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Evaluation of Pressure Changes in HANARO Reactor Hall after a Reactor Shutdown

Gee-Yang Han*, Jae-Sam Han, Guk-Hoon Ahn, Hoan-Sung Jung
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: gyhan@kaeri.re.kr*

1. Introduction

A lot of emphasis has been placed on a better prediction of the pressure change in the reactor hall after a reactor shutdown. A dynamic model for simulating the pressure change response in accordance with the increasing reactor pool water temperature after a reactor shutdown was developed for HANARO. The major objective of this work is intended to evaluate the characteristics of the thermal behavior regarding how the decay heat will be affected by the reactor hall pressure change and the increase of pool water temperature induced in the primary coolant after a reactor shutdown.

The particular reactor pool water temperature at the surface where it is evaporated owing to the decay heat resulting in the local heat transfer rate is related to the pressure change response in the reactor hall associated with the primary cooling system because of the reduction of the heat exchanger to remove the heat. The increase in the pool water temperature is proportional to the heat transfer rate in the reactor pool. Consequently, any limit on the reactor pool water temperature imposes a corresponding limit on the reactor hall pressure. At HANARO, the decay heat after a reactor shutdown is mainly removed by the natural circulation cooling in the reactor pool [1]. This paper is written for the safety feature of the pressure change related leakage rate from the reactor hall.

2. Mathematical Dynamic Modeling

The primary cooling system provides natural circulation cooling to remove decay heat after a reactor shutdown. The energy balance equations of each heat transfer mechanism in the primary cooling system are formulated for a dynamic simulation, based on conservative assumptions, which are made to simplify the modeling aspects as much as possible, while retaining the physical meaning. The dynamic models are described by a set of simultaneous differential equations, which are translated into a computer program. The selected heat transfer correlations and thermo-physical properties are used in this calculation.

The description of the physical dynamic model for the cooling system behaviors after a reactor shutdown is described below.

2.1 Decay Heat Generation

Decay heat is the amount of energy released by the decay of fission products as a function of time following a shutdown for a reactor fueled with fissile materials. To find the decay heat power after a reactor shutdown, the pool water temperature is evaluated in pool natural circulation. The total decay heat power generated in the HANARO pool is given by a polynomial of eleven exponential forms [2].

2.2 Heat Exchanger Analysis

The HANARO heat exchanger is two-plate type heat exchanger. The heat exchanger used in this calculation is a counter-flow and plate type model with single pass units on the primary and secondary sides.

2.3 Energy Balance Equations

If heat continues to be supplied from the decay heat source, heat in the reactor pool will eventually be transferred to its surroundings. These energy balance equations for 1) the reactor pool water, 2) biological shield concrete, and 3) reactor hall air are applied to each heat transfer mechanism and solved in conjunction with the equation of state.

2.4 Additional Heat Transfer Equations

An analysis of the heat transfer rates from any given object for the simulation is usually expressed by employing the heat transfer equations. The additional heat transfer equations include 1) the convection from pool water surface, 2) evaporation from the pool water surface, 3) radiation from the pool water surface, 4) reactor pool to the biological shield concrete, 5) reactor pool biological shield concrete to the reactor hall air, and 6) reactor hall air to the atmosphere.

For the pool natural circulation, the decay heat is transferred to the air in the reactor hall through the heat transfer mechanisms. Since the rate of heat transfer occurs due to air-flow convective heat from the reactor pool water, it is given by the elementary equation for the convective heat transfer rate at the pool surface [3].

Removal of heat from the reactor pool by evaporation of water from the pool water surface is the major means of heat rejection. Since the mass transferred from the water causes a transfer of heat due to the evaporation, the rate of heat transfer term from the water surface to the air can be computed by the convection equation [4].

The equation for the radiation heat transfer rate can be considered only from the reactor pool water surface to its surroundings.

Assuming that the heat source distribution is uniform in the reactor pool, heat is transferred radically outward through the pool water, across the biological shield concrete, and to the reactor hall. Thus, the heat transfer rate at the outer surface of the reactor pool to the biological shield concrete is expressed in terms of the temperature difference across the region and the thermal resistance.

The heat transfer between the biological shield concrete to the reactor hall and the rate of heat transfer from the reactor hall to the atmosphere are given by the thermal resistance of air and the overall heat transfer coefficient of the building.

2.5 Thermo-physical Properties and Correlations

The basic energy balance equations in a fluid dynamic calculation involve certain thermodynamic properties of water and air. The heat transfer coefficient is a function of these variables. The proper correlations selected are used in the calculation model.

The energy balance equations and additional heat transfer equations, including state equations and all assumptions are coupled to produce a mathematical model for the pressure distribution and temperature profile for a dynamic simulation.

A schematic diagram of the overall mathematical model for HANARO cooling system is shown in Fig. 1.

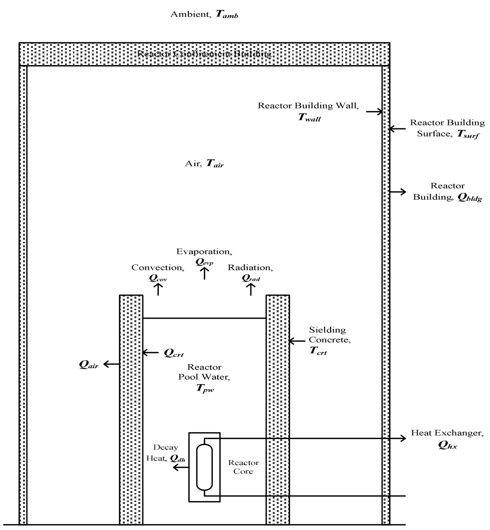

Fig. 1. Schematic diagram of HANARO cooling subsystems for the mathematical modeling.

3. Results and Discussion

The mathematical models are solved numerically to obtain the time-dependent water temperature in the reactor pool and temperature in the reactor hall, as well as pressure in the reactor hall. Various calculations are performed on a PC using the DESIRE code [5].

For the calculation of the pool water temperature after a reactor shutdown, it is very important to exactly estimate the amount of decay heat generation and decay heat removal from the cooling system. The pool water temperature continues to rise until the amount of decay heat generation and removal are balanced. The calculated pool water temperature is increased slowly by as much as 37.7℃, during the first 10,000 sec.

The temperature change in the reactor hall increases slightly due to the resulting low heat transfer rate from a reactor pool water to its surroundings. The calculated value of the maximum reactor hall temperature is represented at about 27.4℃at 36,000 sec. The change of pressure in the reactor hall is not affected significantly due to the relatively small amount of variations in the pool water temperature and the reactor hall temperature.

The calculated maximum air pressure change reached about 8.82 mmWG, which is acceptable below the design limit of 25 mmWG required for the leakage rate in the reactor hall [6], as shown in Fig. 2.

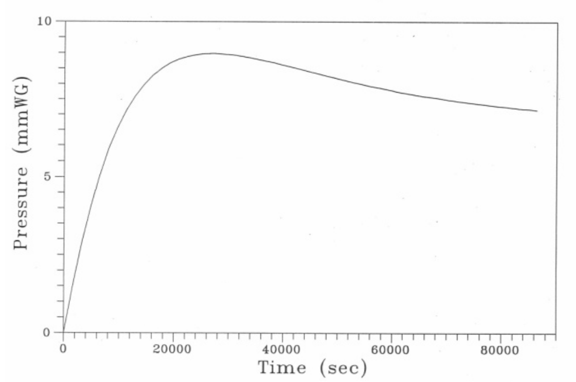

Fig. 2. Variation of pressure in the reactor hall.

4. Conclusions

The calculation results show that the increase of pressure in the reactor hall will not cause any serious problems to the safety limits although the reactor hall pressure is slightly increased. Therefore, it was concluded that the pool water temperature increase is not so rapid as to cause the pressure to vary significantly in the reactor hall.

Furthermore, the mathematical model developed in this work can be a useful analytical tool for scoping and parametric studies in the area of thermal transient analysis, with its proper representation of the interaction between the temperature and pressure in the reactor hall.

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