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SPENT NUCLEAR FUEL STORAGE – BASIC CONCEPT

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ABSTRACT

According to the procedures adopted in others countries in the world, the spent nuclear fuel elements burned to produce electrical energy in the Brazilian Nuclear Power Plant of Angra do Reis, Central Nuclear Almirante Álvaro Alberto – CNAAA will be stored for a long time. Such procedure will allow the next generation to decide how they will handle those materials. In the future, the reprocessing of the nuclear fuel assemblies could be a good solution in order to have additional energy resource and also to decrease the volume of discarded materials. This decision will be done in the future according to the new studies and investigations that are being studied around the world. The present proposal to handle the nuclear spent fuel is to storage it for a long period of time, under institutional control.
Therefore, the aim of this paper is to introduce a proposal of a basic concept of spent fuel storage, which involves the construction of a new storage building at site, in order to increase the present storage capacity of spent fuel assemblies in CNAAA installation; the concept of the spent fuel transportation casks that will transfer the spent fuel assemblies from the power plants to the Spent Fuel Complementary Storage Building and later on from this building to the Long Term Intermediate Storage of Spent Fuel; the concept of the spent fuel canister and finally the basic concept of the spent fuel long term storage.

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1. INTRODUCTION

The Brazilian Nuclear Power Plants, Angra 1 and Angra 2, are under operation and they are responsible for almost 45 % of the necessary electrical energy to supply the Rio de Janeiro State demand. In the future, when Angra 3 starts its operation, the total amount of energy produced by CNAAA will reach to 3.350 MWe, which represents approximately 75% of the present energy demand of Rio de Janeiro State.

Figure 1 presents the spent fuel assemblies stored in Spent Fuel Pools located inside Angra Nuclear Power Plants.

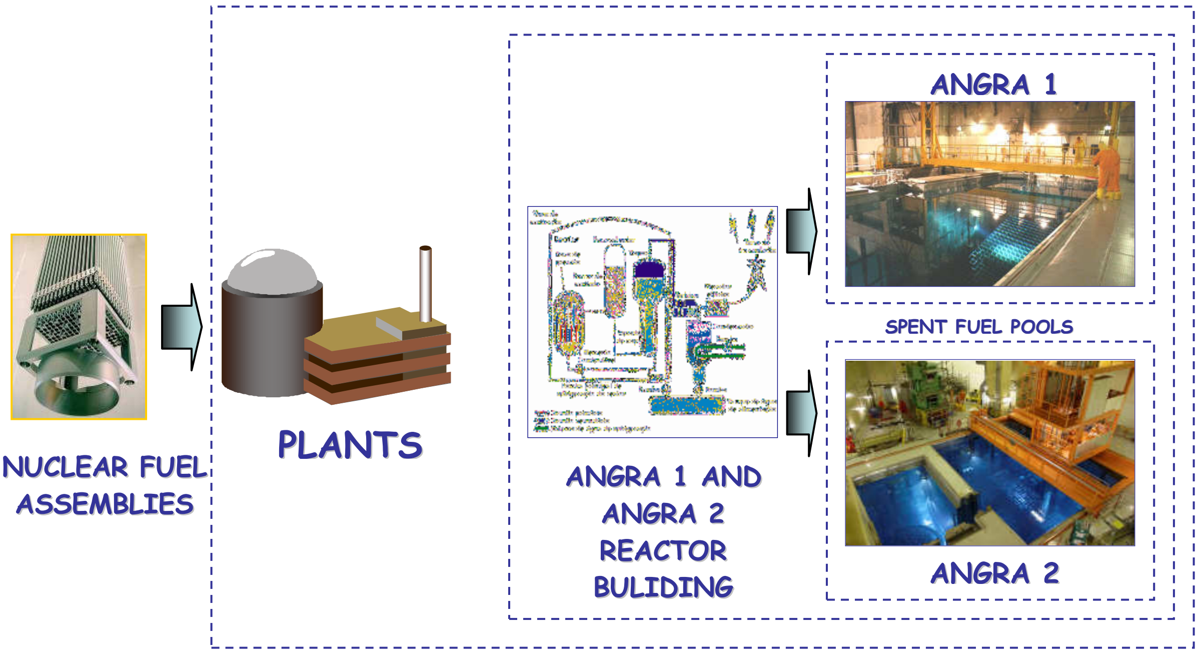

Figure 1 – Spent fuel in Angra Nuclear Power Plants

After the burning of the nuclear fuel assemblies to produce electrical energy, these assemblies have to be stored into the spent fuel pools of each plant, for at least 10 years, in order to decrease their residual heat. Even after 10 years these spent fuel assemblies still have a great amount of energy, which can be reused in the future. Nowadays in the world, the spent fuel materials can be reprocessed in order to produce electrical energy or can be stored to provide in the future a chance to decide how these materials will be treated.

Nowadays, Brazil does not intend to reprocess these spent fuels assemblies as performed by some developed countries. Thus, Brazil intents to build a long term intermediate storage of spent fuel in order to have in the future a chance to make a decision, according to the available technology in that time.

Table 1 presents the spent fuel storage capacity of the internal spent fuel pools of the plants and the number of cycles as well as the number of spent fuel assemblies into the cores.

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Table 1 – Capacity of spent fuel into the internal pools and assemblies into the core

Plants	Capacity of spent fuel into the internal pools (assemblies)	Capacity of spent fuel into to internal pools * (cycles)	Number of spent fuel assemblies into the core
Angra 1	1252	31	121
Angra 2	1084	19	193
Angra 3	1084	19	193

* depends on the level of enrichment used

Considering CNAAA plants life time, estimated in 60 years, and the internal spent fuel pools storage capacity of the plants, a Spent Fuel Complementary Storage Building – UFC has to be foreseen in order to increase the storage capacity of CNAAA, in Angra dos Reis.

Therefore in 2018 the Spent Fuel Complementary Storage Building shall be in operation, able to receive the firsts spent fuel assemblies from Angra 2 and in the next year, from Angra 1. The Spent Fuel Complementary Storage Building will be built and operated by Eletronuclear, and shall be located at the same site of the plants. The same procedure will be applied for the spent fuel assemblies of Angra 3.

Conceptually, the Spent Fuel Complementary Storage Building will be provided by a wet storage, which are a similar solution used to store spent fuel assemblies in the internal pools of the nuclear power plant installation.

According to present world tendencies the spent fuel should be reprocessed or transfered to a Long Term Intermediate Storage of Spent Fuel, although it is not the present intention of Brazil.

The responsible in Brazil to manage and to store spent fuel and radioactive waste for a long term is *Comissão Nacional de Energia Nuclear* – CNEN, defined in the Brazilian Constitution.

In this context for the licensing process of unit 3 of CNAAA (Angra 3 Nuclear Power Plant), the Brazilian institution for environment, *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais* – IBAMA, determined the compliance of environmental requirements namely requirement # 2.18 of the Preliminary License number 279/2008 [1] ("… before start of operation of Angra 3, the design proposal for the final disposition of high level activities waste should be submitted, and the execution of the project approved by environment institution should be initiated …), and the requirement # 2.20, Installation License number 591/2009 [2] (…to present in 180 days the technical-financial planning and execution according to the analytical structure of the RAN Project - *Depósito Rejeitos de Longo Prazo dos combustíveis usados,* certified by CNEN"). Those requirements are under CNEN's responsibility.

So, in 2008, CNEN has created a special group to take care of all the steps involved in the Long Term Intermediate Storage of Spent Fuel, called DICOMBUS, and established 2026 as the starting operation time of this installation.

Eletronuclear, in close cooperation with CNEN, will built a Demonstration Plant of the Intermediate Long Term Intermediate Storage of Spent Fuel – DICOMBUS, in order to show the feasibility of the conceptual design to store spent fuel. This Demonstration Plant shall be in operation up to 2013, when the processes of handle, encapsulation, transference and storage of spent fuel, shall be studied, certificated and validated, according to IBAMA requirements [1].

Figure 2 presents the considered scenario.

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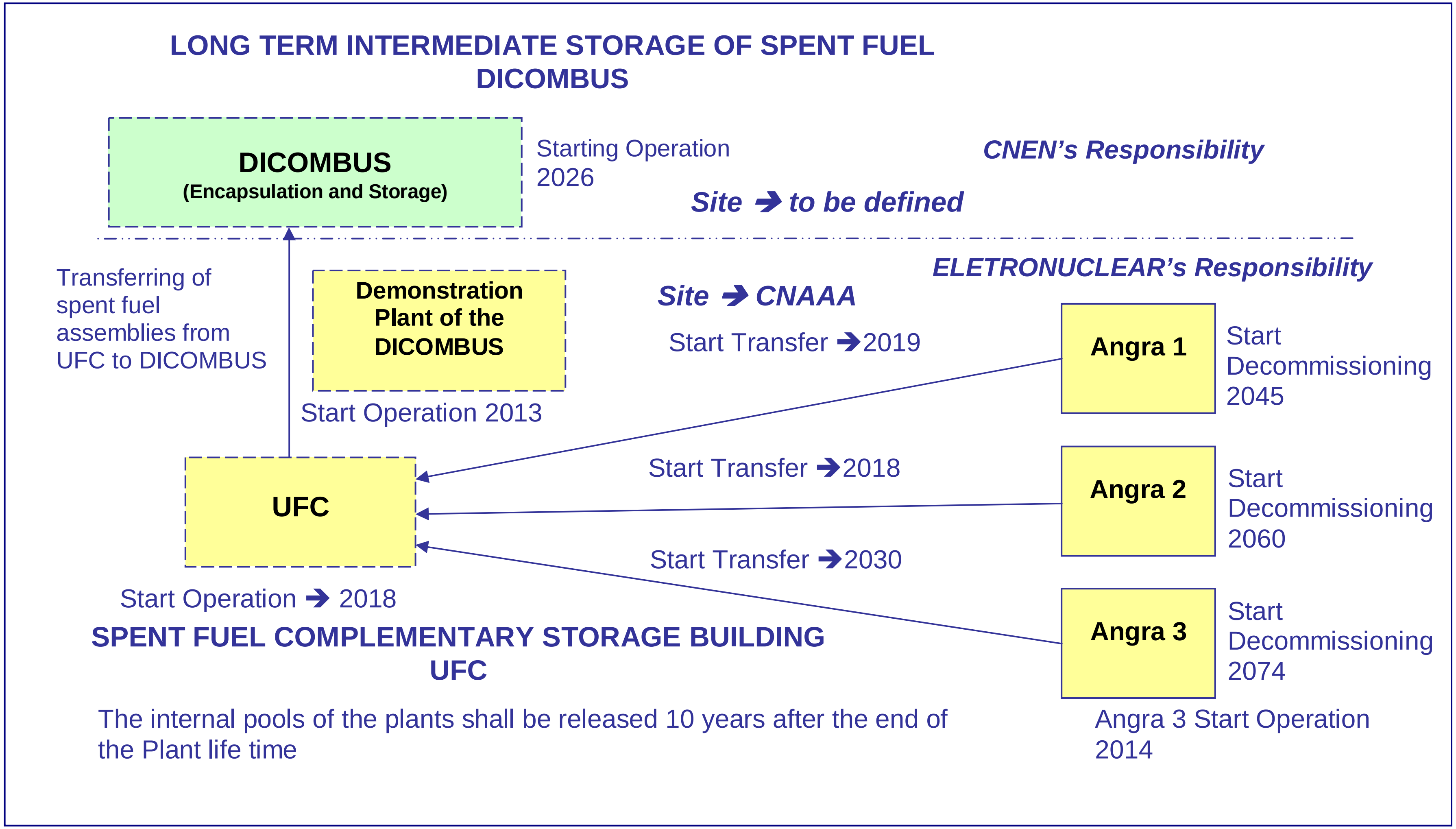

Figure 2 – Considered scenario

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In summary, the spent fuel assemblies will be stored into the existing internal pools of the plants, for, at least, 10 years. Later, these assemblies will be transported to the Spent Fuel Complementary Storage Building to be built in CNAAA area, near to the plants.

Therefore, considering the storage capacity of internal pools of the plants and the Spent Fuel Complementary Storage Building, CNAAA will be able to store all the spent fuel used in the plants during the life time of Angra 1, 2 and 3, even considering the life time extension to 60 years.

These assemblies will be transferred to the Intermediate Long Term Intermediate Storage of Spent Fuel – DICOMBUS, under CNEN responsibility, when this installation starts operation.

2. CONCEPTUAL DESIGN OF SPENT FUEL COMPLEMENTARY STORAGE BUILDING - UFC

The Spent Fuel Complementary Storage Building shall be constructed to increase the spent fuel storage capacity of CNAAA.

The civil structure of this building must follow the requirements of a nuclear installation, built in reinforced concrete and the storage will be wet, in special water tanks, with similar concept and design to Angra Power Reactor Pools. The building shall have the following main characteristics:

- ✓ Storage Facility Site – within CNAAA area;
- ✓ The building will be erected in 2 phases of construction, equipment assemblies and commissioning;
- ✓ Construction of one storage tank by each construction phases;
- ✓ The spent fuel storage tank of the first construction phase shall have a capacity for 2100 assemblies positions, which comprises the different fuel assemblies used in Angra Power Reactors. The spent fuel assemblies storage capacity in the second construction phases, in principle, shall be 2400 positions. This quantity is to be confirmed in the further phases of the design, construction and licensing process of the Long Term Intermediate Storage of Spent Fuel. DICOMBUS is under CNEN's responsibility and the start operation is foreseen up to 2026;
- ✓ There must be in reinforced concrete construction, with shallow foundations, taking into consideration geological and flooding aspects, among others;
- ✓ Spent fuel cooling water tank, through a secondary heat exchange system in a dry cooling tower;
- ✓ Provision for a purification and cleaning system for the pools water, through a floating mobile equipment;
- ✓ Spent fuel storage tanks with demineralized water, without boron addition;
- ✓ Storage racks similar to those used in Angra Power Plants and, in principle, without the use of boron plates – the criticality studies shall recommend or not the adoption of these plates, as well as will define the clearance between the spent fuel assemblies;

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- ✓ Subcriticality must be equal or less than 0,95;
- ✓ The residual heat released from each spent fuel assembly to be stored in the Spent Fuel Complementary Storage Building, must be equal or less than 1 kW;
- ✓ Eventual leakages in the Spent Fuel Storage Tanks shall be possible to be monitored through galleries and shafts around the tanks, as well as a monitoring system embedded in the slabs and walls of the tanks, similar to the used in the CNAAA fuel pools;
- ✓ Release of the fuel pools inside of the Power Plant buildings for decommissioning, 10 years after end operation for each one of the Angra Power Reactors.

Figures 3 and 4 present the basic concept of this building.

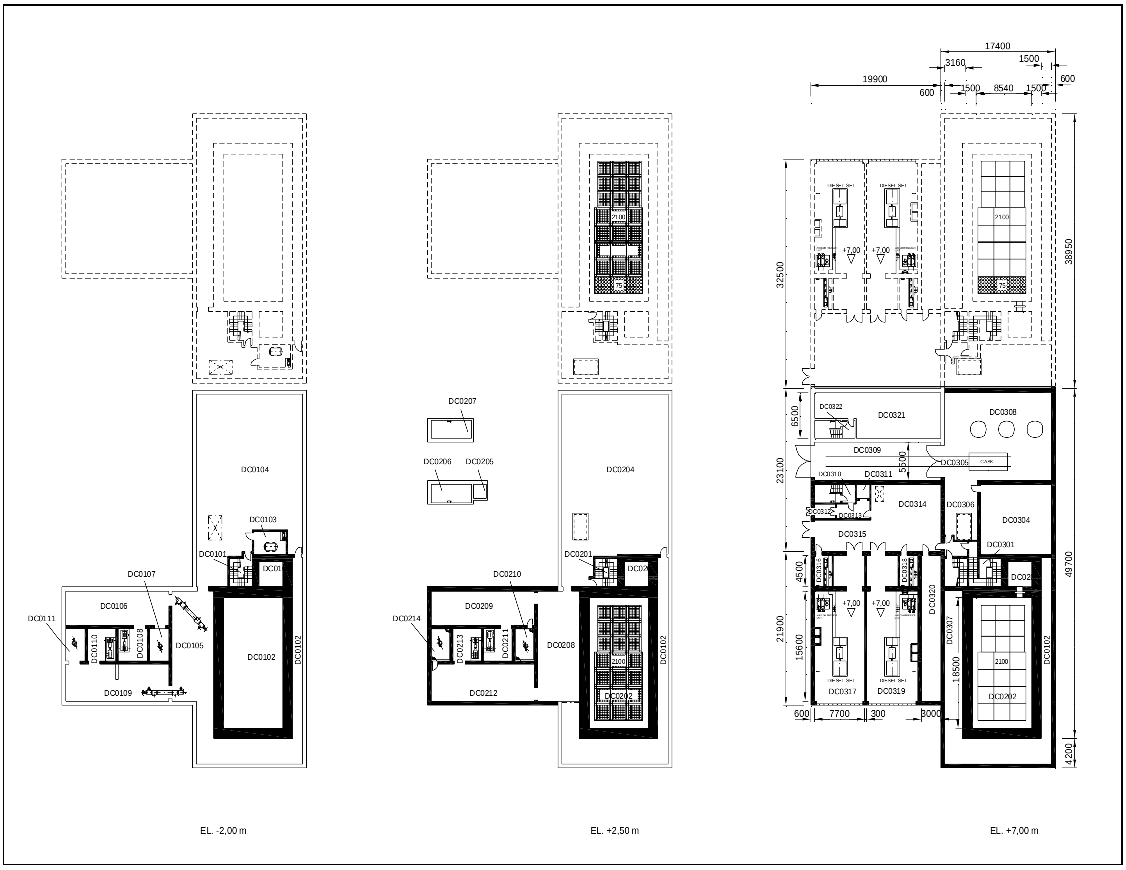

Figure 3 –Spent Fuel Complementary Storage Building - Plant

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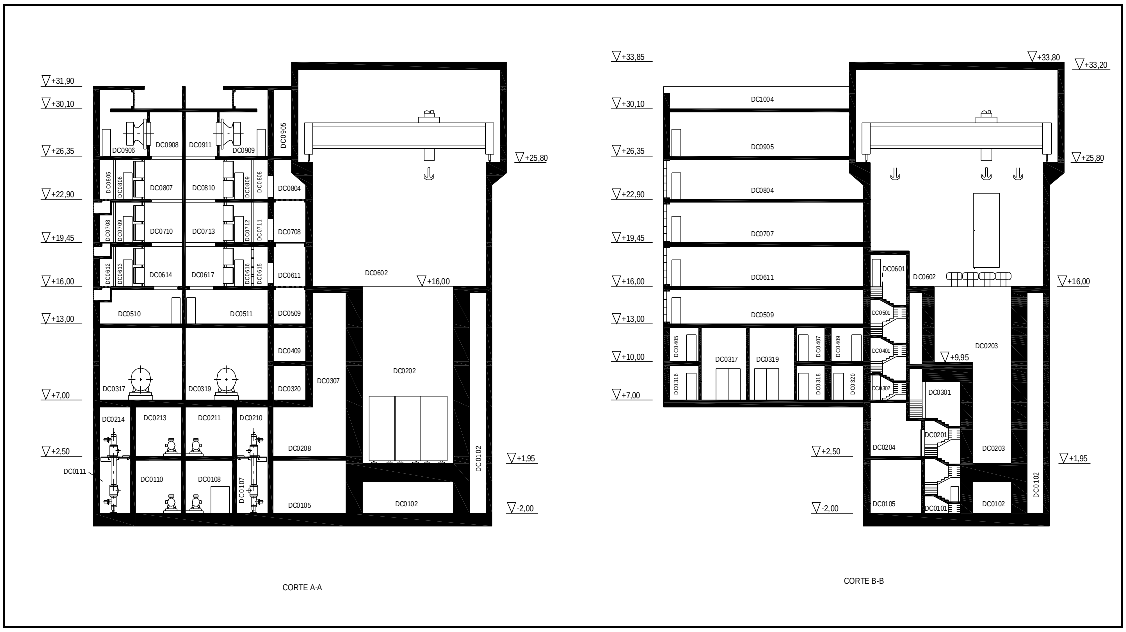

Figure 4– Spent Fuel Complementary Storage Building – Cross Sections

The site investigation is under elaboration considering the CNAAA area. The potential sites are presenting in Figure 5.

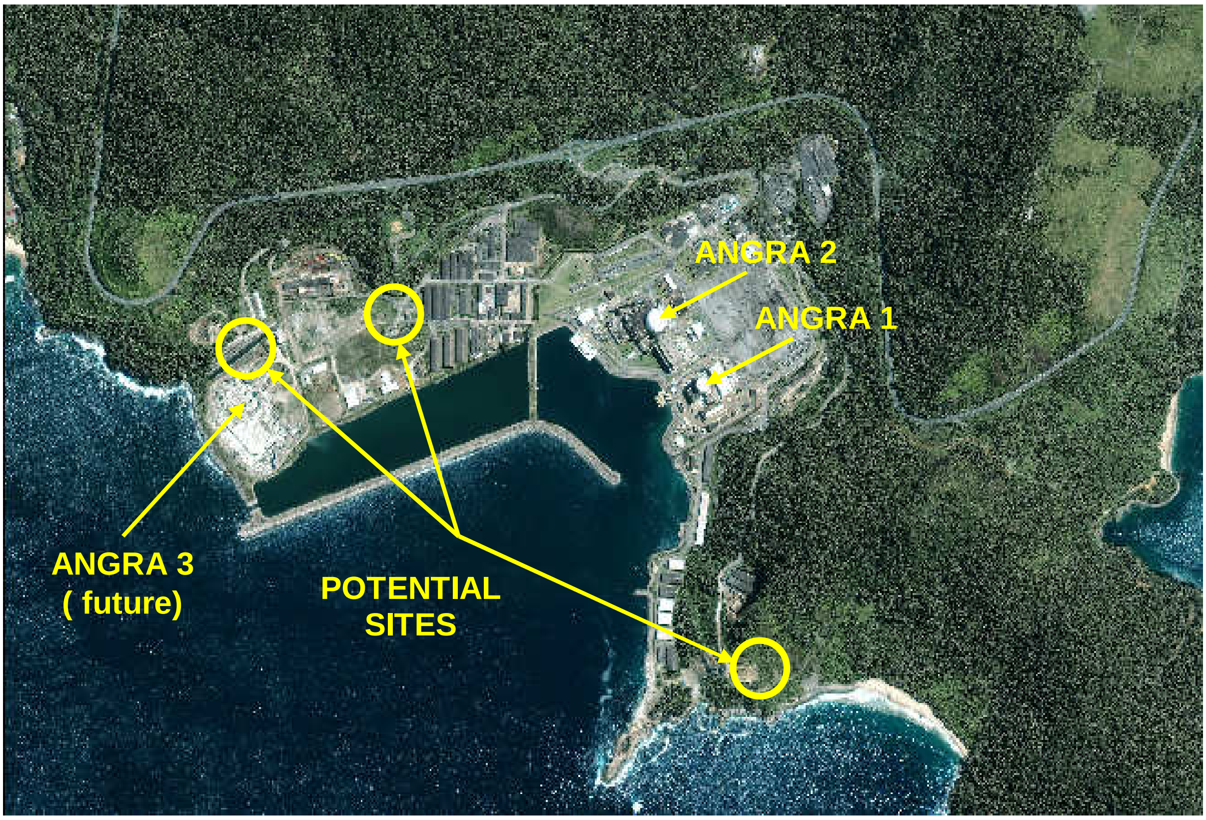

Figure 5 – Potential sites for the Spent Fuel Complementary Storage Building

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3. DEMONSTRATION PLANT OF LONG TERM INTERMEDIATE STORAGE OF SPENT FUEL – BASIC CONCEPT

CNEN has the institutional responsibility for long term storage of spent fuels.

In 2008, CNEN has created a working group with the responsibility to define the concept for the long term disposal of spent fuels. This group shall initially define a conceptual way to pack and store these spent fuels.

In order to support the concept design of the Long Term Intermediate Storage of Spent Fuel, Eletronuclear will build at CNAAA area a Demonstration Plant of this unit. This Demonstration Plant shall be able to carry out investigations and tests in order to define the best processes for encapsulation, handle, storage, maintenance, etc, of the spent fuel. Aspects like safety and material integrity should be considered in the studies and tests to be done and all steps of this process shall be certified.

According to the IBAMA requirements # 2.18 for the Preliminar License for CNAAA - Angra 3 [1], and Installation License # 2.20 for CNAAA – Angra 3, the Demonstration Plant shall be in operation up to 2013.

4. LONG TERM INTERMEDIATE STORAGE OF SPENT FUEL PLANT – BASIC CONCEPT

4.1. Transport of Spent Fuel Assemblies

Whereas the process of packaging of spent fuel assemblies for long term storage will be performed at the destination, i.e. in DICOMBUS, the transport of these spent fuel assemblies from the Nuclear Power Plants Fuel Pools to UFC as well as the transference of spent fuel assemblies from UFC to DICOMBUS, shall be done using of spent fuel transport casks, available on the market and certificated for this purpose.

Before the Cask transport operation a study to assess the logistic and costs aspects shall be required, considering among others the following:

- ✓ Casks storage area;
- ✓ Infrastructure for land transportation at CNAAA;
- ✓ Departure and destination harbor infrastructure;
- ✓ Means of transport:
  - ✓ Maritime: capacity of ships/ferries, and unloading conditions at the destination;
  - ✓ Land: types, capacities, routes (proximity to urban areas, deviations and distance, traffic condition and characteristics such as sinuosity, slope and width), and unloading conditions at the destination;
- ✓ Security aspects involved in transport operations;
- ✓ Security aspects against possible terrorist acts;
- ✓ Security aspects against natural events;
- ✓ Protection aspects for the environment;

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- ✓ Affected or involved community acceptance aspects;
- ✓ Accomplishment of current standards and legislation.

4.2. Characteristics of the Intermediate Long Term Intermediate Storage of Spent Fuel

The Plant concept considers a dry storage for the spent fuel, using Spent Fuel Canisters, which will be disposed in vertical concrete silos, with a multi-canisters capacity.

Main characteristics for the plant:

- ✓ Long term solution;
- ✓ Beginning of operation: 2026;
- ✓ Site outside of CNAAA area;
- ✓ Geological storage;
- ✓ Geological stability of the site;
- ✓ Care according the usual standards and present legislation;
- ✓ Modular constructive design;
- ✓ Fulfill the physical protection requirements;
- ✓ Take account the safety conditions related to a natural occurrences point of view (earthquake, flooding);
- ✓ Minimization and mitigation of environmental impacts;
- ✓ Dry storage;
- ✓ Initial storage capacity of at least 8000 spent fuel assemblies;
- ✓ Possibility of increasing the storage area;
- ✓ Spent fuel retrievability;
- ✓ Automate and remote equipments for movement and deposition of the spent fuel assemblies;
- ✓ Radiological shield;
- ✓ Adoption of passive auxiliary systems, as much as possible;
- ✓ Radiological control of the facility.

4.3. Basic Design Concept of the Long Term Intermediate Storage of Spent Fuel

The Long Term Intermediate Storage of Spent Nuclear Fuel shall have the main characteristics:

- ✓ Guarantee of a safety storage and people protection;
- ✓ Guarantee of monitoring, inspection and retrievability conditions;
- ✓ Guarantee of radiological shield conditions during the movement and storage, even in exceptional storage conditions;
- ✓ Guarantee of an intervention feasibility at anytime;
- ✓ Guarantee of the facility integrity under nature causes or human being acts;
- ✓ Guarantee of the radiation contention inside the facility;
- ✓ Guarantee the external environmental safety;
- ✓ Guarantee of monitoring feasibility of the exceptional conditions evolution inside the Installation;
- ✓ Accordance with the established standards and models;
- ✓ Acceptance by the general public.

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4.4. Design of the Long Term Intermediate Storage of Spent Nuclear Fuel

The Facility shall have mainly:

- ✓ Available area for Casks reception and expedition;
- ✓ Available area for Casks inspection and decontamination;
- ✓ Available area for auxiliary facilities (control, ventilation, electricity, maintenance, etc.);
- ✓ Encapsulation Plant – having sub-compartments such as detached:
  - – Available area regarding casks and Canisters traffic;
  - – Spent fuel assembly encapsulation hot cell;
  - – Welding room for the Canister lid;
  - – Inspection welding rooms for the Canister lid;
  - – Available area regarding canister additional work;
  - – A control room regarding Plant operation;
- ✓ Available area regarding Canister storage;
- ✓ Administrative work and operation processes support areas.

4.5. Long Term Intermediate Storage of Spent Nuclear Fuel Operation

The spent fuel assemblies shall be transported up to the Long Term Intermediate Storage of Spent Nuclear Fuel in Transport Casks. In the Casks reception area, located inside the Plant, there will be an initial Cask inspection. The following steps shall be carried out up to the storage Silo:

- ✓ Transference of the Transport Cask to the Encapsulation Plant ;
- ✓ Removal of the spent fuel assemblies from the Transport Cask;
- ✓ Insertion of the spent fuel assemblies within Canisters;
- ✓ Injection of inert gas inside the Canister;
- ✓ Canister lid closing by welding;
- ✓ Welding inspections;
- ✓ Insertion of the Canisters within the Transference Cask;
- ✓ Transportation of the Transference Cask to the storage area;
- ✓ Transference of the Canisters to the Silos;
- ✓ Radiological shield of Silos.

If indications are found during inspection of lid closing weld, the spent fuel assembly shall be recovered through cutting and opening the Canister.

4.6. Spent Fuel Canister

It is a cylindrical metal casing for the encapsulation of the spent fuel assemblies of Units 1, 2 and 3 of CNAAA.

The purpose of the Canister is to act as a containment barrier of the spent fuel assemblies, and, in case of failure of these spent fuel assemblies, to ensure their isolation.

The Figure 6 below shows the artistic design of this preliminary Canister.

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Figure 6 – Preliminary Spent Fuel Canister

The main features of the Canister are:

- ✓ Flexibility to encapsulate the different spent fuel assemblies of Units 1, 2 and 3 of CNAAA;
- ✓ Hermetic sealing for radioactive content (tightness);
- ✓ Assure the dissipation of heat generated by spent fuel assemblies to the outside;
- ✓ Without radiation shielding function;
- ✓ Loading operation of spent fuel assemblies performed in the dry condition and remotely controlled;
- ✓ Allows wet or dry storage;
- ✓ Long term life time loaded with spent fuel assemblies;
- ✓ Certification of the prototype is required;
- ✓ Licensing standards shall be complied;
- ✓ The principle of retrievability of spent fuel assemblies shall be complied: the Canister can be cut and opened to recover spent fuel assemblies whenever necessary.

The main technical data of the Canister are:

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- ✓ The preliminary study of Canister considered one spent fuel assembly for one Canister. However this quantity can be changed depending on the DICOMBUS Project strategy, under the responsibility of CNEN;
- ✓ Materials under study ➔ Stainless steel or others;
- ✓ Inside environment ➔ Inert gas;
- ✓ Temperature of spent fuel assembly ➔ 184.8 ° C (Angra 1 spent Fuel Assembly);
- ✓ Estimated weight of the one Spent Fuel Canister for one Spent fuel assembly ➔ 850 Kgf (weight of spent fuel assembly not included);
- ✓ Main dimensions ➔ aprox. Ø 450 x 5.300 (preliminary).

4.7. Transference Casks

After the encapsulation of the spent fuel assembly, the Canister shall be transported and stored in the Silo of DICOMBUS.

For this process a specific Transference Cask, with similar feature of Transport Cask is required. This Transference Cask shall consist of cylindrical metal casing, with effective radiation shielding and structural protection of spent fuel assemblies.

The main features of Transference Cask are:

- ✓ Sub-criticality under normal and accident condition;
- ✓ Provided with the same physical, mechanical and radiographic features of spent fuel transport cask available on the market, such as:
  - – Structural integrity for normal and accident conditions;
  - – Radiation shielding;
  - – Facilities for inspection and handling;
  - – Dissipation of heat generated by spent fuel assemblies;
  - – Tightness;
  - – Monitoring easiness.
- ✓ When loaded with Canisters, allows handling and temporary storage in a horizontal or vertical position;
- ✓ Minimum maintenance;
- ✓ Loading of Canisters in dry or submerged condition;
- ✓ Limitations of the final weight and dimensions, to permit their handling by devices usually available;
- ✓ Certification of the prototype is required;
- ✓ CNEN Standard CNEN-NE-5.01 - Transportation of Radioactive Materials, shall be complied;
- ✓ Licensing standards shall be complied.

The main technical data of Transference Cask are:

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- ✓ Transference Cask of multi Canisters for one spent fuel assembly or Transference Cask of multi Canisters for multi spent fuel assemblies, (the decision depends on the study of economy of scale in the transportation and storage process);
- ✓ Estimated weight ➔ 145 tf (Canisters + spent fuel assemblies);
- ✓ Outside dimensions ➔ Similar to Transport Cask;
- ✓ Capacity ➔ Preliminary estimation of accommodation of 12 spent fuel aseemblies packed in Canisters.

5. CONCLUSION

This paper shows the first approach for the long term intermediate storage of spent fuel concept.

The questions related to spent nuclear fuel storage are being treated with total transparency and also considering the newest technology available in the world, as presented in this paper. Additionally all of the engineering solution to be taken about this matter will be submitted to the environmental and nuclear license authorities.

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