Enhanced Performance Fast Reactors with Engineered Passive Safety System

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ABSTRACT

The objective of the proposed project is to study the feasibility of improving the passive safety and performance of sodium cooled fast reactors (SFR) by incorporating within their fuel assemblies the Autonomous Reactivity Control (ARC) system. The ARC system is an engineered safety system recently invented at the University of California, Berkeley, as a spinoff of a previous NEUP sponsored project led by the PI. It is incorporated in each fuel assembly by replacing few (2 to, at most 6) peripheral fuel rods by two concentric tubes the outermost diameter of which need not exceed the fuel rods outer diameter. The inner tube is connected to liquid-filled reservoirs installed at the top and bottom of the fuel assemblies without blocking the coolant flow. The reservoirs are filled with two liquids that stay liquid and immiscible throughout the operating temperature range. At nominal operating temperatures the lower reservoir contains lithium enriched in ^{6}Li while the upper reservoir, the bottom part of the lower reservoir and the central tube connecting the two reservoirs are filled with a heavier potassium liquid that has a small neutron absorption cross section. Argonne gas fills the annular gap between the ARC tubes that is closed above the core and is open at its bottom that is immersed in the ^{6}Li at the lower reservoir.

The proposed ARC system is passively actuated by a coolant temperature increase that inherently induces thermal expansion of the potassium in, primarily, the upper reservoir. The potassium volume expansion pushes the ^{6}Li up into the annular gap between the tubes while compressing the Argonne gas above the ^{6}Li. The larger the coolant temperature rise is, the larger will be the potassium expansion and more ^{6}Li will be inserted into the active core region resulting in more negative reactivity feedback. Its effect is reversible: as the coolant temperature returns to nominal, the ^{6}Li of the ARC system completely and passively exits the active core volume. At nominal operating conditions the ARC system has a very small negative reactivity effect.

Fast reactor cores are usually designed to be short (~1m) and have a significant (> 20%) neutron leakage probability – primarily in the axial direction, in order to reduce the positive coolant temperature reactivity coefficient and coolant voiding reactivity worth and in order to increase the negative temperature reactivity feedback due to core radial expansion and fuel axial expansion. The negative reactivity feedback provided by the ARC systems may enable designing fast reactor cores to be passively safe even when they feature a neutron leakage probability that is significantly smaller than in present SFR designs. The resulting improvement in the neutron economy could be beneficially utilized for improving the performance and economics of SFR designs. A couple of performance improvements will be evaluated: (1) Improving the passive safety of medium (1000MW_{th}) and in particular large (3000MW_{th}) SFR cores without impairing their other performance characteristics. (2) Increasing the power from a reactor module of a given diameter by increasing the active core height preserving the reference core passive safety level and conversion ratio and minimizing penalty on power density and specific power.