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DEVELOPMENT OF A PRELIMINARY DECOMMISSIONING PLAN OF THE REACTOR IPEN/MB-01

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ABSTRACT

Around the world, many nuclear plants were built and need to be turned off at a certain time because they are close to their recommended time of use is approximately 50 years. So the IAEA (International Atomic Energy Agency), seeks to guide and recommend, through publications, guidelines for the conduct of activities both for decommissioning nuclear power plants and for research reactors, with special attention to countries that do not have a framework regulatory Legal that sustain the activities of decommissioning. Brazil, so far, does not have a specific standard to guide the steps of the guidelines regarding decommissioning research reactors, having only a standard applied to decommissioning power plants which was published in November 2012. The Nuclear and Energy Research Institute (IPEN) has two research reactors one being the reactor IPEN/MB-01. The aim of this work is to develop a preliminary plan for decommissioning of nuclear reactor research, considering the technical documentation of the system (RAS-Safety Analysis Report), the existing rules of CNEN (National Nuclear Energy Commission), as well as regulatory instructions and recommendations of the IAEA. The preliminary decommissioning plan consists of the presentation of actions and steps required as well as the strategies to be adopted for the shutdown of the facility under the technical and administrative, seeking the safety, health workers and the general public, minimizing environmental impacts.

1. INTRODUCTION

Around the world, many nuclear facilities were built and need to be shut down at a certain time due they are close to the recommended time of use that is approximately 40 years. Therefore, these facilities must go through the process of decommissioning, i.e., the final step in natural life cycle of the nuclear installation. This process refers to actions taken to the shutdown of a nuclear installation under technical and administrative ambit seeking the removal of all or part of their regulatory controls sticking up the safety of the installation site, the health of workers and the general public and minimization of the environment impacts[1].These actions require planning and organization to ensure safety during activities that are required in the decommissioning plan.

The decommissioning plan is a document in which are described all initial, intermediate and final procedures to be adopted for carrying out of decommissioning with safely in all its stages. The IAEA (International Atomic Energy Agency) proposes a series of recommendations supporting the accomplishment of decommissioning, starting with the plan and their respective stages of preparation and implementation, including all practical procedures for carrying out of the decommissioning tasks, besides the activities of decontamination and disassembling/dismantling of the installation.

Decontamination refers to activities of removal and reduction of the risk of radioactive contamination in all devices and equipment. The dismantling process includes cutting of materials and removal techniques from nuclear installation safely[2].

Brazil does not have a law that defines guidelines for decommissioning, probably for this reason; currently none of the six existing nuclear facilities have a decommissioning plan. However, in 2011a study committee was formed with the main task facing the issues of decommissioning of nuclear installations in Brazil, as published in the daily official journal, on march 21^{th} 2011, ISSN1677-7050[3]. This publication originated the resolution133 of november 8^{th} 2012 which treats on Decommissioning of Nuclear Power Plants [4] thus helping in the development of plans to decommissioning of nuclear research reactors.

The IAEA recommends that the decommissioning plan be prepared in the conception design phase of the nuclear installation. Hungary, one of the member countries of the IAEA, requires a preliminary plan for decommissioning [5] in the commissioning stage of a nuclear facility.

The research reactor IPEN/MB-01 is located on the campus of the University of São Paulo since 1989 and has been licensed without having a preliminary decommissioning plan. Due to the need to adapt to international standards, focused on security, and the tendency in Brazil to have a greater focus on issues related to decommissioning, this study seeks to establish the initial guidelines of the preliminary plan for decommissioning the reactor IPEN/MB-01 following the IAEA recommendations and standards of CNEN (National Nuclear Energy Commission).

2. REACTOR IPEN/MB-01

The Reactor IPEN/MB-01 was built in partnership between the IPEN (Nuclear Energy Research Institute) and CTM-SP (Navy Technology Center in São Paulo) as part of the Brazilian nuclear submarine project. The IPEN/MB-01 is a research reactor classified as zero power type, with maximum power of 100W. The main characteristic is the versatility allowing different critical arrangements of the core, obtaining different configurations, performing tests for a nuclear submarine [6].

The first configuration of the reactor core IPEN/MB-01, in the rectangular form, has a total of 680 elements with an arrangement of 28x26 and 48 control / safety rods controling the nuclear chain reaction and shutdown of the reactor. The current configuration of the core is a cylindrical 26x26 fuel elements. These elements are lined with stainless steel containing 52 pellets of uranium dioxide enriched to 4.3%. The control rods are also lined with stainless steel having inside neutron absorbing materials being Ag-In-Cd alloys. The safety rods are constituted of Boron Carbide (B4C) [7].

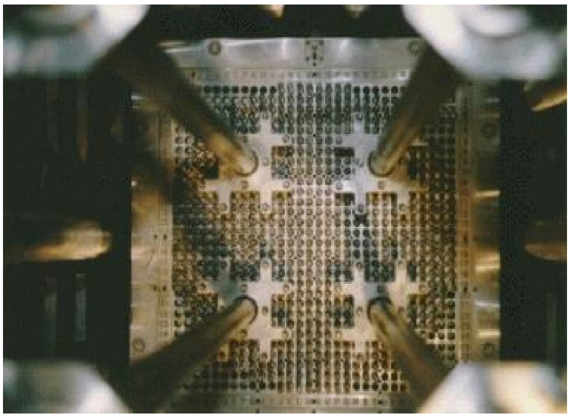

Figure 1- Reactor Core IPEN/MB-01[5]

The reactor core is inserted into a moderator tank in which the neutrons are moderated with light water. The starting source of neutrons is an Am-Be compound with activity of 1Ci.

Figure 2-Top view of the moderator tank [8]

The shutdown of the reactor can be accomplished in two ways: falling down all control / safety rods (first level shutdown) and emptying the moderator tank (second-level shutdown). At first, the control rods fall by gravity due to cut of the electric current on the magnets coupled rods controls / security, stopping the chain reaction. The second level, the valves of the moderator tank open quickly emptying the tank.

The facility was designed by fail-safe mechanism that consists of involuntary shutdown of the facility in the event of any failure of procedure that affects the safe operation of the reactor. This mechanism is called SCRAM that consists in the sudden shutting down of a nuclear reactor usually by rapid insertion of control rods [9]. Thus, any failure that compromises safety, the reactor is shut down automatically by de-energizing the magnets attached the control/safety rods and the emptying of the moderator tank.

3. STANDARDS AND DOCUMENTS

There are many documents and guidelines published by the IAEA that guide the activities of decommissioning as following: *Decommissioning of facilities using radioactive material*, (SAFETY STANDARDS SERIES WS R5) [1] and specifically for decommissioning of research reactors such as *Decommissioning of Nuclear Power Plants and Research Reactors*, (TECHNICAL REPORT SERIES WSG 2.1) [2];*Techniques for Decommissioning research reactors,* (TECDOC-1273) [10];*Planning and management for the decommissioning of research reactors and other small nuclear facilities*, (IAEA-TRS-351) [11], among others.

All these references provide information, guidance and experiences contributing at the carrying out on decommissioning activities taking into consideration the safety and ALARA principles.The *Safety Report Series 45* [12] published by the IAEA provides the items that should contain in a decommissioning plan, it is an important guide, especially for countries that have not yet defined legislation concerning the decommissioning of nuclear reactors.

With regard to national law, Brazil does not have yet a standard or document that guides the decommissioning of research reactors. The CNEN has established standards that control the work with radioactive material dealing from the licensing of nuclear facilities (Standard CNEN-NE-1.04) [13]; the disposal of radioactive waste (Standard CNEN-NN-6.06) [14] and CNEN-NN-6.9 [15]); the standards of physical protection (CNEN-NE-2.01) [16]; fires (CNEN-NE-2.04) [17]; radiation protection guidelines (CNEN-NRM-3.01) [18];radioprotection services (CNEN-NRM-3.02) [19]; transport of radioactive waste (CNEN-NRM-5.01) [20] and storage of radioactive waste (CNEN-NRM-5.02) [21].

There is a standard that addresses the decommissioning of nuclear power plants [4]. This set of standards, besides others, must be followed by the relevance and will be useful to carry out the work and preparation of the preliminary plan of the decommissioning procedures applied for the reactor IPEN/MB-01.

The reactor IPEN/MB-01 has an important document that is required by the standard as part of its licensing called RAS (Safety Analysis Report) [7] which describes the installation as a whole and all programs and actions that are promoted to ensure safety in operation, the safety of workers, the public and the environment according to the requirements and standards CNEN. The RAS has information, items and important programs in the operational phase of the facility that will assist in preparing the preliminary decommissioning plan. Thus, to prepare a preliminary plan for decommissioning the reactor IPEN/MB-01, will be used all recommendations of the IAEA, the standards CNEN and RAS.

4. PRELIMINARY PLAN DECOMMISSIONING

The development of the preliminary plan will have as guideline the document "SAFETY REPORT SERIES No 45" published by the International Atomic Energy Agency "*Standard Format and Content for Safety Related Decommissioning Documents"* [12], where is mentioned all items that should be included in the decommissioning plan, as follow:

1. Introduction
2. Facility description
3. Decommissioning strategy
4. Project management
5. Decommissioning activities
6. Surveillance and maintenance
7. Waste management
8. Cost estimate and funding mechanisms [1]
9. Safety assessment
10. Environmental assessment
11. Health and safety
12. Quality assurance
13. Emergency planning
14. Physical security and safeguards
15. Final radiation survey

Some of these items presented are already implemented in the operational phase of the facility and will be adapted to the decommissioning activities.

In terms of decommissioning strategy the facility will be divided in 5 sectors (see Figure 3), defining the actions according to the existence or not of radioactive material and its magnitude of activity, in line with the standards CNEN-NN-6.05 [22] and IAEA guidelines[23].

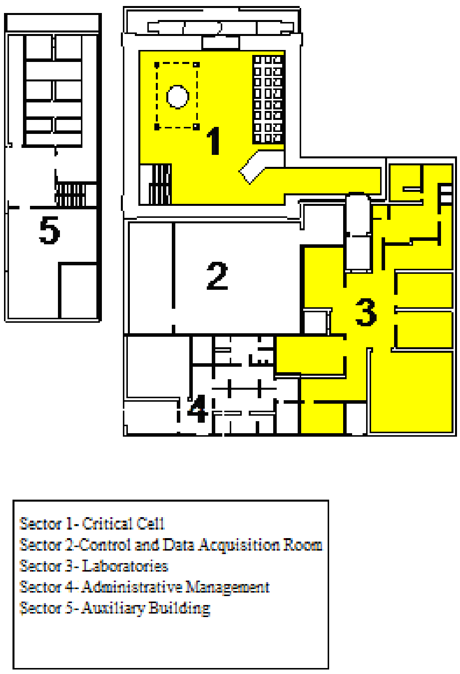

Figure 3 - Sectors reactor IPEN/MB-01 [7]

[1]The cost estimated and funding mechanism will not be contemplated in the project.

The yellow areas are those sectors that contain radioactive materials and white areas sectors do not contain radioactive material. The figures 4 and 5 show in schematic form the decommissioning strategies to be adopted for the sectors.

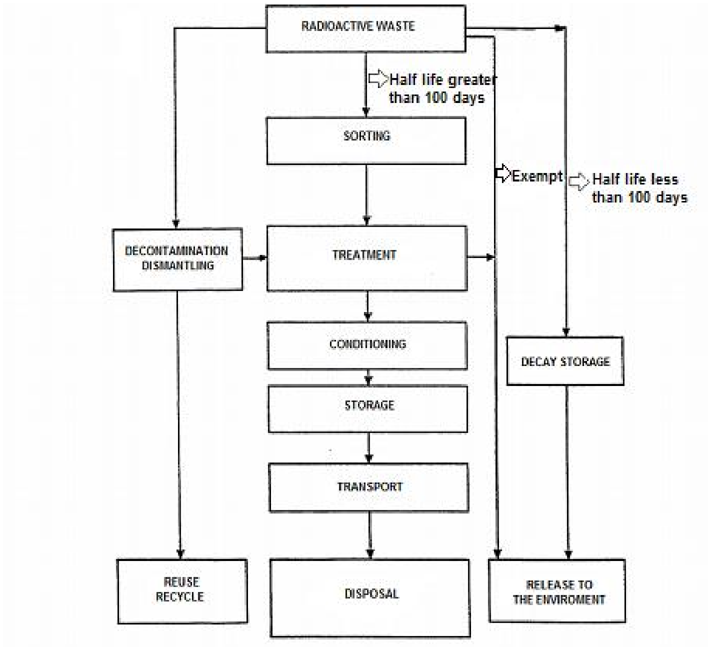

Figure 4: Flowchart for sectors containing radioactive material [24].

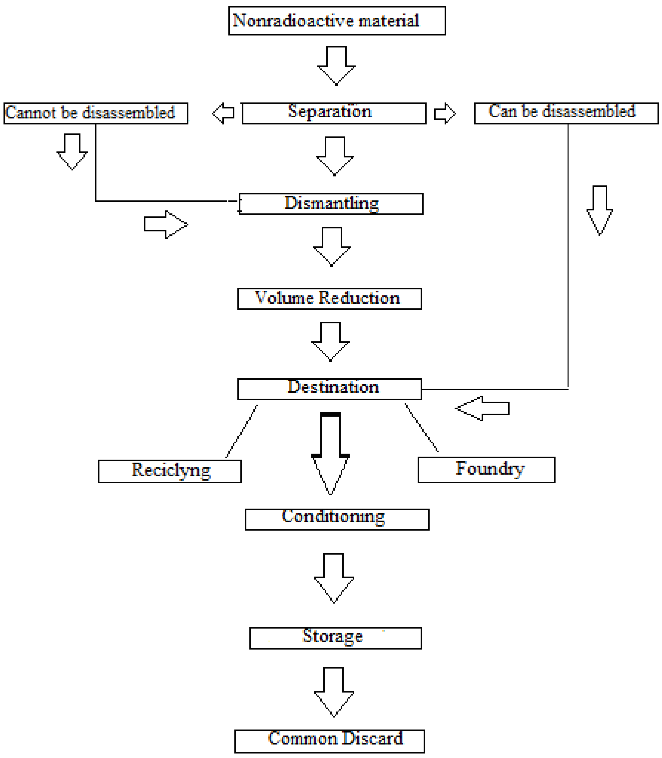

Figure 5: Flowchart for sectors that do not contain radioactive material.

The procedures to be developed for sectors 1 and 3 will be considered all safety measures mentioned in the standard CNEN-NN-3.01 [18], activities such as monitoring and supervision of the radiological protection sector. The identification and classification of the radioactive waste will be carried out considering its mass, volume, material composition, activity level, radionuclide present and physical state CNEN-NN-6.05 [22] as presented in tables as follow,

Table 1- Classification liquid waste (emitter β−γ) [22]

Category	**Concentration(c)**	
	(Bq/m^3)	(Ci/m^3)
Low Radioactive Level	c ≤ 3,7E10	c ≤1
Medium Radioactive Level	3.7E10<c≤ 3,7E13	1<c≤1E3
High Radioactive Level	c >3,7E13	c > 1E3

Table 2- Classification solid waste (emitter β−γ)[22]

Category	**Concentration(c)**	
	mC/kg.h	R/h
Low Radioactive Level	c ≤ 50	c ≤0,2
Médium Radioactive Level	50<c≤ 500	0,2<c≤ 2
High Radioactive Level	c >500	c > 2

Table 3- classification gaseous waste (emitter β−γ)[22]

Category	**Concentration(c)**	
	(Bq/m^3)	(Ci/m^3)
Low Radioactive Level	c ≤ 3,7	c ≤1E-10
Medium Radioactive Level	3.7< c ≤ 3,7E4	1E-10<c≤1E-6
High Radioactive Level	c >3,7E4	c > 1E-6

Table 4- Classification liquid waste (emitter α)[22]

Category	**Concentration(c)**	
	(Bq/m^3)	(Ci/m^3)
Low Radioactive Level	3,7E8 < c ≤ 3,7E10	1E-2< c ≤1
Medium Radioactive Level	3,7E10< c ≤ 3,7E13	1< c ≤1E3
High Radioactive Level	c >3,7E13	c > 1E3

Table 5- Classification solid waste (emitter α)[22]

Category	**Concentration(c)**	
	(Bq/m^3)	(Ci/m^3)
Low Radioactive Level	3,7E8< c ≤ 3,7E11	1E-2< c ≤10
Medium Radioactive Level	3,7E11< c ≤ 3,7E13	1< c ≤1E3
High Radioactive Level	c >3,7E13	c > 1E3

The treatment, storage and disposal of the waste depend on the existing level of radioactivity. Considering the low power and low number of hours in operation, the activation level of the materials is in average low. Therefore, it is excluded the possibility of radioactive waste with high radioactivity level. The radioactive wastes generated during the decommissioning activities will be managed according to references [6], [22], [23], [25], [26], [27]. In the event of some contamination during the decommissioning activities, techniques will be used in accordance with the type of contamination and its level of activity. Tables 6, 7 and 8 show the activity values of the major components and Table 9, the air activity in the critical cell.

Table 6- Activity Concrete [7]

Isotope	A (Bq/cm^3)
^{59}Fe	$1,91x10^{-2}$
^{14}C	$1,55x10^{-9}$
^{31}Si	$5,74x10^{1}$
^{16}N	$9,55x10^{-1}$
^{24}Na	$4,07x10^{10}$
^{28}Al	$4,22x10^{2}$

Table 7- Activity of Steel AISI-340 (Structural Core) [7]

Isotope	Activity(Bq\m^3)		
	Core support	Guide tube	Cladding of rod
^{14}C	$5,03x10^{-8}$	$3,32x10^{-7}$	$2,27x10^{-7}$
^{59}Fe	$1,49x10^{3}$	$4,22x10^{3}$	$3,19x10^{3}$
^{56}Mn	$1,36x10^{6}$	$2,99x10^{7}$	$2,28x10^{7}$
^{31}Si	$5,92x10^{2}$	$3,49x10^{3}$	$2,65x10^{3}$
^{32}P	$7,66x10^{1}$	$4,59x10^{2}$	$3,47x10^{2}$
^{35}S	$3,77x10^{-1}$	$2,24x10^{0}$	$1,70x10^{0}$
^{61}Cr	$6,48x10^{4}$	$3,89x10^{-5}$	$2,94x10^{5}$
^{59}Ni	$1,41x10^{-1}$	$6,44x10^{-1}$	$6,40x10^{-1}$
^{60}Co	$2,32x10^{2}$	$1,36x10^{3}$	$1,05x10^{3}$
^{63}Ni	$2,21x10^{1}$	$1,32x10^{2}$	$1,00x10^{2}$

Table 8-Activity of Steel Moderator Tank [7]

Isotope	A (Bq/cm^3)
^{59}Fe	2,93x10^{2}
^{14}C	3,96x10^{-7}
^{56}Mn	5,33x10^{5}
^{31}Si	1,30x10^{2}
^{32}P	5,55x10^{1}
^{35}S	3,28x10^{-1}
^{51}Cr	6,70x10^{5}
^{59}Ni	5,55x10^{-2}
^{182}Ta	3,25x10^{2}
^{60}Co	1,10x10^{2}

Table 9-Air Activity [7]

Isotope	Activity (Bq/cm^3)
^{41}Ar	1,24x10^{-2}
^{16}H	2,04x10^{-4}
^{19}O	4,81x10^{-5}
^{14}C	4,07x10^{-5}

The radioactive wastes of low-activity below the exemption levels established in [22] may be disposed as ordinary waste, following the environmental monitoring program of the facility [7].

The procedure to be adopted for non-radioactive wastes (ordinary materials) in the first moment is the volume reduction, recycling, in order to obtain the minimum possible material to be discarded taking into account environmental issues. In certain cases it will need to make cuts in specific materials to reduce volume, facilitating storage and disposal. The cutting usual techniques are presented as follow [28].

• Thermal Cut,
• Hydraulic Cutting,
• Cutting with laser,
• Disassemble mechanical,
• Fragmentation in microwave,
• Explosive Cut,
• Pneumatic Cut.

The paper *Decommissioning of nuclear installations at CIEMAT* present in [10] make a comparative study using the techniques of arc plasma (Plasma-Arc), which consists of a thermal technique; CAMC (Contact Arc Metals Cutting), also a thermal technique and mechanical cutting using saw. The paper shows that for stainless steel and aluminum materials, the saw cut is advantageous in questions as low cost and generation of secondary waste.

5. DECOMMISSIONING STRATEGIES

The preliminary decommissioning strategies of the facility are described by sector as follow:

5.1. Sector 1: Critical Cell

The sector 1- critical cell constitutes the reactor building where occurs critical experiments with irradiation of materials, among others proposal. This building is divided into three floors:

Ground Floor: is located the moderator tank, fuel elements, the core itself, control / security rods and auxiliary components such as electronics devices and systems that send information to the control room. Even in this floor there is a pit where is storage the fresh and irradiated fuels.

1st Subsoil: is located the tank storage, piping, control valves, pumps, motors, filters, heat exchangers, the draining fast system and part of the air conditioning and ventilation system.

2nd Subsoil: on this floor is located the decay tank, the starting neutron source and part of the air conditioning and ventilation system.

Considering radioactive materials, the main components that belong to the sector 1 are: the fuel elements of the core, control/safety rods, starting neutron source and the fresh and irradiated fuels. Referring to the fuel elements, control and safety rods, with the shutdown of the reactor, will begin decommissioning activities (immediate dismantling strategy) with supervision of radiological protection, removing these parts. All these radioactive materials will be stored in existing pits. This procedure will be made using special tools available in the facility (Fig.5), avoiding large exposures to radiation.

Figure 5 - Tool for removal of fuel rods [7].

All fuel rods and fuel elements are safeguarded and appropriately conditioned to the final destination that is responsibility of the National Nuclear Energy Commission - CNEN. With the removal of the core elements and control and safety rods completed, the next step consists in disassembling ⁄ dismantling of the moderator tank and its components, analyzing the necessity of cut procedures, following the suggestions of strategies to be implemented.

The systems and components of the other floors will be disassembling ⁄ dismantling, maintaining ventilation systems in operation during the activities. On the 2^{nd} subsoil is located the starting neutrons source, that is an Am-Be neutron source with activity 1Ci. The source is also safeguarded, will be appropriately conditioned and the final disposal is responsibility of the CNEN. All procedures mentioned will be carried out under supervision of radiological protection. The remaining material should be analyzed for the possibility of volume reduction minimizing the waste generated, facilitating conditioning, storage and disposal.

5.2. Sector 3:Laboratories

This sector is divided into three laboratories, L1, L2 and L3, besides decontamination, radiological protection and operators room. Laboratories L1, L2 and L3, are used respectively for counting target, irradiated materials and L3 is a chemical laboratory. The decommissioning procedures to be adopted for the sector will according to standard CNEN-NN-6.05 [22].

5.3. Sector 2,4 and 5

These sectors comprise respectively the control room, data acquisition room, the administrative and auxiliary building. In the control room is where are all components and systems necessary for the operation of the reactor.

The auxiliary building houses the treatment and water supply systems, air conditioning and ventilation systems of Sectors 1 and 2.

Due these sectors do not contain radioactive materials the strategy to be implemented consists on disassembling ⁄dismantling techniques, cutting and volume reduction, recycling possibility.

6. DECOMMSSIONING ACTIVITIES SCHEDULE

As an example of a schedule of activities for the preliminary decommissioning plan are mentioned as follow:

ã *Emptying the moderator tank, removal the fuel elements from the reactor core, temporary storage in the pits and proper conditioning of fuel elements for shipping to CNEN,*

ã *Disassembling/dismantling core and moderator tank, storage tank, auxiliary tanks and tank decay after release water according to the environmental monitoring program of installation,*
√ *Removal of the starting source,*

ã *Disassembling/dismantling of valves, pumps, motors and systems,*

ã *Conditioning and shipping radioactive sources to CNEN,*

√ *Disassembling/dismantling of materials from laboratories,*

√*Disassembling/dismantling of auxiliarybuilding components (water treatment system, compressed air),*

√*Disassembling/dismantling air recycling system, heat exchangers and water demineralization system of critical cell,*

√*Disassembling/dismantling of control room system,*

√ *Disassembling systems of radiological protection,*

√ *Disassembling/ dismantling common air system,*

√ *Full release of the reactor building of regulatory controls,*

√ *Elaboration records and reports,*

Associated costs and estimated time are not contemplated in this proposed plan.

7. CONCLUSION

The preliminary plan for decommissioning the reactor IPEN/MB-01 will contribute as a guideline on the development of the final decommissioning plan itself, to be implemented when the reactor is permanently shut down.

The preliminary plan enables changes and updates due to maintenance or configuration changes, considering that the facility will remain in operation for more years.

To facilitate the updates of information, is part of this project, incorporate a data base program, using Access tool, allowing a control and organization of such information in a efficient way.

The important contribution of this study aims to meet a regulatory requirement of the CNEN at the time of permanent shut down, contributing as a reference in developing of other decommissioning plans of other national nuclear facilities.

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