Parametric Study on a Natural Circulation Cooled Nuclear Battery

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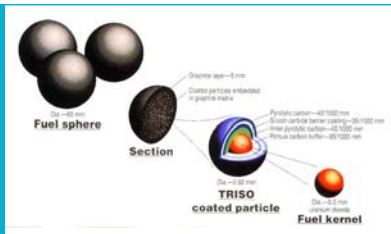
Abstract



This paper describes the design of a small nuclear reactor cooled with natural circulation. The reactor has a power of 20 MW_{th} and should operate for 5 years without refueling.

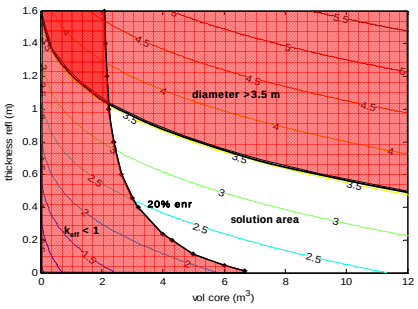
The fuel consists of TRISO coated fuel particles enriched up to 20%. The fuel burnup is 10% FIMA. A prismatic core design has been selected to have some design freedom with regard to the coolant volume fraction in the core. The outer dimension of the radial reflector should be limited to 3.5 m.

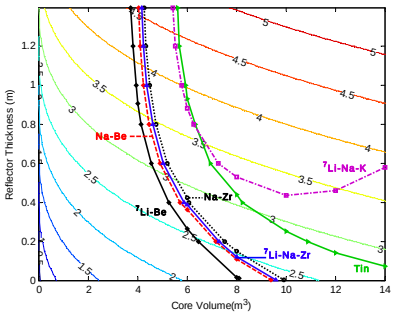
Two types of coolant are considered: molten salts and liquid tin. Among the molten salts are ^{7}Li-Na-Zr, ^{7}Li-Na-K Na-Be, Na-Zr, and ^{7}Li-Be fluorides (FLiBe).

Neutronic feasibility

A solution is sought for the k_{eff} after 5 years of operation at a reactor power of 20 MW_{th}. A design is feasible if k_{eff}>1 at EOL. The figure below (left) shows the solution space for FLiBe. The red areas have either a reflector radius larger than 3.5 m or a k_{eff}<1. The white area is the resulting solution space.

The right figure shows the final results for the salts (10% volume) and for tin (3.5%).

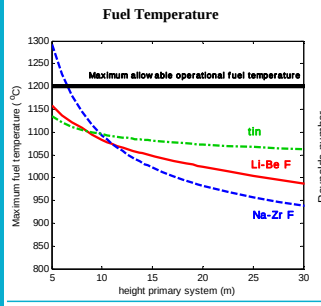


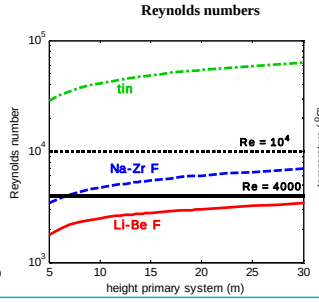


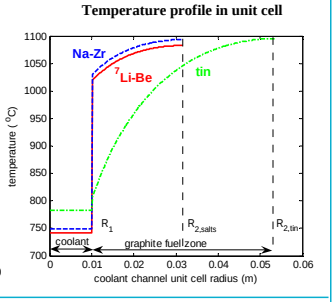
Safety assessment

Coolant	Core vol (m^3)	Coolant vol frac (%)	K_{eff} (BOL)	uniform temp coeff (10^{-5} K^{-1}) 973-1073 K	1073-1173 K	Avg.	Complete voiding reactivity ($)
^{7}Li-Be Fluor	4	10	1.38	-7.07	-8.66	-7.86	-1.66
Na-Zr Fluor	6	10	1.39	-5.64	-4.66	-5.15	3.55
Tin	6	3.5	1.29	-3.84	-4.46	-4.16	12.0
Helium	6	40	1.30	-6.84	-5.80	-6.32	-0.06

Natural circulation results







Some thermal hydraulics results:

- Tin and FLiBe always give fuel temperatures below the maximum.
- Tin gives highest Reynolds numbers. For the fluorides the flow is in the transitional regime.
- Tin gives the smallest temperature step on the coolant-moderator boundary and the largest temperature gradient in the graphite.

Conclusions

Some conclusions:

- FLiBe gives greatest design freedom from the neutronics view. It is the only coolant with a negative voiding coefficient. Also Na-Zr fluoride is promising.
- Natural circulation cooling is possible with all coolants. Tin always operates in the turbulent regime, but has a large positive void coefficient. All fluorides exhibit a transitional flow, but have a negative or (only) slightly positive void coefficient.
- Future work will focus on accident scenarios, gaseous coolants options, and economic optimization studies.

Summary results

	^{7}Li-Be	Na-Zr	Tin
Neutronic properties	good	fair	poor
Neutronic design freedom	good	good	fair
Natural circulation potential	poor	fair	good

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