Theoretical study on passive cooling by radiation and natural convection for fast reactors

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Abstract
This study focused on the passive cooling of a next generation fast reactor in the case of Beyond Design Basis Events (BDBE). We show that passive cooling, through radiation and natural convection, efficiently extracts decay heat from the core.
Keywords: Decay heat, Passive cooling, Radiation, Convection, Heat transfer analysis, SFR

1. Introduction

One of the measures taken to achieve the highest standards of safety is to mitigate the consequences of BDBE such as the loss of heat sink [1]. This paper studied a sodium-cooled fast reactor (SFR) in the case of station blackout. In the absence of pumps, the primary coolant is not able to cool down the reactor core as effectively. It is supposed that the fission reaction has stopped. The decay heat needs to be extracted by some method without electric power and/or human activities in order to prevent the core meltdown.

This study examined the role natural convection in the passive cooling of the reactor.

2. Methodology

The concept of passive reactor cooling is well described in [2] and the heat transfer between the different reactor parts is summarized in Fig. 1. This study focuses on the final stage of the cooling process: heat transfer between the containment vessel and the atmosphere. Theoretical analysis was performed on cooling of 600MWe pool type SFR emitting 10MW decay heat. The heat transfers between the reactor vessel (RV), guard vessel (GV) and containment vessel (CV) were modeled as radiative. The heat transfer from the core to the RV and from the CV to the exterior air was modeled as a convective. The air goes into the channel between CV and the outer building and acquires upward velocity due to thermo-buoyancy. Additionally, a chimney can enhance this effect, increasing convective heat transfer and reducing CV temperature. Air flow was modeled as a steady 1D flow with uniform velocity between an isothermal CV and an adiabatic building. The flow has an initial temperature of 20°C when entering the channel and has a variative density according to the Boussinesq approximation. The model can compute the CV temperature and the air velocity as a function of the distance between the CV and outer building (length *e*) and the chimney height (length *H*). The purpose was to find optimal *e* and *H* such as the CV is kept under the critical safety temperature.

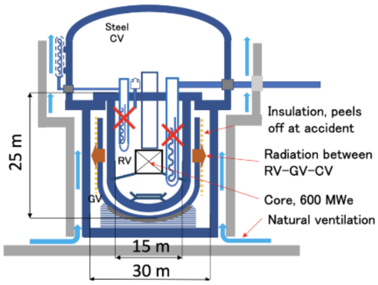

Fig. 1 Schematic description of heat transfer process

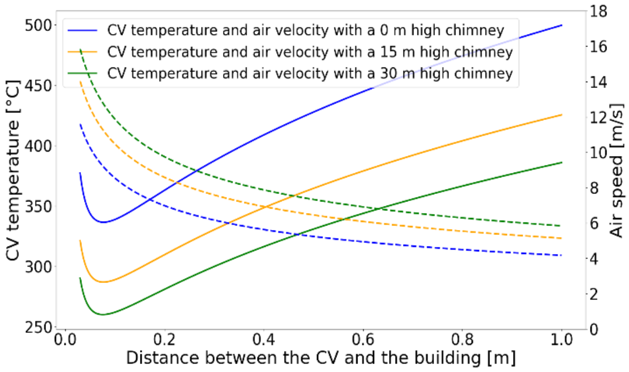

Fig. 2 CV temperature (solid lines) and air velocity (dashed lines) as a function of distance *e* and height *H*

3. Results

Our analysis shed light on the existence of a CV minimum temperature (Fig. 2). Notably, the optimal distance between the CV and the building is surprisingly small, around 0.08m. However, from a civil engineering point of view, the length e must be of the order of a meter and so the temperature of the CV will be greater than 300°C regardless of the height of the chimney. To mitigate this, adding a narrow air jacket around the CV, with a width corresponding to the optimal length *e*, and adding a 30-meter chimney could keep the temperature below 300°C. Thus, with these parameters, the theoretical model predicts the temperatures of different reactor parts for the emissivity of 0.5 or 0.8: outer core (820°C/722°C), reactor vessel (802°C/677°C), guard vessel (647°C/568°C), and containment vessel (266°C).

4. Conclusion

Passive air cooling shows great promise for mitigating the consequences of BDBE in nuclear reactors. However, further in-depth investigation using multiphysics simulations is required to fully understand and optimize this cooling strategy.

References
[1] Naoto Kasahara, *Fast Reactor System Design.* Springer, 2016.
[2] Maxence Laraison, Kensuke Narumi, Takuya Sato, Naoto Kasahara, *Development of failure mitigation technologies for improving resilience of nuclear structures (25) Fundamental study on passive cooling by radiation and natural convection*, AESJ Autumn conference, 1H03 (2023)