Modeling and Optimization of Flow and Heat Transfer in Reactor Components for Molten Chloride Salt Fast Reactor Application

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ABSTRACT:

The Project aims at developing computational fluid dynamics (CFD) models needed to simulate and optimize the flows of chloride molten salt fuel in a reactor vessel and heat exchangers for the Molten Chloride Salt Fast Reactor (MCSFR). This work will be conducted in partnership with Argonne National Laboratory and position Elysium Industries USA to further establish an innovative and marketable nuclear power reactor that provides global, cost-effective, safe, proliferation-resistant energy. This work will benefit the U.S. advanced reactor community with interest in molten salt reactor (MSR) designs, since successful deployment of a CFD-based modeling and optimization capability for molten salt reactors will accelerate deployment and commercialization of these designs. Component optimization will be essential to enhance the reactor's performance and economics.

Elysium will coordinate, guide all research activities and design processes, in addition to performing simulations using OpenFoam to then benchmark against available data and high-fidelity Nek5000 results. Argonne will further develop its open source spectral element code Nek5000 with additional optimization features and perform simulations with its unique high-performance clusters and supercomputers.

The objective of the proposal is to advance and innovate the following research criteria:

- Advanced nuclear reactor designs, including small modular reactors of various technology types;
- Engineering, analyses and experimentation that would address first-of-a-kind reactor design, certification, and licensing issues;
- Modeling and simulation of various elements of plant life cycle.

Liquid fuel designs present several difficulties, which are not typically encountered in other nuclear reactor engineering and design applications. In addition to well-known issues with established properties for molten salts, we discuss two other points that are relevant to this proposal:

- *Heat deposition in the fluid*: Unlike solid fueled reactors, heat deposition in molten salt reactors at steady state operation is primarily in the coolant/fuel. This poses unique design and simulation challenges. In fact, combined with the high Prandtl number of the fluid (requiring less reliance on conduction), there may be significant hot-spots in regions where molten fuel salt recirculation occurs.

- *Different regime of operation*: Water and molten salt coolants present different properties and therefore MSR components operate in different regimes. While experiments ultimately are necessary, the lack of available and reliable correlations constrains the design space and limits design progress. The information gained here will be essential in designing any experimental approach.

The thermal-fluid analysis will employ the steady state distribution of fission power in the core (calculated with a neutronics model) but will not represent the multi-physics coupling to neutronics or structural materials codes. The temperature and pressure distributions predicted by the CFD codes may be employed offline by structural codes to obtain an estimate of the thermal stresses, and scalar transport may be used to track fission products and delayed neutron precursors. Moreover, we treat the heat exchanger and vessel problems as *separate* and *independent*, and they will in fact be pursued in parallel.

For both problems we will proceed in three phases.

- *Phase I - Evaluation*. Phase 1 involves creation of an initial model, development of CFD methodology, assessment of modeling uncertainties, analysis of the flow field to clarify potential areas of improvement, and definition of the optimization strategy based on these results.
- *Phase II - Optimization*. Application of the optimization strategy for each component may involve several iterations and the need for further evaluations as the design may change radically. Adjoint methods may be used to deliver on this stage.
- *Phase III – Scaling*. Once the design has been settled, we will define the scaling strategy for each component's experimental testing.

The application of traditional methodologies (one-dimensional modeling of heat and fluid flow) to the design of MSRs will limit developers' ability to address these thermal-hydraulic issues. In the absence of a vast and expensive experimental program, CFD is necessary to optimize the design and provide data for simulation-driven correlations. Ultimately, a set of experiments will be necessary for validation, but modeling and simulation can help greatly reduce the number, scope, and thus cost of such experiments.