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Improvement of the Reactor Vessel Closure Head Insulation for the Visual Inspection in the Korean Standard Nuclear Power Plant

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1. Introduction

Since the circumferential corrosion crack of Reactor Vessel Head(RVH) penetration nozzles of the Davis-Besse Nuclear Power Station in Oak Harbor, Ohio, was detected, the insulation improvement was required so that the visual inspection could be performed by inspector or a remote inspection device such as crawler during a refueling outage[1,2]. Therefore, the closure head insulation design for the Korean Standard Nuclear Power Plant(KSNP) has been improved.

This paper presents design improvement of the RV closure head insulation design, such as configuration, access openings of head lift rig skirt, height between insulation outer surface and plenum plate inner surface, clearance between insulation and RV closure head surface, access openings of insulation, remote inspection devices, and cooling capability of Control Element Driver Mechanism(CEDM).

2. Design Considerations and Evaluation Results

2.1 Configuration of RV Closure Head Insulation

The configuration of insulation developed to facilitate the visual inspection in the KSNP is shown in Figure 1.

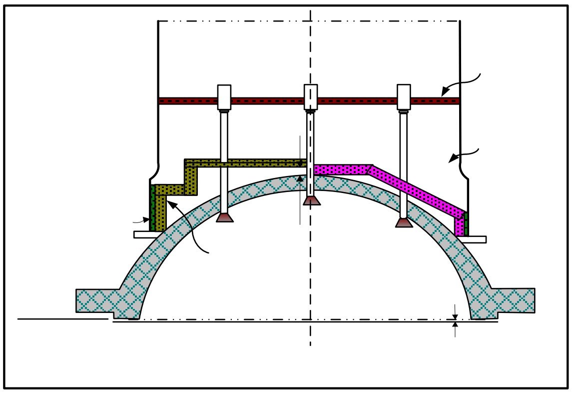

Figure 1. Configuration of RV Closure Head Insulation

The access openings of RV Head Lift Rig Skirt (RVHLRS) are required to put the remote inspection devices in or out of insulation. Also the access openings provide pathways for installation and removal of insulation without removal of the RVHLRS. The RV closure head insulation consists of several small panels that are removable and locked by the strong latches.

The clearance between insulation and RV closure head needs to be increased to allow the visual inspection of all the CEDM nozzles and RV closure head surface with the remote inspection device without adverse affect to the CEDM cooling capability.

The access openings are provided on the insulation wall to put the remote inspection device into the insulation without removal of insulation.

The remote inspection devices is equipped with tilt camera, four magnetic electric driven wheel, flexible cable, navigation with mapping software, and so on[3].

The size of RVHLRS access openings is increased as shown in Figure 2 for the installation and removable of insulation panels as well as putting the remote inspection devices in and out. The openings are oriented to the directions where there was no interference with the ALMS/LPMS cover and conduit.

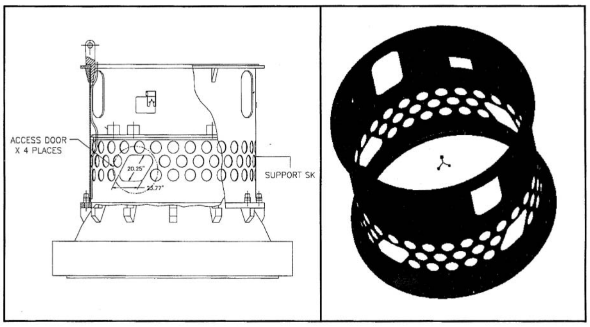

Figure 2. Head Lift Rig Skirt and Access Openings

Therefore, the improved configuration of RV closure head allows the crawler to better access to the vessel head penetrations and dome surface area for inspection.

However, the new configuration of insulation and the decreased gap from insulation outer surface to plenum plate inner surface should be evaluated in view of the heat loss of insulation and the CEDM cooling performance.

2.2 Evaluation of Heat Loss from Insulation Surface

The heat losses through the insulation shall be limited to a total heat transfer of less than or equal to 25,000 btu/hr in the specified environmental conditions. The thermal transference shall not be more than 0.14 btu/hr-ft^2-°F in insulated component surface area. The heat loss with insulation surface is determined by the following equation (1) [4] and evaluated as in Table 1.

$$Q = \left(\frac{T_d}{[L/k]} + (1/f_i + 1/f_o^*)\right) \tag{1}$$

where, T_d = overall temp. difference, °F
L = insulation thickness, inches
k = thermal conductivity, btu-in/hr-ft^2-°F
f_i = inner air space transfer coefficient, btu/hr-ft-°F
f_o^* = surface film heat transfer coefficient, btu-in/hr-ft^2-°F

Table. 1 The sum of the typical heat loss values

Layout	Surface area (ft^2)	Heat loss (btu/hr)	Margin (%)
Dome	114.3	6359.9	3.24
Flange	407.0	17830.7	
Total	521.32	24190.6	

The thermal transference of the improved insulation is calculated to be about 0.10 btu/hr-ft^2-°F in insulated component surface area. Therefore, the improved insulation meets the heat loss criteria.

2.3 Evaluation of CEDM Cooling Capability

The gap between the plenum plate and the insulation, which provides cooling air flow path, shall be determined to keep the CEDM cooling capability. Therefore, the CEDM cooling performance with the installed CEDM Cooling Fan in the plant is evaluated considering the design change insulation.

The cooling air temperature of RV Closure Head per CEDM cooling conditions is determined by the following equation (2)[5,6] and calculation results are shown in Table 2.

$$T = T_{in} + 707.286\ x\ Q_s^{-1} \qquad (2)$$

where, T_{in} : 60 ~ 120 °F (inlet temp.),
x : 38.906 in (CEDM Cooling Shroud Length)
Q_s: SCFM (14.7 psig at 60°F)

Table 2. Cooling Air Temp. of RV Closure Head

Air Flow Rate, Q_S (SCFM/CEDM)	Normal		Upset	
	800		1,200	
T_{in} (°F)	60	120	60	120
T_{out}(°F)	94.4	154.4	82.9	142.9

The cooling air velocity of RV Closure Head per CEDM cooling conditions is determined by the following equation (3)[5,6] and calculation results are shown in Table 3.

$$v_i = 3.207 \times 10^{-5} \left(\Sigma n - \frac{N}{2}\right) \frac{Q_s . T_R}{A_i}, \text{ (ft/sec)} \qquad (3)$$

Table 3. Cooling Air Velocity of the RV Closure Head

Cooling Air Velocity	Velocity, vi (ft/sec)			
	at Qs = 800 SCFM		at Qs = 1200 SCFM	
	T=94.4 (℉)	T = 154.4 (℉)	T=82.9 (℉)	T = 142.9 (℉)
Average	21.5	23.8	31.6	35.0
Maximum	31.0	34.0	45.0	50.0

The pressure drop(△P) between CEDM Cooling Shroud outlet and RVHLRS due to configuration change of the improved insulation is determined by the following equation (4)[5,6]:

$$\Delta p = 2.523 \times 10^{-6} K \left(T_{in} + 707.286\, x\, Q_s^{-1} + 459.7\right) x \frac{Q_s^2}{A^2} \qquad (4)$$

where, A: cross section area of flow pass, $inch^2$.

The pressure drop for the improved configuration is calculated to be 0.56 inch-H_2O. while that for the previous design is 0.17 inch-H_2O. This pressure drop increase of about 0.4 inch-H_2O is expected to results in the cooling fan flow rate of 29,316 CFM which is about 4% decrease from the original design value[7]. Since the minimum cooling fan flow rate for CEDM cooling performance shall be greater than 29,200 CFM per one fan unit at normal operation condition, therefore, the CEDM cooling performance is determined to be maintained for the configuration of improved insulation.

3. Conclusions

An improvement of the RVH insulation design is performed to facilitate the visual inspection of the RV closure head in the KSNP.

The improved insulation design is demonstrated to can meet the licensing requirements for the RVH nozzle integrity, the criteria for heat loss from insulation surface, and the CEDM cooling performance requirement. Furthermore, this can improve the accessibility to the RVH, which can reduce the required time for inspection and radiation exposure of inspector during the visual inspection of CEDM Nozzle and RVH surface.

REFERENCES

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