2003-282-N0 -- CONCEPT DEVELOPMENT FOR RIA LITHIUM THIN-FILM STRIPPER FORMATION AND PRIMARY COOLING OF THE HIGH POWER DENSITY NEUTRON CONVERTER

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Purpose: The objective of the proposed study is to provide insight into the character of two liquid lithium systems proposed as components of the Rare Isotope Accelerator: the injector-based lithium thin-film stripper and the liquid-lithium-cooled tungsten neutron converter that will drive the two-stage isotope production target. A combination of one-dimensional analyses using empirical correlations and computational engineering simulation provide information needed to establish the feasibility of the proposed concepts and aid in the down-selection of engineering options as the concepts are further developed.

Approach: The Rare Isotope Accelerator (RIA), an advanced radioactive beam facility, will enable the next generation of basic research in areas of science such as the nature of nucleonic matter, the origin of elements, and the limits of the Standard Model. In the development of the RIA concepts, a number of areas were identified in which significant engineering and scientific development was needed to insure success. One of the areas identified was the feasibility of the liquid lithium thin-film stripper system. Expertise in the simulation of the break-up of a liquid jet in a vacuum was developed as part of a prior effort examining the break-up of fuel in a diesel engine. These studies extend this expertise to the liquid lithium system proposed as a stripper for the rare isotope. A second area identified was the development of an appropriate engineering concept for the neutron converter target. Expertise in high-power-density accelerator target design was developed through prior accelerator-driven neutron source design activities supporting the Accelerator Driven Test Facility (ADTF) and the reference-design sodium-cooled Accelerator Driven System (ADS). These studies extend this expertise to the development of engineering concepts for the neutron-converter target.

The liquid lithium thin-film stripper simulation activities have focused on developing and qualifying computational simulation capability to establish the stability of the thin-film jet and optimize the design of the thin-film generator to ensure that the jet maintains an appropriate thickness. These studies consider the thin-film experiment completed at Argonne using water as a surrogate fluid for liquid lithium. The neutron converter simulation activities have focused on the selection and development of potential target designs that meet criteria meant to ensure the efficiency of the two-stage target and the integrity of the neutron converter throughout its expected lifetime. The target design must be sufficiently small to work within the size constraints on the two-stage target and should provide for efficient heat removal in order to limit peak temperatures and thermal stresses.

Our studies have used the CFD code FLOW-3D to simulate the thin-film experiment. Flow-3D is a volume tracking code that uses an adaptive computational methodology for the solution of fluid flow problems that require the tracking of sharp discontinuities (fronts) in the flow field. This methodology allows the simulation of the interaction between the liquid jet and the atmosphere to determine the shape of the thin-film as it leaves the thin-film generator as well as the stability of the thin-film as it travels through the atmosphere. Simulations are compared with observations from the water film experiments to provide a basic validation of the code.

Efforts to develop the neutron converter concepts have used standard one-dimensional conduction models and empirical heat transfer correlations appropriate for liquid metal coolants to determine size limits for target components and establish baseline thermohydraulic performance. Design concepts were further developed through multi-dimensional computational fluid dynamics (CFD) simulations of the thermohydraulic behavior of the proposed design using the commercial CFD code Star-CD. Simulations consider the turbulent motion of fluid through the system as well as heat transfer between the fluid and the solid components. Simulations assume that the energy deposited in the target by the ion beam is uniformly distributed, so results should be viewed as indicative of spatially averaged behavior. Future physics evaluations for the proposed concepts will be needed before true peak temperatures and maximum temperature gradients can be determined.

Technical Progress and Results: A preliminary evaluation of the capabilities of the code Flow-3D for the simulation of the liquid lithium thin-film stripper has been completed using the water thin-film experiment as a test case. Preliminary engineering design studies were also completed for two distinct neutron converter concepts, a primary option using solid tungsten as the target material and liquid lithium as the coolant and a reserve option using liquid lead-bismuth eutectic as both target material and coolant.

Since a parallel version of the Flow-3D software is not yet available in a format compatible with the mpi-based multi-processor platforms in use at ANL, a strategy was developed to complete the simulation of the water thin-film experiment using only one processor. The problem was divided into two simulations: (a) the simulation of the flow in the injector and nozzle with the jet generated by the nozzle, and (b) the film development starting with the jet generated by the nozzle. The simulations experiment successfully predicted a stable film with shape, speed, and thickness in good agreement with the experimental estimates (speed of about 30 m/s and a thickness of about 6 microns). The simulation of the flow in the injector and the nozzle predicts the formation of a stable jet with a small cavitation region at the inlet of the nozzle.

One-dimensional conduction models and empirical correlations taken from the literature were first used to establish the feasibility of the solid tungsten target concept. These studies indicated that a solid target using tungsten plates up to 3 mm thick with a coolant channel 1 mm in thickness between plates and a channel-averaged coolant flow velocity of ~1 m/s could potentially satisfy the thermo hydraulic design requirements for the system. Direct contact between the tungsten and lithium is assumed based on preliminary compatibility evidence. For an inlet temperature of 250°C, simulations of this target concept show a peak fluid temperature of 485°C and the peak tungsten temperature of 527°C, which are well below acceptable limits for tungsten and many stainless steels suitable for this application. The window through which the ion beam enters the neutron converter is cooled only on the inner surface since it separates the coolant from the near-vacuum of the beam tube. A concept for separate cooling channel for heat removal in this region has been developed through computational simulation. Preliminary analyses indicate that peak temperatures well below 600°C can be maintained for window thicknesses as large as 2.0 mm using the separate cooling channel concept.

As a reserve option to the solid tungsten target, a liquid lead-bismuth eutectic target concept was also developed. The results of preliminary simulations indicate that peak temperatures are approximately 535°C in the stainless steel structure and 420°C in the liquid-lead bismuth eutectic with an inlet temperature of 250°C and a beam window thickness of 2 mm. Liquid lead-bismuth eutectic is held as the reserve option due to concerns over control of corrosion and erosion of the stainless steel structure.

Future studies of the lithium thin-film stripper concept will include: (a) simulation of ANL water experiment in vacuum (b) evaluation of sensitivity of simulation predictions to grid size; (c) prediction of lithium film thickness, speed and stability versus angle of injection; and d) analysis of lithium flow in injector and nozzle (jet speed, stability and diameter versus injection pressure). Planned neutron converter studies have been completed.

Specific Accomplishments: Publication in preparation: W. D. Pointer, “Development of Compact Neutron-Generator Design Options for the Rare Isotope Accelerator”, International Youth Nuclear Congress 2004, Toronto, Ontario, Canada, May 9-13, 2004. (refereed conference paper).

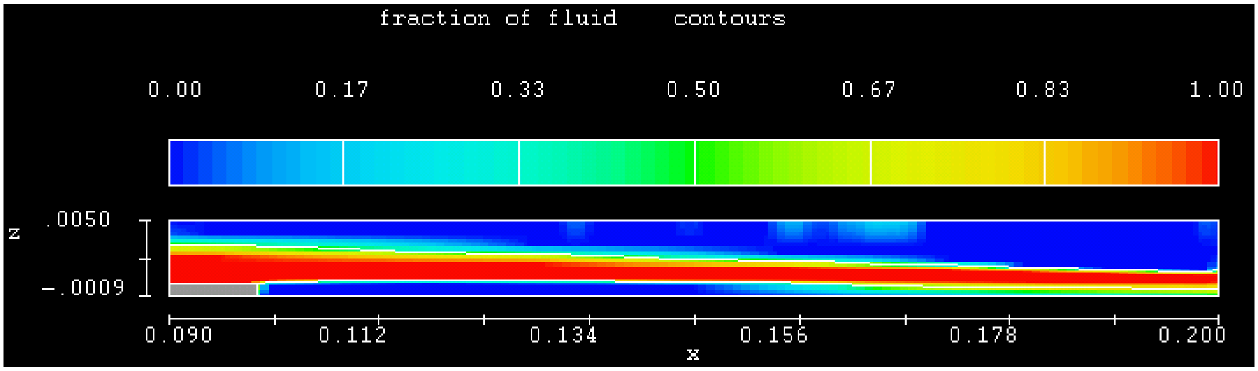

Fig. 1. Predicted thin-film thickness from simulations of water experiments completed at Argonne National Laboratory. The fluid is moving from left to right and is shown as it leaves the surface of the thin-film generator (shown in gray). Color is indicative of the fraction of liquid versus gas in each element of the computational mesh with blue indicating 0% liquid and red indicating 100% liquid.

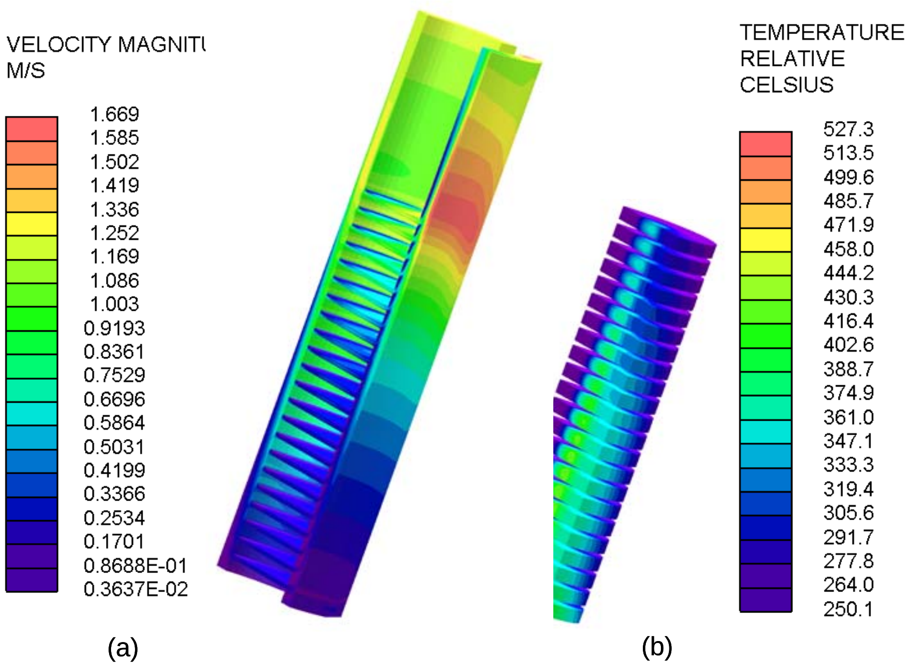

Fig. 2. Contour plots showing (a) velocity distribution within the liquid lithium coolant and (b) temperature distribution within the tungsten target material in the proposed Rare Isotope Accelerator neutron converter target. The tungsten is assumed to be in direct contact with the lithium coolant, which has an inlet temperature of 250°C. In this simulation, the energy deposited by the beam is assumed to be uniformly deposited within the heated region, and the surface of the tungsten plate closest to the beam window (the lower surface of the bottom plate as shown) is assumed adiabatic.