2007 International Nuclear Atlantic Conference - INAC 2007
Santos, SP, Brazil, September 30 to October 5, 2007
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: 978-85-99141-02-1

STRUCTURAL ASSESSMENT OF THE IEA-R1 RESEARCH REACTOR CORE MATRIX PLATE UNDER LOADS FROM A NEW PNEUMATIC IRRADIATION SYSTEM

Gerson Fainer[1], Carlos Alexandre de Jesus Miranda[1] and Miguel Mattar Neto[1]

[1] Instituto de Pesquisas Energéticas e Nucleares, IPEN – CNEN/SP
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
gfainer@ipen.br
cmiranda@ipen.br
mmattar@ipen.br

ABSTRACT

One of the most recent actions related to the continuous modernization of the IEA-R1 research reactor is the replacement of the old pneumatic irradiation system by a new one. The new system has two positions supported by the core matrix plate introducing loads up to five times greater than the usual loads over it in those positions. From the safety point of view, a structural assessment of the core matrix plate under the new loads is strongly recommended. So, this paper presents this assessment considering that the core matrix plate is simply supported on its corners by the core support frame and its holes in several positions to support fuel elements, control elements, reflectors, etc., and to provide the coolant flow through it. To obtain a realistic structural behavior of the plate a three dimensional finite element model was developed and processed considering its support conditions in the corners and the usual loads from a typical core configuration plus the loads from the new pneumatic system in the most unfavorable positions in terms of stress. The obtained results from the finite element analysis show that there are adequate safety margins under the applied loads described above indicating that no modification or reinforcement of the plate is necessary.

1. INTRODUCTION

IEA-R1 is a pool type research reactor, moderated and cooled by light water, and utilizing graphite as reflector. The construction is a Babcock & Wilcox design and the first criticality was achieved in September 16, 1957. After initial tests, the reactor started operating at 2 MW. Due to the growth in radioisotope demand, in 1997 after necessary modifications and upgrading process, the power is being increased to 5 MW.

The IEA-R1 core is underwater, seven meters below the reactor pool surface, mounted over a plate with 80 holes called matrix plate, where the fuel elements may be arranged in several configurations. This plate is supported by a frame that is connected to a crane. The core support frame is built with standardized beams as can be seen on Fig.1.

One of the recent IEA-R1 improvements is the design of a new irradiation system where two irradiation elements will be installed over the core matrix plate. This paper describes the structural assessment of the plate supporting the normal loads plus the new irradiation elements loads based on the structural analysis of the core matrix plate and of its bolting connections to the core support frame. A numerical simulation using finite elements was used to assess the core matrix plate structural behavior and hand calculations were used to check the bolting connections. Details of the structural modeling and of the numerical simulation as well the results and assessment are showed and discussed.

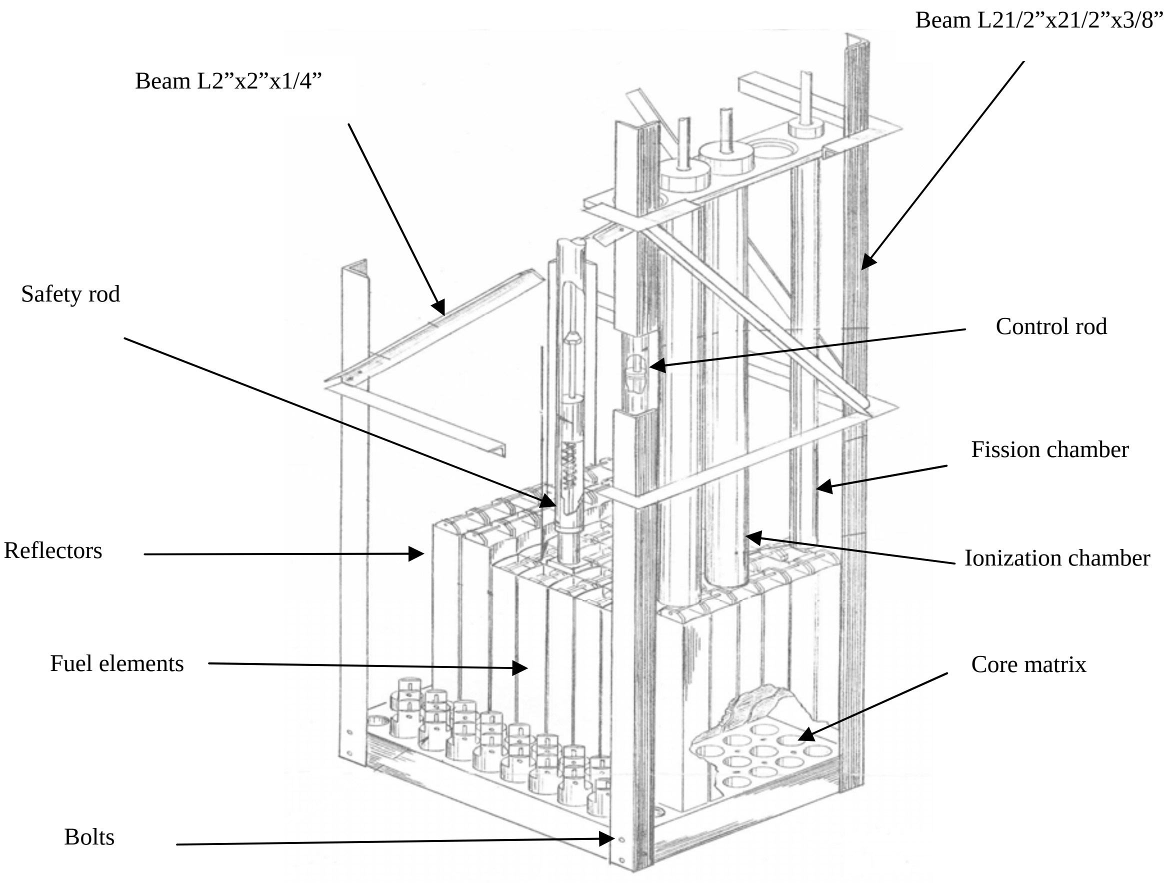

Figure 1: IEA-R1 research reactor – Core support frame and core matrix plate

2. CORE MATRIX PLATE STRUCTURAL BEHAVIOR

The in –plane core matrix plate geometry is showed in Fig.2.

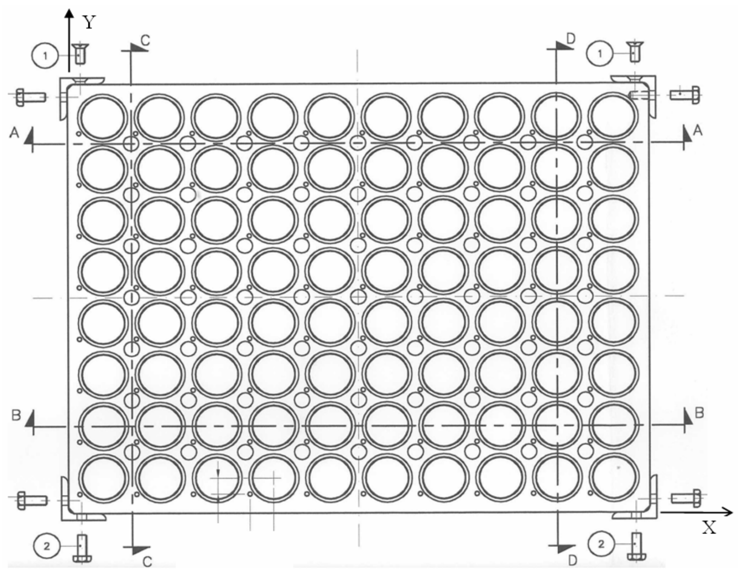

Figure 2: Core matrix plate geometry (830,26 mm X 641,25 mm X 127,0 mm)

2.1. Finite Element Model

The core matrix plate showed in Fig. 2 was fully modeled using three dimensional solid finite elements with three translational degrees of freedom per node called SOLID45 in the elements library of the program ANSYS [1], used in the analysis.

The resultant finite element model is showed in Fig. 3.

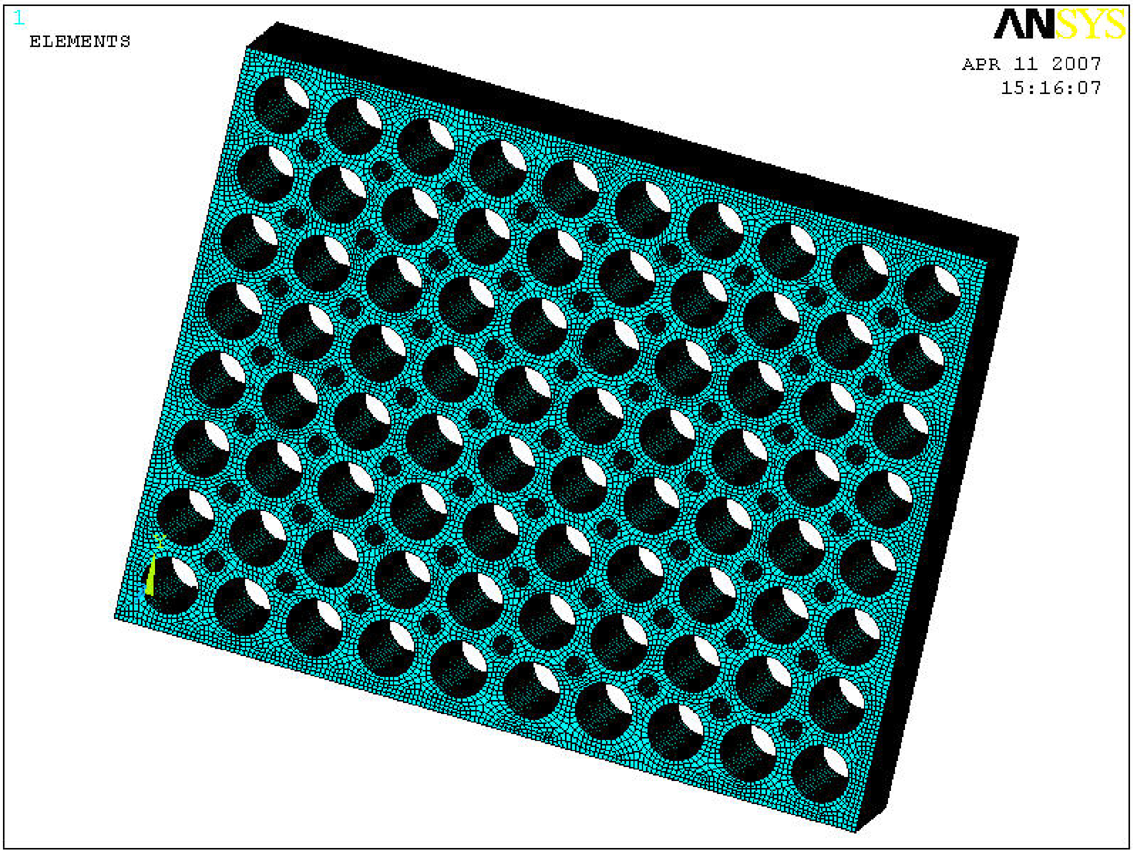

Figure 3: Core matrix plate finite element model

The applied nodes displacements constraints correspond to the bolting connections. According to the coordinates system of the Fig. 2, all the nodes located in bolts positions have the Z direction displacements restrained. Also, for X = 0,0, the nodes located in bolts positions have Y direction displacements restrained and for Y = 0,0, the nodes located in bolts positions have X direction displacements restrained.

The applied loads are the normal loads, i.e., the core matrix plate dead weight and the existing core elements weights plus the additional loads from the new irradiation elements dead weights. They are showed in Tab.1. Conservatively, the normal loads are considered as a force of 100 N applied as equivalent nodal forces in all plate positions except the two positions of the new irradiation elements where a force of 700 N is applied as equivalent nodal forces.

The materials of the core matrix plate and of the bolts and their corresponding mechanical properties are showed in Tab. 2.

Table 1: Core components weights

Item	Quantity	Unit Weight (N)	Total Weight (N)
Fuel elements	20	54	1080
Control elements	4	72	288
Reflectors	36	97	3492
Irradiation elements	4	60	240
New irradiation elements	2	650	1300
Control rod drives	4	150	600
Control rods	4	76	304
		TOTAL	**7604**

Table 2: Materials and mechanical properties

Materials	Limits (N/mm^2)		Density (Kg/m^3)	Elasticity modulus (N/m^2)	Poisson's ratio
	Yielding	Allowable			
A 1100-F (plate)	25,0	16,7	2710	69×10^9	0,33
A 2024-T4 (bolt)	275,0	183,0	2710	69×10^9	0,33

The allowable limits showed in Tab. 2 were obtained according to the ASME Code [2]. It establishes a value of 2/3 of the yielding limit as the basic allowable limit S. The allowable limit for generalized membrane primary stresses (P_m) is 1,0 S, for localized membrane primary stresses (P_l) and for primary membrane plus bending stresses ($P_l \pm P_b$) it is 1,5 S. For bolts under shear loads the allowable limit is 0,6 S. Also, the allowable limit for the bearing stresses is the 1,5 times the yielding limit S_y.

2.2. Numerical Simulations Results and Discussion

The numerical simulations were performed with the program ANSYS [1]. The materials were considered elastic, linear and isotropic therefore the static and linear analysis option was used.

The obtained Tresca stress intensities (the biggest difference between the principal stresses) for the core matrix plate are showed in Fig. 4 and 5.

The stress analysis is based on the ASME Code [2]. Before checking the stresses, it is necessary to linearize and to separate them in the ASME Code [2] stress categories, i.e., generalized primary membrane stresses (P_m), localized primary membrane stresses (P_l) and bending primary stresses (P_b). Using an ANSYS [1] post-processor, the primary membrane stresses are very low, practically zero showing that the core matrix plate is loaded mainly in bending. The maximum values of the primary bending stresses P_b are 3,1 N/mm^2 at positions close to the holes where the new irradiation elements are supported (see Fig. 5). These values are much smaller than the allowable limit of 1,5 S = 25,0 N/mm^2.

It is important to notice that there are peak stresses close to the plate supporting points, at the restrained nodes, that have values around 32 N/mm^2 (see Fig. 4). These stresses arise due to the simplifications in the finite element model near the restraints (just one node is used to represent each bolt at the connections and the restraints are considered rigid and not with the actual stiffness values of the connections between the bolts and the frame beams) and, according to the ASME Code [2], must not be evaluated as primary stresses. The stress check in these positions is completed by hand calculations of the bolting stresses.

The bolts stress check is based on the bolts loading conditions. Three checks must be done: the bolt tension stress, the bolt shear stress and the stress contact between the bolt and the plate.

The bolt tension stress is the ratio between the bolt tension load over the bolt cross section. The bolt shear stress is the ratio between the bolt shear load over the bolt cross section. The bolt contact stress is the ratio between the contact load over the contact area.

To do a conservative check, the tension load, the shear load and the contact load in the most loaded node (bolt) are 548 N, 926 N, and 1076 N, respectively. The bolts cross sections are 101,6 mm^2 and the bolts contact areas are 443,4 mm^2. Thus, the maximum bolt tension stress is 5,4 N/mm^2 (smaller than the allowable limit of 1,0 S = 183 N/mm^2), the maximum bolt shear stress is 9,1 N/mm^2 (smaller than the allowable limit of 0,6 S = 109,8 N/mm^2) and the maximum contact stress is 2,4 N/mm^2 (smaller than the allowable limit of 1,5 S_y = 412,5 N/mm^2).

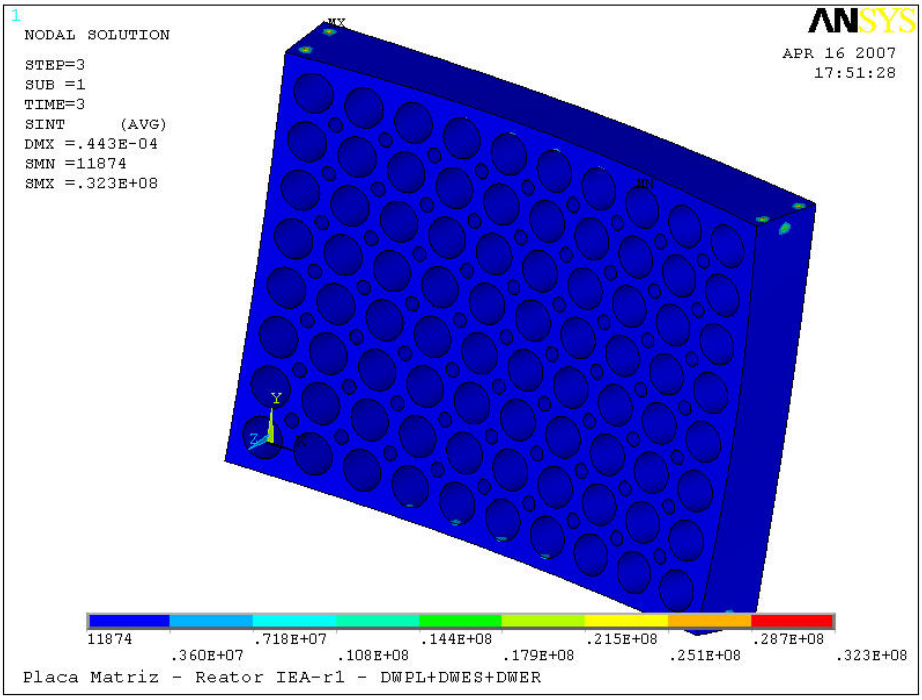

Figure 4: Tresca stress intensities in the core matrix plate (in N/m^2)

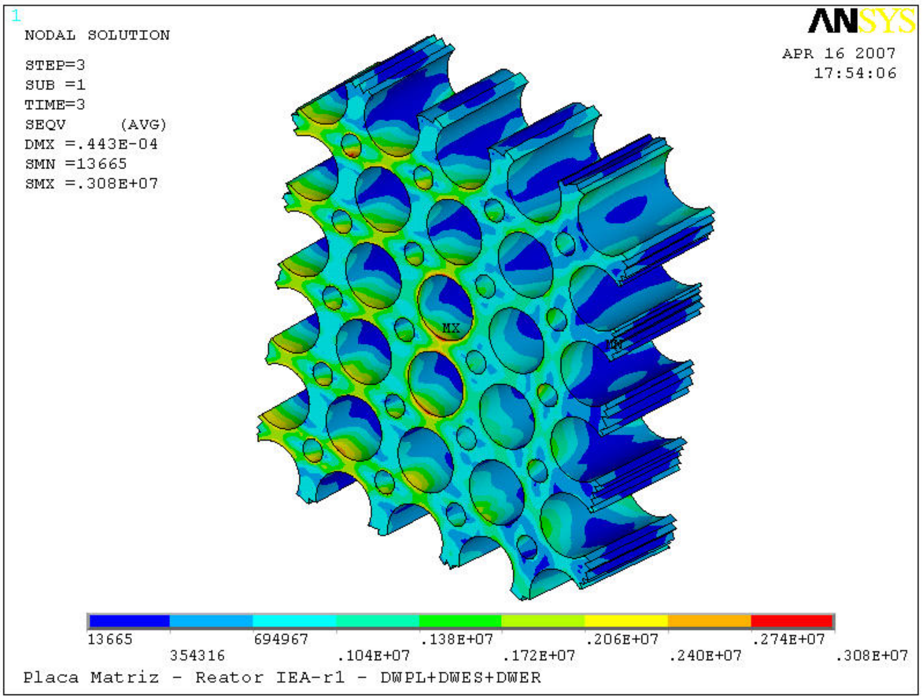

Figure 5: Tresca stress intensities in region of the new irradiation element of the core matrix plate (in N/m^2)

3. CONCLUSIONS

The paper presents the refined simulation using a three dimensional finite element model of the IEA-R1 research reactor core matrix plate under additional loads from a reactor improvement, the inclusion of two new irradiation elements.

The structural assessment combines the plate stress evaluation from the finite element model plus the bolts stress check from hand calculations to confirm the structural qualification of the components according to the ASME Code [2] as the applied stresses are lower than the applicable allowable limits. It is important to mention that is necessary to perform an adequate linearization and categorization of the three dimensional finite element stresses to check the stresses according to the ASME Code [2].

REFERENCES

1. ANSYS, Inc., ANSYS Multiphysics 11.0 Release, Canonsburg, PA, USA, 2007.
2. ASME, ASME Boiler and Pressure Vessel Code, Section III, Nuclear Components, Subsection NB, Class 1 Components", The American Society Of Mechanical Engineers (ASME), New York, NY, USA, 2004.