Heat Removal Capability Analysis of Auxiliary Cooling System of PEACER

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1. Introduction

PEACER is a loop type, lead-bismuth (Pb-Bi) cooled fast reactor with design goals of proliferation resistance, environment friendliness, accident tolerance, continuable energy, and economical reactor [1].

PEACER-550 that generates the electricity about 550MW doesn't have the auxiliary cooling system (ACS) which guarantees the safety when the reactor is in emergency condition. But this design what doesn't have the ACS is a big drawback, because the reactor most certainly requires the safety multiple-barrier. So, the PEACER-300 which is reduced the power through the design shakedown was considered the ACS at the first stage of design. The subject of adoption is RVACS (Reactor Vessel Auxiliary Cooling System) which is cooling the all components that is reactor, steam generator and so on. And it is adopted in ENHS, KALIMER [2][3]. This type of design named PEACER-300 AC. But, it becomes necessary that the new design of ACS because of the properties of reactor and pure heat conductivity of coolant. On that score, the water pad system which is cooling the reactor using water is proposed the alternative ACS. And this type of design named PEACER-300 WC.

2. Numerical Analysis of ACS

2.1 Heat Removal Ability Analysis of PEACER-300 AC

PEACER has a drawback which is the area of heat transfer is relatively small because it is loop-type reactor. Consequently, PEACER-300 AC equipped bucket-shape steam generator, guard vessel that contains all primary system. And these designs could enlarge the heat transfer area.

The decay heat transient refers to the result of FFTF (Fast Flux Test Facility) [4]. Assume that the initial temperature when the emergency condition, we could get the average temperature transient of coolant. Figure 1 shows that the average temperature transient of coolant which is calculated using that assumptions.

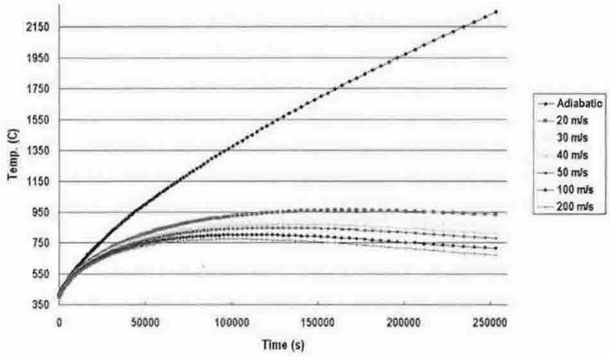

Figure 1. Average Temp. Transient of Coolant (AC type)

In the event, the coolant temperature is higher than the design limit, nevertheless the air is high velocity. These results mean that RVACS which is adopted to ENHS and KALIMER is not compatible to PEACER. Both ENHS and KALIMER are pool-type reactor and it is differ to PEACER. So, the compatibility of RVACS has the difference. Especially, the KALIMER uses the sodium for coolant, the heat transfer capacity is higher than that of PEACER which uses the lead-bismuth for coolant. And the case of ENHS, though it uses same coolant, the power is one seventh as much as that of PEACER-300.

2.2 Heat Removal Ability Analysis of PEACER-300 WC

The heat transfer capacity of a water is very higher than that of an air. So, if ACS uses water for coolant, it is not necessary to change the design of steam generator and reactor vessel. PEACER-300 WC equipped the water channel named water pad function as heat removal system when the emergency condition.

2.2.1 CHF Analysis

To know the quantity of heat transfer to the water pad, we assumed that the quantity is about CHF. In case of the heating section is vertical surface and the channel is sealed, the heat transfer correlation is below [5],

$$Nu = 0.046 Ra^{1/3} \tag{1}$$

The Rayleight number(Ra) which is for calculate the Nu is,

$$Ra = Gr \cdot \Pr = \frac{g\beta(T_1 - T_2)d^3}{\left(\frac{\mu}{\rho}\right)^2} \cdot \Pr \tag{2}$$

But the surface temperature, T_1, is unknown value. So, we should calculate the CHF. The CHF correlation is used Zuber's correlation [5].

$$q''_{CHF} = C_{cr} h_{fg} \left[\sigma g \rho_v^{\ 2} (\rho_l - \rho_v) \right]^{1/4} \qquad (3)$$

Where, the C_{cr} is the constant vary as the shape of heating section and the case of PEACER, it is about 0.12.

$$q''_{CHF} = 898.36 \qquad [kW/m^2] \qquad (4)$$

The heat flux and the temperature of the heated surface is calculated as follow,

$$q'' = h(T_1 - T_2) \qquad (5)$$

And the heat transfer coefficient is calculated as follow,

$$h = \frac{k}{D_h} \cdot Nu \qquad (6)$$

So, the temperature of the heated surface, T_1, is calculated.

$$T_1 = \frac{11011847}{Ra^{1/3}} + 363 \ [K] \qquad (7)$$

The calculated result shows that the heat flux from heated surface to the water pad is less than CHF.

2.2.2 Nucleate Boiling Analysis

We could know the heat flux from the heated surface to water pad is less than CHF from the commented result. So, we could assume that the state of water pad when the emergency condition is nucleate boiling. the heat flux of nucleate boiling in pool is appeared as follow [5],

$$q'' = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma} \right]^{1/2} \left[\frac{C_{pl}(T_s - T_{sat})}{C_{sf} h_{fg} \Pr_l^{\ n}} \right]^3 \qquad (8)$$

Where, the C_{sf} is 0.013 in case of PEACER-300 and n is experimental constant vary as fluid is 1. Assumed the temperature of water in water pad as 90℃, eqn. (8) is simplified as follow,

$$q'' = 0.1134(T_s - 373)^3 \qquad (9)$$

Using the energy conservation equation, the relation of decay heat and the temperature of inner side of vessel is as follow,

$$Q = M_{total} C_p \frac{\partial T}{\partial t} + k \frac{\partial T}{\partial x} A \qquad (10)$$

The temperature transient of inner side of reactor vessel is showed at figure 2.

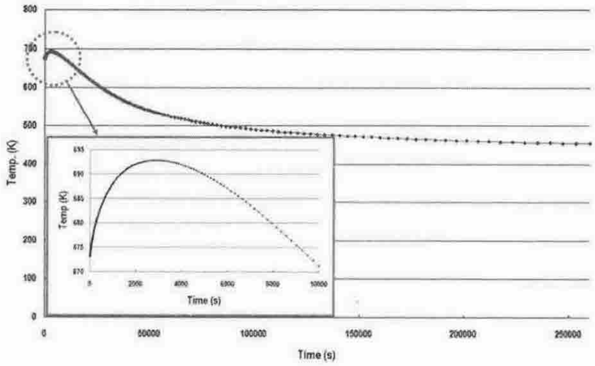

Figure 2. Inner side Temp. of Reactor Vessel (WC type)

3. Conclusion

Pursuant to the ASME code, the temperature limit that guarantees the safety of reactor vessel is about 650°C in case of PEACER-300. In case of the design of AC type, there is limit of cooling that is not sufficient the design limit. Because the PEACER is a loop-type reactor and the heat conductivity of coolant, lead-bismuth, is low compared with that of sodium. On the other hand, the WC type has an ample safety margin against the temperature. Some components are removed such as the guard vessel and the size of reactor is compact. Further, there is capacity to enlarge the power.

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