Thermal Analysis of Fission Moly Target Solid Waste Storage

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1. Introduction

Technetium-99m ($T_{1/2}$= 6h) is one of the most widely used radiopharmaceutical sources in medical diagnosis industry which is a daughter isotope of Molybdenum-99 ($T_{1/2}$= 66h)[1]. There are various ways to produce Mo-99. Among them, nuclear transmutation of uranium target became the major one owing to its superior specific activity. After the fission molybdenum (FM) target is irradiated, it is transported to treatment facility to extract wanted isotope. During the process, various forms of wastes are produced including filter cake and other solid wastes[2]. The filter cake is mostly consisted of decaying uranium compounds. The solid wastes are then packaged and moved to storage facility which will stay there for considerable amount of time. Being the continuous source of heat, the solid wastes are required to be cooled for the certain amount of time before transported to the storage area. In this study, temperature evaluation of the storage facility is carried out with pre-cooling time sensitivity to check its thermal integrity.

2. Methods and Results

In this section, analysis geometry, governing equation and assumptions applied in calculation are explained.

2.1 Analysis Geometry

Figure 1 shows a simplified geometry of the storage facility base which will be analyzed in this study. It is basically a thick concrete structure with vertical holes to store the wastes. The diameter of the hole is 100 mm with 1 mm of air gap between concrete and waste container, which are temporary values that requires further study. It is conservatively assumed that the heat generated from the wastes will only be removed by transverse heat conduction along the concrete structure. Therefore, convective cooling along the top surface by air and downward conductive heat transfer are ignored which leads to two-dimensional problem. In this study, finite volume method is utilized to numerically solve the governing equation on the region of interest. Figure 2 shows a discretized geometry with assumed storage direction where rectangular grid system is used.

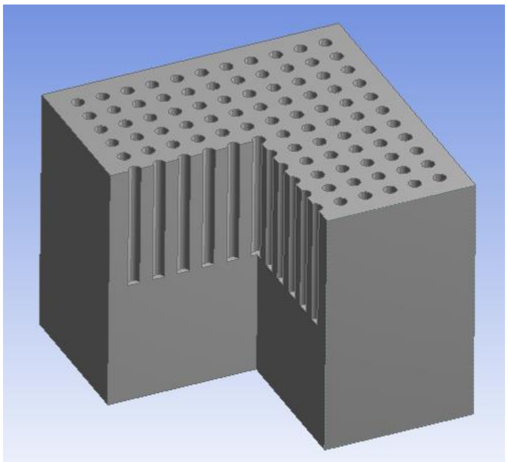

Fig. 1. Storage facility base.

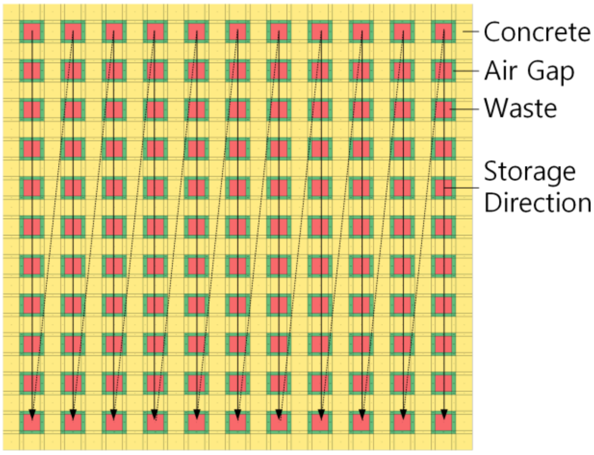

Fig. 2. Discretized geometry (not to scale).

2.2 Governing Equation

In order to obtain the temperature distribution of the solid geometry, transient two-dimensional heat conduction equation as shown in Eq. (1) is numerically solved for each control volume (Figure 3)[3]. Discretized form of the governing equation for the finite volume is shown in Eqs. (2)~(7) where forward difference scheme is used for time advancement.

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \dot{q}''' \tag{1}$$

$$\dot{q}_N = \frac{\Delta x_j}{\frac{\Delta y_{i-1}}{2k_{i-1,j}} + \frac{\Delta y_i}{2k_{i,j}}}\left(T_{i-1,j} - T_{i,j}\right) \tag{2}$$

$$\dot{q}_S = \frac{\Delta x_j}{\frac{\Delta y_{i+1}}{2k_{i+1,j}} + \frac{\Delta y_i}{2k_{i,j}}}\left(T_{i+1,j} - T_{i,j}\right) \tag{3}$$

$$\dot{q}_W = \frac{\Delta y_j}{\frac{\Delta x_{j-1}}{2k_{i,j-1}} + \frac{\Delta x_j}{2k_{i,j}}}\left(T_{i,j-1} - T_{i,j}\right) \tag{4}$$

$$\dot{q}_E = \frac{\Delta y_j}{\frac{\Delta x_{j+1}}{2k_{i,j+1}}+\frac{\Delta x_j}{2k_{i,j}}}\left(T_{i,j+1}-T_{i,j}\right) \quad (5)$$

$$\dot{q}_{gen} = \dot{q}'''_{i,j}\Delta x_j \Delta y_i \quad (6)$$

$$\rho c_p \Delta x_j \Delta y_i \frac{dT_{i,j}}{dt} = \dot{q}_N + \dot{q}_S + \dot{q}_W + \dot{q}_E + \dot{q}_{gen} \quad (7)$$

where, k is thermal conductivity [W/m-K], T is temperature [K], and $\dot{q}'''$ is volumetric heat generation rate [W/m^3], respectively.

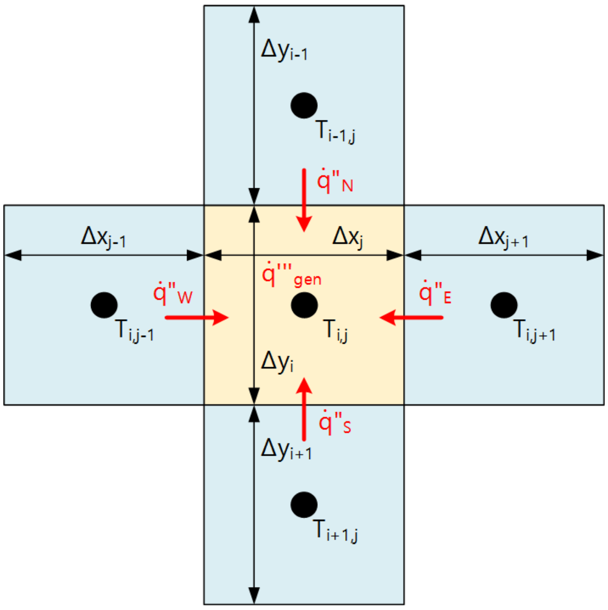

Fig. 3. Finite volume (interior point).

2.3 Calculation Assumption

In this study, the initial power of the single waste container is conservatively set to be same as that of the target assembly, where its maximum value (~100 kW) is used[4]. In evaluating decay heat, ANS 2005 Standard for infinite operating time assumption is used with 10% of penalty[5]. Assuming that the storage building is in ground level, the temperature at the concrete boundaries are assumed to be held constant at 37 °C based upon the environmental temperature survey data of South Korea during recent 10 years[6]. A value of 1.4 W/m-K is used for thermal conductivity of concrete structure, assuming normal concrete is used[7]. Considering the container is mostly composed of uranium compounds such as uranium oxides, and the cladding material, the thermal conductivity of irradiated uranium dioxide (3 W/m-K) is adopted[8]. The FM targets are irradiated for 7 days, cooled in pool water for another day, and then taken out of the core to processing hot cell[4]. This gives the 8 days of minimum time interval between each storage of container. Lastly, it is supposed that each hole can accommodate up to 6 containers. Assuming 9 month of minimum cooling time and 300 operation days/year, the number of required storage holes for the 20 years is 120 in maximum. Therefore, a simple 11 × 11 square array configuration is assumed.

2.4 Analysis Results

For each time a storage hole is filled with the container, Eq. (7) is iteratively solved for each finite volume to obtain temperature distribution which meets convergence criteria (maximum deviation from previous time step < 0.1 deg.). The time step, and specific heat values are adjusted to accelerate the convergence rate. Figure 4 shows the evolution of maximum container temperature as the storage progresses (9 months of cooling time) where the highest point is seen when the last hole is filled. Figure 5 illustrates the temperature distribution of the structure for the worst case, which shows the concrete bulk temperature near 200 °C. According to the literature, the strength of the concrete is deteriorated for the temperature above 100 °C[7]. In order to resolve this, extended pre-cooling period is required as depicted in Figure 6 which shows that at least 13 months of cooling is necessary to preserve integrity of structure.

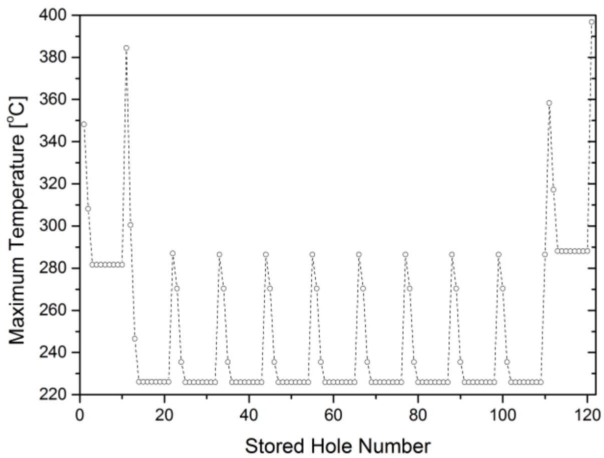

Fig. 4. Evolution of maximum container temperature.

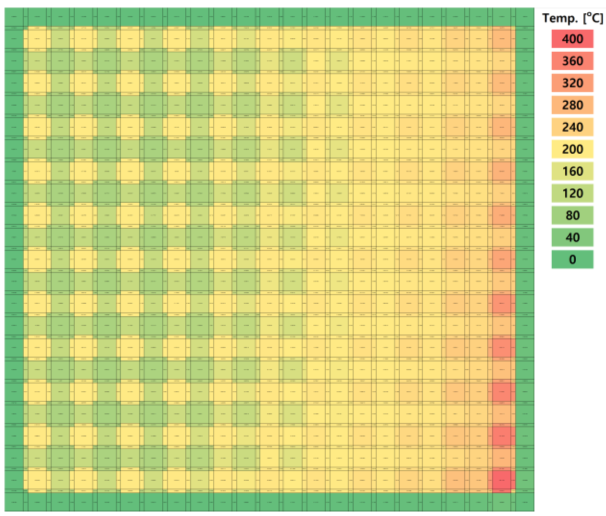

Fig. 5. Temperature distribution for 121-th hole storage.

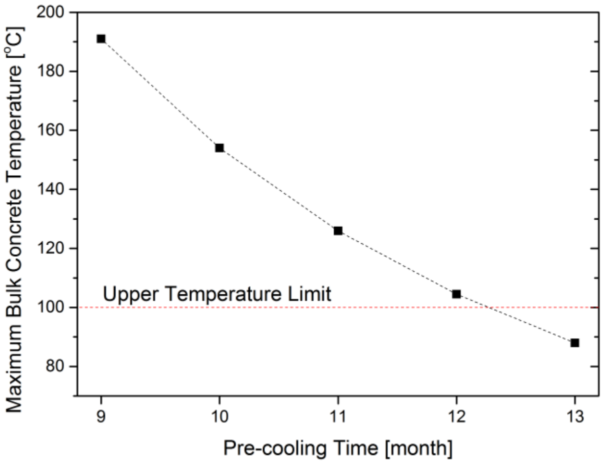

Fig. 6. Effect of pre-cooling time on concrete temperature.

3. Conclusions

In this study, thermal analysis on the FM target solid waste storage is performed. Finite volume method is utilized to numerically discretize and solve the geometry of interest. Analysis shows that the developed method can simulate temperature behavior during storage process, but needs to be checked against other code to see calculation accuracy. Highest temperature distribution is observed when every hole is filled with waste containers. Sensitivity results on pre-cooling time shows that at least 13 months of cooling is necessary to keep the structure integrity.

ACKNOWLEDGEMENTS

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