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Analysis on Fission Products Diffusion Using Finite Difference Method

Hyedong JEONG, Yong Hoon JEONG and Soon Heung CHANG
Korea Advanced Institute of Science and Technology
hyedong@kaist.ac.kr

1. Introduction

It is necessary to calculate the transport of fission products or trace their concentration for safety assessment. The ultimate purpose is to give the comprehension of fission product (FP) behavior during the accident conditions.

To make the scope narrow, this paper aims to analyze how much FPs become diffused to outward from the fuel source, one pebble. With this aim, numerical calculation was done in order to solve the complicated diffusion equation. The finite difference method (FDM) is a well established numerical approach which has been employed many application fields. There are many popular FDM developed, however, Crank-Nicolson, the basic scheme is used in this study.

2. Method

There are several assumptions to model the problem conveniently:

1) When isotopes decay, they disappear and are not converted into others. Activity may be under-estimated.

2) All isotopes have the same diffusivity under the given material.

3) For conservative calculation, all fuel element failure occur only the surface between the fuel region and pyro-carbon. Furthermore, a SiC layer of a pebble already loses its retention capability before accident happen, and it means FPs are diffused directly to coolant from the end of the pyro-carbon surface.

4) Diffusion progresses the only outer radial direction, because the inside concentration is always higher or at least equal.

Then the governing equation can be written down as eq.(1).

$$\begin{aligned}\frac{\partial C_1}{\partial t} &= D\nabla^2 C_1 - \lambda_1 C_1 \\ \frac{\partial C_2}{\partial t} &= D\nabla^2 C_2 - \lambda_2 C_2 \\ &\text{M} \\ \frac{\partial C_j}{\partial t} &= D\nabla^2 C_j - \lambda_j C_j\end{aligned} \tag{1}$$

,where *C, D, λ, j* are the concentration, the diffusion coefficient, the decay constant, and the species of nuclide, respectively.

It is hard to solve and sum up all *Cj* for activity calculation. To simplify the problem, this paper suggests that all nuclide should be perceived as the one equivalent nuclide. Then, the sum of activities, ∑Ai, is following as;

$$A_{1,0}\exp(-\lambda_1 \cdot t) + A_{2,0}\exp(-\lambda_2 \cdot t) + A_{3,0}\exp(-\lambda_3 \cdot t)\Lambda = A_{eff,0}\exp\left(function(\lambda_{eff}, t)\right) \tag{2}$$

By calculating the left hand side of eq.(2) from Ref[1], the trend of curve can be analyzed to determine the form of the right hand side. In final, let the form of A_{eff} be:

$$A_{eff}(t) = A_{eff,0}\exp\left(-\lambda_{eff}\ln(t)\right)$$

Then, one obtains

$$\frac{dA_{eff}}{dt} = -\frac{\lambda_{eff}}{t}A_{eff}(t) \tag{3}$$

In fact, $A_{eff,0}$ and λ_{eff} are the function of burn-up. At given burn up condition, the equivalent decay constant can be considered as constant. The equivalent decay constant, 0.3047 at 8.4%FIMA, was deduced from Ref[1]. Taking into account the above mentioned suggestion, the following simple equation can be inferred after rearranging eq(1) and eq.(3).

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r}\right) - \frac{\lambda}{t}C \tag{4}$$

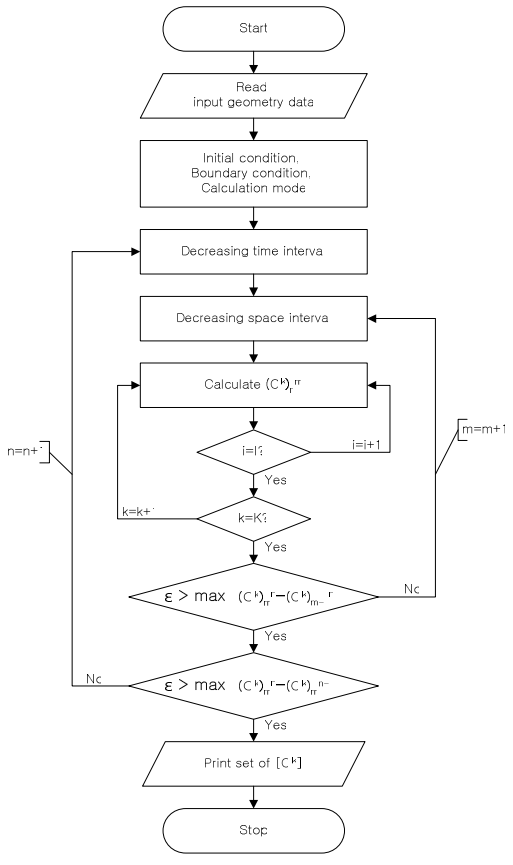

Figure 1. Flowchart of solving process

Let C_0^0 be used as 1 for the initial condition. Although more realistic value can be counted, the simple value is preferred here to comprehend the main point of the problem first. When accident happens, the source concentration would be higher suddenly; 10 times more then usual. Thus, C_0^k is 10 for the boundary condition. Also, at $r=r_1$ there is evaporation into the outward for which the equilibrium concentration is kept as $C_{equilibrium} = \phi \cdot C_{r=r_1}$.

The calculation process is shown below in Figure 1. The error bound for aborting iteration calculation was set 10^{-6}. The time interval, δt, and spatial interval, δr, were determined as 10^{-1}, 10^{-5}, respectively.

3. Results

As shown in Figure 2, the concentration according to time and space was calculated. The difference with time is rarely figured out, except the source vicinity. The concentration of the outer surface is quite much lower, around ~10^{-6} times, than that of the source.

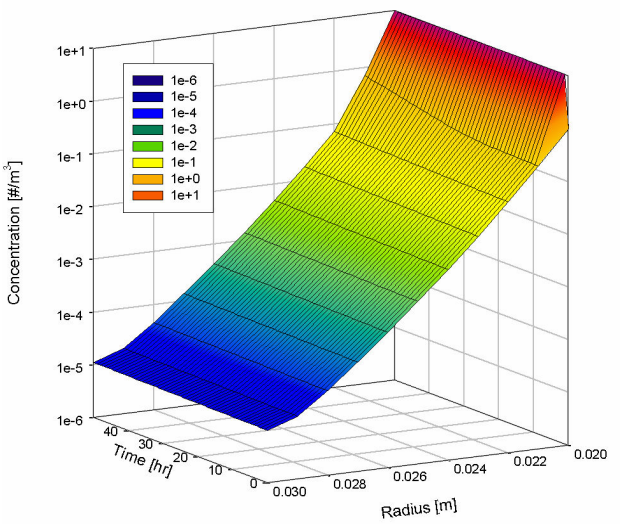

Figure 2. Spatiotemporal concentration distribution

4. Discussion

It is shown, in Figure 3, that fission products may not be diffused into outward significantly even when accident occurs, some time wears on and the source of fission products released rapidly increase.

Furthermore, three results by each different numerical scheme are compared together in Figure 3. The difference is too small (~10^{-11}) to distinguish and each scheme shows similar accuracy.

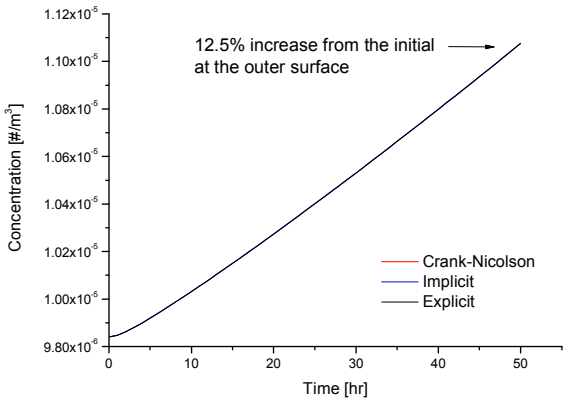

Figure 3. Concentration change at the outer surface boundary.

5. Conclusion

To obtain the concentration distribution within a pebble, one simplified diffusion equation was solved, instead of the simultaneous diffusion equations. The numerical FDM was applied to calculate the equation and the trend of the result was quite reasonable. The hypothetical accident conditions were simply assumed to understand the kernel of the FP release problem. As shown in Figure 3, even though the initial concentration is 10 times higher, the amount of release is about 10% larger than that in normal. Meanwhile, a pebble whose SiC layer is intact will discharge FPs much smaller, because the diffusion coefficient of SiC is much lower than that of PyC.

The numerical approximation result seems to be accurate. In spite of some assumptions implied in solving process, they are still advantageous because of the economy in calculation time. They are helpful for making quick estimations and providing the insight of the problem.

ACKNOWLEDGMENT

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REFERENCES

[1] Hyedong JEONG et al., Estimation of Fission Product Release from the TRISO Fuel, KNS Spring Meeting, 2006.