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STUDY AND PROJECT OF THE NEW RACK WITH BORON FOR STORAGE OF FUEL ELEMENTS BURNED IN THE IEA-R1 RESEARCH REACTOR

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ABSTRACT

The IEA-R1 research reactor works 40h weekly with 4.5 Mw power. The storage rack for spent fuel elements has less than half of its initial capacity. Under these conditions (current conditions of reactor operation 32h weekly will have 3 spend fuel by year, then, approximately 3 utilization rate Positions/year). Thus, we will have only about six years of capacity for storage. Whereas the desired service life of the IEA-R1 is at least another 20 years, it will be necessary to increase the storage capacity of spent fuel. Hence, it is necessary to double the wet storage capacity (storage in the IEA-R1 reactor's pool). After reviewing the literature about materials available for use in the construction of the new storage rack with absorber of neutrons, the BoralcanTM (manufactured by 3M) was chosen, due to its properties.

This work presents studies: (a) for the construction of new storages racks with double of the current capacity using the same place of current storages racks and (b) criticality analysis using the MCNP-5 code. Two American Nuclear Data Library were used: ENDF / B-VI and ENDF / B-VII, and the results obtained for each data bases were compared. These analyzes confirm the possibility of doubling the storage capacity of fuel elements burned in the same place occupied by the current storage rack attending to the IEA-R1 reactor needs and attending the safety requirements according to the National Nuclear Energy Commission - CNEN and the International Atomic Energy Agency (IAEA). To calculate the keff were considered new fuel elements (maximum possible reactivity) used in full charge of the storage rack. With the results obtained in the simulation we can conclude that doubling the amount of racks for spent fuel elements are complied with safety limits established in the IAEA standards and CNEN of criticality (keff < 0.95).

1. INTRODUCTION

The IEA-R1 reactor is open pool type and reached its first criticality on September 16, 1957. During the first three years of operation, the reactor power was up to 1 MW. From 1960 to 1995, the operating regime of the reactor was 40 hours per week at a power of 2 MW. From

1995, the Reactor had its operation regime modified for 64 hours without interruption, aiming at the production of ^{153}Sm and service to the scientific body of IPEN-CNEN / SP.

The IEA-R1 nuclear reactor has been used intensively for more than 50 years, being one of the oldest and best used research reactors in the world, according to the International Atomic Energy Agency (IAEA), for research and development activities. It should be noted here that, in addition to research, the reactor is, also, thoroughly used for the generation of several types of products and services, among which the production of primary radioisotopes is the most important, for the preparation of radiopharmaceuticals used in Nuclear Medicine [1]. During the last 15 years, the reactor underwent several alterations in its vital systems and equipment, due to wear and tear, and these improvements continue, in view of the proposed increase of the reactor power from the current 4.5 to 5.0 MW and operation of 120 hours per week, in the future.

These changes will meet the growing demand for radioisotope production for use in medicine, such as ^{153}Sm, ^{131}I and ^{99}Mo. Aiming at this new rhythm of work and the adequacy of the installation for higher power, a project for the continuous upgrading of the reactor was started.

1.1. Objective

The objective of this work was the study and design of a humid storage system to double the current storage capacity of burned fuel elements of the IEA-R1 research reactor, using borated material in the racks manufacture.

1.2. Storage of Fuel Elements in the IEA-R1 Research Reactor

The irradiated fuel elements are stored in stainless steel racks located in the storage compartment of the reactor pool, as shown in Figure 1. In the storage compartment of the reactor pool there are three hanging racks affixed to the pool wall, with capacity of storing 24 + 24 + 36 fuel elements, reaching a total of 84 positions, where the burned fuel elements are stored. At each position of the fuel storage racks, aluminum coating boxes are installed to minimize galvanic corrosion between the fuel element plates and the structural material of the storage basing.

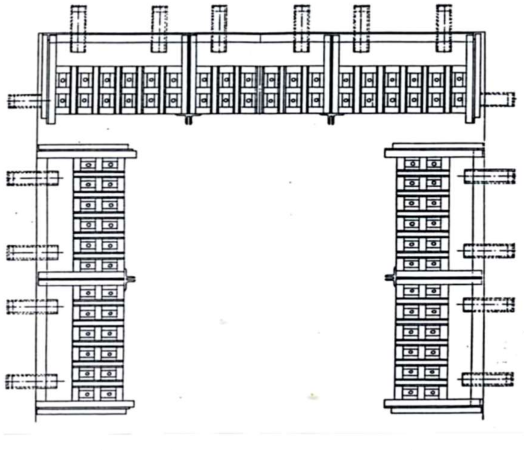


Figure 1: Top view of the storage racks in the reactor pool.

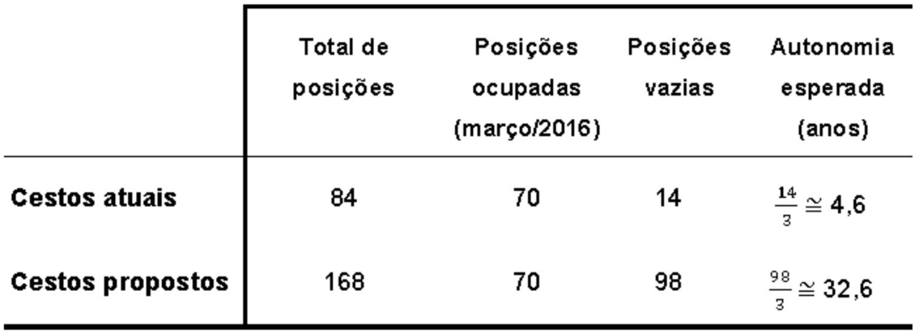
1.3. Current Situation of the Storage Racks

Currently, the racks available for storage of the irradiated fuel elements present an occupation fraction greater than 83% (70 occupied positions out of the total 84), as shown in Table 1, with the current level of use of the racks.

Thus, maintaining the present operating conditions of the reactor (32 hours per week, at 4.5 MW of power), we will have a utilization rate of ~ 3 positions/year, what results in an autonomy of around 5 years of operation, since we do not have a definite destination for this type of waste.

Considering that the estimate IEA-R1 reactor lifetime is about another 20 years, it will be necessary to increase the storage capacity of the spent fuel [2]. To make it possible, neutron-absorbing material has to be used in its construction, in view of the limited availability of space within the reactor pool, also, to meet the safety requirements of the licensing agency (CNEN) and Standards established by the IAEA.

Table 1: Comparison of the current racks with the new units proposed in the project (condition in March 2016) (source: owned)



	Total de posições	Posições ocupadas (março/2016)	Posições vazias	Autonomia esperada (anos)
Cestos atuais	84	70	14	$\frac{14}{3} \cong 4{,}6$
Cestos propostos	168	70	98	$\frac{98}{3} \cong 32{,}6$

2. MATERIALS AND METHODS

After studies that led to the accomplishment of this work, the traditional option of the borated- stainless steel basin was discarded due to the need of an internal aluminum coating and constant inspection of its integrity, ensuring that there is no contact between the aluminum structure of the fuel element and the stainless steel from the basing, generating galvanic corrosion [3]. Such an inspection procedure is quite laborious and expensive, since it has to be carried out underwater [4].

From the analysis of the literature on high density racks for the storage of irradiated fuel elements from research reactors, BORALCAN^{TM} was chosen for this work.

BORALCAN^{TM} is a metal matrix composite (MMC) made by Rio Tinto Alcan, comprising an aluminum alloy (1100 or 6351) added with nuclear grade B_4C powder and titanium (Ti). The addition of small amounts of Ti (<2.5%) in the molten aluminum makes the mixture of B_4C particles more stable and uniform, avoiding interactions of Al with B_4C [5].

2.1. The MCNP-5 Code

Monte Carlo N-Particle is a general-purpose transport code that considers continuous spectrum of energy, generalized geometries, time dependence and neutron / photon / electron set effect. It may be used in several transport modes: only neutrons, only photons, only electrons, combined neutron / photon transport, where photons are produced by neutron, photon / electron, photon / electron or electron / photon interactions. The neutron energy range is 10-11 MeV at 20 MeV for all isotopes and up to 150 MeV for some isotopes. For photons, it ranges from 1 keV to 100 GeV and the energy range for electrons is 1 keV to 1 GeV. It can calculate keff values for fission systems, as well as keff for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells delimited by first or second degree and fourth degree elliptical toroid surfaces [6].

2.2. Modeling and Results

For the development of the project, the computational code MCNP version 5 was used because it is a widely accepted calculation tool and highly indicated in the analysis of this type of problem [6].

The computationally simulated arrangement with the MCNP-5 consisted of a 16X3 basin totaling 48 fuel elements, what would double the capacity of the current racks of 24 elements, yet occupying the same physical space, that is, with practically the same external dimensions. Figure 2 shows a 3D illustration comparing the current basin with that to be constructed.

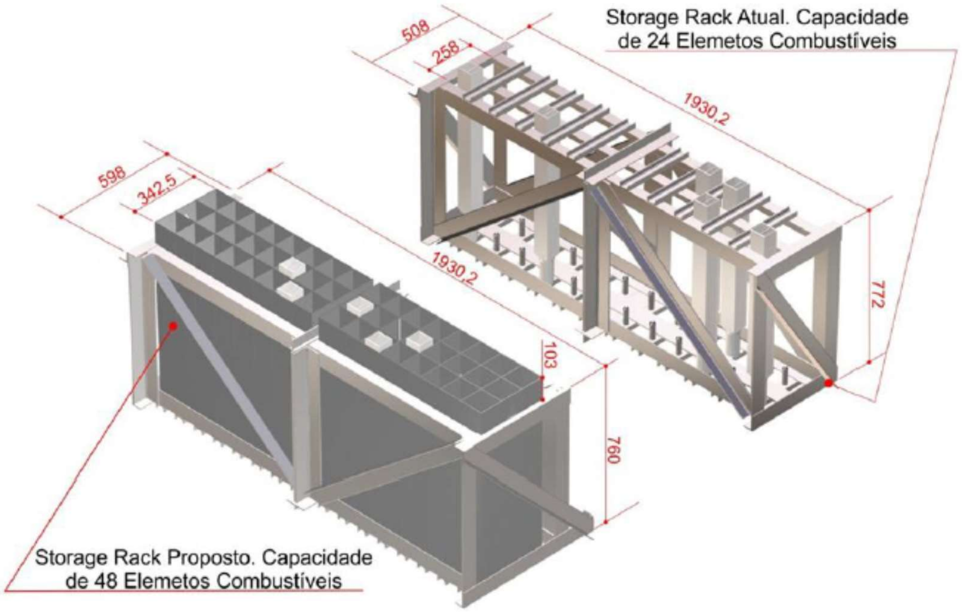
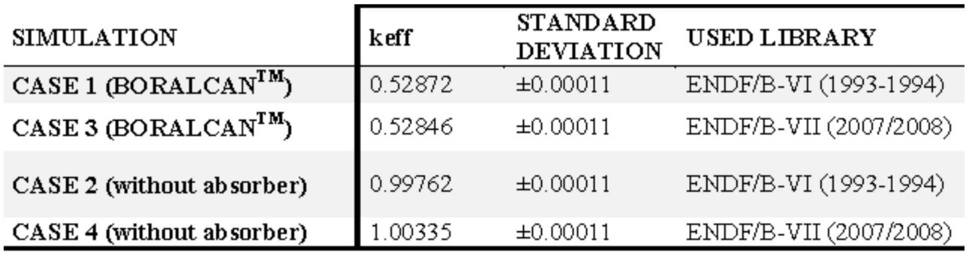


Figure 2: 3D comparative drawing of the two racks with dimensions.

2.3. Results Obtained in the Calculation of k_{eff}

For keff calculation, four cases were analyzed: two with the ENDF / B-VI library (cases 1 and 2) and two with the ENDF / B-VII library (cases 3 and 4). In the analysis of the cases, two situations were considered: one with the BORALCAN^{TM} absorber and the other with pure aluminum. For the simulation, it was considered that the basin was fully loaded with U_3Si_2-Al fuel elements of new 3.0 g/cm^3 (0% of burning), corresponding to the most critical condition in terms of criticality risk (called a more conservative condition). The structure of the output of the program results is divided into phases of the simulation, where the first half corresponds to the results obtained in the initial 235 iterations (active cycles) and the second half, in the next 235 final iterations. The final result is calculated taking into account all the active cycles, in our case, 470. Table 2 presents an outline of the results for keff.

Table 2 – Summary of the results obtained for keff.



SIMULATION	keff	STANDARD DEVIATION	USED LIBRARY
CASE 1 (BORALCAN^{TM})	0.52872	±0.00011	ENDF/B-VI (1993-1994)
CASE 3 (BORALCAN^{TM})	0.52846	±0.00011	ENDF/B-VII (2007/2008)
CASE 2 (without absorber)	0.99762	±0.00011	ENDF/B-VI (1993-1994)
CASE 4 (without absorber)	1.00335	±0.00011	ENDF/B-VII (2007/2008)

3. CONCLUSIONS

Based on the results obtained, it can be safely concluded that, by doubling the amount of fuel elements burned in the basin, the limit established in the IAEA and CNEN standards for criticality (keff <0.95) will be met, as long as the absorber material is used.

From Table 2, we conclude that for the new racks it is necessary to use the neutron absorber (in our case BORALCAN^{TM}), since the system without the absorber can reach the criticality and, possibly, the supercriticality (keff> 1), as it may be verified in Cases 2 and 4, respectively.

The preparation of the new racks, proposed in this work, should be done using the absorber material with 25% (of volume) aluminum boron carbide alloy 1100 that is produced by Rio Tinto Alcan.

Thus, we will meet all the requirements of the standards and will be able to double the storage capacity of burned fuel elements of the current racks, increasing the operational autonomy of the IEA-R1 reactor.

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