Effective Reactivity Control system on long-term cycle NaCl-KCl-UCl3 fueled MSR core

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1. Introduction

FNC technology is developing Molten Salt Reactor (MSR) that has long-term cycle as 30 years with using NaCl-KCl-UCl_3(U235 enriched 19.75 w/o), 100MWth power. In order to make long term fuel life time, this MSR is not using breeding system or TRUs, so the core must be large size. However, as core size getting larger, surface area of core per volume is getting smaller, it causes difficulty in reactivity control system.

This paper is studied about more effective reactivity control by the of area of control drums getting closer, by changing curved surface of the core. It seems like the control drums' are inserted into active core, so it could get enough shutdown margin.

2. Methods and Results

NaCl-KCl-UCl_3 molten salt is used as fuel, and the operating temperature is calculated to be 610°C. The composition of NaCl-KCl-UCl_3 is shown as table 1.

Table 1: Composition of NaCl-KCl-UCl3 (610 ℃)

Component	Density (g/cm^3)	Composition (a/o)
NaCl	1.659	0.429
KCl	1.610	0.203
UCl3	4.932	0.368
NaCl-KCl-UCl_3	3.325	1

2.1 Standard Model

The core of the MSR without control drums is shown as figure 1, and specification is shown as table 2.

Table 2: Specification of MSR core

	Material	Thickness (cm)
Fuel	NaCl-KCl-UCl_3 (^{235}U 19.75 w/o)	Diameter: 180 Height: 260
Coating	Alloy625	0.08
Reactor Vessel	SS316H	0.8
Reflector	BeO	95
Outer Vessel	SS316H	5

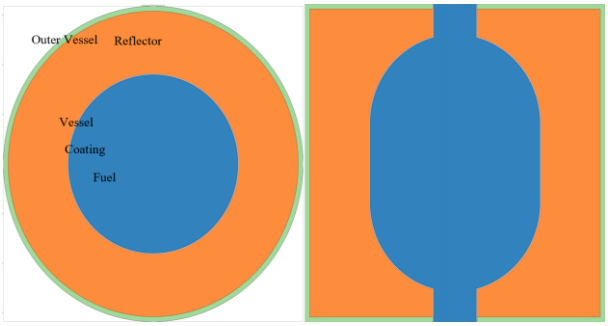

Fig. 1. The x-y and x-z plane of the MSR core without control drums

The reactivity swing of this core is shown as table 3 and figure 2. Around 13500 pcm is need to be controlled by control drums.

Table 3 k_{eff} during 30 years burn calculation

year	k_{eff}
BOL	1.20059
3 EFPY	1.18002
6 EFPY	1.16631
9 EFPY	1.15226
12 EFPY	1.13957
15 EFPY	1.12767
18 EFPY	1.1156
21 EFPY	1.10324
24 EFPY	1.08928
27 EFPY	1.07733
EOL	1.06503

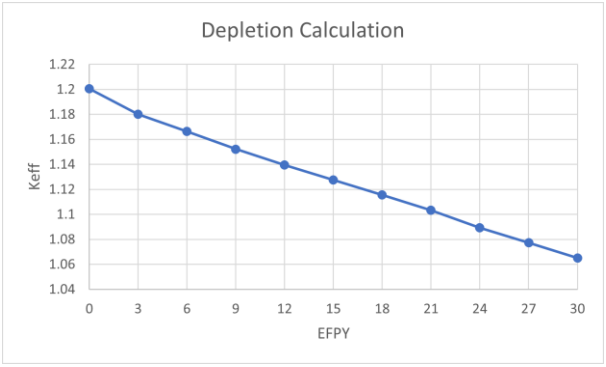

Fig. 2. Depletion calculation with 30 years without control drum

The specification of control drum is shown as table 4 and figure 3 below. This control drums can be added with maximum 14 units. The angle of control drum pad is 90°.

Table 4 Specification of control drum

	Material	Thickness (cm)
Drum canning	SS316H	0.1
Drum Pad	B_4C (^{10}B 90 w/o)	5
Drum Reflector	BeO	24.9
Drum room	Air	0.25

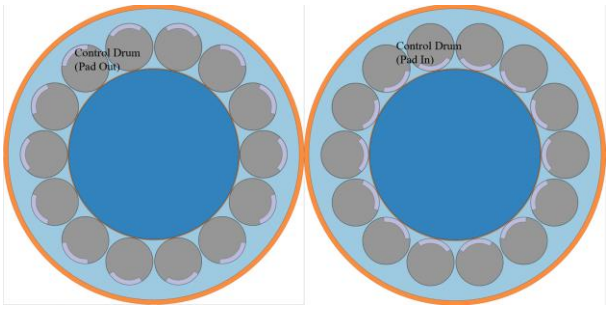

Fig. 3. 14 Control drums in MSR core, All Drums Out (left), All Drums In (Right)

This model has over than 30 years of fuel life length, the depletion result for 30 years is shown as table 5 and figure 4. The reactivity swing is around 13000 pcm.

Table 5 Depletion Calculation on Standard Model with 14 Control Drums

year	k_{eff} (std)
BOL	1.16413 (14)
3 EFPY	1.14611 (14)
6 EFPY	1.13215 (14)
9 EFPY	1.11872 (14)
12 EFPY	1.10646 (13)
15 EFPY	1.09439 (15)
18 EFPY	1.08232 (13)
21 EFPY	1.07006 (13)
24 EFPY	1.05785 (13)
27 EFPY	1.04582 (13)
EOL	1.03339 (13)

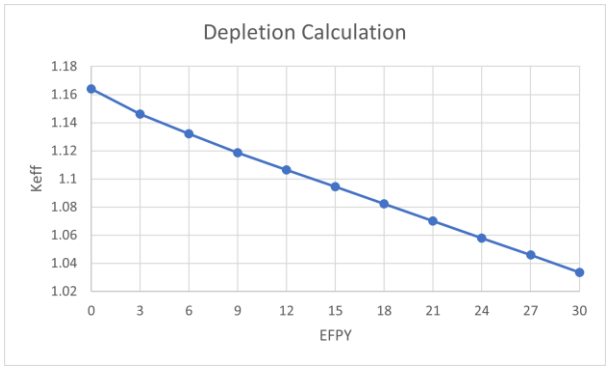

Fig. 4. Depletion calculation on standard model with 14 control drums

However, 14 control drums are installed, it needs more enough access reactivity control when BOL state, because of MSR's characteristics and other uncertainty. The k_{eff} of All Drums Out condition is 1.16413(14) and k_{eff} of All Drums In condition is 0.97615 (std 13). Considering with uncertainties, ADI's k_{eff} should be under 0.95.

2.2 Drum Inserted Model

The control drum is get inserted into cylinder to get more control drum worth. The configuration of this model is shown as figure below.

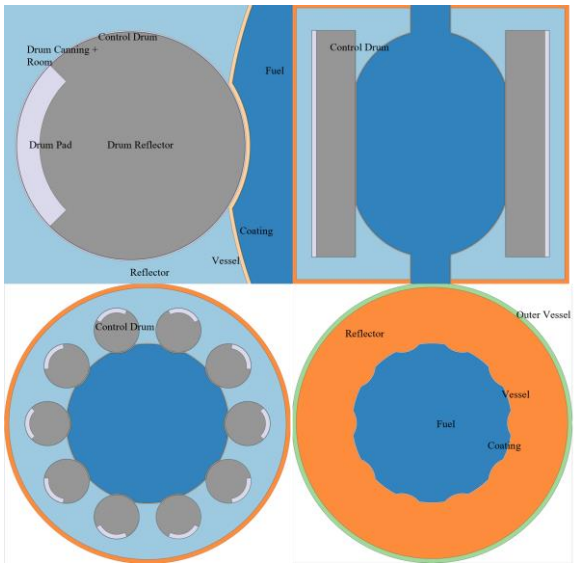

Fig. 5. Inserted control drum model

The more effective reactivity control system can be made by adjusting with this model with the less control drums. The volume of the active core is changed, depletion calculation is shown as table and figure below. The changed reactivity swing is around 13600 pcm.

Table 6 Depletion calculation on inserted model without control drum

year	k_{eff} (std)
BOL	1.19838
3 EFPY	1.17894
6 EFPY	1.1639
9 EFPY	1.15028
12 EFPY	1.13663
15 EFPY	1.12512
18 EFPY	1.11272
21 EFPY	1.09981
24 EFPY	1.08671
27 EFPY	1.0749
EOL	1.06228

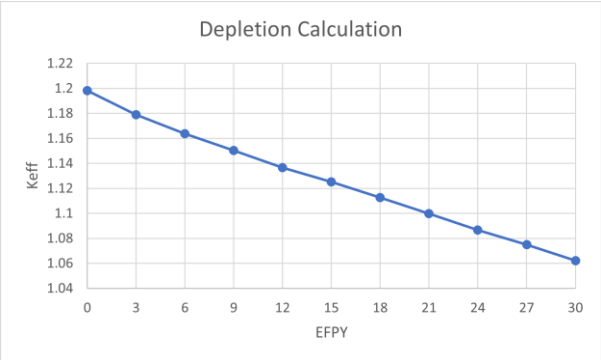

Figure 6 Depletion calculation on inserted model without control drum

The result of sensitivity test to find k_{eff} is under 0.95 state is shown as table 7.

Table 7 Sensitivity test with inserted control drums thickness

Case	ADI k_{eff} (std)	ADO k_{eff} (std)
0.5 cm	1.00297 (13)	1.17288 (15)
1.0 cm	0.99620 (14)	1.17221 (14)
1.5 cm	0.98976 (14)	1.17178 (13)
2.0 cm	0.98320 (12)	1.16995 (14)
3.0 cm	0.97106 (14)	1.17006 (15)
4.0 cm	0.95917 (17)	1.16883 (14)
5.0 cm	0.94810 (14)	1.16724 (14)
6.0 cm	0.93630 (13)	1.16591 (14)
7.0 cm	0.92619 (12)	1.16416 (14)
8.0 cm	0.91519 (13)	1.16260 (14)

When 5.0 cm inserted, the k_{eff} is under 0.95. The depletion calculation of this model is shown as table 8 and figure 7.

Table 8 Depletion calculation on inserted model with 10 control drums

year	k_{eff} (std)
BOL	1.16720 (14)
3 EFPY	1.14859 (14)
6 EFPY	1.13433 (14)
9 EFPY	1.12155 (13)
12 EFPY	1.10903 (13)
15 EFPY	1.09690 (13)
18 EFPY	1.08468 (13)
21 EFPY	1.07237 (13)
24 EFPY	1.06015 (13)
27 EFPY	1.04777 (14)
EOL	1.03567 (13)

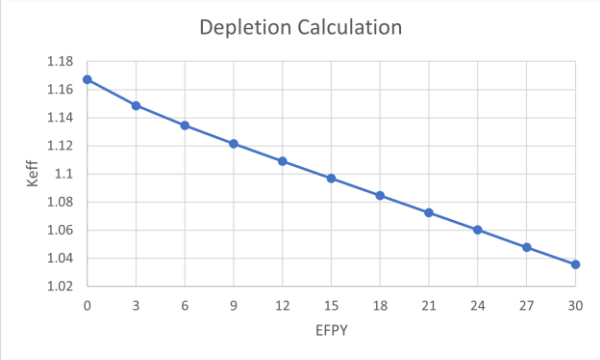

Figure 7 Depletion calculation on inserted model with 10 control drums

The ITC and other control drum worth is calculated to evaluate safety of this model. The result is shown as table 9. The ADI's k_{eff} is under 0.95, even if one of the control drum is turned out by out of control, the k_{eff} is under 0.97.

Table 9 Control drum worth

Condition	k_{eff} (std)	Difference [pcm]
Reference (Critical position)	1.00000 (14)	-
ITC (+ 100K)	0.99162 (13)	- 8.38 pcm/K
All Drums in	0.94810 (14)	- 5190
8 Critical pos 2 Drums in	0.98953 (13)	- 1047
9 Critical pos 1 Drum in	0.99470 (14)	- 530
1 Drum out 9 drums in (N-1)	0.96970 (13)	- 3030
1 Drum out 1 Critical pos 8 Drums in (N-1)	0.97521 (14)	-2479

3. Conclusions

This paper studied get more access reactivity worth with inserted control drum on ultra long life MSR. The core of diameter 180 cm and height 360 cm half sphere – cylinder - half sphere is net 13600 pcm of reactivity swing for 100 MWth 30 EFPY, when 14 control drums are installed, reactivity swing is 13000 pcm. It is hard to normal drum control system, by changing surface of active core to get more closer with control drum pad with active core, the 10 control drums inserted system gets more access reactivity control margin and safety margin.

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