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Accelerator Driven Nuclear Reactor Development at Fermilab

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Nuclear Power Plants (NPP) based on Mu*STAR [1] superconducting ADS (Accelerator Driven System) subcritical reactors can economically produce carbon-free energy by consuming the remaining energy in SNF (Spent Nuclear Fuel) that has been accumulated at many NPP sites in the US and the world. The innovations include a superconducting multi-MW CW proton accelerator that drives the internal spallation neutron targets of several small modular reactors that are based on the Molten Salt Reactor Experiment (ORNL MSRE [2],1965-69). Operation does not require a critical mass of fissionable material. The molten salt fuel is continuously circulated through devices inside the reactor containment area to reduce the inventory of volatile radioisotopes in the core to mitigate their accidental release. Circulation of the fuel through other devices reduces the inventory of neutron-poison fission products in the core to allow higher burnup of the fuel for lowest cost and effective destruction of long lived actinides that reduces the need for repositories with geologic timescales. The design has nuclear weapons proliferation advantages in that it does not require any enriched uranium and never separates fissile elements from the molten salt fuel. A non-radioactive molten salt heat storage system allows the power output to be continuous in case of accelerator downtimes and allows for decay heat removal in the case of a loss of power accident. An adjacent hot cell is used to convert the SNF fuel from oxides to fluorides [3] and to store the fission products as they are removed from the operating reactor. Muons, Inc. is developing a preconceptual design using computer codes that can be validated using Fermilab facilities.*

*Data are needed for accelerator-driven salt-cooled spallation-neutron targets feeding graphite moderated reactor cores. Especially lacking are measurements of the neutron energy spectra that such a combination of target and moderator produces that are needed to verify and optimize the choices of materials and geometries for thermal-spectrum molten salt cores. For example, the accelerator-driven spectrum has more high-energy neutrons than conventional reactors. A major interest is the rate of moderation of fast and high-energy neutrons becoming thermal neutrons that have higher probabilities of inducing fissions. Understanding and verifying the moderation of the higher-energy neutrons is also important since they have a greater ability to damage the moderator and other reactor components like heat exchangers. Another example is the verification of the prediction that extruded graphite will have a beneficial advantage over conventional graphite as a moderator for an ADSR. Variations in the spectrum and flux as a function of moderator depth can be modeled by various simulation programs, but much of the spectrum is above the energy where accurate tables are used, so programs like MCNP use less accurate nuclear-physics models. Experimentally validating those models is an important aspect of ensuring that future ADSR systems will operate as designed. Eventually, a Fermilab beamline could demonstrate the operation of a prototype Mu*STAR module.

[1] Muons Subcritical Technology Advanced Reactor
https://accelconf.web.cern.ch/ipac2022/papers/thpoms043.pdf
[2] https://en.wikipedia.org/wiki/Molten-Salt_Reactor_Experiment
[3] Mu*STAR ADSR Fuel Conversion Facility ORNL/TM-2018/989

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