycle		Second Cycle		Third Cycle	Fourth Cycle
		1st core	2nd core	original	modified		
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
	Control	76	76	90	130		120
	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.

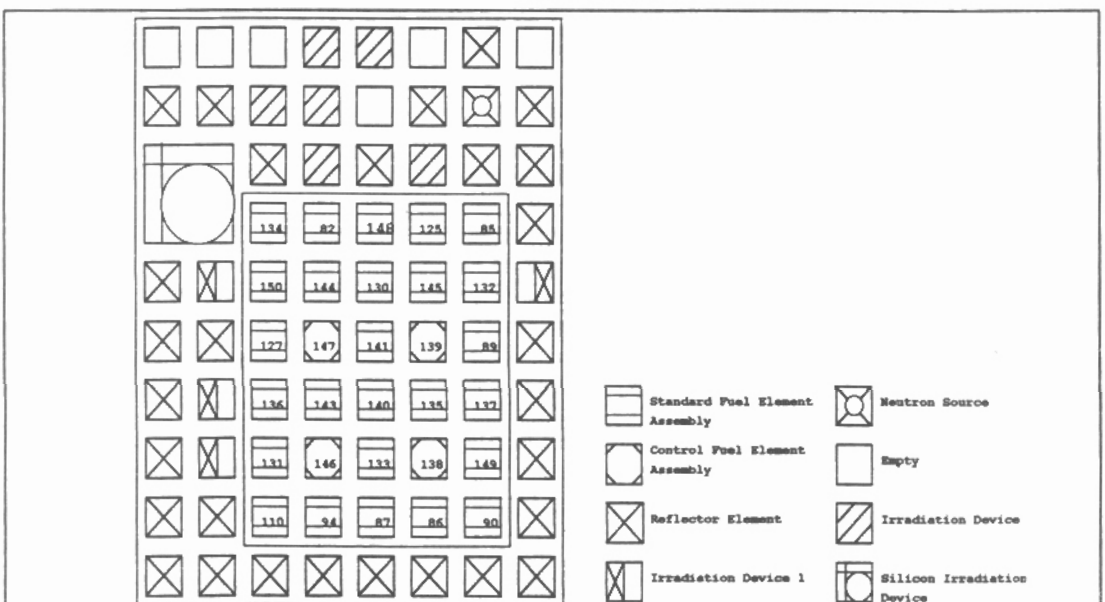

Figure 1 - IEA-R1 Configuration Number 181 (September 1996).

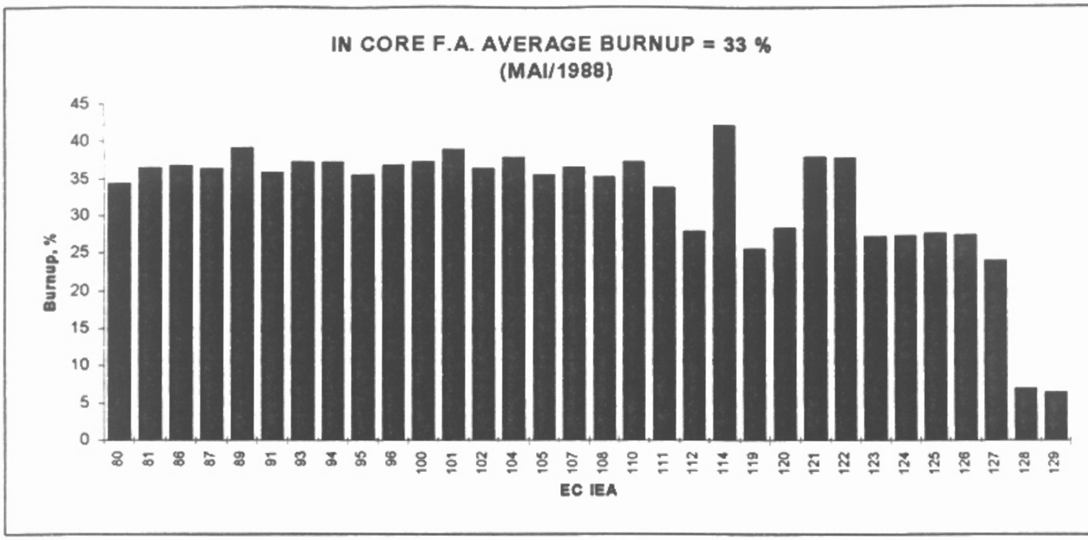

Figure 2 - Fuel Element Assembly Burnup in May 1988

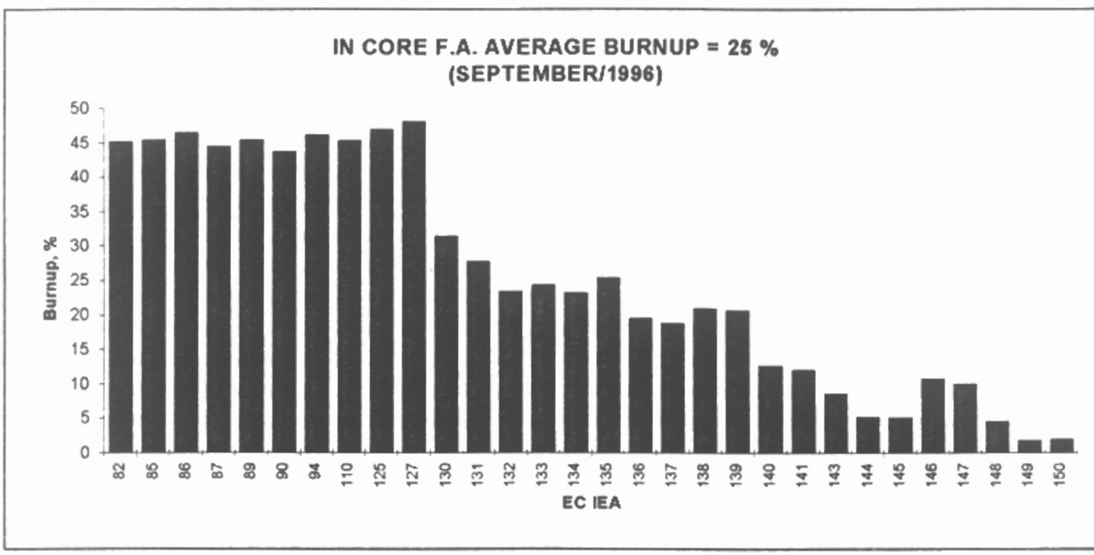

Figure 3 - Fuel Element Assembly Burnup in September 1996

IPEN had also participated at the Brazilian development of uranium enrichment by centrifugation and this could be the source for enriched uranium for the IEA-R1 fuels.

All these areas together gave the necessary background and support to the decision and the implementation of the IEA-R1 conversion from HEU to LEU by an autonomous development.

The design characteristics of IPEN fuel are shown in Table 2, and the fabrication characteristics in Figure 4.

The specifications of IPEN fuel are typical of MTR fuels for low power research reactors, according to the numerous works after RERTR Program. Also the uranium content in fuel plates is low which gives a good plate production quality and also a good chance for high burnup fuel performance in normal operation, as proven by the international experience. These were the main points of concern pointed to the licensing authority for the approval to the utilization of IPEN fuel in IEA-R1 Research Reactor [18,19].

Table 2 - General Fuel Element Assembly Specification

U_3O_8 Powder	
Particle Size	< 89 μm ; maximum of 20% < 44 μm
Particle Density	> 8.0 g/cm^3
Specific Surface	<0.1 m^2/g
Enrichment	19.75 ± 0.2 wt%
U content	> 84.5%
Maximum Impurities Level (μg/gU)	Al-250;B-2;C-500;Ca+Mg-200;Cd-0.5;Cl+F-350;Cr-200,Co-3;Cu-250;Fe-250;Li-5;Mn-250;Mo-250;N-200;Ni-200;P-250;Pb-250;Si-250;Sn-250;Th-10;Ti-250;V-250;Zn-250,W-250
Maximum humidity	< 1%
Al Powder	
Particle Size	< 44 μm
Al Content	> 99%
Al_2O_3 Content	< 0.7%
Impurities	< 0.1%
Chemical Composition Limits (ppm)	Cu-20000;Fe+Si-95000;Mn-5000;Zn-10000;Other-5000;B-10;Cd-10;Li-10;Co-10
U_3O_8-Al compact	
U_3O_8 Mass	58.5 ± 0.2 g
Al Mass	46.5 ± 0.2 g
Density	4.1 ± 0.2 g/cm^3
Nominal Dimensions (mm)	104.2 x 59.1 x 4.2
Picture Frame and Cladding	
Material	Aluminum , alloy 1060
Fuel Plate	
Homogeneity	
Nominal	26.8 mg^{235}U/cm^2
Maximum Central Deviation	± 12%
Maximum Extremities Deviation	± 25%
Blister Test	500 °C/1 hour without any blister
Dimensions (mm)	
Internal Plate Dimensions	625 x 70.75 x 1.52
External Plate Dimensions	714 x 70.75 x 1.52
Active Region Dimensions	590 (min.) x 60.35 (min.) x 0.76
Cladding Thickness	0.38 (nominal) ; 0.25 (min.)
Defects	
White Points	< 0.5 mm of diameter. ; > 0.4mm from plate border
Cladding Surface	< 0.1 of depth
Surface Contamination	< 10 μg of U per plate
Side Plates, Bottom Nozzle and Handle Pin	
Material	Aluminum - alloy 6262 T6
Fuel Element Assembly	
Fuel Plate Extraction Force (mechanically assembled)	20 to 30 N/mm
Channel Width	2.89 mm

The fuel element assembly geometry is the same for HEU and LEU fuels. The difference is the fuel material and the fuel plate meat (and cladding) thickness. Fuel plate thickness was kept without any change for all different fuels, and this was done due to the criteria of maintaining a homogeneous water channel in the assemblies even in an heterogeneous core configuration with HEU and LEU fuels.

Quality assurance is applied both in design and fabrication of fuel element assembly. Specifications and drawings are well established for fuel materials, components and assemblies. Written procedures are established for all processes involved. Process parameters verification and control during fuel fabrication, and quality control upon all fuel element assembly specification parameters (materials, components, and assembly), are important tasks.

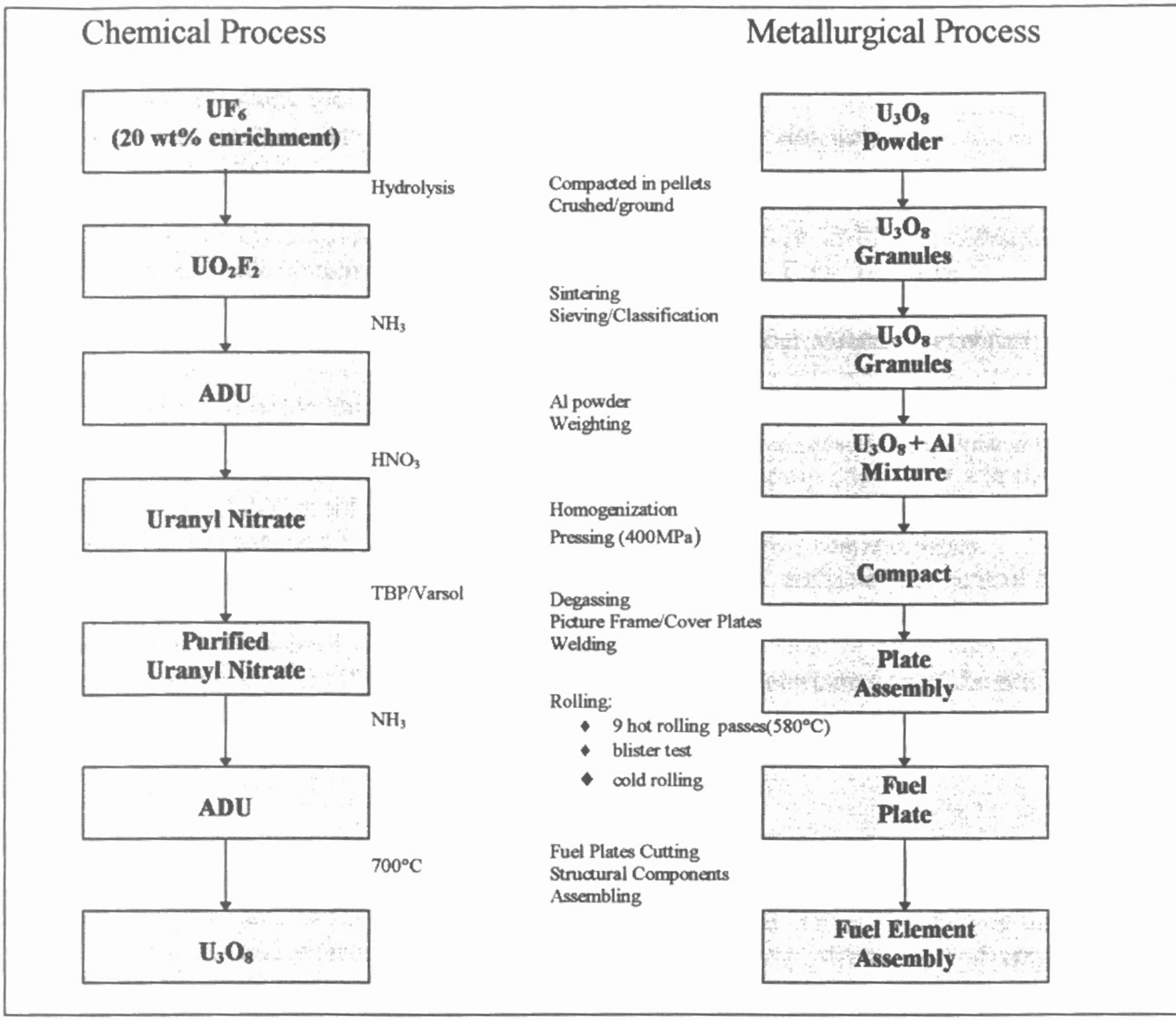

Figure 4 - Fabrication Characteristics of IPEN Fuel.

FUEL TESTING AND EVALUATION

Brazil has no hot cell laboratories for testing irradiated fuels or irradiated materials. Irradiation and post-irradiation analysis of miniplates and full size plates at foreign countries would be very expensive and there were no budget for this. As IPEN fuel specification was conservative for a dispersion fuel and as the power of reactor is low it was decided to take the risk of testing and evaluating the fuel performance, in pile, during reactor operation. A sequence of testing events and procedures was set to qualify the fuel. It started with irradiation of some miniplates at the border of the reactor core just to identify any abnormal event. A fuel element assembly with only two fuel plates (the external plates) and 16 aluminum plates was placed in the core to start fuel qualification (July 1985). After this, a fuel element assembly with 10 fuel plates and 8 aluminum plates was also placed in the core (November 1985). These two fuel element assemblies were identified as the precursor fuels and a periodic monitoring and evaluation was done upon them. After good experience with the precursor fuels it was decided to start loading standard fuel element assemblies in the reactor core (September 1988). The criteria adopted was that each IPEN fuel element assembly had to start irradiation at peripheral positions of the core, with lower power densities, up to 4 % burnup (almost one year of irradiation) and then it could go to higher power density positions in the core. It was decided that the precursor fuels had to stay in the core up to the time that a complete fuel assembly could equal their burnup.

The program of evaluation has been consisted of the following items:

i) monitoring:

reactor power; time of operation; neutron flux calculation at the position of each fuel assembly; burnup calculation; inlet and outlet water temperature in the core; water pH; water conductivity; chloride content in water; radiochemistry analysis of reactor water.

ii) inspection:

periodically underwater visual inspection of each fuel assembly; eventual sipping test of fuel assembly.

The last precursor fuel assembly was taken out of the reactor core with 18% burnup (average). Today (September 96) there are 20 IPEN fuel element assemblies, with a fuel element assembly leading burnup of more than 30% (maximum peak burnup around 50% in the fuel plate) without any detectable problem. Also this year the reactor operated, experimentally, for 48 hours at 5 MW and the fuels performed without any modification of their characteristics.

A special development was carried out for the mechanical design of the control fuel element assembly . A dummy assembly was built and tested in the core for the necessary mechanical adjustments to the dashpot device. Today all the control fuel element assemblies of the reactor core are LEU, made by IPEN. Under the evaluation program, determination of the profile (space x time) of control rod insertion during scram action is being periodically made.

FUTURE PLANS

Due to the growth of radioisotope demand in Brazil, for medical diagnosis and therapy, IPEN had decided to increase IEA-R1 power to 5 MW and to operate it continuously around the week. ^{99}Mo (^{99}Tc) will be the main radioisotope to be produced. Three projects are under way to achieve this goal: fuel element production; adequacy of systems, structures and components of IEA-R1 Reactor; and adequacy of the radioisotope production.

In order to optimize the core flux for radioisotope production and also to increase the core reactivity without increasing the number of fuel assemblies in the core, it was decided to increase the uranium content in fuel assembly. The IPEN U_3O_8-Al dispersion fuel will have the content of uranium in the fuel plate increased from 1.9 gU/cm^3 to 2.3 gU/cm^3. This new fuel has, in terms of fabrication process and material specification, no significant change compared to the present one. Also in terms of fuel performance under irradiation it is not foreseen any significant change compared to the present fuel. Up to the middle of 1997 eight fuel assemblies with 2.3 gU/cm^3 fabricated by IPEN will replace the HEU fuel assemblies that are still in the core. This new fuel will be also qualified under irradiation as has been qualified the present IPEN fuels. These new fuels will allow the core to operate with 25 or less fuel assemblies, to increase power from 2 to 5 MW and the continuous operation schedule of the reactor with a reposition rate of 10 to 12 fuel assemblies per year.

IPEN is also planning to use U_3Si_2-Al dispersion fuels in substitution to the U_3O_8-Al fuels. The strategy is to use, in the fuel plate, the same volume of U_3Si_2 that is used for the U_3O_8 in the 1.9gU/cm^3 fuel plate (27%, in volume, of U_3O_8). This U_3Si_2 volume percentage will increase the uranium density of the fuel plate to 3.0 gU/cm^3. Research in this subject has already been done [20], and IPEN is also buying U_3Si_2 powder in order to produce some fuel assemblies prototypes and initiate their irradiation at IEA-R1 Reactor.

Besides these fuel changes IPEN will try to change the actual graphite reflectors to metallic beryllium reflectors and will also use fluxtrap devices in order to achieve the desired core configuration for good radioisotope production.

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