Evaluation on In-vessel Source Term in PGSFR (2015 Results)

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1. Introduction

❑ The effectiveness of mitigative capabilities in nuclear plants is subject to quantitative analysis. The radionuclide input to these quantitative analyses of effectiveness is the Source Term (ST). All features of the composition, magnitude, timing, chemical form and physical form of accidental radionuclide release constitute the ST [1]. Also, ST is defined as the release of radionuclides from the fuel and coolant into the containment, and subsequently to the environment [2].

❑ The results of extensive calculations and experiments have been used to formulate an alternative to the simple TID-14844 ST [3] for regulatory purpose. This Alternative ST (AST), NUREG-1465 ST categorizes radionuclides into eight chemical classes based on chemical and physical similarity [4].

❑ AST is certainly not applicable to SFR. AST provides a valuable insights and framework for the development of a mechanistic ST model for SFR to be used in licensing as well as risk analysis.

❑ There are not much experimental data or experience about the source term of metal fuel in SFR. Since one example of the source term about metal fuel comes from that of the Super-Safe, Small and Simple (4S) reactor [5], KAERI is preliminarily evaluating the in-vessel ST using 4S methodology in the Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR).

2. Calculation of In-vessel Source Term

2.1. Assumptions of Radiological Consequence Analysis

❑ In-vessel STs are estimated using a nonmechanistic and conservative methodology like that of 4S reactor. The fraction of fuel damaged is assumed 1 % (~ 243 fuel pins).

❑ The radioactivity inventory is assumed 110 % of the estimated inventory at the end of life that is very conservative but used to cover uncertainties in estimating the Fission Products (FPs) and activated primary sodium inventory.

❑ No fuel retention is assumed for the FPs group in the release into the primary sodium. The high primary sodium temperature (650 °C) is used for estimating the release fraction in the release into the cover gas region.

2.2. Radionuclide Groups and Inventory

❑ The elements to be evaluated and the radionuclide groups were specified based on NUREG-1465 ST [4] and Regulatory Guide (RG) 1.183 [6]. Because uranium is not defined in RG 1.183, it was included in the cerium group. A separate group was added, because the operation of liquid metal-cooled reactors results in the activation of the sodium coolant. Radionuclides with a half-life of more than 1 minute are considered [5]. The radionuclide groups and the elements are as follows:

1. Nobles Gases : Xe, Kr
2. Halogens : I, Br
3. Alkali Metals : Cs, Rb
4. Tellurium Group : Te, Sb, Se
5. Barium, Strontium : Ba, Sr
6. Noble Metals : Ru, Rh, Pd, Mo, Tc, Co
7. Lanthanides : La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm Am
8. Cerium Group : Ce, Pu, Np, U
9. Coolant : Na

❑ The inventory of each radionuclide is calculated by ORIGEN-2 code using the realistic burnup condition as shown in the Fig. 1. The radiological inventory may include errors in excess of 10 % in magnitude by taking in account various uncertainties associated with fuel mass in the core. The nominal value of the radiological inventory is multiplied by a factor of 1.1 as an uncertainty margin to give the radiological inventory. The inventory of the coolant is calculated by using the sodium mass (kg) and the specific activity (Ci/kg).

Fuel Assembly		Realistic
IC (52)	IC-I (13)	1 y
	IC-II (13)	2 y
	IC-III (13)	3 y
	IC-IV (13)	4 y
OC (60)	OC-I (12)	1 y
	OC-II (12)	2 y
	OC-III (12)	3 y
	OC-IV (12)	4 y
	OC-V (12)	5 y

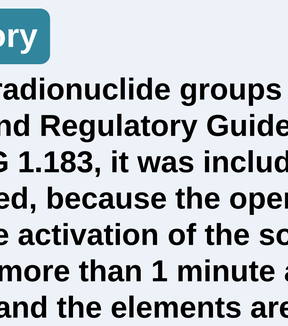

Fig. 1. The realistic burnup condition in ORIGEN-2 code.

2.3. Release Path

❑ Fig. 2 shows the radioactive release path used in the PGSFR ST evaluation. The release path includes transport of the fission products from the damaged fuel to the primary coolant, release of fission products and activated sodium from the primary coolant to the cover gas space, leakage from the cover gas space to the containment, and the leakage from the containment to the environment. The leak rate from the cover gas region will be 0.5 %/day. And, the leak rate from the containment will be 0.1 %/day as shown in Fig. 2. These design leak rates are demonstrable under the design pressure and temperature limits of these boundaries.

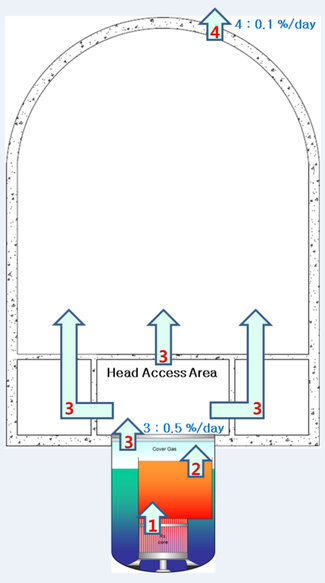

Fig. 2. Release path for ST evaluation in PGSFR.

2.4. Release from the Core to Primary Sodium

❑ ST in the release from the core to primary sodium is calculated by using the assumption of 4S methodology. Table I shows the release fraction from the core to primary sodium using for this calculation.

Table I: Release Fraction from the Core to Primary Sodium

Radionuclide Groups	Release Fraction (Core to Primary Sodium)
Noble Gases	0.01 (10^{-2})
Halogens	0.01 (10^{-2})
Alkali Metals	0.01 (10^{-2})
Te Group	0.01 (10^{-2})
Ba, Sr	0.01 (10^{-2})
Noble Metals	0.001 (10^{-3})
Ce Group	0.00001 (10^{-5})
Lanthanides	0.00001 (10^{-5})
Coolant	-

2.5. Release from the Primary Sodium to Cover Gas Space

❑ ST in the release from the primary sodium to cover gas space is calculated by using the assumption of 4S methodology. Table II shows the release fraction from the primary sodium to cover gas space using for this calculation.

❑ Fig. 3 shows the temperature dependency of the sodium mass fraction in the cover gas space and the release fraction for NaI and Cs in the PGSFR reactor system.

Table II: Release Fraction from the Primary Sodium to Cover Gas Space

Radionuclide Groups	Release Fraction (Primary Sodium to Cover Gas Space)
Noble Gases	1
Halogens	$7.9 \cdot 10^{-6}$
Alkali Metals	$1.4 \cdot 10^{-4}$
Te Group	$3.7 \cdot 10^{-6}$
Ba, Sr	$3.7 \cdot 10^{-6}$
Noble Metals	$3.7 \cdot 10^{-6}$
Ce Group	$3.7 \cdot 10^{-6}$
Lanthanides	$3.7 \cdot 10^{-6}$
Coolant	$3.7 \cdot 10^{-6}$

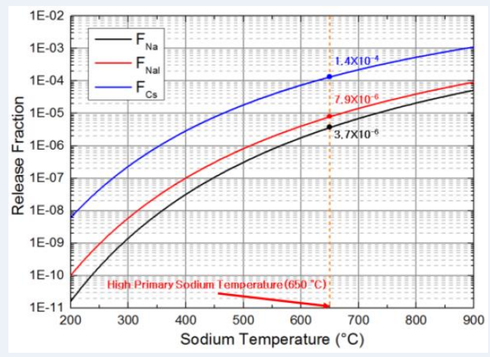

Fig. 3. Release fraction of sodium, NaI and Cs from coolant to cover gas.

❑ Table III shows the result of the in-vessel ST in PGSFR by using the assumption of 4S methodology.

Table III: Result of the In-vessel ST in PGSFR

Radionuclide Group	Elements	Mass (g)	Radionuclide Group	Elements	Mass (g)
Noble Gases	Xe	4.39496E+02	Lanthanides	La	4.77959E-07
	Kr	4.62520E+01		Zr	3.21490E-05
Halogens	I	2.39730E-04		Nd	1.40441E-06
	Br	2.07996E-05		Eu	2.56746E-08
Alkali Metals	Cs	5.25273E-02		Nb	2.06224E-08
	Rb	5.90118E-03		Pm	1.14719E-07
Tellurium Group	Te	2.07916E-04		Pr	4.33195E-07
	Sb	2.35175E-05		Sm	2.53532E-07
	Se	2.61019E-05		Y	2.15475E-07
Barium, Strontium	Ba	5.24106E-04		Cm	3.07875E-12
	Sr	4.23429E-04		Am	1.13605E-10
Noble Metals	Ru	8.03944E-05	Cerium Group	Ce	1.05652E-06
	Rh	1.89944E-05		Pu	5.78650E-06
	Pd	2.25723E-05		Np	1.38801E-07
	Mo	1.25720E-04		U	2.87778E-04
	Tc	3.03901E-05	Coolant	Na	2.67460E-06
	Co	0.00000E+00			

3. Conclusions

❑ The in-vessel STs of PGSFR are estimated using a nonmechanistic and conservative methodology like that of 4S reactor. The many assumptions and equations evaluated in 4S are used.

❑ The in-vessel STs are calculated through several phases:
- The inventory of each radionuclide is calculated by ORIGEN-2 code using the realistic burnup condition.
- The nominal value of the radiological inventory is multiplied by a factor of 1.1 as an uncertainty margin to give the radiological inventory.
- ST in the release from the core to primary sodium is calculated by using the assumption of 4S methodology.
- Lastly, ST in the release from the primary sodium to cover gas space is calculated by using the assumption of 4S methodology.

❑ The leak rates from the cover gas region (0.5 %/day) and containment (0.1 %/day) will be used the design leak rates that are demonstrable under the design pressure and temperature limits of these boundaries.

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