11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Analysis and optimization of a liquid Pb-Bi target for ISOL facilities

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Key Words: *ISOL, Liquid metal flow, Compact geometry, Design optimization, Recirculation*

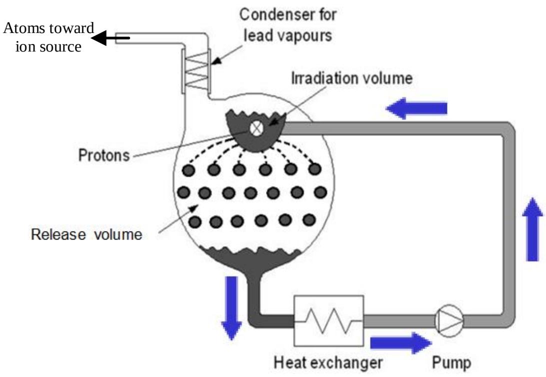

Fig 1: Conceptual view of circulating LBE target

Isotope Separation On Line (ISOL) is a technique developed for the production of Radioactive Ion Beams (RIBs)[1]. Radioactive nuclei are produced by various reactions of a light projectile with a thick target and diffuse out of the target towards the ion source, where they are ionized and subsequently extracted, mass-separated on-line and (in some cases) reaccelerated. In the context of new-generation ISOL facilities, liquid-metal loop targets are proposed to deal with the high driver-beam power on target. In this framework, the circulating liquid Lead Bismuth Eutectic (LBE) target (see Fig 1) is of interest for high-power facilities like ISOL@MYRRHA[1] and EURISOL[2][2]. When developing this proof-of-concept target, one of the important challenges is to design and optimize the shape of the irradiation container so that, once irradiated, the LBE is immediately evacuated into a uniform shower of very small droplets. This is necessary in order to enhance the diffusion of isotopes formed during irradiation, especially for isotopes with short half-lives.

This presentation deals with the optimization of the flow of a heavy liquid metal in a compact and complex geometry. The full target geometry and its dimensions have been set as design variables. Among other aspects, this includes optimizing the number and positions of the target inlets and outlets. For this multiple-objective design optimization, the following quality criteria were considered: a residence time of LBE inside the irradiation volume below 100 ms, a uniform distribution of velocity vectors through the few thousands outlet apertures and a reduced cavitation risk. In addition, several constraints have to be taken into account, such as a maximum pressure-drop limit and maximum limits on target dimensions.

Three-dimensional (3-D) computer simulations of the LBE flow have been used for the evaluation of design modifications. Indeed, over the past years, these tools have steadily gained acceptance as effective tools for liquid-metal flow simulation in fields such as spallation-targets design [3] and liquid-metal cooled reactor design [4]. Starting from the initial design, the flow features in the target geometry as well as the evolution of these features with the design changes have been computed with the CFD tool FLUENT (Ansys

[1] http://isolmyrrha.sckcen.be/
[2] http://www.eurisol.org/site02/index.php

Inc.). The modeled CFD geometries comprise a half-symmetry of the target geometry with respect to the vertical mid-plane of the flow inlet. The modeled geometries were also restricted to the fluid domain and the fluid-container interaction has been modeled by the “no slip wall” boundary condition. Still, about fifteen million cells were required to get mesh-independent results for the most-developed cases. At each step of the target optimization, insight was gained into the influence of different parameters on the flow features.

Results pertaining to the initial design geometries have revealed issues such as long residence time due to irradiated LBE recirculation, non-uniform distribution of LBE-velocity vectors at outlet apertures and regions with pressure dropping below the vapor pressure of LBE. Thorough analysis of the results led to successively-improved target-design options. Among other improvements, the design of a feeder volume equipped with a feeder grid was required in order to uniformly distribute the high-momentum inlet jet over the irradiation volume. In a first approach, a thin feeder volume combined with an optimized distribution of feeder grid apertures was investigated. A nonlinear system of equations including the continuity equation and generalized Bernoulli equation applied on a discretized one-dimensional (1-D) representation of the feeder volume was used here to model the optimized distribution of feeder-grid apertures. However, it was found from the 3-D simulations that the non-uniform LBE flow across the feeder grid was mostly due to mixing pressure-drop effects not accounted for in the above-mentioned 1-D model.

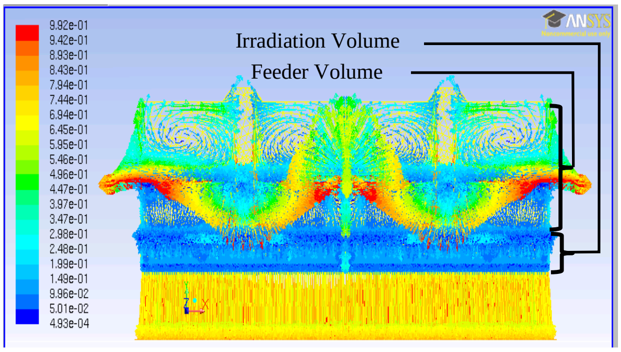

Fig 2: Velocity-vectors plot [m/s] - uniform distribution at outlet apertures

In a second approach, a uniform distribution of feeder-grid apertures with a larger feeder volume (few-cm thick) was investigated in 3-D. Two different optimized target geometries were eventually obtained. The velocity-vectors plot obtained for one of these is illustrated on Fig 2. Each of them showcases a different way to deal with the jet effect initially observed due to the high-momentum inlet liquid stream. By ensuring a transverse uniform flow, minimal residence time of irradiated LBE in the different optimized geometries is achieved. Suitably-designed flow straighteners were used to suppress recirculation of irradiated liquid inside the irradiation volume of the target. Full-scale prototyping and testing of the two optimized geometries is ongoing.

REFERENCES

[1] P. Van Duppen, Isotope Separation On Line and Post Acceleration, in: J. Al-Khalili, E. Roeckl (Eds.), The Euroschool Lectures on Physics with Exotic Beams, Vol. II, Springer Berlin Heidelberg, 2006, pp. 37-77.

[2] E.p.C. Board, Final report of the EURISOL design study (2005-2009), Cornell, John C ed., GANIL, 2009.

[3] J. Wolters, G. Hansen, K.E.M. J., R. F., Validation of CFD Models with Respect to the Thermal-Hydraulic Design of the ESS target, IAEA Technical Meeting, Karlsruhe, Germany, 2003.

[4] M. Vanderhaegen, J. Vierendeels, B. Arien, CFD analysis of the MYRRHA primary cooling system. Nuclear Engineering and Design 241 (2011) 775-784.