# Dynamic Burnup Studies of Seaborg Compact Molten Salt Reactor by Serpent 2

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## ABSTRACT

Seaborg Technologies is actively developing a design for its compact molten salt reactor (CMSR), a liquid-fuel MSR with a thermal power output of 250 MWth. The liquid-fuel of the reactor provides important benefits over the traditional solid-fuel reactors with passive safety and fuel utilization. However, during the fuel circulation, the position of delayed neutron precursors continuously changes both in the core and in the external loop, and the fission products (FPs) are extracted by an online fuel reprocessing unit. The online fuel reprocessing limits to most of the simulation tools used with the solid-fuel in the conventional reactor. One exception is the Monte Carlo code Serpent 2 which has recently included the capability to do on-the-fly modification of the material definitions model online fuel reprocessing.

In this paper, the burnup characteristics of CMSR is studied by performing different burnup calculations with and without continuously removing FPs using Serpent 2. Three burnup calculations are performed 1) without removing any FPs, 2) six noble gases are continuously removed, 3) six noble gases and other noble metals are continuously removed. Reactivity control by inducing soluble boron into the moderator is also investigated.

## INTRODUCTION

- Seaborg Technologies is developing the CMSR.
- Sepent 2 has recently included the capability to do on-the-fly modification of the material definitions model online fuel reprocessing.
- The burnup characteristics of CMSR is studied by performing different burnup calculations using Serpent 2.
  - **No-pro**: without removing any FPs
  - **Degas1**: six noble gases(He, Ne, Ar, Kr, Xe, Rn) are continuously removed
  - **Degas2**: six noble gases and other noble metals(Nb, Mo, Tc, Ru, Rh, Pd, Ag, Sb, Te) are continuously removed

## DESCRIPTION

- **Seaborg CMSR Core Design**

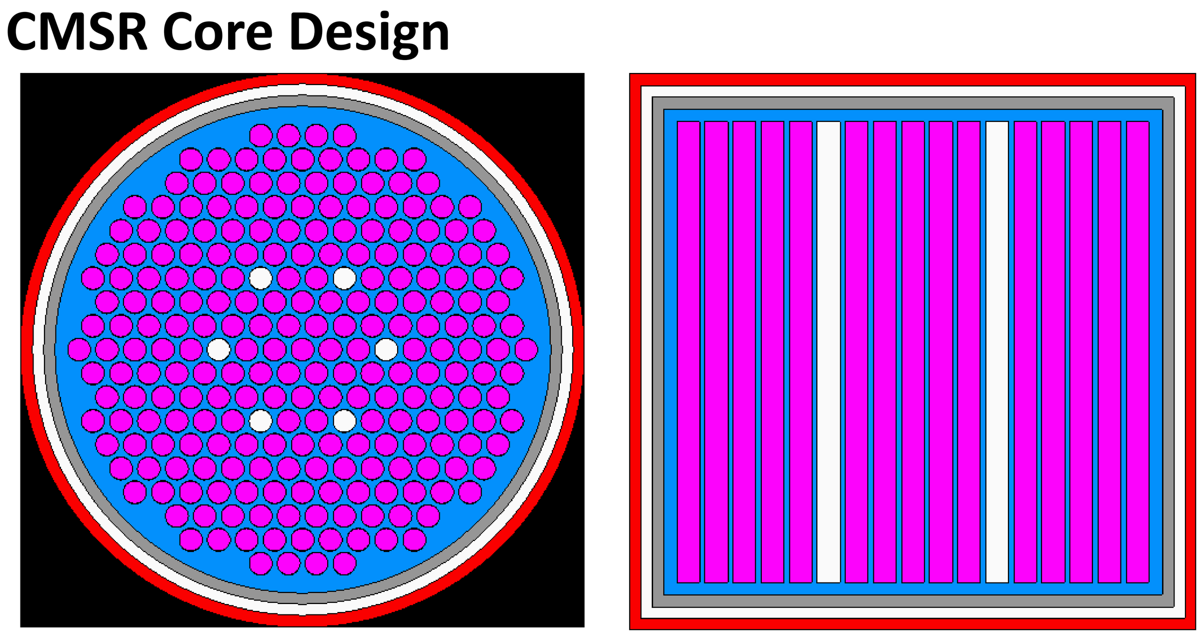

**Figure 1.** The layout of the CMSR reactor in Serpent 2 code.

| Type | Materials | Density [g/cm$^3$] |
|---|---|---|
| Fuel (pink) | NaF-KF-$UF_4$ | 4.261 |
| Moderator (blue) | NaOH | 1.637 |
| Cladding (grey) | Hastelloy N | 8.860 |

- The 3D geometry incorporates 235 slots of about 10 centimeters in diameter through which the fuel salt flow in and out the core.
- The uranium enrichment of the fuel is adjusted such that the reactor able to reach the equilibrium in 12 years of continuous operation.
- The core was 2.5 meters in diameter and 2 meters in height.

## RESULTS AND DISCUSSIONS

- **Effective Multiplication factor**

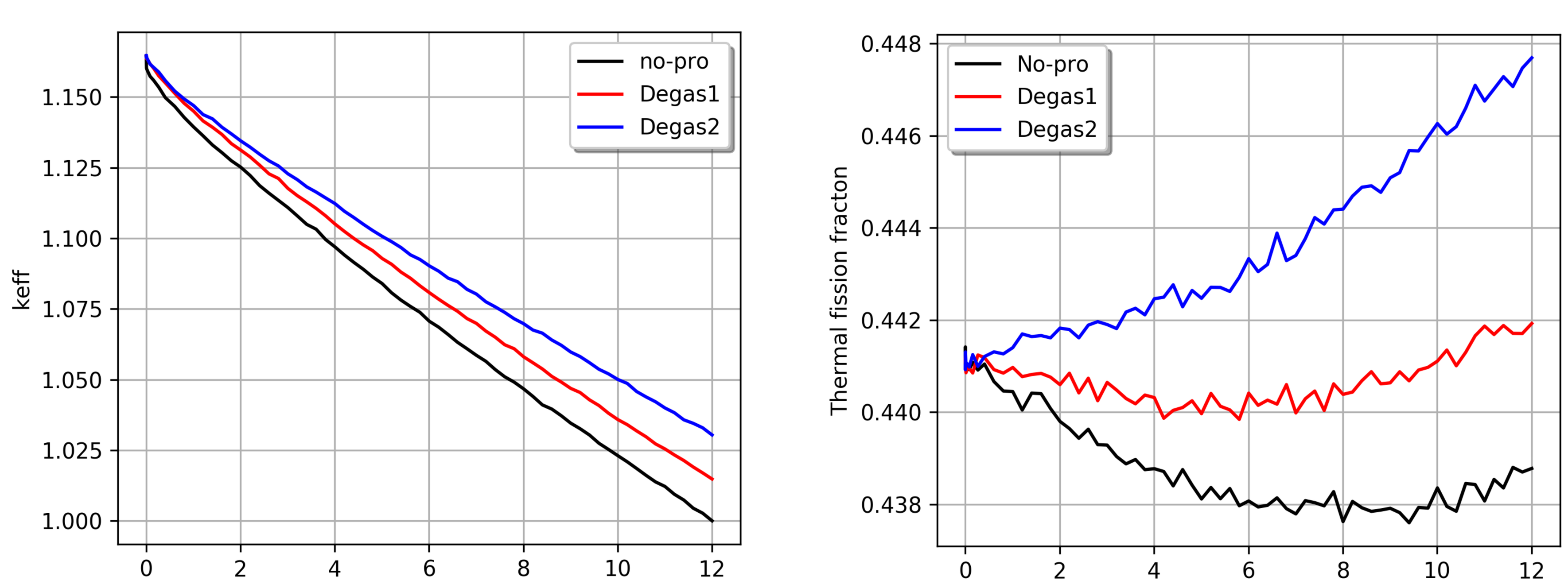


**Figure 2.** Changes of the effective multiplication factor (left) and thermal fission fraction with various depletion schemes

- Removal of neutron poisons leads to a relative improvement of the k-eff at EOC by 1.5% for Degas1 and 3% for Degas2 compared to the no-pro scheme.
- As the neutron poisons are continuously removed, the thermal fission fraction is increased as the flux spectra get softer.

- **Evolution of Fission Products**

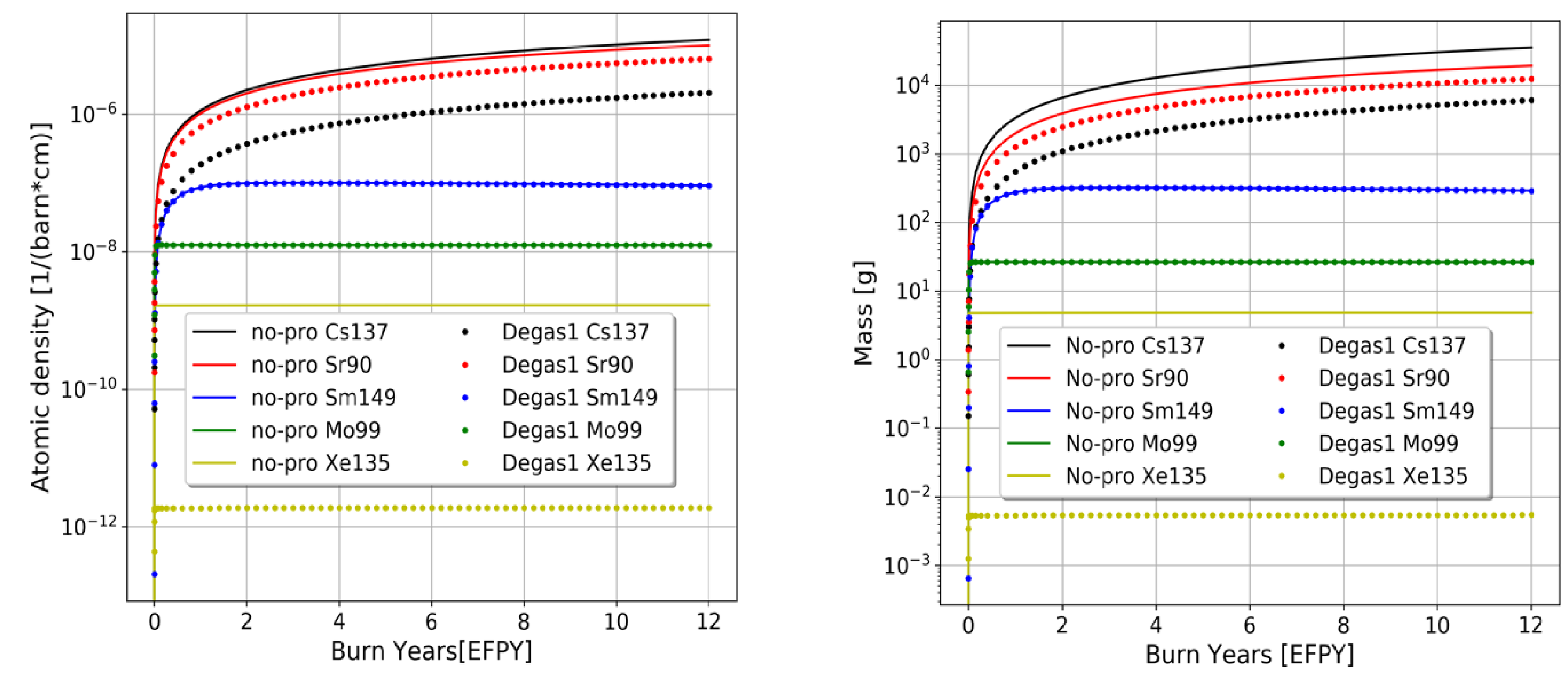


**Figure 3.** The atomic density and mass of FPs in fuel salt of no-pro and Degas1.

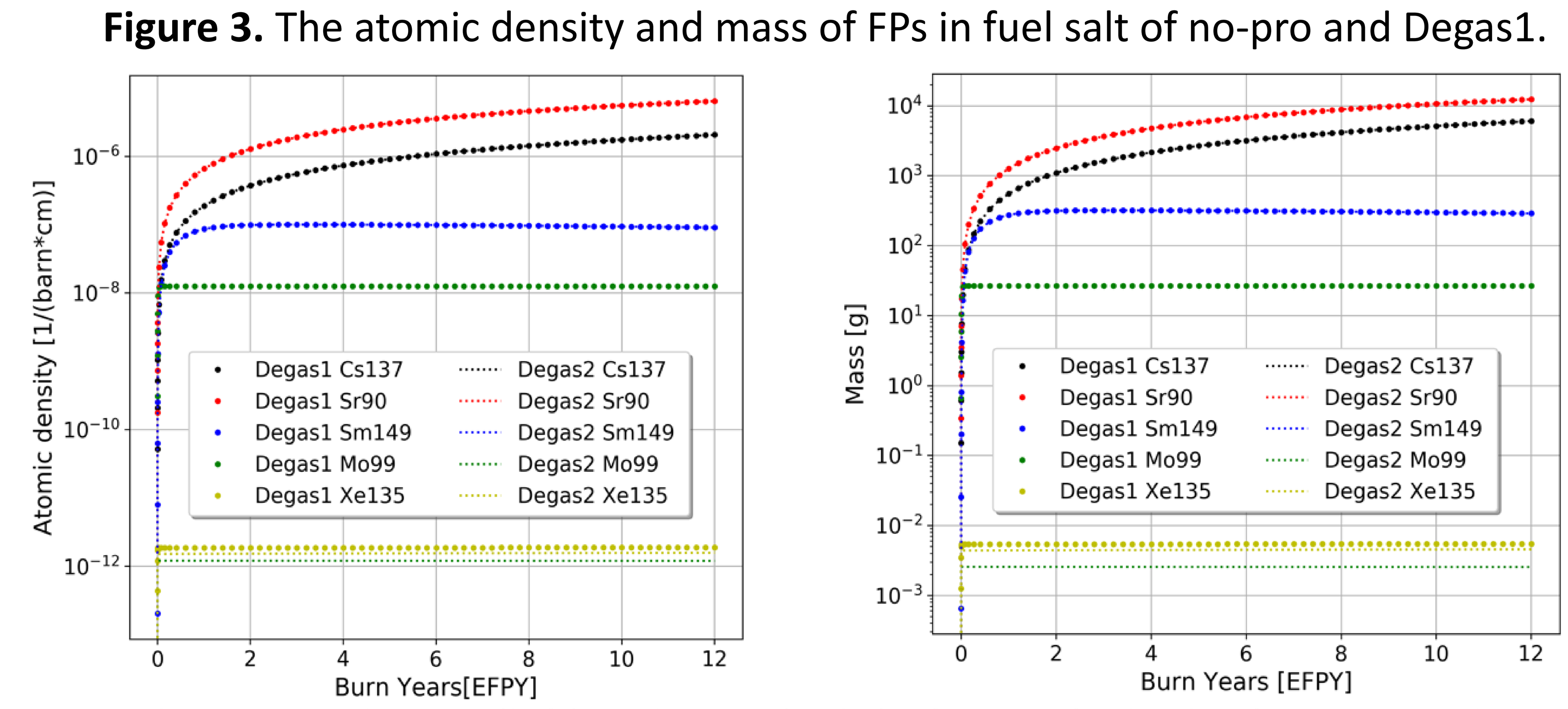


**Figure 4.** The atomic density (left) and mass (right) of FPs in fuel salt of Degas1 and Degas2.

- Figure 3 shows that $Xe^{135}$ quickly reaches its saturation due to its extremely large XS, and its formation directly from fission production. By removing XE-135 at Degas1 scheme, the changed of $Xe^{135}$ concentration becomes very small.
- Figure 4 shows that for the noble-gases only/and noble-metal degassing schemes do not change much because those noble-metals do not have large cross-section compared to xenon-135.

- **Reactivity Control**

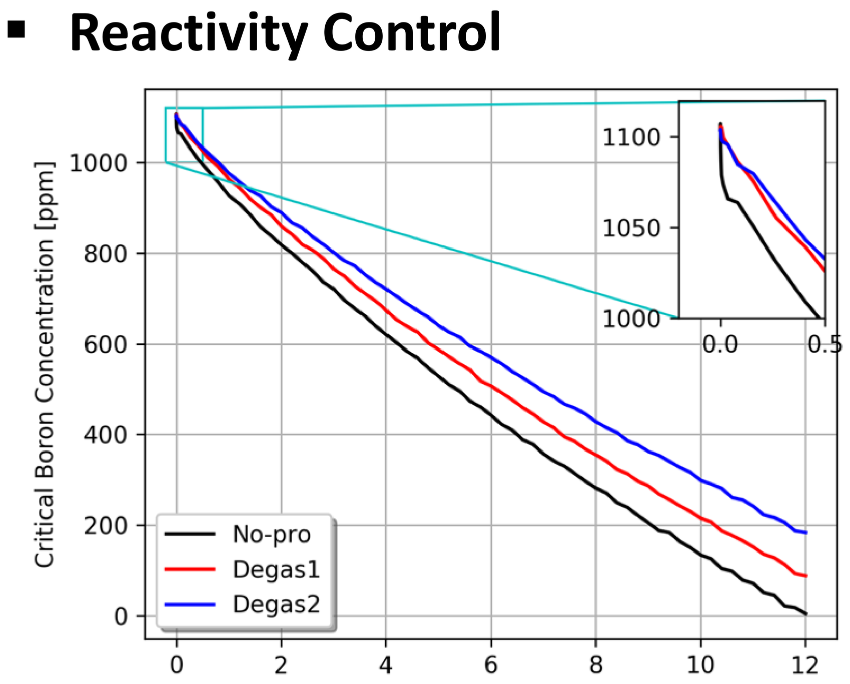


**Figure 5.** Boron letdown curve in CMSR.

- At BOC, the boron concentration in the simulation without degassing is very rapidly dropping at first as xenon and samarium build-up to an equilibrium level.
- However, for the boron concentration of Degas1 and Degas2 reprocessing schemes the drop is small BOC due to the continuous removal of FPs such as xenon-135

## CONCLUSIONS

- Online-processing schemes clearly improve the neutron economy performance by reducing the concentration of fission products such as $Sr^{90}$, $Cs^{137}$, $Sm^{149}$, $Xe^{135}$ and thereby minimizing the depletion of uranium.
- It has been successfully demonstrated using Serpent 2 a critical boron concentration can be obtained when using boric acid mixed in the moderator.
- In the future, the temperature coefficient which is important for safety will be studied. In addition, the results of fuel composition at EOC would be used to characterize the CMSR spent fuel and propose an appropriate design for a spent fuel storage.