Ageing Assessment of the Brazilian Research Reactor IEA-R1 Core Support Structures

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Abstract

IEA-R1 is a research reactor developed by Babcock & Wilcox [1] and operating in Ipen-Cnen/SP since 1957. The core of the reactor is located 7 meters below the swimming pool water level and mounted over an eighty holes supporting plate. Over theses holes fuel and control elements, guides, and other structures are located, displaced in a way to optimize experimental arrangements. The main plate is supported by a frame that is connected to an overhead crane through aluminum profiles.
This work evaluates the support structure of the core and estimates its service life, taking into account the deformation of the aluminum alloy 6061 – T6 due to a critical integrated neutron flux of 0.5xE22 neutrons/cm^2. Considering the reactor neutron flux as the main life criteria to the aluminum profiles that support the core structure, we evaluate the remaining working hours of the frame.
It also estimates the consequence of a change in the reactor power from 2 MW to 5 MW.
Future works should include a visual inspection and an evaluation of the frame materials.

1. Introduction

IEA-R1 is the first nuclear research reactor installed in Brazil and was first critical in 1957. It was constructed in the campus of University of Sao Paulo (USP), inside the Nuclear and Energy Research Institute – IPEN-CNEN/SP. Figure 1 shows the reactor pool and its core structures.

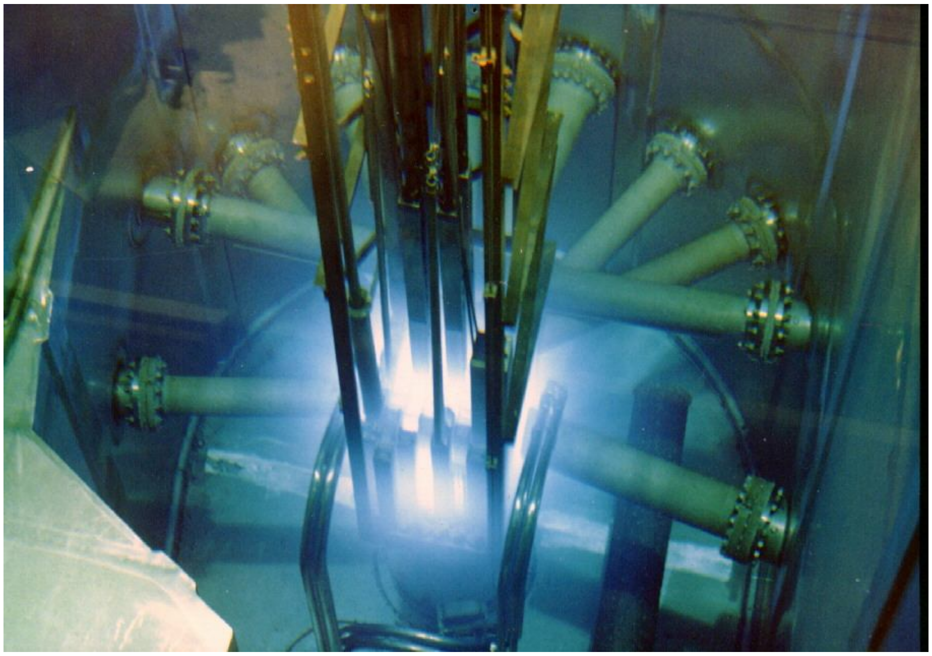

Figure1 : Reactor core

The Institute uses the reactor to produce some radioisotopes that are useful for the industries and for medicine. Another experiments for physics, engineering, chemistry and health are accomplished using the research reactor.

This work describes the reactor core support structure, an structural analysis data of the core plate, and a simple stress analysis of the frame, (fig.2), including considerations of the remaining service life due to a change in the reactor power from 2 to 5 MW.

A description of the materials used in the main plate support and in the different elements used in the core arrangements is also included.

Figure 2 - Core Frame

2. Core Support Structure

The nuclear reactor core is supported by an aluminum alloy plate, that has eighty holes to engage a variety of elements.

This plate, called “main plate”, is sustained by a frame of “L” profile that form the entire structure that is supported at the swimming pool board by an overhead crane.

The frame described above is formed by different materials as detailed below:

Frame profiles	Aluminum Alloy 6061 – T6
Main plate	Aluminum Alloy 1100 – F
Main plate plugs	Aluminum Alloy 1100 – F
Main plate pins	Aluminum Alloy 2014 – T6
Hexagonal head screws	Aluminum Alloy 2024 – T4
Washers	Aluminum Alloy 7075 – T6

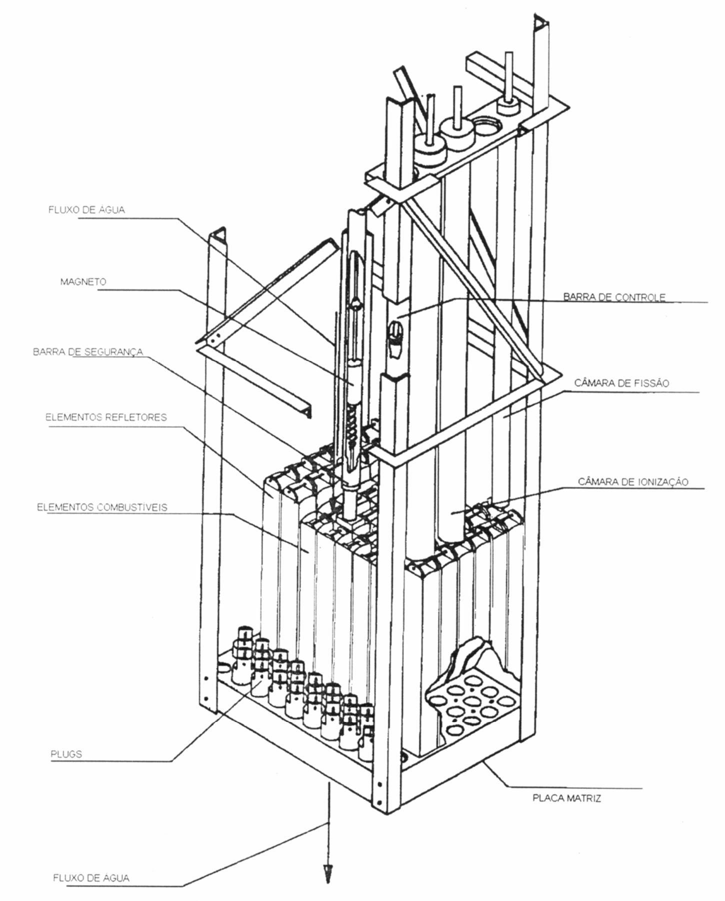

Figure 3 – Main Plate and Frame

3. Loading definitions

In order to evaluate the main plate loadings, the following masses were considered:

Item	Quantity	Weight(Kg)	Total(Kg)
Fuel Elements	20	5.4	108
Control Fuel Elements	4	7.2	28.8
Reflective Elements	39	9.7	378.3
Irradiation Elements	10	6	60
Guide Structures	4	15	60
Control Bars	4	7.6	30.4
Total			665,5

The dead weight of the main plate was estimated, ref. [2], as 185.2 Kg.

4. Main Plate Stress Analysis

In a finite element analysis of the plate, ref. [3], considering the main plate and the elements described above with 10% of additional load to consider some eventual effect of the control rods, the deflection and stresses obtained are very low and about 10% of the allowable stresses, as shown in the table below:

Local	Strain (mm)	Stress(N/mm^2)	Allowable stress (N/mm^2)
Main Plate	-0.04	2.56	25
Screws		17.8	183

5. Frame Profile Analysis

These aluminum profiles have an “ L” section and shall resist the elements and the main plate weights. For the calculation we doubled the weight of the control elements in order to consider some dynamic effects:

Total mass of the elements and the control bars added: 665.5 + 60 = 725.5 Kg
Mass of the main plate: 185.2 Kg
Total weight: 9107 N.
Area of the “L” profile = 11.16 cm^2 J1 = J2 = 40.8 cm^4 W= 9.34 cm^3
Tension(σ) = 9107/(4x11,16) = 204 N/cm^2 = 2.1N/mm^2

This value is far below the allowable stress for the aluminum alloy: σ_{adm}=200N/mm^2, ref. [4].

6. Stress Cycling

There are different causes associated with the ageing in research reactors. The most common studies are over the stress and thermal cycling, radiation and corrosion.
The dynamic load in this type of research reactor is the static load added to the highest load occurring in a transient, that is, the load loss produced by the water passing through the reactor core. The differencial pressure calculated for 20 fuel elements and a flow rate of 3000GPM (5MW of reactor power) is given as Δp=0.016 N/mm^2 through the core.
The calculated area of the main plate is 5640 cm^2 (Apm = 66,4X84,93).
We have the load F = 9107 N calculated above, so the total stress in the profiles (**σ_c**) due to F will be:

σ_c = 9107/(4X11.16X100) = 2.04 N/mm^2.

σ_{peak} = σ+σ_c=2.1+2.04 = 4.14 N/mm^2.

This value is very low and produces no cycling problems when compared with the fatigue analysis SN curves, ref. [5], for this alloy, that gives 60 N/mm^2 as a limit.

7. Frame Life Assessment

The most important factor that induces damage to the aluminum profiles in the frame is the radiation-induced silicon precipitate, a rim of intergranular cracks formed at the originally oxidized surfaces that comes from the reaction:

$^{27}\text{Al}\,(n, \gamma) \rightarrow {}^{28}\text{Al} \rightarrow {}^{28}\text{Si} + \beta$.

This alloy reduces its final elongation to 5% for a flux of $1.3\text{X}10^{23}$ neutrons/cm^2 (0.1 MeV) in contact with a 55°C water, ref. [6].

In the IEA-R1 Reactor, the temperature is less than 55°C and the frame material has not been inspected frequently, so we can adopt a critical flux(Φ_c) of $0.5\text{X}10^{22}$ neutrons/cm^2.

8. Estimated Critical Flux for the Reactor IEA-R1

When estimating the total integrated flux for the reactor we can summarize the original data since 1957 until 1995:

Total dissipated energy in a 2 MW reactor power: 93086.52 MWh.

Total time: $1.68\text{X}10^8$s

We consider a neutron flux of $2\text{X}10^{12}$ neutrons/cm^2, corresponding to the maximum flux obtained for the reflector region (E>0.85 MeV).

Integrated Flux: $1.68\text{X}2\text{X}10^8\text{X}10^{12} = 3.36\text{X}10^{20}$ neutrons/cm^2

The new critical flux (Φ_{cnew}) will be:

$\Phi_{cnew} = \Phi_c - 3.36\ \text{X}10^{20} = 4.664\ \text{X}\ 10^{21}$ neutrons/cm^2 .

9. Estimated Service Life for the Reactor IEA-R1 Core Support Frame

The total dissipated energy of regular 2MW reactor power operations until 1995 was 93086.52 MWh. From 1995 till Mar/2010, the reactor has run 33700 hours, ref. [7], that is, $1.21\text{X}10^8$ s.

Considering a neutron flux of $2\text{X}10^{12}$ neutrons/cm^2, we can calculate the integrated flux below:

$\Phi_2 = 1.21\text{X}10^8\text{X}\ 2\text{X}10^{12} = 2.42\text{X}10^{20}$ neutrons/cm^2

The limit flux will be obtained subtracting this one from the new critical flux:

$\Phi_5 = \Phi_{cnew} - \Phi_2 = 4.664\ \text{X}\ 10^{21} - 2.42\text{X}10^{20} = 4.421\text{X}10^{21}$ neutrons/cm^2

9.1. Reactor Power of 2 MW

So, if we consider the original flux of $2\text{X}10^{12}$ neutrons/cm^2 for the 2 MW reactor power, the estimated service life for the reactor core support frame will be:

$t = 4.421\text{X}10^{21} / 2\text{X}10^{12} = 2{,}2105\text{X}10^9$ s

If we estimate a 120 hours/week of operation, it gives $22.464\text{X}10^6$s per year.

The total estimated service life for the 2 MW reactor power frame (V_{2MW}) is:

$V_{2MW} = 2{,}2105\text{X}10^9 / 22.464\text{X}10^6$

V_{2MW} = 98 years.

9.2. Reactor Power of 5 MW

In 1997 the reactor was prepared to operate at 5 MW, what has not been happened until now.

For a reactor power operation of 5 MW, from now on, the new flux will be 2.5 times the 2 MW flux, that is, $5X10^{12}$ neutrons/cm^2. With this flux, the new estimated service life (V_{5MW}) is:

$t = 4.421X10^{21} / 5X10^{12} = 0.8842X10^{9}$ s

$V_{5MW} = 0.8842X10^{9} / 22.464X10^{6}$

V_{5MW} = 39 years and 4 months

10. Conclusions

The core support structures of the IEA-R1 were calculated for three different loadings:

1- Weight of the elements and the main plate;

2- Weight of the control rod elements added to and with dynamic influence;

3- Load loss (inertial pressure loss when the water passes through the core elements).

All of these loadings combined are far below the stress limit of the aluminum alloy. So we can conclude that the stresses will not limit the life assessment of the structures.

It was highlighted that the 6061 – T6 alloy, when subjected to a neutron flux over $1.3X10^{23}$ neutrons/cm^2 and at temperature around 55°C can produce aluminum precipitates of Mg_2Si that will be formed in Al-Mg alloys. These precipitates can increase the strength and decrease the ductility what means a degradation in the mechanical properties.

The elongation limit of 5%, ref.[6], was used to evaluate the frame life for 2 MW of reactor power it will take 98 years to degrade and for 5 MW the reactor structure will resist 39 years and 4 months.

11. References

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