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Preliminary study on the passive cooling method for spent fuel storage pool of SMR

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Introduction

- Small modular reactors (SMRs) are reactors with generation capacity below 300MWe that strongly rely on serial, factory-based production of reactor modules.
- Providing reliable spent nuclear fuel pool cooling became more important in light water reactors after the Fukushima accident.
- In this paper, for the size of spent nuclear fuel from a water-cooled SMR, the size of the passive cooling system for the spent nuclear fuel pool is estimated. Two passive cooling methods are compared. One passive cooling method used a heat pipe technology and the other passive cooling method uses a natural circulation loop.

Methods and Results

- From the spent nuclear fuel design of recently licensed APR+, the water-cooled SMR spent nuclear fuel pool heat load is estimated. The maximum SMR spent nuclear fuel storage pool thermal output is assumed to be 13.3MWth in this study.

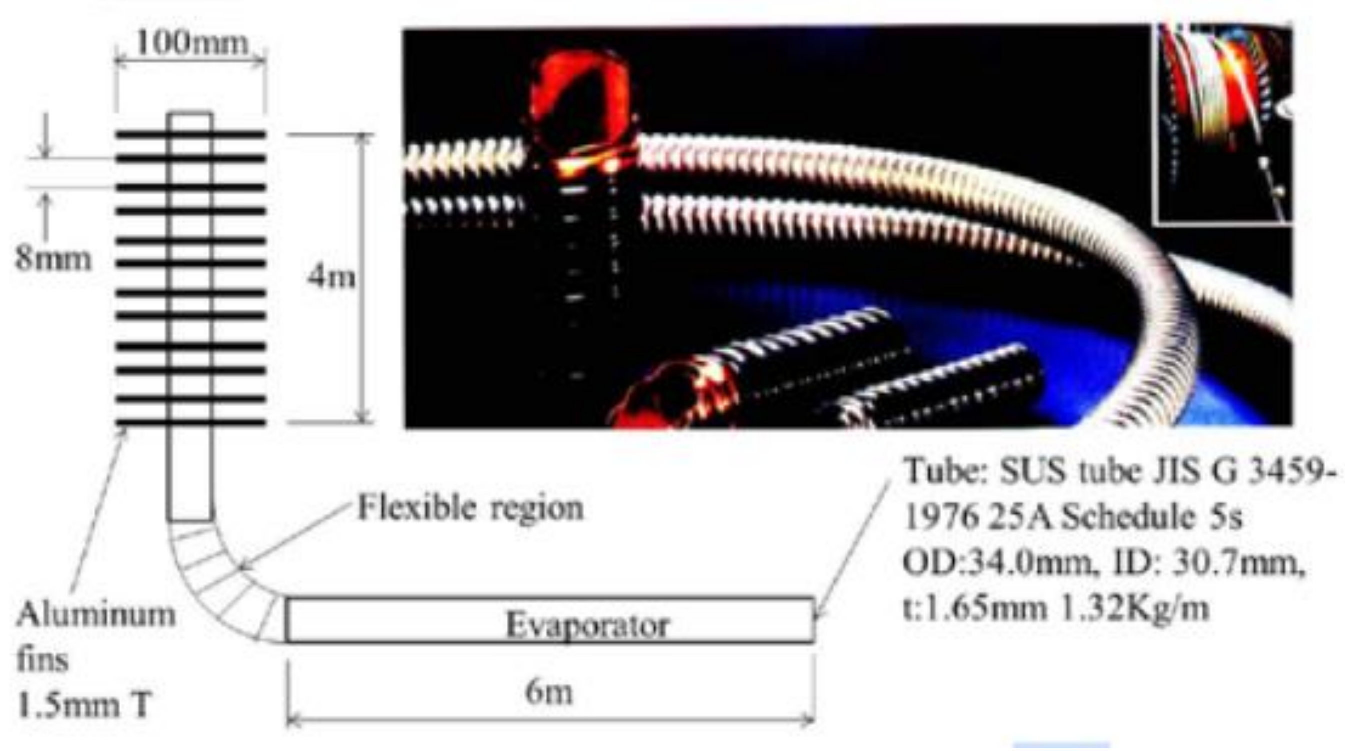

Fig.1. Corrugated heat pipe

- The temperature of the final heat sink air is assumed to be 50° C, and the sensitivity analysis is performed for the temperature of the spent fuel storage pool from 60° C to 90° C. Ammonia is selected as the working fluid for heat exchange due to compatibility of the working temperature and evaporation and condensation temperatures of ammonia.

$- T_{SFP} = T_{air} + \frac{Q_{spentfuel}}{n_{tube}} R_{th}$ - Total $R_{th} = 0.0177°C/W$

Table 1. Required number of heat pipes according to target pool temperature

Target temperature [°C]	Number of heat pipes
60	23,541
70	11,772
80	7,847
90	5,886

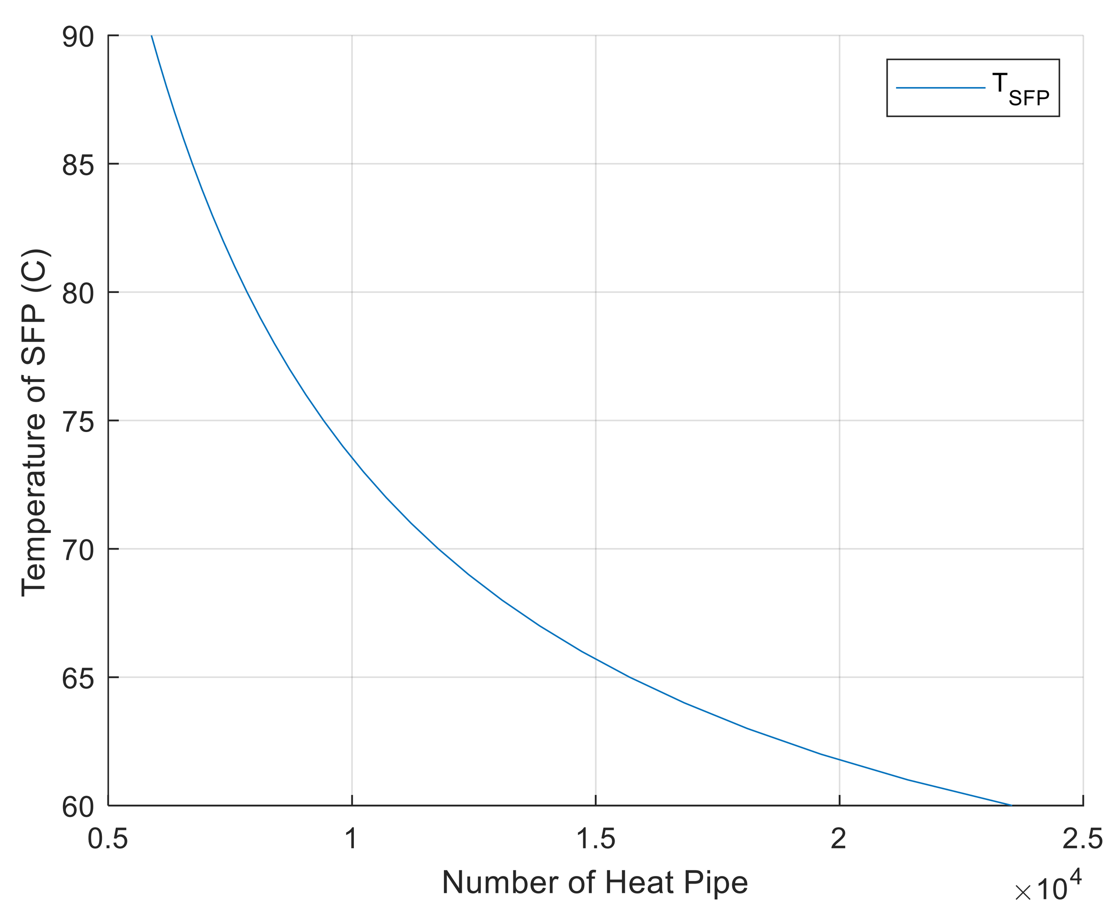

Fig.2. Number of heat pipes required for cooling the spent nuclear fuel pool

- A method of passively cooling the spent nuclear fuel pool using a natural circulation loop with two heat exchangers is evaluated.
- When water is used in natural circulation system, it is impossible to form a natural circulation system operating in between 12.35 - 19.95kPa condition for a height of 27m. Therefore, ammonia is again used for the naturally circulating fluid.

- Saturation pressure of ammonia at 50° C: 2034.0 kPa
- Saturation pressure of ammonia at 60° C : 2615.6 kPa

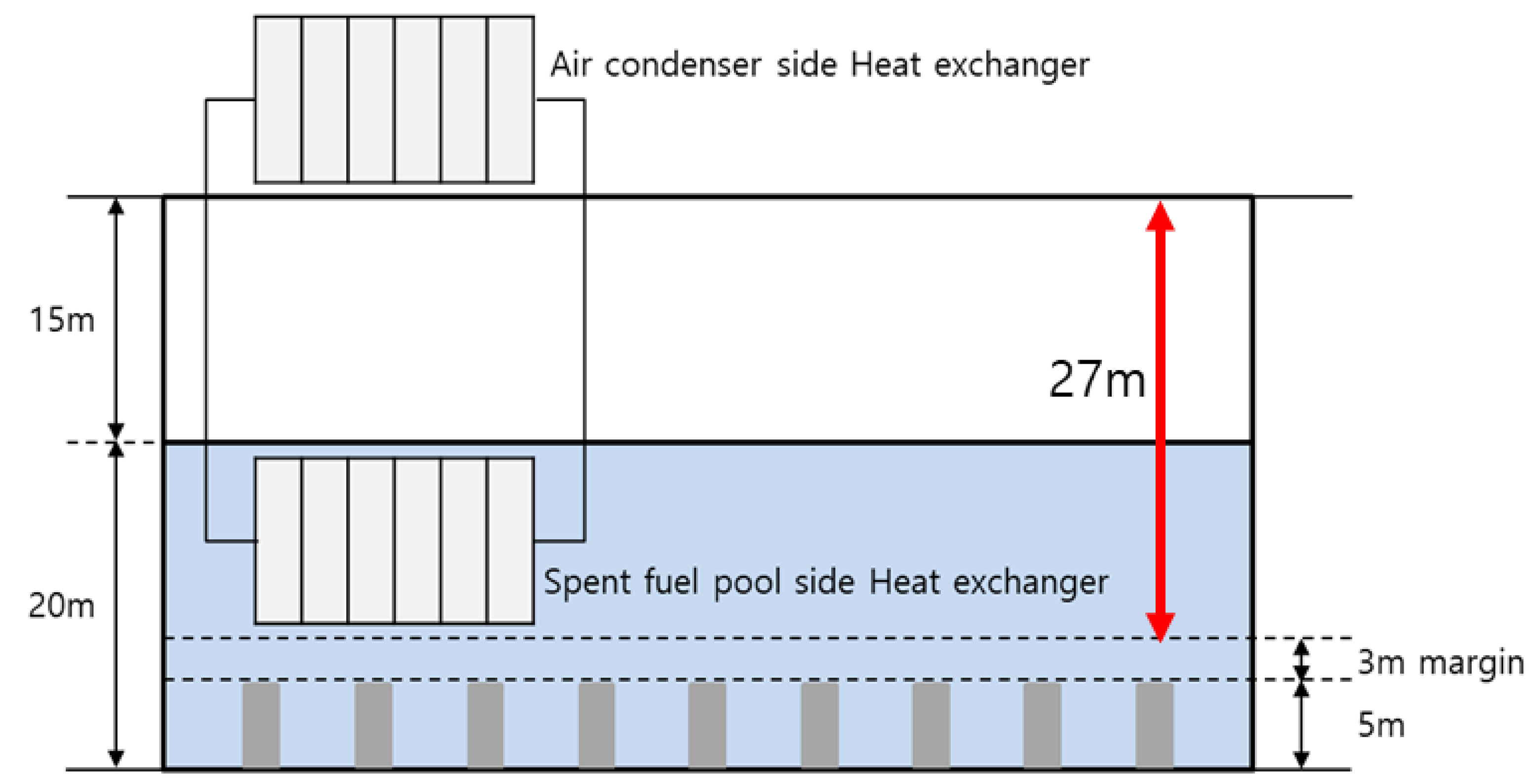

Fig.3. Spent nuclear fuel pool using natural circulation cooling system

- Tube inner diameter: 12mm
- Tube thickness: 2mm
- P/D ratio: 1.5
- Loop system pressure:(2034.0 + 2615.6)/2 = 2324.8kPa
- $\frac{1}{UA} = \frac{1}{h_1 A_1} + \frac{t}{k A_2} + \frac{1}{h_3 A_3}$, $A_1 = A_2 = A_3$ (assumed)
- Stainless steel conductivity: 14 W/mK

- The water side heat transfer coefficient of the spent fuel pool side heat exchanger and the air side heat transfer coefficient of the air side heat exchanger are all calculated using the Dittus-Boelter equation.
- The size of the heat exchanger required to cool 13.3MWth for the target pool temperature is obtained as follows.

Spent nuclear fuel pool side
- Required heat transfer area: 5341.6m^2
- Required heat exchanger volume: 61.21 m^2

Air condenser side
- Required heat transfer area: 144905.7 m^2
- Required heat exchanger volume: 1660.5 m^2

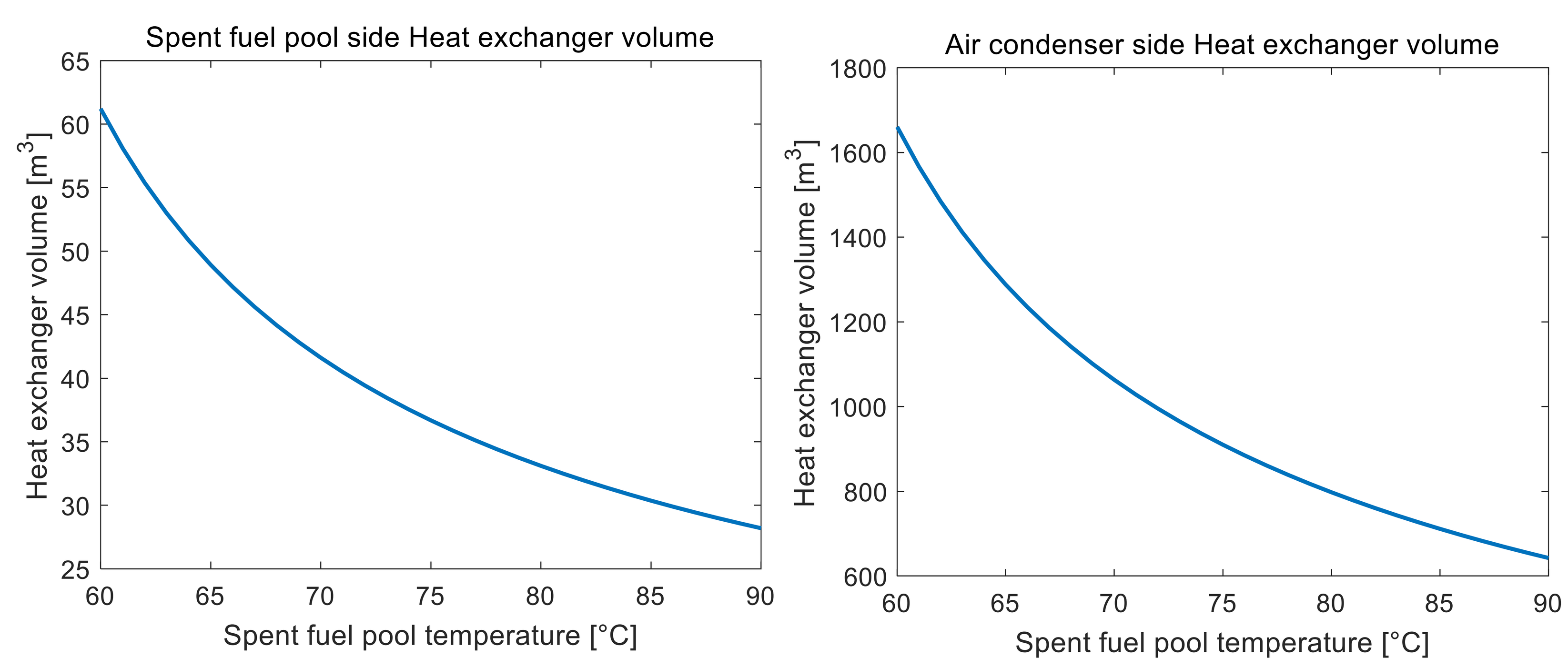

Fig.3. Spent nuclear pool side Heat exchanger and Air condenser side Heat exchanger volume according to the target pool temperature

Conclusions

- Although the temperature of the final heat sink air is assumed to be relatively high for conservative analysis, it is confirmed that excessively large number of heat pipes may be required for the spent nuclear fuel cooling for an SMR.
- In the case of using ammonia as a natural circulation loop working fluid, it is evaluated that the passive indefinite cooling can be provided for a realistic system size when sufficient air velocity is guaranteed.