Characteristics of a molten salt reactor fueled by actinide trifluorides with limited chemical processing

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The molten salt reactor (MSR) concept is very important for consideration as an element of future nuclear energy systems. The MSRs appear to have substantial promise as advanced TRU free system operating in U-Th cycle with limited chemical processing. A useful attribute of MSR is the capacity of the flibe based carrier salts to contain TRUs in the form of actinides trifluorides with solubility in excess of 1 mole % at operating temperatures.

The data presented show that U-Th fueled MSR - converters uses the nuclear resources more effectively than ALWR designs. Core configurations without graphite moderator uses the nuclear fuel less effectively than graphite moderated, but still 2 times better than today LWRs. For U-Th fueled MSR -converters the opportunity of the ^{233}U production with minimal concentration of ^{232}U ($c_2/c_3=3x10^{-7}$) at UF_4 removal times of about 10 days is noted.

The principle reactor & fuel cycle variables available for optimizing the performance of MSR as TRU transmuting system are discussed. A preliminary study was made to examine the conceptual feasibility of MSR cores fueled with actinide trifluorides discharged from standard power reactors and operated with limited chemical processing. Different conceptual core configurations with and without graphite moderator as well as fuel cycle policies were considered in which the fuel power density was high enough to provide effective actinide transmutation rates. For the reactor fuel cycle calculations of MSR-transmuter system a special calculation procedure was used which recover the specific characteristics of MSR: (1) fuel salt-circulating both in the core and external part of fuel circuit and (2) continual feeding and clean up of the fluid fuel. In the procedure of burn-up calculations the fueling and fission product removal policy for different core configurations were optimized. A detailed study of TRU content effects was made. The use of different calculation methods (deterministic and probabilistic) and evaluated neutron data files permitted to do the estimation of the neutronic calculations accuracy of the method.

Note, that the maximum power density in graphite moderated MSR cores is limited by fast neutron damage to moderator material. For 2250 MWt MSR, the principal effect of increasing the core diameter from 4m (MSBR case - 4 year graphite life, core average neutron flux is about $2\text{-}3x10^{14}n/cm^2/s$, about 50% of fuel inventory outside core) to 8,3 m (DMSR case – 30 year graphite life, core average neutron flux is about $5x10^{13}n/cm^2/s$, less than 20% of fuel inventory outside core) was to increase the fissile inventory by 50%. These type of cores could be made critical with about 0,3 mole % concentration of reactor grade plutonium trifluoride. For MSR transmuter with out on-line removal of soluble fission products depending on the on the core specific power the solubility of the combined trifluorides (actinides plus lanthanides) will place a limit of 8-30 years on the salt clean up interval. Potential for reactor fuel cycle improvement is considered.

MSR transmuter operating with hardened spectrum without graphite moderator (homogeneous core) should have initial concentration and additions of fissile fuel specific inventory, kg(fissile)/MWe) significantly higher than that of previous one. Note, that phase behavior of some fluoride mixtures (e.g. Li,Na,Zr/F) appears suitable to permit use of a higher concentration of PuF_3 in melts whose freezing point will acceptable for single fluid MSBs. For 2250 MWt MSB this core configuration avoid constrains dealt with graphite life time and provide operation with core average neutron flux from $1x10^{15}$ $n/cm^2/s$ to $2x10^{15}$ $n/cm^2/s$ for core diameters 4m and 3m with respectively less than 30% and 50% of fuel inventory are outside core.

The preliminary studies of MSR transmuter systems indicate that these reactors could have attractive fissile fuel utilization performance and TRU burning features while providing delivering minimum of the waste in an optimal form and substantial resistance to proliferation of nuclear explosives, thus contributing to the developing of the sustainable future nuclear power.