Literature Review on Metallic Fuel Source Term for 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 designing 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, most of the knowledge we have for SFR source term comes from the research performed before 1980s. Moreover, majority of the work on metallic fuels was done during the late 1950's through the 1960's. This paper reviews and summarizes the main characteristics of SFR source terms based on the available literatures.

2. In-Core Fission Products Inventory

Fig.1 shows the fission yields of ^{235}U and ^{239}Pu as a function of the isotope mass number (A) for thermal and fast neutrons. The asymmetric fission of both isotopes results in similar curves with some differences. In those regions of high fission yields the main differences occur in the lower range of A(85-105), where significant differences of fission yields exist for important fission products like Rb and Sr, between ^{235}U thermal fission and ^{239}Pu fast fission. There are other major quantitative differences but either they are in the low yield region of the curves or they do not affect significant radiological isotopes. This is the case, for instance, of ^{110}Ag which ^{239}Pu yield is nearly 2 orders of magnitude higher. On the contrary, ^{131}I, ^{132}Te and ^{137}Cs, all of them radiologically relevant, have very similar fission yields. Thus, no major discrepancies should be expected in terms of relative contributions of radiologically significant radionuclides, ^{90}Sr excepted, in the LWRs and SFRs inventory. Nevertheless, the total inventory in core could be substantially larger in a SFR since their fuels are anticipated to be irradiated for much longer periods. [4]

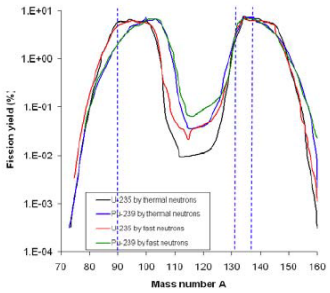

Fig.1. Fission yield spectra of ^{235}U and ^{239}Pu for thermal and fast neutrons [4]

3. General Behaviour of Fission Products in SFR

Sodium readily reacts with iodine to form NaI, so that ^{131}I and the other isotopes get efficiently trapped within reactor pool (overall iodine volatility is drastically reduced); this makes the potential radiological impact outside the plant to be dominated by ^{137}Cs , instead of ^{131}I as in the case of LWRs. Erdman et al. [5] summarized the work up to 1973 and concludes that:

(a) The noble gases escape from the sodium to the cover gas in minutes,
(b) Iodine is present in the sodium as dissolved sodium iodide,
(c) Cesium is in elemental form in the sodium,
(d) The low volatibility of alkaline earth metals, e.g. Ba and Sr, in sodium indicate their presence as some sort of oxide compounds,
(e) The rare earths, e.g. Ce, La, etc., are not found to any significant extent in the sodium,
(f) No information is available for transition metal retention in sodium, e.g. Zr, etc.

Also considering the sodium solubility data and the limited experimental data lead to the following generalization for the release fractions from fragmented fuel [6]:

(1) All the noble gases are released to the cover gas,
(2) All the halogens are released to the sodium,
(3) All the volatile metals are released to the sodium, e.g. Cs, Rb, Te
(4) The rare earths, e.g. Ce, La, etc., are released to the sodium to only a minor extent, probably forming insoluble oxide with oxygen in the sodium,

(5) The alkaline earths, e.g. Ba and Sr are probably released to the sodium, but form insoluble oxides,
(6) The noble metals, e.g. Ru, Rh, Pd, etc., are released to only a minor extent,
(7) The transition metals, e.g. Zr, Nb, Mo, etc., are released to only a minor extent; they may or may not form insoluble oxides depending on the oxygen level in the sodium,
(8) Fuel is not significantly released to sodium.

In short, the release fractions, from fragmented fuel to sodium, appear to be essentially either zero or unity. Because of the lack of experimental data, these estimates are based chiefly on engineering intuition; thus they should be used cautiously.

4. Research Needs for SFR Source Term

Recently, a gap analysis for SFR source term was performed and 20 gaps of varying degrees of importance were identified.[7] The highest-priority topical areas important to safety are listed in Table 1 below. This table shows that for a mechanical modeling of the source term to be feasible, we need much research to improve the level of knowledge.

Table 1. Source Term Gap Topical Areas

Name of Gap Topical Areas	*Importance to Safety*	*State of Knowledge*
Radionuclide release from fuel debris into a quiescent sodium poo	H	L
Radionuclide behavior in containment	H	L
Radionuclide transport within a sodium pool	H	M
Radionuclide chemistry in sodium bond between fuel and cladding	H	M
Mechanical release of radionuclides from the surface of a sodium pool	H	M
MELCOR/Contain-LMR integration	H	L

5. Conclusion

Literature survey on the metallic fuel source term of SFR was done. Most of the research done for metallic fuel source term was done, unfortunately before 1960's. More data are available for oxide fuel source term. Some conclusions we could draw for the source term of SFR based on the limited data are the following.

- Species of in-core fission products important to safety might be similar to LWR. Inventory should be different because of the higher burnup condition.
- Most critical fission product to consequence is ^{137}Cs instead of ^{131}I as in LWR, because I reacts with Na to make NaI and is effectively trapped in sodium pool.
- Fission products in SFR generally behave as is summarized in Section 3.
- For a mechanical modeling to be feasible, we need to resolve the gaps mentioned in Table 1.

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