The Scope Calculation for the Distribution of the Plate-out in the "OGL-1" experiment using MIDAS and Its model review

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1. Abstract

The scope calculation on the plate-out in the HTGR related OGL-1 experiment using the MIDAS code was performed in the frame of the preliminary study to develop the MIDAS/GCR for simulating the plate-out, dust and tritium in a HTGR.

From this scope calculation, the user specified type of the fission product vapor species in the circuit and the distribution of the circuit surface temperature were identified as the important factors that can have a strong effect on the distribution of fission product plateout over the HTGR loop. Also the analytical solution for calculating the plate-out by considering a radioactive decay was derived for MIDAS. These identified factors and the new analytical solution will be taken into account in developing the MIDAS/GCR.

2. Introduction

The plate-out is a complex phenomena, which is dependent on the mass transfer, the adsorption and the desorption, the temperature distribution, the type of fission product species. The information on the plate-out from the circulating fission product gas is applied to construct a safety engineering system, to calculate the necessary shielding and to estimate the environmental impact.

The status of the model development and available data are performed extensively but the data still has a large uncertainty with one order of magnitude with the model. The main reason for the uncertainty is that most of the available data comes from different measuring conditions from that of the real plant under a accident.

Now, several representative codes are able to simulate the plate-out phenomena in the HTGR such as SPATRA, PATRAS, PLAIN [1] and PADLOC. However all these codes were developed in the 1960s or 1970s. Also all these codes have a weakness in that all the transient conditions such as the pressure, the gas temperature, the mass flow rate and the structure surface temperature at each of the circuits should be given as a function of the time.

The MIDAS code has a capability to calculate the transient thermal-hydraulic condition over the circuit if the mass injection rate and the geometrical dimensions are given. Also it has a primitive plate-out model for condensing the fission product vapor on the structure surface.

An OGL-1 test was performed to study the plate-out phenomena by JAERI in 1979. The objective of this study is to perform the scope calculation for the OGL-1 test with MIDAS. Also the governing equations concerning the "fission product vapor condensation" in the MIDAS code were modified to be able to consider the radioactive decay phenomena. The analytical solution for these governing equations is described in section 3.3.

3. Description of the Actual Work

3.1 Scope calculation on OGL-1 with MIDAS

The primary gas temperature of the OGL-1 test was changed from 700°C to 30°C. The measurement of the plate-out for Cesium-137 and Iodine-131 was done at 15 points along a circuit of 100 m after the end of 500 hrs of operations. To predict the plate-out information from an experiment with MIDAS code well, it is important to impose the circuit temperature in the input deck as close as possible with that of the measured data. However, a heat exchanger that has suffered from a rapid temperature change is difficult to represent for the entire heat exchanger as an one representative average temperature. Therefore two calculations were performed in this study.

The first calculation was done by a simple input-deck. It means that the special region, which will suffer from a rapid temperature change, was modeled as one control volume and one average temperature. The second calculation has a difference from the first case in its modeling such as the kind of special region. For example, the special regions such as the heat exchanger or the cooler were modeled as three separate volumes.

Figure 1 shows the difference of the distribution of the plate-out of Cs-137 according to the degree of the nodalization for the heat exchanger and the cooler.

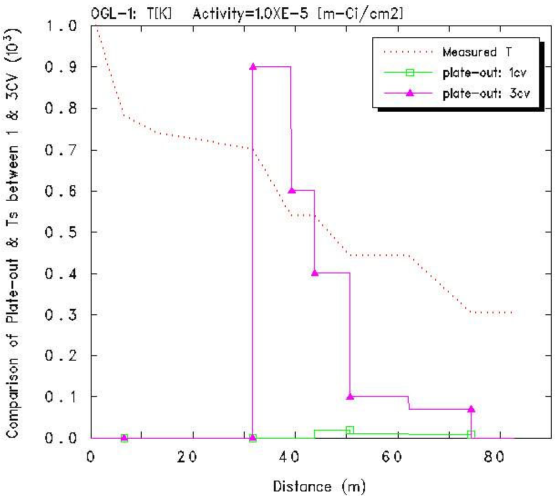

Figure 1. Comparison of distribution of plate-out between 1cv and 3cv nodalization for OGL-1 test

3.3 Derivation of the analytical solution for the governing equation for the condensation of the fission product vapor by considering the decay.

The derivation of the new governing equation for the fission product vapor condensation was done by implementing the mass gain and mass loss by the radioactive decay of the specific species into the current MIDAS governing equations. In general, the radioactive species to be considered were Cesium and Strontium. The new governing equation was set up as below.

$$\frac{dM_{a,k}}{dt}+\sum_i \frac{dM_{i,k}}{dt}-\lambda_j \frac{M_j}{VM_{A,j}}+\lambda_k \frac{M_{a,k}}{VM_{A,k}}=0$$

$$\frac{dM_{i,k}}{dt}=A_i k_{i,k}(C_{a,k}-C^s_{i,k})$$

where V = space volume
$M_{a,k} = C_{a,k}/V$=mass of FP 'k' in bulk space
$M_{i,k}$ = mass of FP 'k' species on surface I
λ_j = decay constant on the parent for FP 'k'
λ_k = decay constant of FP 'k'
$C^s_{i.k}$ = saturation concentration of FP 'k' on the surface 'i'
$k_{i,k}$ = mass transfer coefficient of FP k on i

But the decrease of the surface concentration by its radioactive decay was neglected. The solution of the above governing equations can be obtained by applying the "Laplace transformation" method. Consequently, the analytical solutions for two variables such as the bulk concentration of FP 'k' and the surface concentration (plate-out) 'k' were obtained as follows.

$$M_{a,k}(t)=\frac{\beta}{\alpha}-\left(\frac{\beta}{\alpha}-VM_{a,k}(0)\right)e^{-\alpha t}$$

$$M_{i,k}(t)=M_{i,k}(0)+A_i k_{i,k}\left(\frac{\beta}{\alpha}-\frac{M^s_{i,k}}{V}\right)t-A_i k_{i,k}\left(\frac{\beta}{\alpha}-\frac{M_{a,k}(0)}{V}\right)\left(\frac{1-e^{-\alpha t}}{\alpha}\right)$$

where

$$\alpha=\sum_i \frac{A_i k_i}{V}+\frac{\lambda_k}{VM_{A,k}}$$

$$\beta=\sum_i \frac{A_i k_i M^s_{i,k}}{V}+\frac{\lambda_j M_j}{VM_{A,j}}$$

$M_{A,k}$, $M_A j$ = molecular weight of FP 'k' and 'j'

This analytical solution will be implemented into the MIDAS code and the effect of considering the radioactive decay on the plate-out phenomena will be estimated.

4. Conclusion

The results from this study can be summarized as follows.

1) Exact specification of the mass flow rate of the fission product vapor and of their chemical type was important to determine the amount of plate-out.
2) It is important to impose the circuit temperature in the input deck as close as possible with that of the measured data.
3) The governing equations concerning the "fission product vapor condensation" in the MIDAS code were modified to be able to consider the radioactive decay phenomena. The analytical solution for these governing equations was derived.

These derived new solution and the important results will be taken into account in developing MIDAS/GCR.

ACKNOWLEDGEMENTS

Authors would like to thank MOST for supporting this research with the frame of MOST long term R&D program.

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