A Study of MSR Depletion Behavior based on Molten Salt Type

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1. Introduction

$KCl-UCl_3$ molten salts are used as potential fuels for MSR (Molten Salt Reactor) due to their inherent safety [1]. Using $NaCl-MgCl_2-TRUCl_3$ as fuel has the advantage of reducing the size of MSR. These two types of molten salt, $KCl-UCl_3$ and $NaCl-MgCl_2-TRUCl_3$ were considered for MSR core designs in this study. To evaluate MSR's core characteristics, the ratio of components constituting each molten salt fuel was determined, as well as the shape, structure and size of the core to maintain the critical state until the end of the cycle. This paper briefly describes some of preliminary results of the burnup calculation performed under these core configurations such as the k_{eff} falloff and the fission products generation.

2. MSR Core Conditions

The reactor core conditions of the MSR depend on the type of molten salt used as nuclear fuel.

2.1 $KCl-UCl_3$ MSR

Fast neutron spectrum is taken into account for the MSR that is currently being designed. As a result, Plutonium is preferred over Uranium for fuel material, even though the major research was done for Uranium-based fuel to account for supply and demand uncertainty. At a fuel temperature of 908K, the composition ratio of KCl and UCl_3 was 0.46 to 0.54 while in-core to ex-core volume ratio was 0.55 to 0.45. Table I summarizes the reactor specification and Fig. 1 shows the conceptual geometry of $KCl-UCl_3$ fueled MSR.

Table I: Reactor specification ($KCl-UCl_3$)

moten salt fuel	$KCl-UCl_3$ (0.46:0.54) at 908K
reactor vessel	SS316H
reflector	BeO, YH
Cl-35:Cl-37	0.01:0.99
$V_{incore}:V_{excore}$	0.55:0.45

2.2 $NaCl-MgCl_2-TRUCl_3$ MSR

If the TRU supply is stable, it is advantageous to reduce the reactor size by utilizing TRU-based molten salt fuel. In order to set the size of the ex-core to be the same as in the former case, in-core to ex-core volume ratio was set to 0.3:0.7. The remaining core conditions are the same as in the previous $KCl-UCl_3$ case.

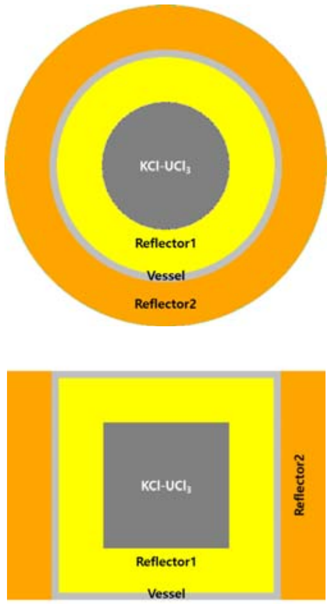

Fig. 1. $KCl-UCl_3$ MSR geometry (xy and xz surfaces).

3. Burnup Analysis

To compare the depletion behavior based on the different two molten salt fuels, the depletion calculation was performed for the first five years. The core criticality should be greater than 1.0 during the cycle operation, and thus it revealed that the k-eff were greater than 1.0 for the five years (See Fig. 2). The core size and the volume ratio of in-core to ex-core were determined under this constraint. The burnup was estimated using OpenMC, a Monte Carlo code [2]. It simulates the reactor in a static state. For this reason, a mixing method [3] was introduced to account this flow effect. When one burnup step calculation is completed, the number density of in-core is mixed with the number density of ex-core into account as each volume ratio as Eq. (1) and this value is set as $\mathbf{n}_{in}^{i+1}$ and $\mathbf{n}_{out}^{i+1}$

$$\mathbf{n}_{out}^{i+1} = \mathbf{n}_{in}^{i+1} = \frac{\left(\mathbf{n}_{in}^{i+1}\right)^{tmp} V_{in} + \mathbf{n}_{out}^{i} V_{out}}{V_{in} + V_{out}} \quad (1)$$

Table II: Monte Carlo calculation conditions

	Total Cycle	Active Cycle	History
$KCl\text{-}UCl_3$	400	250	500,000
$NaCl\text{-}MgCl_2\text{-}TRUCl_3$	400	250	500,000

When the burnup calculation is performed for the two reactor types, the decrease in k_{eff} over time is shown in Fig. 2. It is possible to confirm that there is enough excess reactivity in both reactor types. In addition, as shown in Fig. 2, it can be carefully concluded that the core reactivity (k_{eff}) falloff rate decreases when the U-based molten salt fuel is used, which can be attributed to the breeding of Pu-239 from U-238.Table III provides an overview of the 30 and 32 different nuclear fission products that are produced (>0.01%) in the two reactors, for U and TRU based salt, respectively, and it can be seen that there are considerable differences between the ratios of the fission products produced for each type of molten salt.

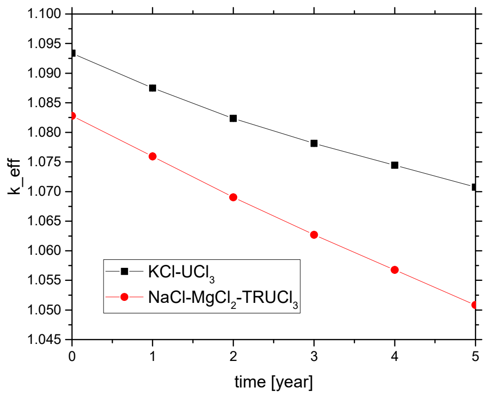

Fig. 2. k_{eff} falloff over time.

Table III: Fission product fraction (>0.01) [w/o]

element	$KCl\text{-}UCl_3$ [%]	element	$NaCl\text{-}MgCl_2\text{-}TRUCl_3$ [%]
Xe	12.467	Xe	13.427
Zr	12.254	Cs	11.643
Nd	11.554	Ru	9.406
Cs	10.948	Nd	9.143
Mo	9.859	Mo	8.788
Ce	8.472	Ce	7.428
Ru	5.399	Zr	7.210
Ba	4.168	Pd	6.722
La	3.791	Ba	3.896
Sr	3.465	La	3.392
Pr	3.410	Pr	2.823
Tc	2.573	Rh	2.699
Y	1.798	Tc	2.536
Sm	1.711	Sm	2.501
Rh	1.357	Te	1.623
Kr	1.343	Sr	1.288
Rb	1.301	I	0.925
Te	1.233	Ag	0.795
Pm	0.940	Pm	0.776
Pd	0.932	Y	0.663
I	0.425	Kr	0.571
Se	0.177	Rb	0.509
Nb	0.127	Cd	0.388
Sn	0.0859	Sn	0.219
Br	0.0673	Gd	0.215
Cd	0.0434	Nb	0.139
Gd	0.0335	Se	0.115
Sb	0.0299	Sb	0.0750
Ag	0.0289	Br	0.0515
-	-	In	0.0209
-	-	Dy	0.0114

3. Conclusions

The design of MSR is influenced by a number of factors, including the type of molten salt, its composition ratio, its temperature, the size of the core, and the type of reflector, and so on. To simulate the MSR core depletion and reactivity falloff using static OpenMC code, a mixing method was introduced in isotopic depletion. The conditions discussed in this paper were acquired during the scoping design process. Since reactor control means and methods have not been thought of, additional study thereof is necessary. In addition, the impact of temperature change should also be examined when the core thermal hydraulic conditions are taken into account.

ACKNOWLEDGMENTS

This work was supported by Korea Research Institute for defense Technology planning and advancement(KRIT) grant funded by the Korea government(DAPA(Defense Acquisition Program Administration)) (21-107-F00-018(KRIT-CT-22-017), Next Generation Multi-Purpose High Power Generation Technology(Liquid Fueled Heat Supply Module Design Technology), 2022)

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