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Preliminary Evaluation on Metallic Fuel Source Term of Sodium-Cooled Fast Reactor

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1. Introduction

Source term is defined as the release of radionuclides from the fuel and coolant into the containment, and subsequently to the environment, following a severe accident where a significant portion of the reactor core has melted.[1] Of the many issues associated with the development and deployment of SFRs, one of high regulatory importance is the source term to be used in the siting of the reactor. Apart from assessing the radiological consequences for siting, it is also important for setting up filtering systems and even reactor components. Overly conservative source term for light water reactor, TID-14844 [2] demands for very fast closure of main steam isolation valves, rapid startup of emergency diesels, and safety systems designed to mitigate gaseous iodine.[3] In spite of this importance, there are not much experimental data or experience about the metallic fuel source term of SFR. Since one example of metallic fuel source term comes from that of Power Reactor Innovative Small Module (PRISM) [4], KAERI is expected to use the same source term for domestic prototype reactor MIRERO under development. Thus, it is needed to understand the general characteristics of fission product behavior of SFR and to evaluate whether the PRISM source term might be applicable to domestic prototype SFR. This paper presents our preliminary evaluation results on the issue.

2. Modeling of SFR Source Term

The transport behavior of fission products in SFR is quite different from that of LWR source term. Fig. 1 shows the schematic diagram of the initial stages of a transient. In the figure, the white part is the gas plenum, the red one is the bond material, yellow one is the fuel, orange one is the sodium and the gray one is the cladding material. At the time of fuel melt, the arrow indicates the axial movement of the fuel; the fuel melts upward and reduces the reactivity. Then at the time of pin failure, molten fuel and steel form a eutectic, the clad ruptures, and releases a bubble of gas, bond material, and molten fuel into the channel.[4]

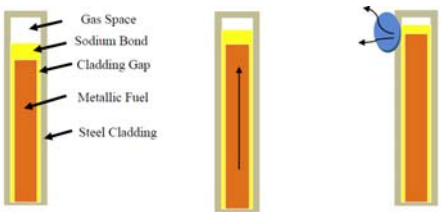

Fig.1 Schematic Diagram of Initial Fuel Failure

Most of the fission products coming from the core goes into the sodium pool and then they are transported to cover gas region either by the bubble transport or the evaporation of gas at the surface. This is shown schematically in Fig.2 below.

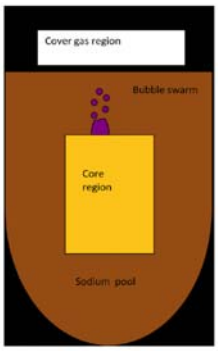

Fig.2 Transport of FP to Cover Gas

Thus, to calculate the quantity of source terms in the containment, we need first to calculate the FP inventory coming out of the core to the sodium pool at the accident and then transport of FP from the pool to the cover gas. Unfortunately, there is no model to predict reliably the release of various radionuclides from the metallic fuel yet. The transport of FP from sodium pool occurs both by the bubble transport and the evaporation from the pool. The transport by bubble could be estimated by referencing the models implemented in VANESA code.[5]

One approach to calculate the evaporation is to use the partition coefficient obtained from experiment. The gas-liquid equilibrium partition coefficient K_d is defined as the ratio of the mole fraction of the solute in the vapor to that in the liquid. Kazuo et al. [6] has, for example, obtained an empirical correlation of Cs as $\log K_d[Cs] = 1940/T(K) - 0.738$, with an error band of ±20% in the temperature range of 450 to 650 ℃. The relation between K_d and the liquid sodium temperature is reported to agree well with other theoretical approach which will be explained in section 3. The K_d for I, Cs, Te are obtained and the correlation agrees well for some condition, and it does not agree well for the other condition.

3. Calculation of ALMR Source Term

SCHRAM et al. have calculated the source term of the Advanced Liquid Metal Reactor (ALMR) of General Electric for a metallic fuel which utilizes Pu, U and Zr.[7] They performed a thermodynamical calculation of the release of fission products to the gas

phase using both the basic data of the pure compounds and also the so-called excess Gibbs energy of mixing which accounts for the interaction of the fission products with sodium. But the solutions are, in general, highly non-ideal so that excess functions of these systems must be collected. The excess functions are only available for a limited number of fission products. Especially the lanthanides and the actinides require further experimental data. In case the excess chemical potentials are not available, a conservative estimate of the release of the fission products can be obtained, if it is assumed that none of the compounds dissolves in sodium. With this background, they simulated assuming that the complete inventory of the core was released in the sodium coolant at the boiling temperature of sodium. Their results for a few radionuclides are the following. The case of assuming homogeneous mixing and non-mixing are compared.

Table 1. Phase Equilibrium Calculations for sodium pool T=1,156K

Element	Release Fraction	
	Homogeneous Mixing	Without Mixing
Xe	1.0	1.0
I	1.03E-5	0.32
Cs	0.56E-3	0.61
Sr	1.43E-6	0.77E-1

This result clearly shows that the source term calculation depends highly on assumptions, models used and thermodynamic data. Also the results coming from the theoretical calculation agree sometimes with the partition coefficient calculation explained in section 2 and sometimes it does not.

4. Evaluation of PRISM Source Term

PRISM is a reactor with an electric power of 1395MWe and utilizes a metallic-type fuel, a ternary alloy of U-Pu-Zr. Thus the source term used in PRISM cannot directly applicable to the MIRERO of KAERI. But it is the only source term applied in site suitability evaluation, it is expected that KAERI might be tempted to utilize the same source term. So it is needed to evaluate, even preliminarily, the feasibility of the PRISM source term. We still lack much knowledge on the metallic fuel source term, but even a trial evaluation of the PRISM source term could shed light to the MIRERO source term. The source term used in the evaluation of the site suitability is given in Table 2.

Table 2. PRISM site suitability source term

Element	Assumed Release
Noble gases	100%
I	0.1%
Cs	0.1%
Sr	0.01%

This PRISM source term comes basically from engineering judgement based on the source term data of oxide fuel. Because the fuel type, the sodium pool condition , accident condition etc. are different, it is not reasonable to compare directly the PRISM source term with that of the ALMR source term. But what we can learn by comparing the Table 1 and Table 2 is the following;

- source term calculation depends very much on the assumptions used,
- since there is no generally accepted methodology, both the empirical correlation and the thermodynamical calculation should be performed and compared,
- basically the PRISM source term has no strong experimental and theoretical support.

5. Conclusion

Source term could be calculated using equilibrium partition coefficient or using excess Gibbs free energy concept which is used for ALMR source term calculation. The results coming from two approaches agree some case and it does not agree for other case. Comparing the source term of ALMR and PRISM, it is prudent to say that PRISM source term might not applicable to domestic prototype SFR. The source term for KAERI's MIRERO needs to be obtained utilizing both the experimental correlation and thermodynamical data. KINS will review the feasibility of source term in this respect.

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