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REFURBISHMENT OF THE IEAR1 PRIMARY COOLANT SYSTEM PIPING SUPPORTS

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ABSTRACT

A partial replacement of the IEA-R1 piping system was concluded in 2014. This paper presents the study and the structural analysis of the IEA-R1 primary circuit piping supports, considering all the changes involved in the replacement.
The IEA-R1 is a nuclear reactor for research purposes designed by Babcox-Willcox that is operated by IPEN since 1957. The reactor life management and modernization program is being conducted for the last two decades and already resulted in a series of changes, especially on the reactor coolant system. This set of components, divided in primary and secondary circuit, is responsible for the circulation of water into the core to remove heat.
In the ageing management program that includes regular inspection, some degradation was observed in the primary piping system. As result, the renewing of the piping system was conducted in 2014. Moreover the poor condition of some original piping supports gave rise to the refurbishment of all piping supports. The aim of the present work is to review the design of the primary system piping supports taking into account the current conditions after the changes and refurbishment.

1. INTRODUCTION

The IEA-R1 is a nuclear reactor for research purposes designed by Babcox-Willcox that is operated by IPEN since 1957. The reactor life management and modernization program is being conducted for the last two decades and already resulted in a series of changes, especially on the reactor coolant system [1] and [2]. This set of components, divided in primary and secondary circuit, is responsible for the circulation of water into the core to remove heat. In the ageing management program [3] that includes regular inspection, some degradation was observed in the primary piping system. As result, the renewing of the piping system was conducted in 2014. Moreover the poor condition of some original piping supports gave rise to the refurbishment of all piping supports.

The objective of this paper is to present the results of the structural analysis of piping supports of the IEA-R1 research reactor primary circuit. This work considers the partial replacement of the primary piping and the modifications of the piping supports. All supports were inspected, assessed and some were redesigned but, in no case, their functions were modified. In order to develop this work the following schedule was carried out:

- ⇨ Assessment of the as built support drawings [4] to [15];
- ⇨ Support loadings from piping stress analysis obtained from reference [16];

⇨ Three-dimensional models of the supports were developed with SolidWorks program [17];

⇨ Development of structural models of the supports with Ansys program [18].

The ASME III code, subsection NF-1200 [19], classifies the supports taking into account their functions, the type of structure to be supported and the feasibility of serial production, like:

- **Plate and shell type supports** – a support such as a skirt or saddle fabricated from plate and shell elements and normally applied in components;
- **Linear type support** – a support acting only in one degree of freedom, such as tension and compression struts, beams and columns subjected to bending, trusses, frames, arches and cables;
- **Standard supports** – supports described in MSS-SP-58 [20], which were developed and approved by Manufactures Standardization Society of the Valve and Fittings industry and that are also applied to conventional plants, according to ASME B31.1 [21].

The item 121.1 of ASME B31.1 points to the rules of MSS-SP-58, which means that all supports are Standard Supports. The IEA-R1 piping supports fit in this case.

2. GENERAL DESCRIPTION

The reactor coolant system of the IEA-R1 is composed by: a pool with the reactor core inside, primary and secondary systems. The primary system is a circuit with two heat exchanger, two pumps, a decay tank and the piping attaching all this equipment. It is connected to the reactor through a discharge and suction nozzle localized at the bottom of pool in order to provide the circulation of the water to remove heat. Figure 1 shows a simplified flow chart and Figure 2 a three-dimensional solid model of the Primary Circuit of the IEA-R1 reactor.

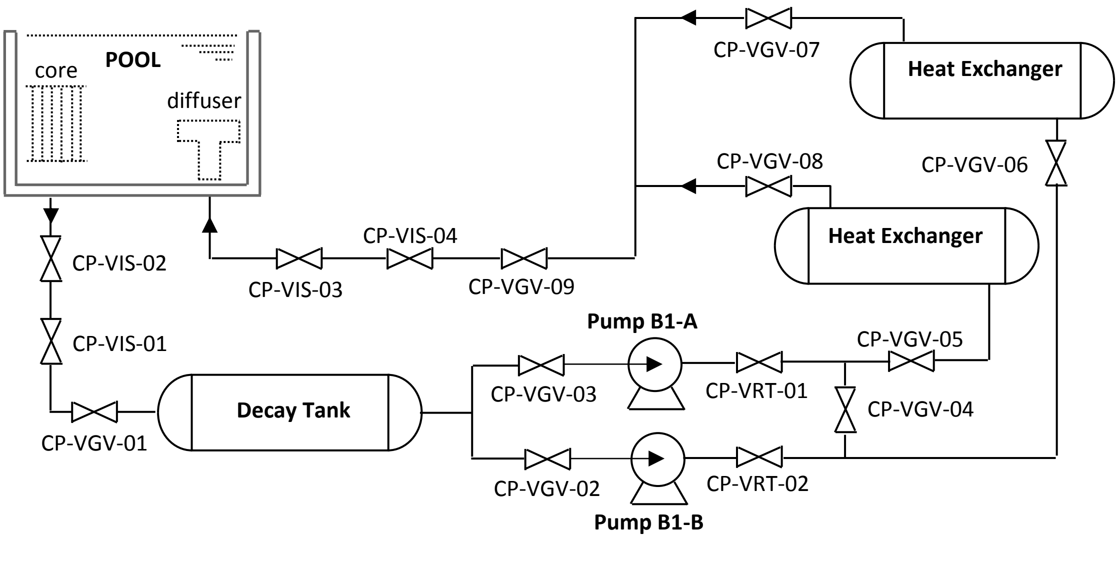

Figure 1: IEA-R1 Primary Circuit System Flow Chart

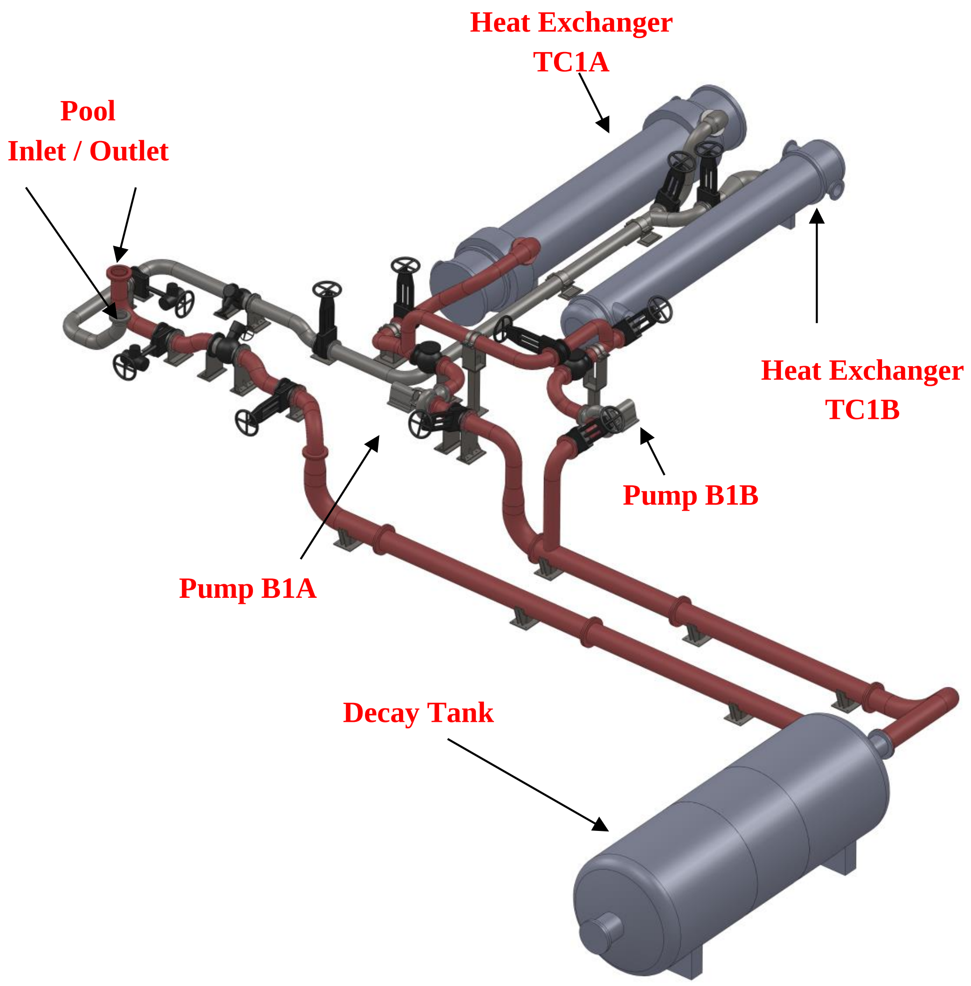

Figure 2: 3D Model of the IEA-R1 Primary Circuit

The IEA-R1 primary circuit parameters process defined in [1] are:

Pressure = 0.69 N/mm^2 and Temperature = 43.9 ºC operating as showed in Table 1.

Table 1: Operation Modes of the IEA-R1 Primary Circuit

⇨ **Operation Mode 1 -**	Pump B1A e Heat Exchanger TC1A running.
⇨ **Operation Mode 2 -**	Pump B1B e Heat Exchanger TC1B running.
⇨ **Operation Mode 3 -**	Pump B1A/B e Heat Exchanger TC1A/B running.

The piping system of the IEA-R1 primary circuit was simulated applying the following three-dimensional models:

Model #1 – from outlet nozzle of Pool till inlet nozzle of Decay Tank;

Model #2 – from outlet nozzle of Decay Tank till suction nozzles of the pumps;

Model #3 – from discharge nozzles of the pumps till inlet nozzle of the Heat Exchangers;

Model #4 – from outlet nozzle of the Heat Exchangers till inlet nozzle of the Pool.

The stress analysis was developed in software CAESAR [22], forces and moments in nozzles of the equipment and pumps were generated as well as in supports, points of supports. In the Figure 3 is showed an isometric indicating the supports / points of supports of the IEA-R1 primary circuit piping.

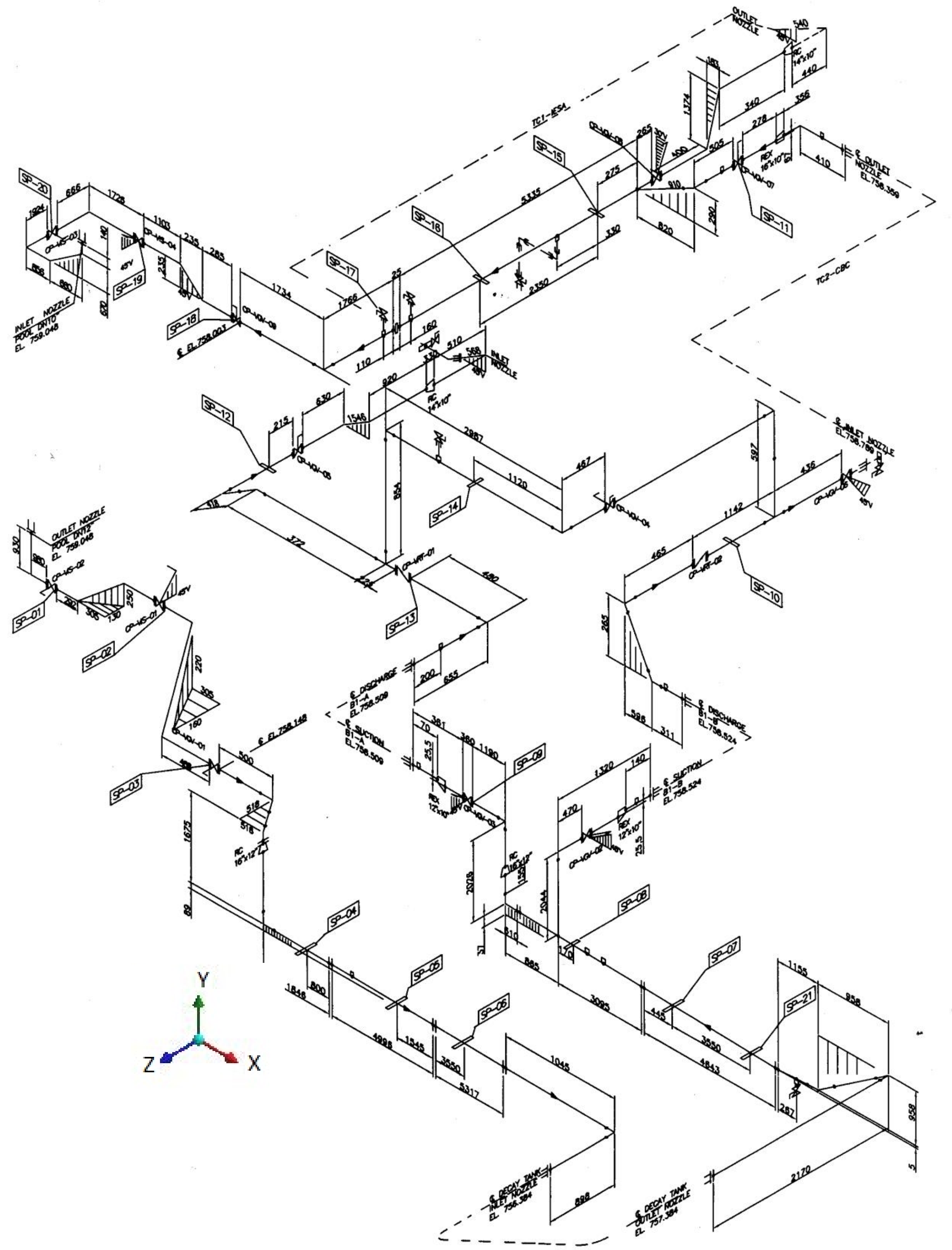

Figure 3: IEA-R1 Primary Circuit Isometric

The Table 2 lists all of the supports, the type of supports according to Figure 4 and the support location.

Table 2: Supports of the IEA-R1 Primary Circuit

Support	Type	Location	Support	Type	Location
SP-01	I	Valve CP-VIS-02	SP-11	VI	Valve CP-VGV-07
SP-02	VI	Valve CP-VIS-01	SP-12	III	Valve CP-VGV-05
SP-03	I	Valve CP-VGV-01	SP-13	IV	Valve CP-VRT-01
SP-04	II	Before Decay Tank	SP-14	III	By-pass
SP-05	II	Before Decay Tank	SP-15	V	Return line
SP-06	II	Before Decay Tank	SP-16	V	Return line – Plate
SP-07	II	After Decay Tank	SP-17	-	Flow meter – Plate
SP-08	II	After Decay Tank	SP-18	-	Valve CP-VRT-01
SP-09	VI	Valve CP-VGV-03	SP-19	VI	Valve CP-VGV-04
SP-10	III	Valve CP-VRT-02	SP-20	VI	Valve CP-VGV-08
			SP-21	II	After Decay Tank

Figure 4 shows the typical piping supports of the IEA-R1 reactor primary circuit.

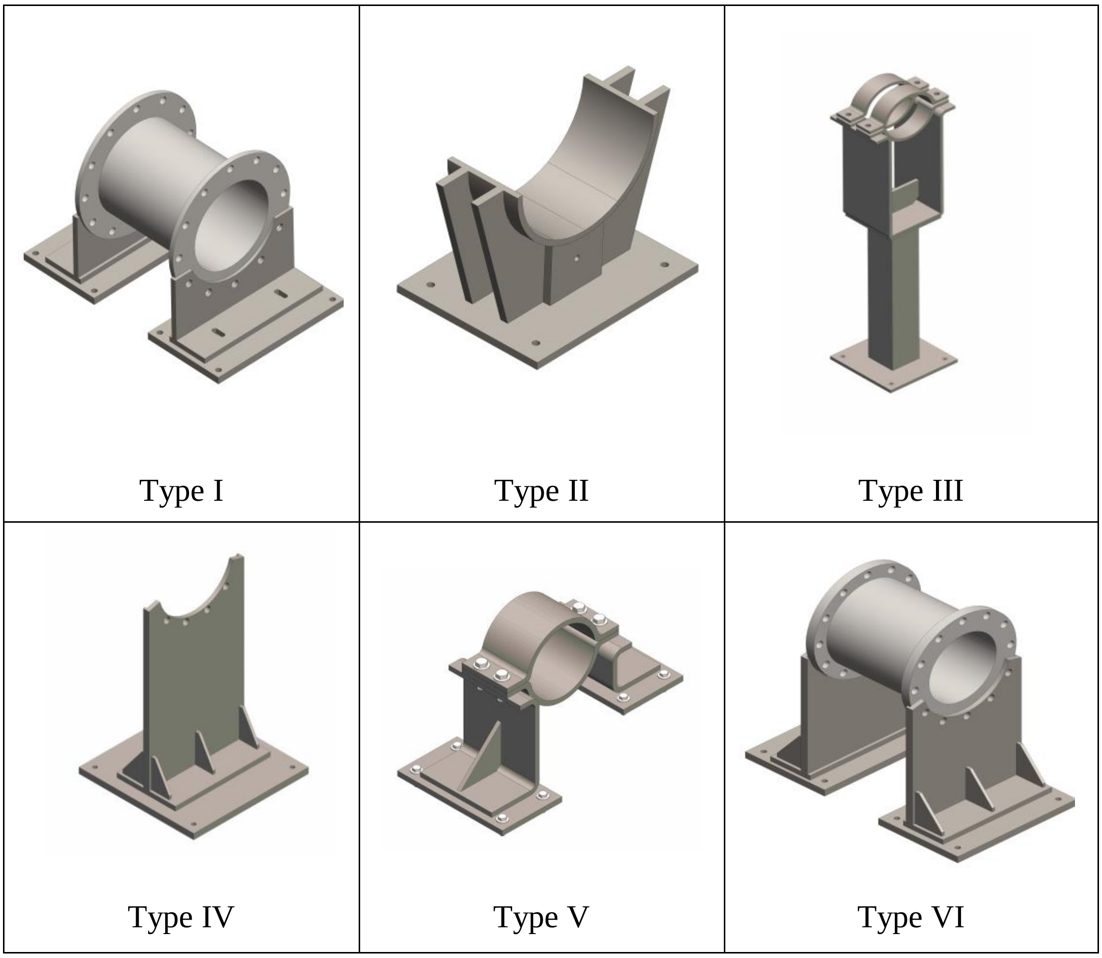

Figure 4: Supports of the IEA-R1 Primary Circuit

3. STRUCTURAL MODEL

The stress analysis of the piping supports shown in Figure 4 was performed by developing structural models of the supports with the finite element computer software ANSYS [18]. The finite element "SOLID95", with twenty nodes and three degree of freedom per node (displacements: Ux, Uy and Uz) was used. The mesh generated for the structural models can be seen in Figure 5.

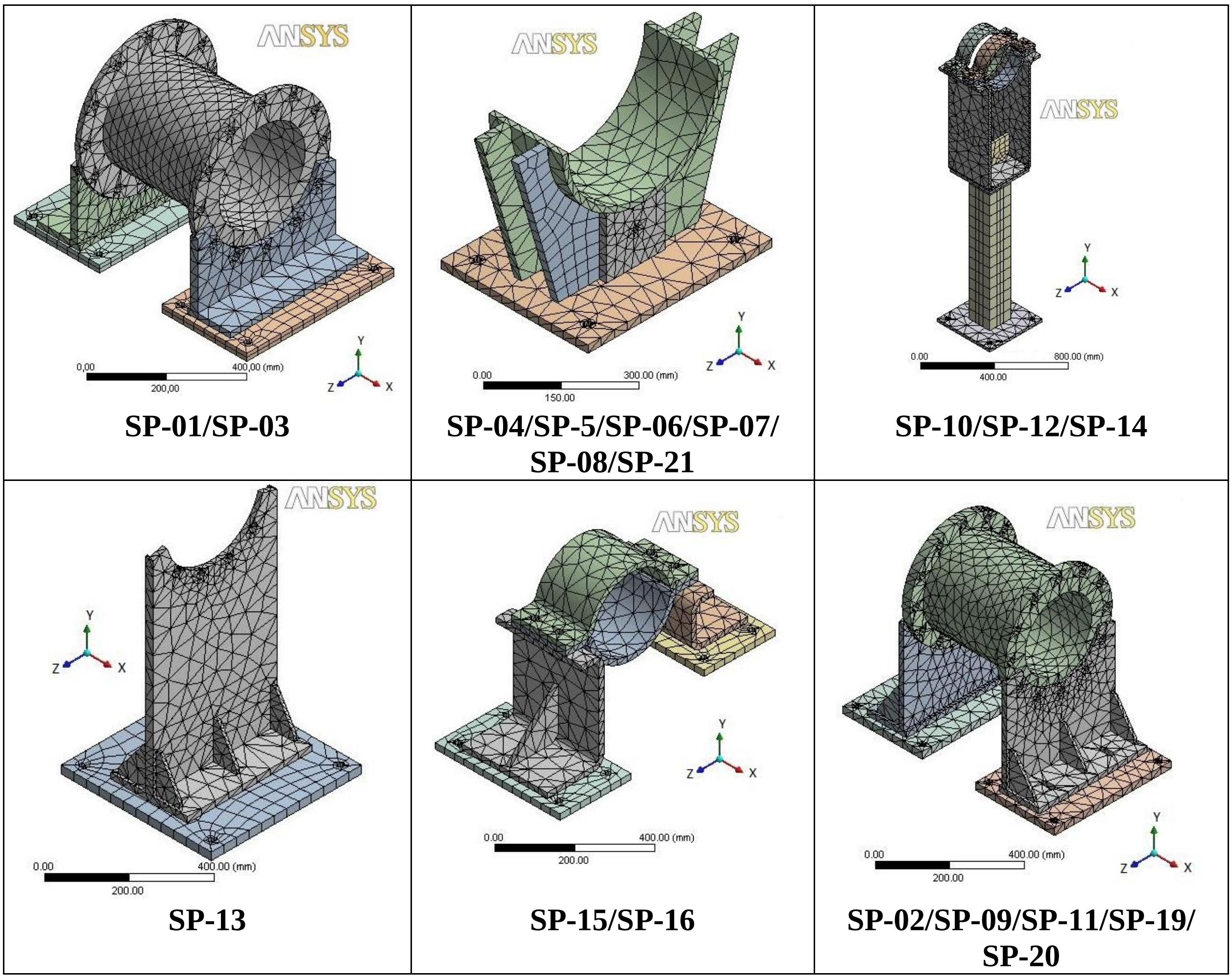

Figure 5: Finite Elements Models of the IEA-R1 Primary Circuit Supports

The displacements in directions X, Y and Z were restricted in the anchor plate that connects the piping support to the building structure in order to avoid the rigid body motion of the structural model. Loads resulting of the load case combinations were applied to connection of the piping support with the pipe, according to the Table 3. The values of the forces in axial direction are calculated as:

$$Fz = 0.3\,x\sqrt{Fx^2 + Fy^2} \tag{1}$$

Table 3: Supports of the IEA-R1 Primary Circuit

SUPORTE	FX	FY	FZ	SUPORTE	FX	FY	FZ
SP-01	0	-6496	0	SP-11	0	-3732	0
SP-02	0	-1589	0	SP-12	0	-5816	0
SP-03	6782	14059	-1898	SP-13	0	-7778	0
SP-04	0	-24714	1010	SP-14	0	-4764	0
SP-05	0	-7534	1446	SP-15	0	-5334	0
SP-06	0	-7206	-2691	SP-16	0	-677	0
SP-07	0	-5391	2364	SP-17	0	-3419	0
SP-08	0	-30157	1592	SP-18	0	-4925	0
SP-09	0	-8731	0	SP-19	0	-7324	0
SP-10	0	-10824	0	SP-20	0	-7514	0
				SP-21	0	-13930	-4420

The bulletin WRC-353 [23], states that the relationship between the stiffness of a piping support and piping system might be greater than 200 and the deformation in the restrained direction lesser than 1.5 mm. In this case we adopt the value of 1.0×10^5 N/mm that is the stiffness value applied in the restrained direction, for instance, in nuclear power plants Angra 1 and Angra 2.

4. STRESS ANALYSIS

The stress analysis of the IEA-R1 piping supports was performed according to the procedures and rules of MSS-SP-58. This code establishes that tension / compression, shear, bending and combined stress resulting of any kind of combination among the load cases of the plant, such as design, service and test loadings, has to attend the limits shown in Table 4.

Table 4: Allowable stresses for standard support

STRESS	MSS-SP-58	Allowable Stress (MPa)
Tension	4.1.1	114.5
Compression	4.1.5	114.5
Shear	4.1.3	91.6
Bending	4.1.2	114.5
Combined	4.1.6	$\frac{fa}{Ft} + \frac{fby}{Fby} + \frac{fbz}{Fbz} \leq 1.0$

Where: Ft ⇨ Allowable stress (tension/compression); fby, fbz ⇨ stress (bending);
fa ⇨ stress (tension); Fby, Fbz ⇨ Allowable stress (bending);

The stress limits are defined as a function of the allowable stress of the piping support material at design temperature.

Material properties of the piping supports were obtained from ASME B31.1 and are shown in Table 5.

Table 5 – Material properties (A-36)

E	(modulus of elasticity)	=	195000 MPa
S_Y	(yield stress)	=	250.0 MPa
S_h	(allowable stress)	=	114.5 MPa

5. SIMULATION AND RESULTS

Once the structural model was built, the boundary conditions and the loads were defined, then a numerical simulation using the ANSYS program could be performed. The results of the computational simulation for normal, bending, shear and combined stresses as well as its stress limits, as defined by MSS-SP-58, are summarized in Table 6.

Table 6: Stress Results and combinations – ASME (MPa)

Support	**Normal**		**Bending**		**Shear**		**Combined**	
	Calc	**Limit**	**Calc**	**Limit**	**Calc**	**Limit**	**Calc**	**Limit**
SP-01	1.9		8.6		1.3		0.10	
SP-02	0.4		0.6		0.4		0.01	
SP-03	14.1		15.5		7.7		0.31	
SP-04	21.0		24.6		10.5		0.49	
SP-05	7.2		7.5		3.5		0.16	
SP-06	7.8		7.3		3.9		0.16	
SP-07	5.8		5.4		3.0		0.12	
SP-08	30.9		30.0		13.7		0.64	
SP-09	8.6	**114.5**	3.5	**114.5**	3.2	**91,6**	0.12	**≤ 1.0**
SP-10	15,2		23,5		18,8		0.39	
SP-11	8.2		7.2		5.2		0.16	
SP-12	6,1		12.8		8,2		0.20	
SP-13	6.0		2.5		3.0		0.08	
SP-14	4,8		4,8		4,1		0.10	
SP-15	4.9		5.4		3.7		0.10	
SP-16	0.7		0.9		0.6		0.02	
SP-19	6.0		6.3		2.8		0.12	
SP-20	2.1		1.5		2,6		0.04	
SP-21	14.6		13.7		7.2		0.30	

The piping support **"SP-08",** located as indicated in Figure 3, has the highest normal, bending and shear stresses, as shown in Table 6 and Figure 6. The support **"SP-11"** has the maximum deflection in the direction of the load (0.06 mm).

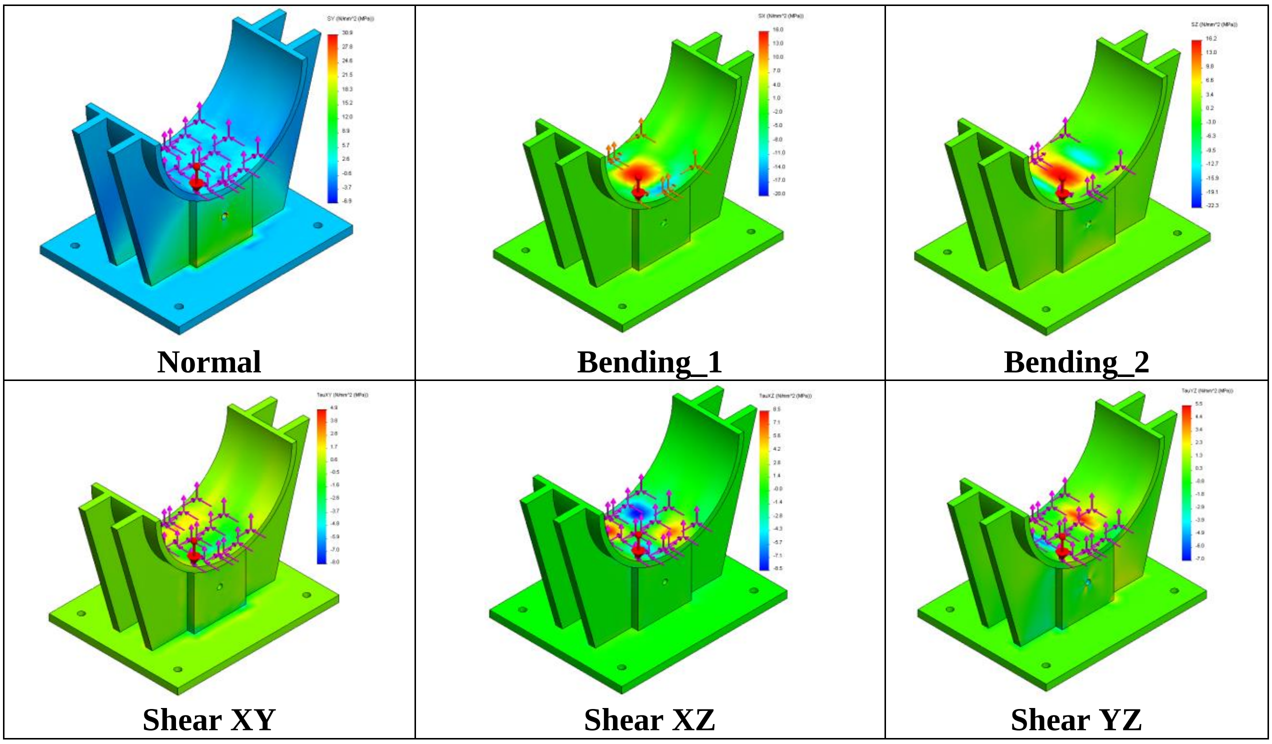

Figure 6: Normal, Bending and Shear Stresses for Support SP-08

Therefore, the stresses acting in all of the piping supports of IEA-R1 Primary Circuit are below the ASME-B31.1, MSS-SP-58 and WRC-353 recommended limits.

6. CONCLUSIONS AND RECOMMENDATIONS

Stress in the piping supports of IEA-R1 Primary Circuit, after the renewing of piping system that was conducted in 2014 are in accordance with the limits prescribed by ASME B31.1, MSS-SP-58 and WRC-353, which allows the safe operation of the IEA-R1 nuclear research reactor.

Design recommendations to develop a piping support:

⇨ **Stiffness and deformation**: piping support design must be considered according to WRC-353.

⇨ **Nuclear piping support:** for Class 1, 2 & 3 Nuclear Piping, choose standard piping support according to ASME III NF and MSS-SP-58 Standards, where applicable.

⇨ **Conventional piping support:** for Process and Chemical Plant Piping, choose standard piping support from MSS-SP-58, as indicated by ASME B31.1 and ASME B31.3, respectively.

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