Management of Spent Fuel from Research Reactors - Brazilian Progress Report (within the framework of Regional Project IAEA-RLA-4/018)

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Introduction

There are four research reactors in Brazil. For three of them, because of the low reactor power and low burn-up of the fuel, except for the concern about ageing, spent fuel storage is not a problem. However for one of the reactors, more specifically IEA-R1 research reactor, the storage of spent fuel is a major concern, because, according to the proposed operation schedule for the reactor, unless an action is taken, by the year 2009 there will be no more racks available to store **its** spent fuel. This paper gives a brief description of the type and amount of fuel elements utilized in each one of the Brazilian research reactors, with a short discussion about the storage capacity at each installation. It also gives a description of the activities developed by Brazilian engineers and researchers during the period between 2001 and 2004, within the framework of regional project "RLA-4/018-Management of Spent Fuel from Research Reactors". As a conclusion, we can say that the advances of the project, and the integration promoted among the engineers and researchers of the participant countries were of fundamental importance for Brazilian researchers and engineers to understand the problems related to the storage of spent fuel, and to make a clear definition about the most suitable alternatives for interim storage of the spent fuel from IEAR1 research reactor.

1. - Brazilian Research Reactors

Brazil has 4 research reactors (RR) in operation. IEAR1, considered the most important one, is the oldest in the southern hemisphere. The reactor, a MTR open pool RR is located at IPEN[1], in the campus of São Paulo University, in São Paulo city. It started to be built in September 1956, and reached criticality for the first time on September 16th of 1957. Although designed to operate at 5 MW, from 1957 until 1995 the power level was maintained between 200 kW and 2 MW. In 1995 a program was established with the objective to start production of ^{153}Sm, and to prepare the reactor to produce ^{131}I and ^{99}Mo. As result of this decision the regime of operation was changed to continuous 64 hours per week, from Monday through Wednesday, keeping the reactor power at 2 MW, and some modifications started taking place to allow the reactor to operate continuously during 120 hours per week at 5 MW. The burn-up rate, which is actually 360 MW-Day per year, is expected to increase to 1100 MW-Day per year.

IPR-R1 is the second Brazilian RR. Located at CDTN[2], in the campus of Federal University of Minas Gerais, in Belo Horizonte city, the reactor, a 100 kW Triga Mark I reactor, achieved criticality for the first time on November of 1960. The reactor operates as required, and can reach the rate of 8 hrs per day, 5 days per week, 40 weeks per year. The accumulated burn-up of the reactor since its first criticality until present time is about 150 MWDays. Due to the low nominal power of the reactor, except for ageing concern, spent fuel is far from being a problem.

The third Brazilian RR is called Argonauta, and is located at IEN[3], in the campus of the Federal University of Rio de Janeiro, in Rio de Janeiro city. The first criticality of the reactor, which has a nominal power of 200 W, was reached on February of 1965, and actually it operates 4 hours per day, 5 days per week, 43 weeks per year. The accumulated burn-up of the reactor since its first criticality is about 0,25 MWDays, and as in the case of IPR-R1, due to the low nominal power, storage of spent fuel is not a problem.

The most recent Brazilian RR is IPEN/MB-01. Located at IPEN[1], it is the result of a national joint program developed by the Brazilian Nuclear Energy Commission and the Brazilian Navy. The reactor, a water tank type critical facility rated 100 W, is mainly used for simulation of small LWR and research in reactor physics. It reached criticality for the first time on November of 1988. For IPEN/MB-01 the accumulated burn-up is below 0,1 MW-Day.

Maximum fuel enrichment for IPEN/MB-01 is 4,3%, and for the other 3 reactors is 20%. Table 1 summarizes the characteristics of the fuel elements of the four Brazilian RRs, and figures 1 to 4 show a picture of them.

As explained before, due to the low nominal power rating of IPR-R1, ARGONAUTA and IPEN/MB-01 RRs, except for ageing concern,

1- IPEN – Nuclear and Energetic Research Institute
2- CDTN- Nuclear Technology Developing Center
3- IEN – Nuclear Engineering Institute

for them storage of spent fuel is not a problem. In the case of IPR-R1, the first refueling is expected to occur around 2010, and the installation has a capacity to storage 60 spent fuels.

TABLE 1. Fuel Characteristics of Brazilian Research Reactors

Reactor	Type of fuel element	Fuel Elements per assembly	Number of assemblies in core
IEA-R1	U_3O_8-Al & U_3Si_2-Al plates	Standard: 18 Control : 12	Standard: 20 Control: 4
IPR-R1	UZrH rods	1(each rod is one assembly)	1961 : 54 2003 : 59
Argonauta	U_3O_8-Al Plates	Standard: 17 Control : 7	Standard: 6 Control : 2
IPEN/ MB-01	UO_2 pellets within SS tubes	1(each tube is one assembly)	680

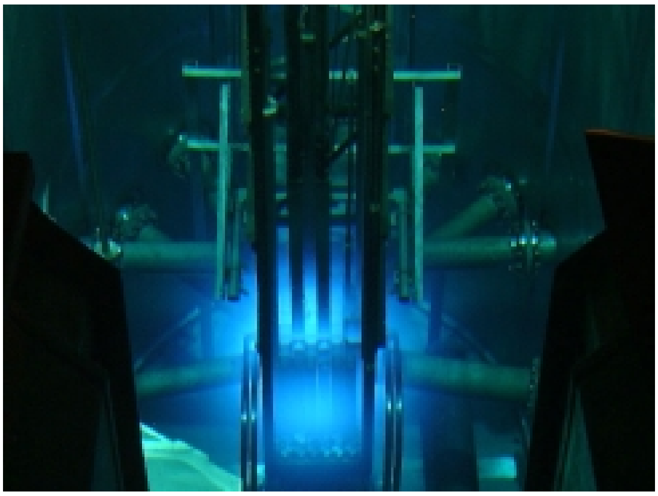


Figure 1 – IEA-R1 Reactor

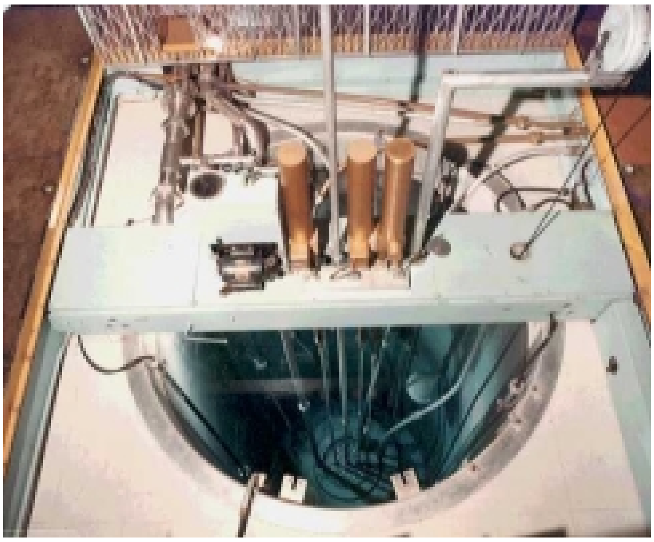


Figure 2 – IPR-R1 Reactor

For the ARGONAUTA reactor the situation is similar. The facility has a fuel storage capacity for 12 elements, in dry storage, and there is no expectation to replace any fuel assembly in the next 10 years. IPEN/MB-01 also has a very comfortable situation, since it has only 680 fuel elements and 3500 position available for dry storage. Since it is a critical assembly, the expectation is to replace all fuel elements (with low burn-up) at the same time, to study a new core configuration.

Figure 3 – Argonauta Reactor

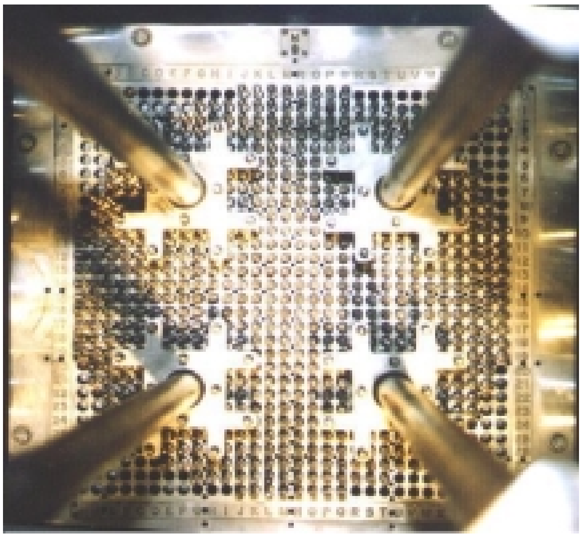


Figure 4 – IPEN/MB-01 Reactor

When we analyze the situation for IEAR1, we see that its situation is not so comfortable, even considering that in 1999, 127 spent fuel elements were sent back to United States of America, within the USA "Research Reactor Spent Nuclear Fuel Acceptance Program", because, according to the new proposed operation schedule of the reactor, the refueling frequency is expected to be between 22 and 24 fuel assemblies per year. Since the total storage capacity of the facility is 156 assemblies in the (wet) storage area of the pool, and from these, 29 are already being used to store spent fuel, and 24 are required to store the fuel used in the reactor core, in case of necessity, this means that only 103 positions are available for storage of new spent fuel, and if no action is taken until 2009, there will be no more racks available to store new spent fuel assemblies.

2. – The IAEA RLA4-018 Regional Project

Considering that the option to send spent fuel to USA will cease on 2006, on 1999 Dr. Gonzalo Torres, a research reactor manager from Chile, decided to propose a regional project to study the problems of spent fuel in the Latin America region. After one year of discussions, the project was finally approved by IAEA, for the biennium 2001-2002, with participation of Argentina, Brazil, Chile, Mexico and Peru. The project was defined with one main objective: to define a regional strategy for the management of the spent fuel from the research reactors of the region, based on the economic and technological realities of each participant country; and two specific objectives: to define specific conditions for operational and interim storage of the spent fuel for each specific research reactor, and to establish forms of regional cooperation for final disposal of the spent fuel, or its sub-products.

During a first Coordination Meeting, held in 2001, four working groups, considered of fundamental importance for the success of the project, were defined: characterization, storage options, public communication and regulation and safety. Due to the large range of activities related to the characterization of spent fuel, this working group was subdivided into 5 subgroups, namely: burn up, visual inspection, sipping, corrosion, and Eddy current testing.

What follows is a description of the activities developed by Brazilian researchers and engineers on each one of the above areas.

3. - Characterization of Spent Fuel

3.a - Burn up

Two methodologies have been used in Brazil for fuel burn up calculation: Monte Carlo simulation combined with Monteburns code system, and a combination of LEOPARD, HAMMER-TECHNION, and CITATION codes.

Monte Carlo simulation with Monteburns is used for IPR-R1 reactor. It is an automated computational tool that links the Monte Carlo code MCNP with the burn up and decay code ORIGEN2.1.

Monte Carlo simulation, with Monteburns was used in an inter-comparison exercise to calculate the burn up of fuel element PO4, from Argentine RA3 research reactor. The result of the inter-comparison is shown on tables 2 and 3.

Table 2. Calculated discharged average burn-up for the P04 fuel assembly.

Country	Codes	Burn-up (% U_{235})
AR	WIMS-PUMA	23.5
BR	ORIGEN-MCNP-MONTEBURNS	19.5
CH	WIMS-CITATION	22.8
MX	ORIGEN	16.8
PE	WIMS-CITATION	23.2

Table 3. Average burn-up for fuel plates 09 and 19 of the P04 fuel assembly.

Country	**Average Burn-up, Plate 9** [% U_{235}]	Average Burn-up, Plate 19 [% U_{235}]
BR	19.0	20.7
CH	19.7	22.6
PE	17.0	20.9
AR	18.2 (experimental)	22.2 (experimental)

The burn up calculation methodology used for IEA-R1 reactor is based on LEOPARD and HAMMER-TECHNION programs for cross section generation, 2DB program for the core and burn up calculations in a two-dimensional geometry and CITATION program for a three-dimensional analysis to obtain effective multiplication factor, neutron flux and power density distributions, integral and differential control rod worth, reactivity coefficients and kinetic parameters.

For fuel burn up measurements, an experimental arrangement has been developed to measure the burn up of MTR type fuel elements of IEAR1 reactor, using the non destructive methodology based on gamma spectroscopy. The methodology considers the use of fission product ^{137}Cs for fuel elements with cooling time longer than 2 years, and the ratio $^{144}Ce/^{144}Pr$ for elements with cooling time shorter. The system, shown in figure 5, was developed in 2000, and can be used whenever it is necessary.

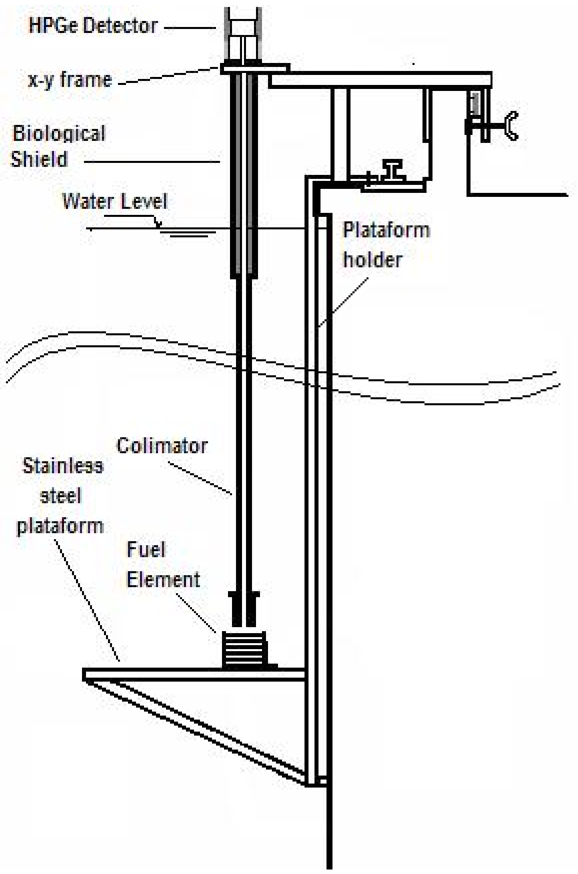


Fig. 5 - Experimental apparatus for burn up measurements installed at the pool area of IEA-R1 research reactor.

3.b- Visual Inspection

IEAR1 irradiated fuel element assemblies have been routinely inspected using an underwater radiation resistant video camera, inside the reactor pool. The system, shown in figure 6, has a B&W camera and allows only the visualization of the surface conditions of the two external fuel plates and the two external support plates. The visualization of the internal fuel plate’s conditions is not possible.

The system has been extensively used during the last four years, to inspect reflectors, fuel elements, and reactor safety and control rods. The inspection of the fuel elements realized on October 2002, resulted in a proposition for a spent fuel catalog, which is shown on top of next page**.**

A digital camera, operated from the top of the reactor pool, has been used as an alternative device to visualize components of the reactor, and last month we received a color system, camera and monitor, which is being used to update the spent fuel catalog.

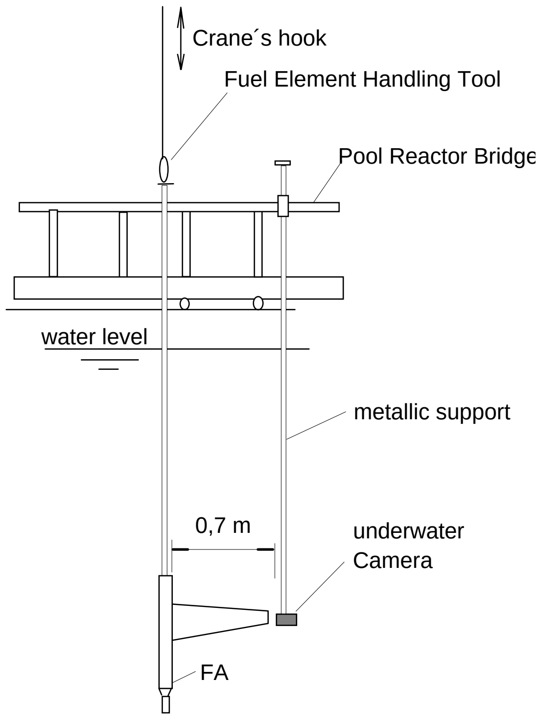


Fig. 6 – Fuel Inspection arrangement

3.c- Sipping

Sipping tests are performed to detect and quantify failures in fuel elements. At IPEN, the system is basically composed by an aluminum tube which has in its bottom extremity an inlet coupled to a ¾“ PVC tube as shown in figure 7. The PVC tube is connected to a demineralyzed water circuit or to a compressed air system, depending on the operation phase.

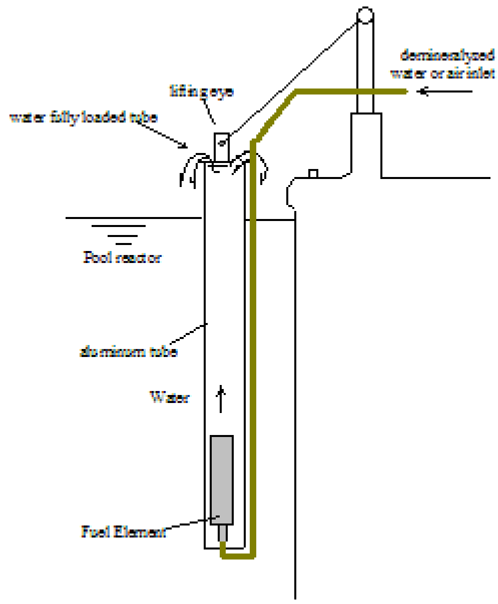
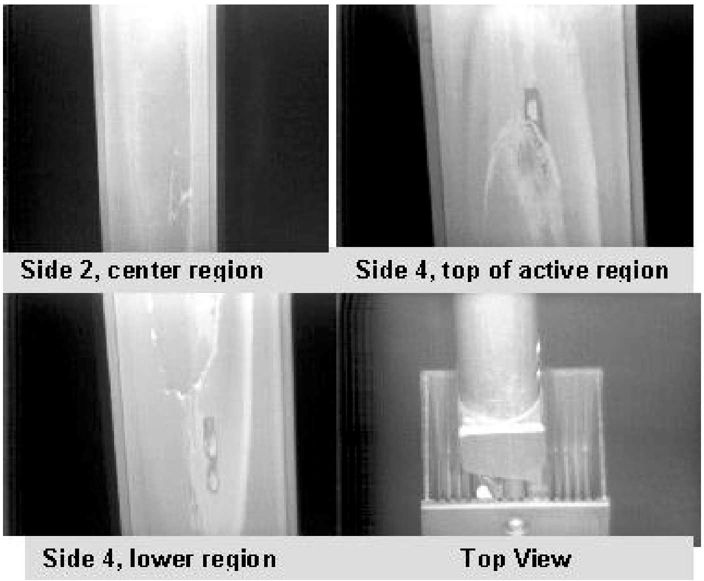


Figure 7- Fuel sipping system

Facility Name: **IEA-R1 Research Reactor** Country: **BRAZIL**

FUEL ASSEMBLY CHARACTERIZATION DATA SHEET



Fuel Identification: IEA-148

Supplier : Ipen

Type - MTR - Enrichment : 20%

Dimensions (cm) : 7,97x7,61x87,30

Material - U3O8- Al 1100

Cladding - Al ASTM 1060

Number of fuel plates : 18

Initial Mass of U-235 : 180 g

Specific Mass - 1,9 g(U3O8)/cm3

First day in Reactor Core : 16/10/95

Removed from core on : 13/09/99

Calculated Burn up (% 235 U) : 23,48

Measured Burn up :

Date:	**Classification**	
	Visual Inspection	**Sipping**
Oct/2002	**V1**	**S0 (Oct/99)**

GENERAL REMARKS:

1 - At central region, thin thickness of aluminum oxide layer was lost

REVISION 0: November/2002 By: JERS; AJS

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Proposal for a spent fuel catalog based on visual inspection and sipping tests

Because of some increase on the radiation level within the reactor room, due to fission products, on February 2003 it was necessary to make sipping testes of all fuel elements used in the reactor core. No leak was detected from the fuel elements, and after an exhaustive analysis, the source of radiation was found to be a leaking element (IEA-156), replaced 1,5 years before, and stored at a position about 8 meters away from the reactor core. After isolation of the leaking element, the radiation levels returned to normal values.

3.d - Corrosion

During the first coordination meeting, it was decided to establish an experimental program to study the corrosion of the materials (aluminum and stainless steel) used as cladding of the several fuel elements. To do this, a test rack was specified, and a test program was defined. Figure 8 shows a typical test rack used in the program. Each rack was built with 15 coupons, as follows:

Al-1050
Al- 6061
Al-1050 (pre-oxidized and scratched)
Al-1050/Al-1050 (crevice couple)
Al-1050/Al-6061 (crevice couple)
Al-6061/Al-6061 (crevice couple)
Al-1050/SS 304 (galvanic couple)
Al-6061/SS-304 (galvanic couple)
Al-5052/SS-304 (galvanic couple)

Figure 8 - Test rack used in the corrosion program.

A total number of 13 positions were selected for the test, being 6 in Argentine, 2 in Chile, 2 in Brazil, 2 in Peru, and 1 in Mexico. Each position should receive 3 racks, to be removed one per year, during the next three years. It was decided that the analysis of all racks should be made at the corrosion laboratory available at IPEN, in Brazil, using a LEICA image analyzer bought by IAEA.
After overcoming some bureaucratic problems the test racks were delivered by middle July of 2002. In the Brazilian reactors, the racks were placed as indicated in Figures 9 and 10

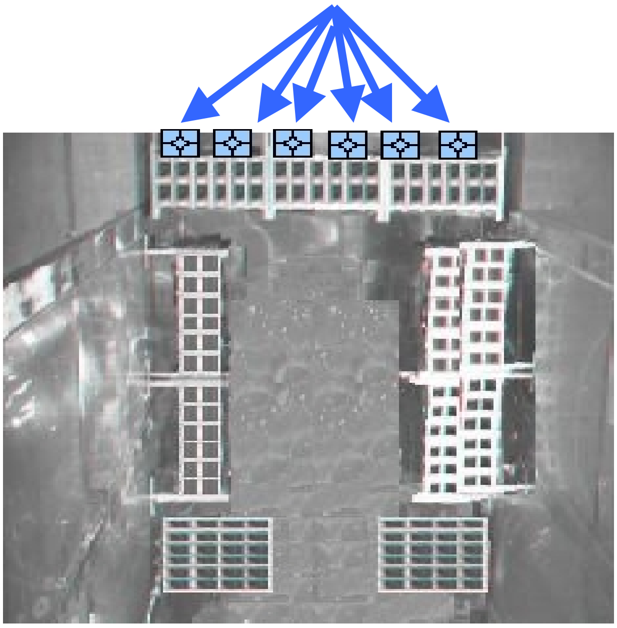

Fig 9 – Location of racks in IEAR1 storage pool (IPEN).

The withdrawn and analysis of the first set of racks was as follows:

Rack	Immersed	Withdraw	Analysis
CDTN	Jul/02	Jul/03	Aug/03
IEAR1	Jul/02	Jul/03	Aug/03
Chile	Oct/02	Oct/03	Oct/03
Peru	Oct/02	Oct/03	Oct/ 03
Argentina	Nov/02	Sep/03	Oct/03
Mexico	Feb/03	Sep/03	Oct/03

The results of the first set of racks were discussed in a RWS on December of 2003. During this RWS, the specialists updated the test protocol and raised the possibility that the decontamination process affected pitting corrosion features. Then, a decision was taken to evaluate this effect in IPEN, prior to withdraw of the second rack. This effect was evaluated and the final conclusion was that decontamination performed with 5 and 50% (in volume) of phosphoric acid does not change the characteristics of the pits. Also, during the RWS, a decision was taken to evaluate how the orientation of the coupons could affect their corrosion, and a new set of coupons was specified and are being made available to all participants, to repeat the tests using a vertical orientation for the coupons.

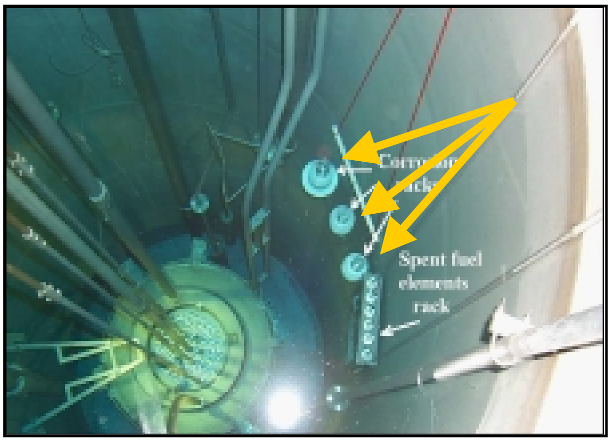

Figure 10 – Location of racks in IPR1 tank (CDTN)

The withdrawn and analysis of the second set of racks is being performed during the period of September-November of 2004, and the results will discussed in a WS to be hold on December 2004.

Since water quality control is an essential part of the corrosion monitoring program. Water quality of IEAR1 is monitored daily, for conductivity, pH, clorine., and weekly for some specific radioisotopes. During the RWS on corrosion, all participants reported the presence of sediments on the reactor pool, therefore a decision was taken to determine the quantity and composition of the sediments in the different basins. To this effect, the procedure to obtain this information was elaborated and the design of the sediment collector was detailed. The proposition was to install the collectors in all basins until March/04 (except in Peru), withdrawn then by September/04 and have measurements made on October/04.

3.e - Eddy Current testing

Eddy current testing was proposed and accepted as an additional activity within the group of spent fuel characterization. Two experts and two technicians from CDTN have worked in this activity since 2001. During the period of 2001-2002, they designed and developed special inspection probes and a series of 22 calibration standards, as shown on figure 11, to test TRIGA type fuel elements. The calibration standards were built using electric discharge machining on rectangular 1050 Aluminum sheets. After machined, all sheets were carefully bent in order to reproduce the adequate shape and curvature of the Triga fuel type.

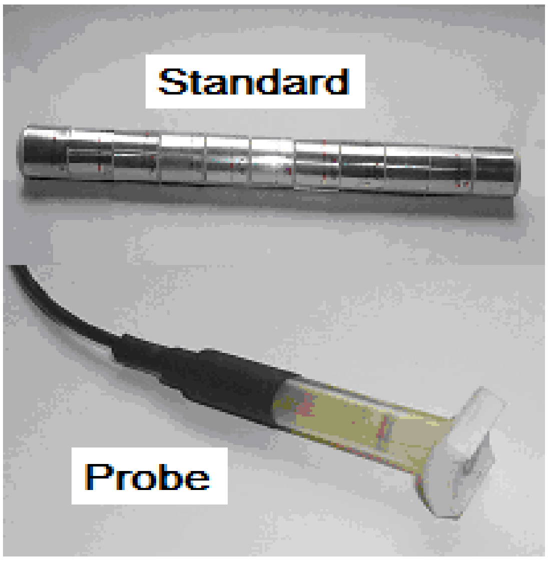

Figure 11 – Developed standard set and probe for Eddy current tests of Triga type fuel elements

For testing MTR fuel types, a set of 15 reference standards for IEAR1 fuel elements, using Al-1050 was prepared. Each set has three laminated plates, two of them external, (0.38 mm in thickness) corresponding to the cladding material. A central piece (0.76 mm in thickness) represents the meat of the fuel plate. For each reference standard a different discontinuity, in the form of holes or cracks, was machined in one of the cladding plates. The probes, shown in figure 12, were developed with the adoption of printed circuit technology and utilization of ferromagnetic core.

Figure 12 – Probe developed for MTR type fuel elements

Test results, performed at laboratory conditions, demonstrated the applicability of the Eddy current methodology to inspect both, IPR-R1 TRIGA type and IEAR1 MTR type fuel elements, however, in order to consolidate the methodology, we still need to develop an appropriated scanning system for both reactors, to make in situ measurements.

4. - Storage Options

Initially, the main activity for the group of options was to outline the contents for a document which should define the options for research reactor spent fuel management, storage, conditioning, transportation and ultimate disposal in the countries of Latin America. In sequence a draft of the document was consolidated. The document considers interim and final disposition, including the definition of a transport cask with both possible applications for it, transport and storage. The final version of the document will be issued by the end of the year.

During the period of 2001-2002, IPEN started an internal discussion about the necessity of an interim storage facility to be built before 2009, when all positions on the fuel storage pool of IEAR1 research reactor will be loaded. Therefore within the scope of this project, the engineers and researchers of IPEN, started discussions toward a decision about what is the most suitable solution for interim (temporary) storage of the spent fuel from IEAR1. Two possibilities were defined. The first one considers the possibility of using an installation close to the reactor building, which in part overlaps with the reactor building (see Figure 13), and transform it in a dry interim storage facility. The

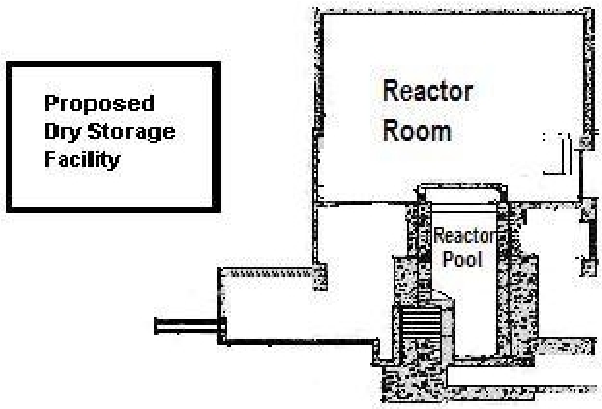

Figure 13 – Location of an alternative dry storage facility for spent fuel from IEAR1 RR.

second option considered is to store the spent fuel within a dual purpose cask, which is being developed as part of the regional project. A final decision, including the emission of the safety related documents for approval of the regulatory authority, is expected by the end of 2006.

4.a – The dual purpose cask

During the first RWS on "Options", held in 2002, Brazilian engineers and researchers were asked to design and development of a dual-purpose cask, for transport and storage. In this activity the principal designers are the engineers of CDTN, who have developed the infra-structure to test a B type transport cask, as shown on figures 14 to 16.

Figure 14 – Lift and release mechanism

The proposed cask was dimensioned for 21 MTR type and 78 TRIGA type spent fuel elements. Figure 16 shows the conceptual design of the cask.

Preliminary shielding calculations were made using the SAS4 modulus of the SCALE code. SCALE is also being used to obtain the source term (using modulus ORIGEN-ARP). In this phase, MCNP code is being used for criticality calculations, because it is faster, and is used to obtain the dimensional parameters needed for the structural analysis, however calculations for the Safety Analysis Report, to be submitted to the regulatory authority, will be made using KENO, a modulus of the SCALE code, which was bought by IAEA and distributed to all participant countries. Also, SCALE will be used to determine the fuel decay heat.

Figure 15 – Concrete and SS platform

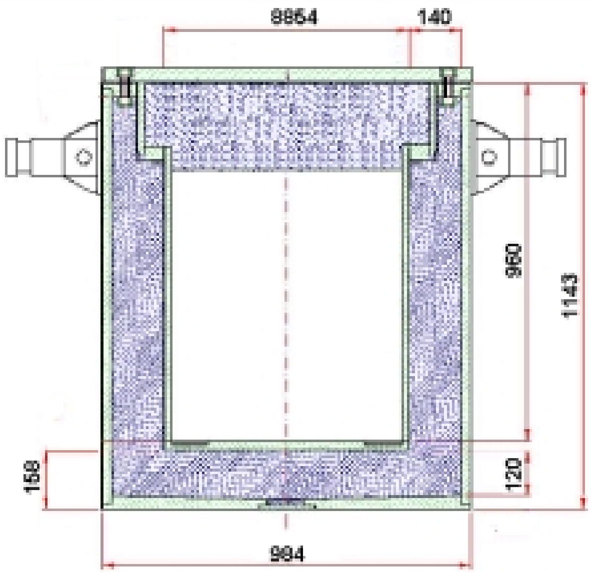

Figure 16 – Proposed storage and transport cask.

For the year 2004 it was proposed to build a half scale model of the cask to be tested by the end of year, however, because of some difficulties during the design phase of the model, the signature of the contract is schedule for the last quarter of 2004, and we expect to build and perform the tests during first semester of 2005. A set of 55 drawings has been produced for the model, and were made available for the participant countries. Regarding the tests, Figure 17 shows the necessary test sequence. As acceptance criteria, after the tests, the specimen must keep its shielding integrity, thermal protection, and must present no leakage or, at the most, a very limited leakage.

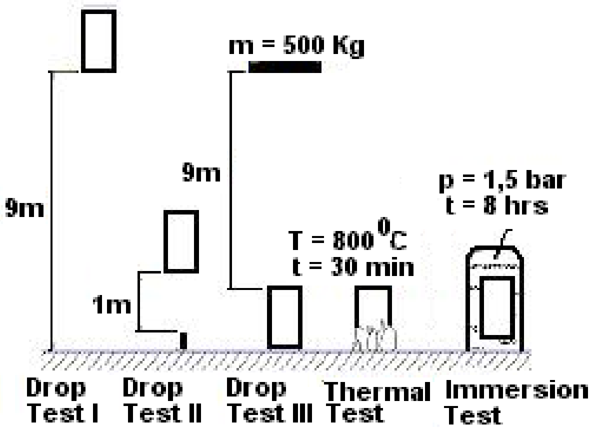

Figure 17 - Test sequence for Type B packages

4.b - Processing and Conditioning

During the 1st RWS on Options, held in 20002, it was decided to include activities related to processing and conditioning of burned fuel. In a extra meeting called specifically to discuss these activities, we reached the conclusion that this activity still needed a lot of research and development, and a proposed program, related to HALOX processing method, electrochemical separation and vitrification was planned. On this meeting, Brazilian researchers agreed to study the efficiency of the electrochemical separation process to reduce the volume of spent fuel. To verify the best conditions of Al electrodissolution some experiments were planned, using U_3Si_2/Al targets. The targets, containing about 0,5 gr of meat with natural Uranium, were irradiated, during 40 hours at thermal flux level of 10^{13}. The best conditions, established in previous experiments, were the basis to dissolve only the Al, keeping, as much as possible, the fission products insoluble in the media studied. A preliminary report of this work was presented during the coordination meeting held on March 2004.

Regarding "conditioning", in the beginning of 2003 a joint program was established between researchers of IPEN (Brazil) and Centro Atomico de Bariloche (Argentina), to study the behavior of some matrices proposed for immobilization of high level waste. Within this program, 7 matrices were selected, as listed on Table 5. The matrices are being produced and characterized in both laboratories, and at Centro Atomico la Reina, in Chile, which has a laboratory that allows to accelerate the corrosion process of glasses used for vitrification, using a technique known as "Vapor Hydratation Test" (VHT). The work developed at CAB is mainly related to melting in electrical furnaces and sintering. The work developed at IPEN is mainly related to melting in electrical furnaces, melting in microwave ovens, and sintering. Therefore, some of the work done at CAB and IPEN are similar, and the results will be used as part of a "joint qualification process".

Table 5. Glass matrices used in vitrification studies.

a) Iron Phosphate glasses

	[% mol]			
Batch ID	P2O5	Fe2O3	Al2O3	Na2O
CAB 1	60	40	-	-
CAB 2	60	30	-	10
CAB 3	60	30	10	-
CAB 4	61	19	11	9

b) Niobium Phosphate glasses

	[% mol]				
Batch ID	P2O5	Nb2O5	BaO	K2O	PbO
BP12-18	30	15	12	25	18
NB40	37	40	-	23	-
NB20	40	20	30	10	-

5. - Public Communication

The program of activities related to public communication was considered one of the most important in the project, because it is directly related to public acceptance of the proposed alternatives for storage and disposal of the spent fuel from research reactors. It started with a questionnaire about "communication strategy" prepared by Mr. Rosamel Muñoz from Chile, and answered by the professionals from other countries. During the 1st WS, held in Santiago de Chile, on December 2001, the communication strategy of each participating country was evaluated, and for a common activity, it was decided to produce a brochure to be distributed to politicians, media professionals, professors, and general public. The purpose of the brochure is to describe the benefits of nuclear energy, provided by research reactors, with a description of research reactors in all participant countries, and an introduction of the spent fuel problem. The brochure included a questionnaire for the receivers to produce some feedback information to be used in future activities. A draft of the brochure was prepared during the 2nd WS held in São Paulo, in February 2003, and the final version published in June of that year. A total of 10.000 copies were produced, being 8000 in

Spanish and 2000 in Portuguese. According to the strategy defined, the brochure, and the questionnaire, should be mailed with a letter signed by the highest possible national authority related to nuclear activities in the country, but because of some transition in the Brazilian Nuclear Energy Commission, only in 2004 it was possible to obtain such a letter. The distribution process is under way, and we expect to conclude the analysis of the questionnaire before the end of this year.

6. - Safety and Legislation

During the first coordination meeting, it was observed that most of the participant countries did not have a specific legislation to deal with transport and storage of spent fuel from research reactors, therefore a RWS on Safety and Legislation was planned, with legislators of all participant countries. During this RWS, held in Mexico City in 2001, it was defined that five documents, related to regulation and legislation of spent fuel from research reactors (SFfRR), should be prepared. Four of documents would be applied for storage, and the last one for transport. The proposed documents were:

I-Safety evaluation for storage of SFfRRs;
II-Requirements for operational storage of SFfRRs;
III-Requirements for interim storage of SFfRRs;
IV- Requirements for final storage of SFfRRs.
V-Design guide for transport of SFfRRs;

A draft of above documents was prepared, but during the 2nd RWS, held in Lima, it was realized that the regulatory body of participant countries could not accept the documents as initially proposed, and a decision was made to review the number of documents and their titles. In a first instance, the “requirements” became “guides”, and finally the “guides” became “recommendations” .Therefore, the final decision was to produce 4 documents in the form of “recommendations”, namely:

A- Recommendations for design of casks to transport SFfRRs;
B- Recommendations for design of installations for interim storage of SFfRRs,;
C- Recommendations for the safety analysis of installations for interim storage of SFfRRs.
D- Recommendations for the transport of SFfRRs;

The four documents were concluded on February 2003, and actually Mr. Santiago Edgar Marzana Flores, a researcher from CDTN, is making the translation to Portuguese, while Ms. Vera Lucia Cavalcante, from Brazilian Regulatory Authority is making the final revision. We expect to have all four documents published in Portuguese by March 2005.

7. - Effective participation

Year	2001	2002	2003	2004
Number of persons involved	26	34	41	41
Man-Hour	2350	4355	11070	7870

8. - References

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