Analysis of Air Temperatures around Reactor Vessel in EU-APR

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1. Introduction

EU-APR, modified and improved from its original design of APR1400, has been developed to comply with European Utility Requirements (EUR) and nuclear design requirements of the European countries [1].

In EU-APR, the removable concrete shielding blocks is newly adopted to reduce the radioactive dose rate in order to allow personnel access to the containment building during power operation [2].

During plants startup, hot shutdown and power operation, the reactor cavity HVAC system maintains temperature and humidity for the in-core instrument (ICI) chase, ex-core detector spaces, reactor cavity and the hot and cold leg penetration opening.

To prevent concrete dehydration and ex-core/in-core instrumentation degradation, the maximum air temperature shall be limited to 120℉ (48.9℃) in the reactor cavity and the maximum concrete temperature shall be limited to 150℉ (65.6℃) around the reactor vessel.

The concrete shielding block will be installed on the upper side of Permanent Pool Seal (PPS) to shield radiation from the reactor cavity. And the ventilation pipes (6 EA, ø200 mm) from under the PPS to outside of the primary shield wall are newly installed through the concrete wall in order to exhaust the confined air as shown in Fig.1.

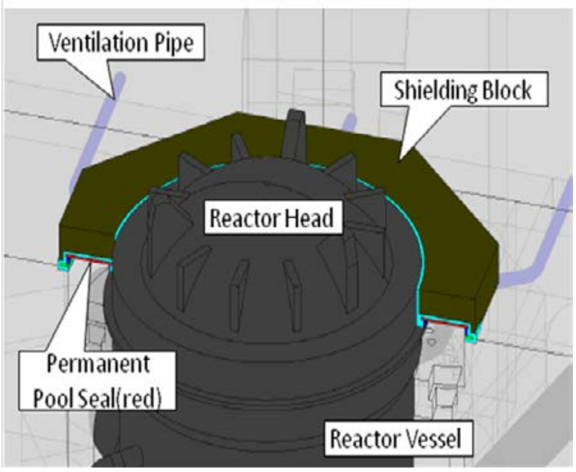

Figure 1 Cutting view of Shielding Blocks and Ventilation Pipes

Due to the installation of the shielding blocks and ventilation pipes, there is no vent hole at the PPS which means the cooling air cannot be exhausted from the upper side of reactor cavity. The air flow configuration and the temperature distribution in the reactor cavity and concrete in EU-APR are changed from the APR1400. Therefore, it is necessary to confirm whether high temperature regions above temperature limits exist by CFD analysis.

2. Method and Result

2.1 Method

In CFD analysis, the continuity equation, momentum equation and energy equation are solved to calculate air flow and temperature fields in the reactor cavity. To consider turbulence effect, standard K-e model is adopted. The Boussinesq approximation is considered in the field of buoyancy-driven flow such as a natural convection. Detailed equations can be found in reference [3, 4]. Fluent Ver.13 (ANSYS, USA) is used for numerical simulation. FLUENT's VNV (Verification and Validation) report is available in reference [5].

2.2 Air flow configuration and Data monitoring location

The cooling air supplied from the reactor cavity Air Handling Unit (AHU) flows through the process below as shown in Fig.2.

1) The cooling air from the Reactor Cavity AHU (Capacity: 20,000 CFM (33.980 CMH)) flows to the ICI chase and reactor cavity to manage temperature (The outlet temperature of AHU is 74 ℉ (23.3℃)).

2) The cooling air toward the reactor cavity flows to bottom of lower streaming shield through bottom head of the reactor vessel. Some of the cooling air is directly exhausted through the relief damper plate opening if the opening exists.

3) After the cooling air passes through the gap between reactor vessel insulation and lower streaming shield, and vent holes (8 EA) in the lower streaming shield, some of the cooling air is exhausted through the hot/cold/DVI leg penetration tunnels.

4) The rest cooling air flow to the lower side of upper streaming shield. The cooling air at the lower side of upper streaming shield flows to the upper side of the upper streaming shield through the gap between reactor vessel insulation and upper streaming shield and vent holes (24 EA) in the upper streaming shield.

5) The Cooling air at the upper side of upper streaming shield is sucked out through the added ventilation pipes (6 EA) connected to reactor cavity AHU.

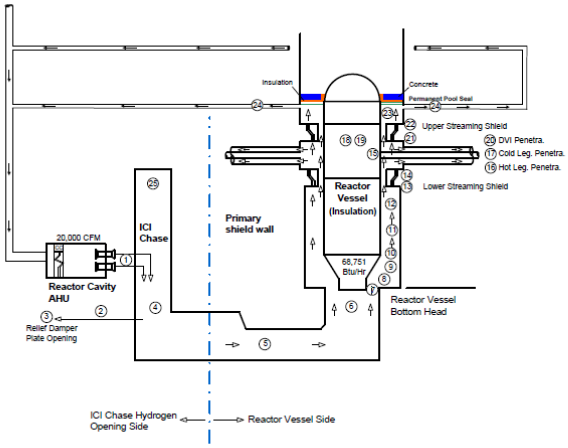

Figure 2 Air flow and Temperature monitoring location

2.3 Calculation Domain

In order to calculate air flows and temperature distributions in the reactor vessel cavity and concrete in EU-APR, CFD analysis model have generated for the concrete building and reactor cavity flow zone for EU-APR as shown in Figure 3 thru Figure 6.

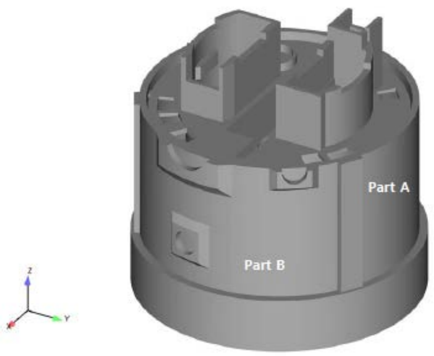

Figure 3 Geometry of Building (concrete) Zone

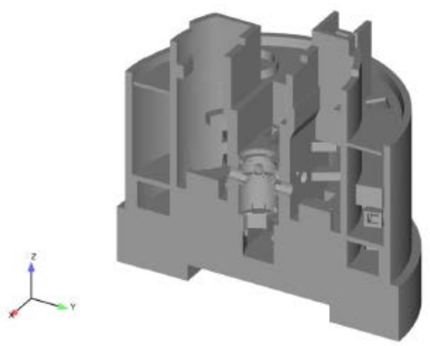

Figure 4 Geometry of Building (concrete) Zone (Part A)

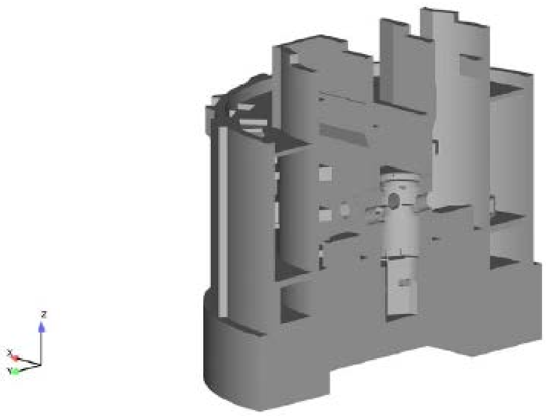

Figure 5 Geometry of Building (concrete) Zone (Part B)

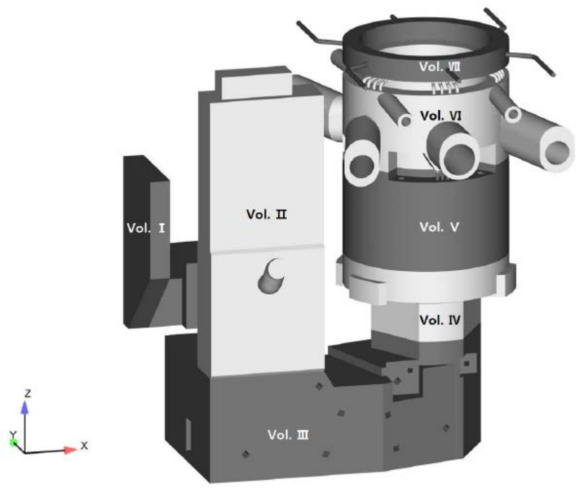

Figure 6 Geometry and Volume classification of Flow Zone

2.4 Boundary Condition

CFD analysis for EU-APR is performed in six cases with different opening areas at relief damper plate and air flow rates sucked out through newly installed six ventilation pipes as shown in Table 1.

Table 1 Calculation Cases

Case	Relief Damper Plate Opening Area, A_{Relief}	Air Flow Rate exhausted vent pipe (6 EA), Q_{Vent}
	[ft^2(m^2)]	[CFM(CMH)]
1	4.0 [a] (0.372)	1,250 [c] (2,124)
2	4.0[a] (0.372)	2,849 [d] (4,840)
3	0.0	1,250 [c] (2,124)
4	0.0	2,849 [d] (4,840)
5	2.92[b] (0.271)	1,250 [c] (2,124)
6	2.87 [b] (0.267)	2,849 [d] (4,840)
a) Original opening area in APR1400		
b) Area when air flow rate exhausted through relief damper		

plate opening becomes 2,000CFM (3,398 CMH)
c) Designed flow rate exhausted through PPS holes (8 EA) in APR1400
d) Flow rate exhausted through PPS holes (8 EA) in APR1400, when 2,000 CFM (3,398 CMH) is exhausted through relief damper plate opening

2.5. Results

The regions above a temperature of 120 ℉(48.9℃) in the reactor cavity are found. These regions are mainly found in the zone between the upper streaming shield and PPS as shown in Table 2, Fig.7 and 8.

Table 2 Maximum air temperature and its location

Case	Max. Temp., [°F (°C)]	Location
1	120.9 (49.4)	Vent pipe (24)
2	115.6 (46.4)	Between Upper Streaming Shield and PPS
3	117.7 (47.6)	
4	114.8 (46.0)	
5	119.5 (48.6)	
6	115.5 (46.4)	

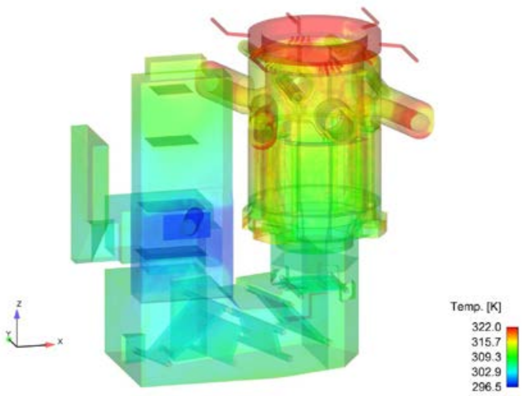

Figure 7 Temperature distributions in cavity for Case 1

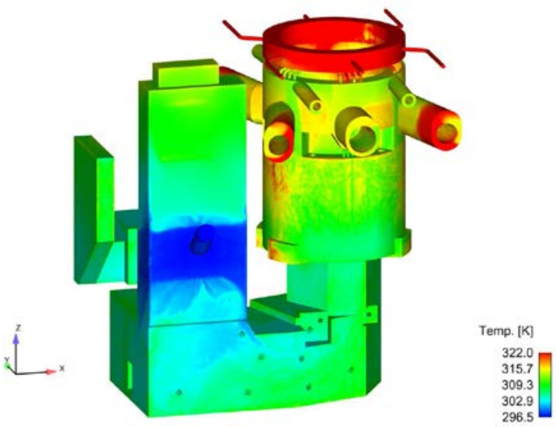

Figure 8 Temperature distributions in cavity (outer surface) for Case 1

The regions above a temperature of 150 ℉ are not observed in the concrete. But, high temperature regions (about 140 ℉(60.0℃)) are found. These regions are found around the zone in which the Gamma and Neutron heat source is applied as shown in Table 3 and Fig.9.

Table 3 Maximum temperature in concrete

Case	1	2	3	4	5	6
Max. Temp., [°F (°C)]	144.1	144.3	144.0	144.2	144.4	144.3

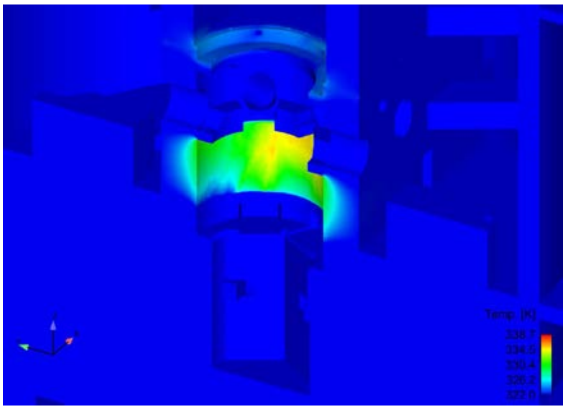

Figure 9 Temperature distribution in Concrete for Case 5

6. Conclusion

CFD analysis has been performed in order to check if the air temperature in the reactor cavity and concrete in EU-APR are exceeded the temperature limits. Six calculations for EU-APR have been carried out with different opening areas of the relief damper plate and air flow rates sucked out through six ventilation pipes.

For the temperature distribution in the reactor cavity, it is found that there are the regions above a temperature of 120 ℉(48.9℃). However, these regions are relatively small and are observed very near the reactor vessel insulation. Therefore, these high temperature regions do not directly influence on concrete.

Furthermore, the heat emission used in the current calculations already includes 20% margin including the conservative margins used for the metal reflective heat losses and the margins used to estimate Gamma & Neutron heat into the primary wall. Totally, 10% margin is included.

For the temperature distribution in concrete, the regions above a temperature of 150 ℉(65.6℃) are not observed in the concrete. However, it is found that there are high temperature regions (about 140 ℉(60.0℃)). The size of these regions is relatively very small.

In conclusion, the air flow configuration is sufficient to cool the cavity and the concrete with the design modification. Also, the opening area in the relief damper plate does not highly influence on air temperature.

REFERENCES

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