IRPA 12
19 - 24 October 2008
BUENOS AIRES - ARGENTINA

IPR-R1 TRIGA RESEARCH REACTOR DECOMMISSIONING PLAN

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Abstract. The International Atomic Energy Agency (IAEA) is concerning to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes. In this way the IAEA recommends that decommissioning planning should be part of all radioactive installation licensing process. There are over 200 research reactors that have either not operated for a considerable period of time and may never return to operation or, are close to permanent shutdown. Many countries do not have a decommissioning policy, and like Brazil not all installations have their decommissioning plan as part of the licensing documentation. Brazil is signatory of Joint Convention on the safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, but until now there is no decommissioning policy, and spacifically for research reactor there is no decommissioning guidelines in the standards. The Nuclear Technology Development Centre (CDTN/CNEN) has a TRIGA Mark I Research Reactor IPR-R1 in operation for 47 years with 3.6% average fuel burn-up. The original power was 100 kW and it is being licensed for 250 kW, and it needs the decommissioning plan as part of the licensing requirements. In the paper it is presented the basis of decommissioning plan, an overview and the end state / final goal of decommissioning activities for the IPR-R1, and the Brazilian ongoing activities about this subject.

KEYWORDS*: *Decommissioning, Research Reactor, TRIGA Mark I.

1. Introduction

All nuclear installations should be commissioned, and after their shutdown they should be decommissioned. There are many factors that bring to the decision to shutdown a nuclear installation, for example obsolescence, security, regulatory aspects, political changes, accidents, low performance, etc. There are over 200 research reactors that have either not operated for a considerable period of time and may never return to operation or they are close to permanent shutdown [1, 2].

Decommissioning is defined as all administrative and technical actions that should be taken at the end of a nuclear installation in order to assure the suitable physical and radiological protection to the workers, general public, and environment [3]. These actions allow also the removal of the installation from the regulatory control. This process involves two phases: decontamination and dismantling. The decontamination is the phase in which the complete or partial removal of contamination is done by a physical, chemical or biological process. The dismantling consists on the disassembly and removal of any structure, system or component during decommissioning. Dismantling may be performed immediately after permanent retirement of a nuclear facility or it may be postponed.

The decommissioning plan is the document, in which is organized all information about the proposed decommissioning activities for the facility. It allows the regulatory body to make a proper evaluation and to ensure that decommissioning of the facility can be performed in a safe manner. IAEA is concerned to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes. In this way the IAEA recommends that decommissioning planning should be part of all radioactive installation licensing process. Many countries do not have a decommissioning policy, and like Brazil not all installations have their decommissioning plan as part of the licensing documentation.

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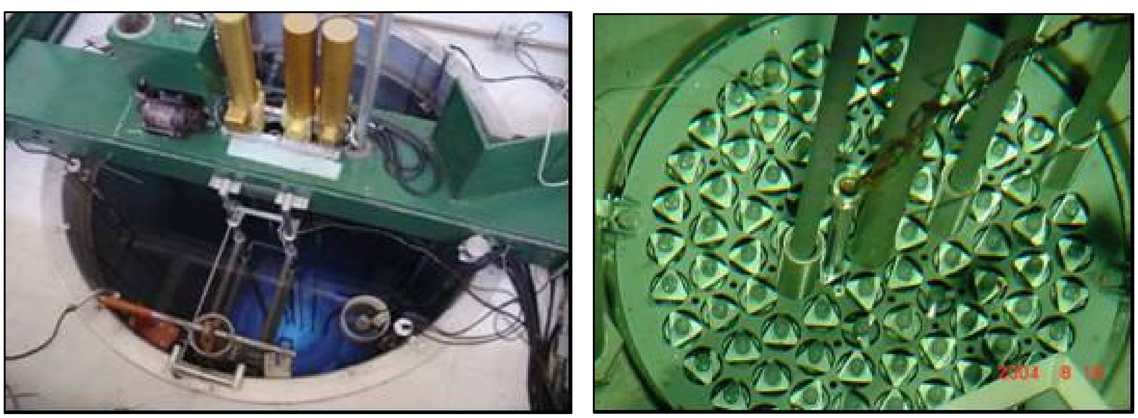
Currently the search of the sustainable development proposes that the potential for redevelopment should not be ignored. Sustainable development implies the need to combine economic development with conservation of natural resources such as land. In the case of decommissioning, the recycling of land implied by redevelopment of a site offers a valuable means of avoiding the need to obtain further "greenfield" sites. This also implies economic development with the maintenance of social and community integrity. Both of these benefits can be attained by the sensitive and organized redevelopment of sites to provide continuity of employment and new production opportunities. Finally, the principles of sustainable development suggest a transparent and participative decision making process that has been the practice to date in many aspects of nuclear development [4].

The Nuclear Technology Development Centre (CDTN/CNEN) has a TRIGA Mark I Research Reactor in operation for 48. The original power was 100 kW and it is being licensed for 250 kW, and as no decommissioning policy was adopted, it needs to do the decommissioning plan for it. This paper presents the description of IPR-R1 TRIGA Reactor and the preliminary plan for its decommissioning, as part of the licensing requirements.

2. IPR – R1 TRIGA Reactor

The first and very important step to establish the decommissioning plan is to know and to define the installation to be decommissioned. The IPR-R1 TRIGA (*Training, Research, Isotopes, General Atomics*), located at the Nuclear Technology Development Centre – CDTN (Belo Horizonte, Brazil), has been operating for 48 years (since November of 1960). The IPR-R1 is a pool type nuclear research reactor, with an open water surface and the core has a cylindrical configuration. The maximum core power is 250 kW, cooled by light water and with graphite reflectors. The fuel is an alloy of zirconium hydride and uranium enriched at 20% in ^{235}U. The reactor core has 63 cylindrical fuel elements, 58 with aluminum-clad and 5 with stainless steel-clad. The regime of operation of the reactor is about 4 hours per day, 4 days per week, and 40 weeks per year. The integrated burn-up of the reactor since its first criticality is about 130 MW-Days. In the Fig. 1 is presented external and internal aspects of the TRIGA IPR-R1 reactor.

Figure 1. Top View of the TRIGA IPR-R1 Core



IPR-R1 Reactor is installed in a building especially constructed to shelter it in a reinforced concrete structure. The main characteristics of the fuel element and of the reactor are presented (Table 1). The IPR-R1 has no short and medium-term storage problems, due to its low nominal power. The first fuel assembly replacement is expected to occur only in 2010. In Table 2 is presented the IPR-R1 spent fuel assembly (SFA) inventory.

A policy regarding spent fuel or high-level waste disposal was not yet defined by Brazilian government. However, given that the legal framework regarding waste disposal is being defined, this issue will be discussed at the national level.

Table 1. Fuel element and reactor characteristics [5]

Fuel Element Type	*Aluminum*	*Stainless steel*
Number	58	5
Geometry	Cylindrical	Cylindrical
Active length	35.56 cm	38.10 cm
Cladding material	Aluminum 1100F	S. Steel AISI-304
Cladding thickness	0.07 cm	0.05 cm
Cladding diameter	3.73 cm	3.76 cm
Fuel diameter (U-ZrH)	3.56 cm	3.63 cm
Fuel-moderator material	$U\text{-}ZrH_{1.0}$	U- ZrH1.6
Amount of U (% weight)	8.0	8.5
Enrichment (% ^{235}U)	20	20

Table 2. SFA inventory of the IPR-R1 Reactor

Facility	*# of Fuel Element inside the Core*	*SFA Storage*	
		At Research Reactor	*Away Research Reactor*
IPR-R1	63 rods	0	0

3. Life Time Estimation

The MCNP transport code, the ORIGEN 2.1 burn-up code and MONTEBURNS radioactive decay code were applied to evaluate the total fuel (^{235}U) burn-up throughout 48 years of operation [6]. The results indicate a reduction of 96 g of ^{235}U mass, regarding to initial inventory of 63 elements, and a total burn-up near to 4%. Each rod has approximately 37 g that results a total mass 2.3 kg of ^{235}U inside the core. The total heat generated until June 2008 was evaluated in 2000 MWh.

The estimated lifetime for the IPR-R1 is of more 34 years with a total burn-up of 3500 MWh. This estimation was performed by numerical simulations considering the following parameters: 68 fuel elements inserted on TRIGA core (note: there are 5 fresh stainless-steel elements that have never been used); operation at 250 kW (conservative hypothesis); and an average work demand based on the past 48 operation years. The thermal power calibration since 2000 is based on the energy balance and presents an assign uncertainty of 7.5 % [7]. In this assessment a relative small burn-up of 12.1 % (mean of 68 elements) were observed, indicating a reduction of 307 g of ^{235}U mass. Even for the central elements the total burn-up would be less than 20% as recommend by the manufacturer.

The IPR-R1 Research reactor could operate at least 3 decades by the actual work demand. Other factors must be considered as structural integrity of mechanical devices and fuel cladding, obsolescence of the instrumentation for measurement and control of operational parameters. All this factors can be managed and corrected by corrective and predictive maintenance, periodic inspections, acquiring new instrumentations and changing suspected or denied fuels.

3.1. Radionuclide Inventory

An attempt to assess the radionuclide inventory was made simulating the end of life of fuel elements (spent fuel) [8]. The radionuclide inventory assessment for the spent fuel, considering 68 fuel elements and final burn-up of 6000 MWh (maximum without core reconfiguration) was calculated by CDTN's experts [20], where the lifetime is a function of: power, released energy and operation schedule. In the same way they can carry out the inventory assessment for the activation of the structures and shielding can be carried out by the same group, using e.g. Monte Carlo Simulation.

4. Decommissioning Plan

The decommissioning plan shall include an evaluation of one or more decommissioning options suitable for the studied installation and that achieve the requirements of the regulatory body [1, 2, 4, 8].

4.1. Legal and Regulatory Framework

The legal and regulatory framework for decommissioning in general is presented in small paragraphs in the CNEN licensing norms for specific facilities (mining, enrichment etc.). They give the guidelines for the report preparation, but there aren't any established requirements for each step. These guidelines are only a suggestion and then the operator has no fixed rules to accomplish the decommissioning work. Then the report is send to the regulatory body for each phase to be approved. Specifically for research reactor there is no decommissioning guidelines in the standards.

4.1.1. Documents

For all nuclear and radioactive issues in Brazil when the national regulations do not cover a specific situation the consensus is to use the IAEA recommendations.

In a discussion with the Regulatory Body it was identified the lack of a specific decommissioning regulation, and there is already preliminary document. As one of the primary tasks of the Brazilian Nuclear Program is to review and update the legal framework, elaborating, and editing the missing documents, this will include also the Decommissioning subject. In the Brazilian Radioactive Wastes Management Program that absence was also pointed out.

In the items 4.1.2.1 to 4.1.2.4 are presented some documents where there is information about the decommissioning. The decision on level for the release of materials, buildings and sites from nuclear regulatory control is established in national regulations that are pointed out in the items 4.1.2.5 to 4.1.2.7.

4.1.1.1. National Report of Brazil for the Joint Convention

The *"National Report of Brazil*" for the Joint Convention on the safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [9], presents the following statements:

- ✓ There's no regulation that establish the funds composition for the decommissioning.
- ✓ For the NPP Angra 1 and Angra 2 the strategy is the deferred dismantling, that means, confinement of the plants for 10 to 30 years, based in international studies of similar facilities. The funds for the decommissioning will subsidized by the electrical energy taxes. The wastes from this activity will be managed later when the national repository will be ready.
- ✓ For research reactors no decommissioning policy has been adopted.
- ✓ In this document is described the decommissioning of one nuclear facility in Brazil: USAM Monazite Sand Treatment Facility. This facility has produced rare earth since 1950's. Now the area is free of regulatory control for unrestricted use.

This document is being updated to be presented in the general meeting at IAEA in October 2008.

4.1.1.2. "*Nuclear Facilities Licensing*" – CNEN -NE-1.04 [10].

4.1.1.3. "*Safety Assessment Report Guidelines*" – CNEN-NE-1.08 [11], CNEN-NE-1.09 [12], CNEN-NE-1.11 [13].

4.1.1.4. "*Brazil: A Country Profile on Sustainable Energy Development*"[14] - Discussion about Nuclear Power Plants Decommissioning.

4.1.1.5. *Basic Instructions for Radiation Protection* - CNEN 3.01[15]

Includes the levels surface contamination for release of regulatory control**;**

4.1.1.6. *Licensing of Radioactive Installations* - CNEN 6.02 [16].

This national standard deal with the licensing for shutdown and decommissioning activities, including final destination for the radioactive material and waste, record keeping and management and technical procedures for facilities decontamination.

4.1.1.7. *Management of Radioactive Wastes* - CNEN 6.05 [17]

The limits for the waste levels, Low Level Waste, Intermediate Level Waste and High Level Waste for solid and liquid wastes are established in this regulatory standard. Also levels for free release of liquids and gases are presented.

4.2. Decommissioning Plan and Strategy

To comply with CNEN requirements the basic Decommissioning planning will include these phases:

✓ a detailed decommissioning plan, including waste management and radiological procedures for the demolishing of the buildings (floors, walls, sanitary system, water distribution system, etc);

✓ procedures that would be adopted for the radiological characterization of the site (deepness of soil samples, frequency, etc) and frequency of reports to be submitted to CNEN;

✓ the radiological criteria to be used for clearance;

✓ a radioactive waste plan including the necessary and appropriate description of packages;

✓ description of the scenarios that would be used for the determination of area clearance values (cut off limit) in accordance of the previewed use;

✓ radiological procedures for the workers involved in the clean up; and

✓ procedures to control and guarantee that the doses on the neighboring population would not exceed 1 mSv/y.

Following these phases some guidelines for IPR-R1 decommissioning were established:

a) It will be followed the safety and environmental principles defined by the regulatory bodies;

b) The procedures for radioactive waste management of CDTN and IAEA will be used. For the hazardous and regular wastes it will be used the procedures established by the environmental institution.

c) The packages will be selected among the qualified ones, in accord of the waste to be conditioned. The preliminary qualitative assessment showed that the radioactive waste will include some concrete, aluminum and stainless steel structural pieces, pumps, contaminated with U, fission products and activation products.

d) The spent fuel elements will be stored in a special package, which is being developed by a multinational group in South America (IAEA Project). After a cooling period their final destination will be decided in accord of the future political scenario.

e) The equipment and staff requirements will be defined depending on the decontamination activities and on the material defined as radioactive waste.

f) The safety and environmental assessments will be done by CDTN´s radiological and environmental protection staff, respectively.

g) Costs should be estimated in advance, so that it would be provided the necessary budget.

h) A special report with the decommissioning plan should be prepared and sent to the regulatory body just before the reactor shutdown requesting the license for that.

4.3. Decommissioning Plan Structure (Status)

The structure of the Decommissioning Plan Report will be in accordance of the IAEA decommissioning documentation.

Some parts of the final document is already finished regarding to the introduction and facility description (physical description of the site and facility, operational history, systems and equipment, radioactive and toxic material inventory).

The parts of the decommissioning plan that still under development are related to decommissioning strategy (objectives, decommissioning alternatives, safety principles and criteria, waste type, volumes and routes, dose estimates, cost estimates, financial arrangements, selection and justification of preferred option), project management (resources, organization and responsibilities, review and monitoring arrangements, training and qualifications, reporting and records), decommissioning activities (description and schedule of phases and tasks, dismantling, waste management, surveillance and maintenance programs), safety assessment (dose predictions for tasks, demonstration of ALARA for tasks, radiation monitoring and protection system, physical security and materials control, management of safety, risk analysis, operating rules and instructions, justification of safety for workers, general population, and environment), environmental impact assessment, quality assurance program, radiation protection and safety program, final radiation survey proposal / radiological criteria to be used for clearance

Since that the reactor has about at least 30-year operation time, now the strategy was not already decided. In our case an immediate dismantling is not envisaged and the safe enclosure is the expected decision. This option postpones the final removal of controls for a longer period, usually of the order of 40–60 years. The facility is placed into a safe storage configuration until the eventual dismantling and decontamination activities occur. During this period a nuclear museum can be set up in this area

As options for the decommissioning it can be considered: either the removal of the fuel assemblies and decontamination for following restricted uses, or the removal of all radioactive materials and thorough decontamination of the remaining structures to permit unrestricted use.

Just little time before the shutdown the decommissioning will be selected in accordance with the Brazilian actual legislation, and the political and economical situation.

As the reactor is at CDTN`s site probably the strategy will be: take off the fuel elements and the interns of the reactor. The concrete will be classified and the area can be used for other applications, because the core is in an excavated hole.

4.4. End State / Final Goal of Decommissioning Activities

The final goal of the first strategy is the unrestricted use of the local. In the second strategy initially the local will be classified for restricted use, for example, as a historical piece of a TRIGA technology. After some decades the goal will be the unrestricted use of the place, after the total decontamination.

A good solution was adopted by Forschungszentrum Karlsruhe. The reactor was decommissioned and the auxiliary installation and rooms were completely decontaminated, so that the area is now a museum of nuclear science (Figure 3).

Figure 3. View of the FR2 research reactor facility as a Museum

4.5. Management of materials and waste

As the IPR-R1 reactor is situated in a building, where there are laboratories, offices, a library and a cafeteria, the dismantling will occur only where it will be necessary.

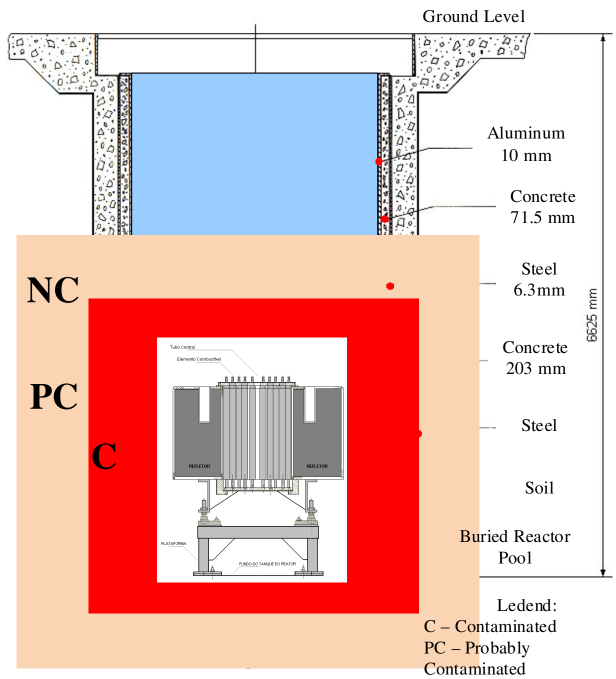
From the international experience only a small part of the wastes arising from the research reactor decommissioning is classified as radioactive, and from this one more than 90% is in the low-level category. Materials that cannot be released from nuclear regulatory control must be disposed as radioactive waste. The decommissioning waste must be stored until a repository will be available. On-side storage facility is typically applied.

Before the radioactive waste is delivered to a storage or disposal facility, it must be properly conditioned. Radioactive waste arises in solid or liquid form. Solid waste can be, for example, compacted, melted or simply put in containers, in accord of its type. Liquid waste is converted into solid waste forms, e.g. by drying / evaporating or cementing. The waste is packaged into drums, steel containers, concrete containers or cast-iron containers and stored. For the disposal of the waste additional packaging may be required.

During the operation of a reactor, components can become radioactive (activation) or contaminated with radioactive substances (contamination). The reactor pressure vessel and the biological shield (protective concrete wall) are activated by neutron radiation during operation and have to be treated as low- and intermediate-level waste. Components contaminated with radioactive substances have to be decontaminated or disposed of as radioactive waste.

For the IPR-R1 a preliminary qualitative evaluation showed that the radioactive waste could be some concrete, aluminum and stainless steel structural pieces, pumps, contaminated with U, fission products and activation products. The assessment of the type and the amount of the waste can be done through simulation program, which should be carried out by simulation models using Monte Carlo Methods. The Figure 4 illustrates an expected result of this assessment, defining the limits of contaminated, probably contaminated and not contaminated areas.

Figure 4. Assessment of Type and Amounts of Radioactive Waste.



The radioactive wastes will be classified and collected following the CNEN – 6.05 standard [17].The radiological protection staff will classify the radioactive wastes, and define the criteria for the release of material and facility rooms following CNEN standards [16, 17], and internal procedures.

The radioactive wastes from the decommissioning activity will be transferred to the SN1 for proper treatment, where they will be converted into packages suitable for storage and disposal. SN1 (Waste Management Service) is the group responsible for the waste management at CDTN. Some facilities to treat the waste are already available: Bailing, crushing, cementation, chemical precipitation and immobilization. Other materials will be classified as recyclable, regular or hazardous material and treated according to the environmental standards (10.000 ABNT Norm Series). There are already some systems to store safely and temporally all activated materials. Other materials will be classified as recyclable, regular or hazardous material and treated according to the environmental standards (10.000 ABNT Norm Series). The low and intermediate waste packages will be stored in the Intermediate Storage Facility at CDTN site, which the area is 30 m x 15 m, and 7m high. This facility has the requirements to store low and intermediate level radwaste (Figure 5)

Figure 5. Intermediate Storage at CDTN

As one result, in the estimated end of life of IPR-R1 TRIGA, the mass, activity, heat decay and radiotoxicity for the 68 spent fuel elements is presented by CDTN's staff [20].

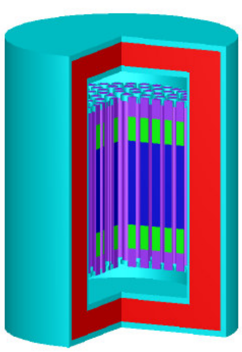
For the end point the most suitable option would be to use the area for nuclear proposes in view of the fact that this reactor area is in the CDTN's site, and there are often demands for new nuclear facilities.

4.6. Decommissioning Expertise and Tools

There was already a decommissioning experience in Brazil, done in USAM Monazite Sand Treatment Facility. This facility has produced rare earth since 1950's. The area is now free of regulatory control for unrestricted use. As presented in the Guidelines at CDTN there is the expertise to perform the majority of decommissioning works, and for other ones there is enough expertise in Brazil to carry out them. The necessary equipment, tools and instruments to dismantling the reactor are available either in CDTN or to be hiring. A description of these materials / procedures to use them are presented in [18].

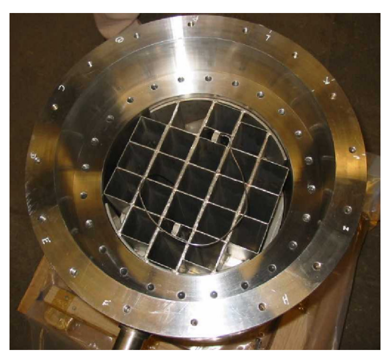
Some technical alternatives have been made for spent fuel storage and transport: cask / wet storage, and other packages, which were developed and licensed for the Goiania's accident could be also used in emergency cases. Some information about the cask developed jointly with other South American Countries is done [19]. The Figure 7 presents a diagram used to make the simulation for this cask using Monte Carlo, some structural aspects of this package.

Figure 7. Cask numerical simulation (MCM), External and internal view of the cask prototype.



Cask numerical simulation

Prototype – external view



Prototype – internal view

5. Conclusions

The decommissioning plan should take part of the documentation presented to commission nuclear installations. The IPR-R1 a research reactor operating at CDTN/CNEN is being commissioned for 250 kW. The draft of the decommissioning plan for it is being written.

The decommissioning plan should take part of the documentation presented to commission nuclear installations. In the initial IPR-R1 licensing, the decommissioning aspects were not considered and no decommissioning plan was developed during the commissioning activities. Nowadays, the reactor operating at CDTN/CNEN is being commissioned for operation in 250 kW. The decommissioning plan for it is being written and will take part of this new licensing documentation.

This documentation, as [21], regarding to the decommissioning planning can be used as a guide for other radioactive installation for licensing future processes or for revision of existent documentation.

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