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Title: Power Converter Modeling and Testing

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Niowave Low Power Converter Modeling and Testing

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Introduction

Niowave has designed, built and is now using in-beam a low power (up to 10 kW) lead bismuth eutectic (LBE) converter. In this concept, an electron beam is passed through a falling layer of LBE, converting the electron to neutrons which then pass into a vessel which is functionally a subcritical reactor configuration. A detailed report has been written by Niowave, entitled "LBE Neutron Converter Manual." The LANL contribution has been modeling, followed by a flow visualization model made in quartz. The LANL contribution is reported herein.

Free Surface Conjugate Heat Transfer Modeling: Rectangular Test Geometry

A relatively simple model of a rectangular trough, affectionately known as the cattle trough model, was used to validate finite element solutions to the free surface flow problem with a local volumetric heat deposition.

A 3 X 3 X 45 cm channel with open top at near zero psia was modeled. Mass flow rate o LBE was2.9 kg/s, corresponding to about 4.4 gpm. The channel has a weir at the downstream end to maintain the channel fill height. The flowing LBE in the trough that results is shown in Figure 1. Velocity contour plots are shown in Figure 1.

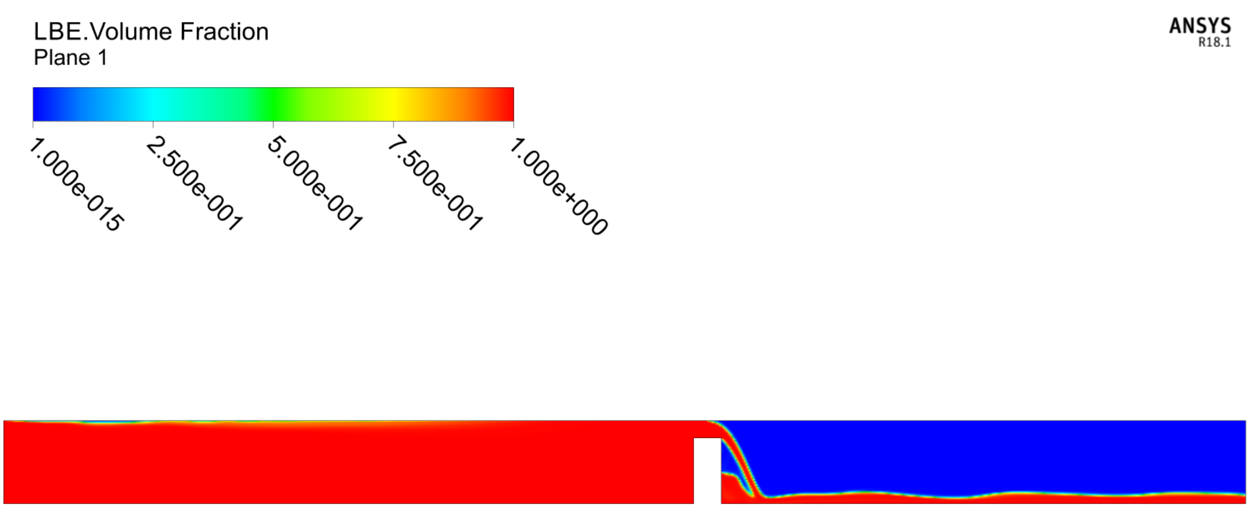


Figure 1. Fill level of flowing LBE.

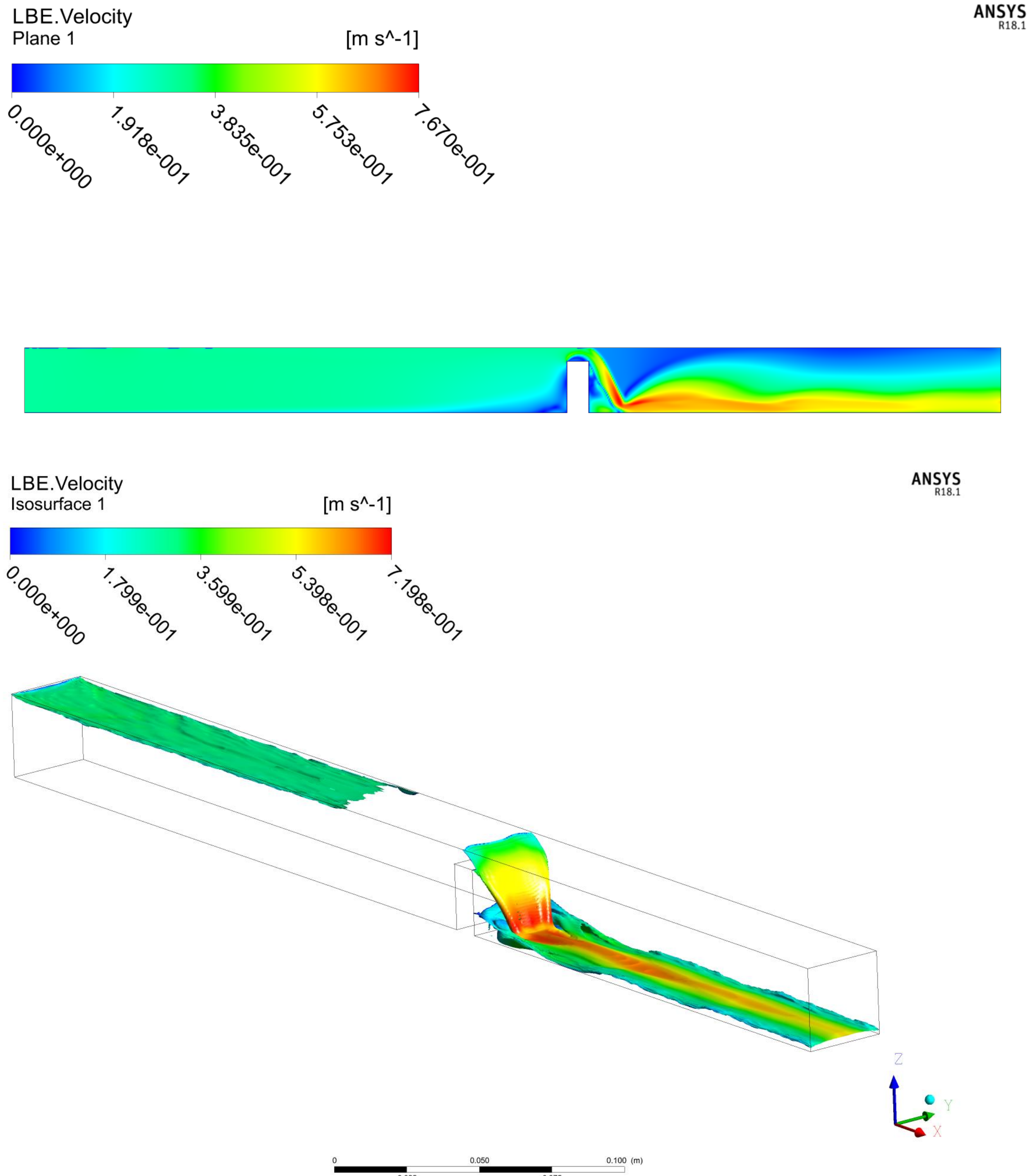


Figure 2. Velocity of LBE in channel cross-sectional view (above) and on the surface (below).

Electron beam heating as expected from a 40 MeV beam, 6.8 kW total power was applied near the flow entrance plane to calculate the thermal response. The heating profile ia shown in Figure 3 and the calculated thermal response is in Figure 4.

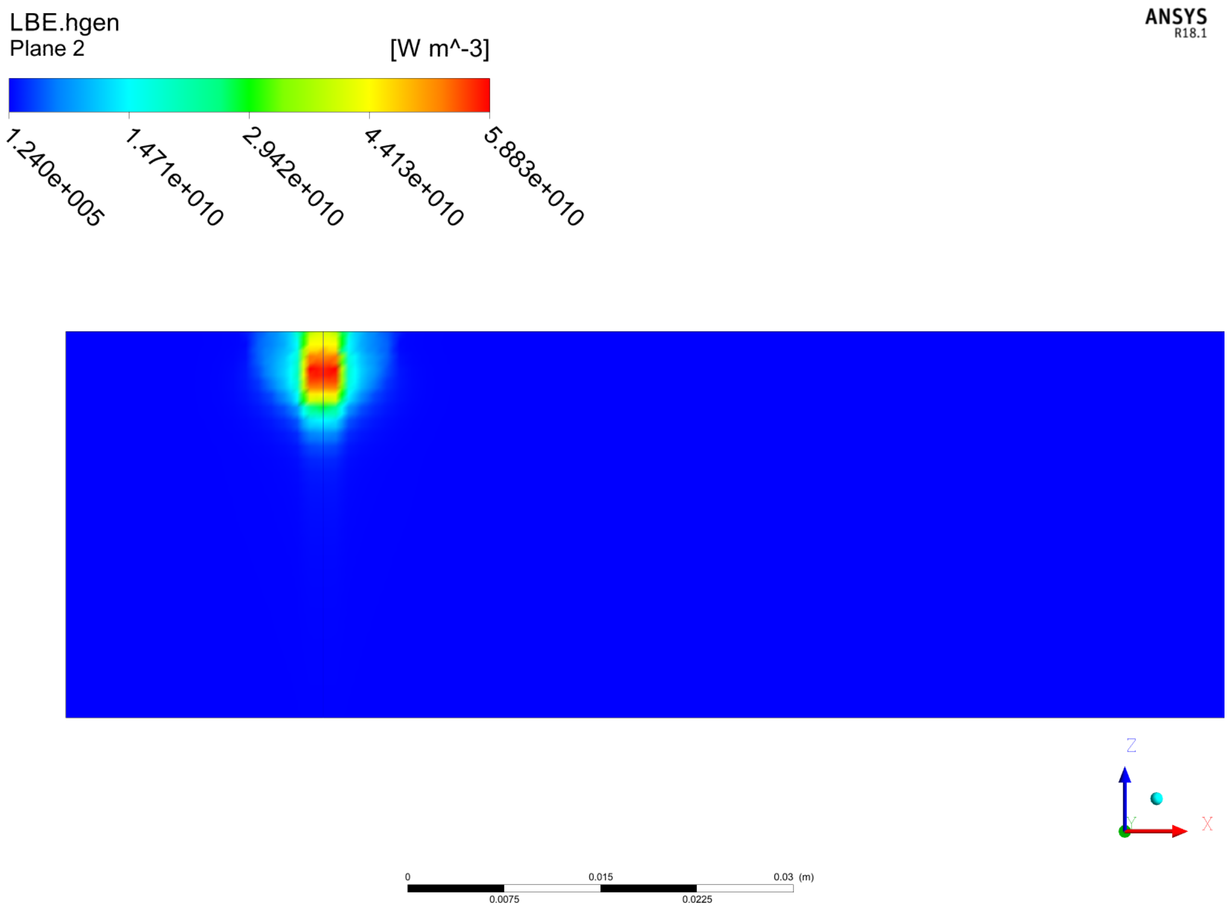
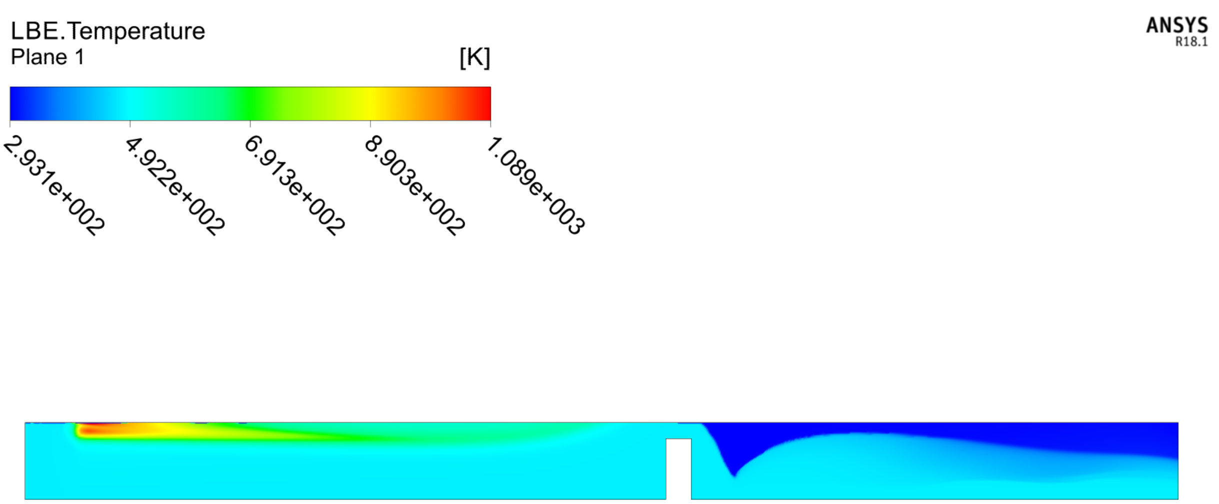


Figure 3. Beam heating profile in the channel.



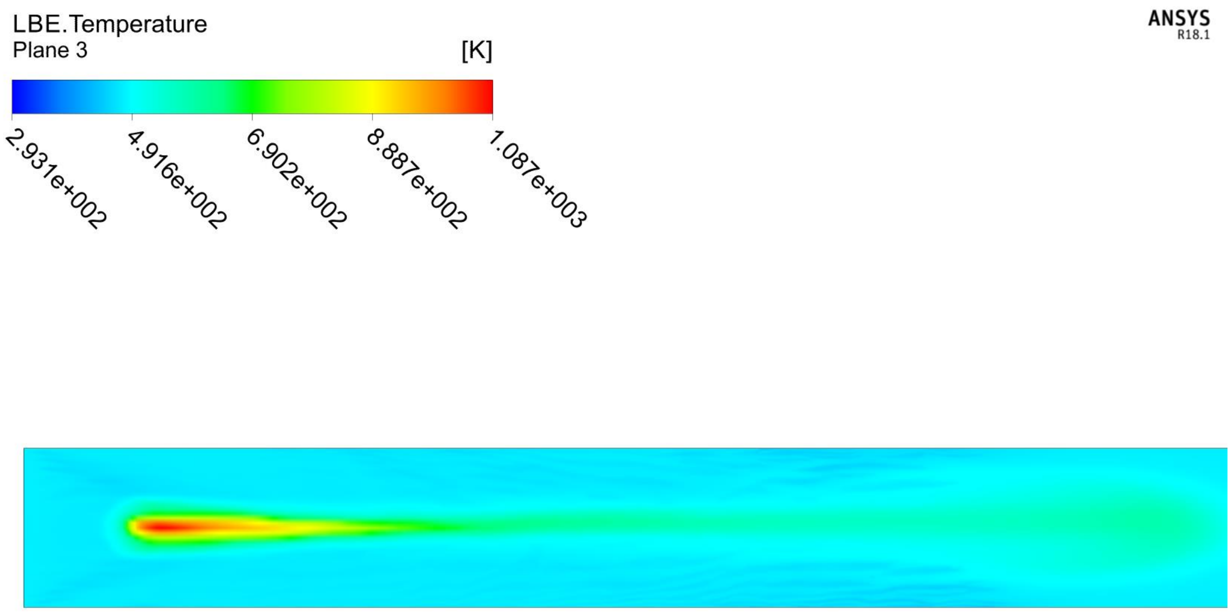


Figure 4. Channel cross-sectional view showing the temperature profile in the LBE (top) and the surface temperature profile at the bottom.

2-D Model of the Low Power Converter

The design of this converter was made entirely at Niowave without LANL support. LANL expressed concern that it would not work because a nozzle effect of accelerated flow at the restriction would disrupt the required flow profile. This nozzle effect was indeed observed, but at the required flow rate the converter produced the desired quasi-stable LBE film thickness of 5 cm. An illustration of the converter appears in Figure 5.

LANL performed a 2 dimensional analysis of the flow to validate the actual flow conditions over the lip at the end of the baffle and the stability of the flow. The flow rate for this analysis is 3 gpm, or 2 kg/s. The series of images in Figure 6 show the development of the flow over the lip of the baffle and the ensuing steady state flow condition. Note the small region of separation or void in the recirculation region on the downstream side of the baffle. The model analysis indeed shows a steady state performance meeting the requirements of the converter, a layer of LBE nominally 5 cm thick in the beam direction.

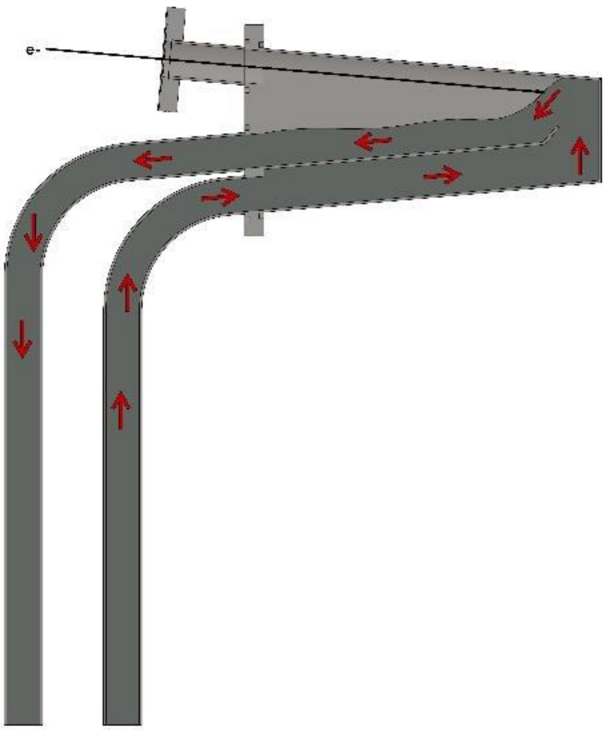


Figure 5. This figure is an artist's representation of the LBE flowing in from the lowest tube and exiting from the middle tube. The line entering from the upper flanged tube represents the beam, which ideally impinges on a 5 cm thick layer of LBE.

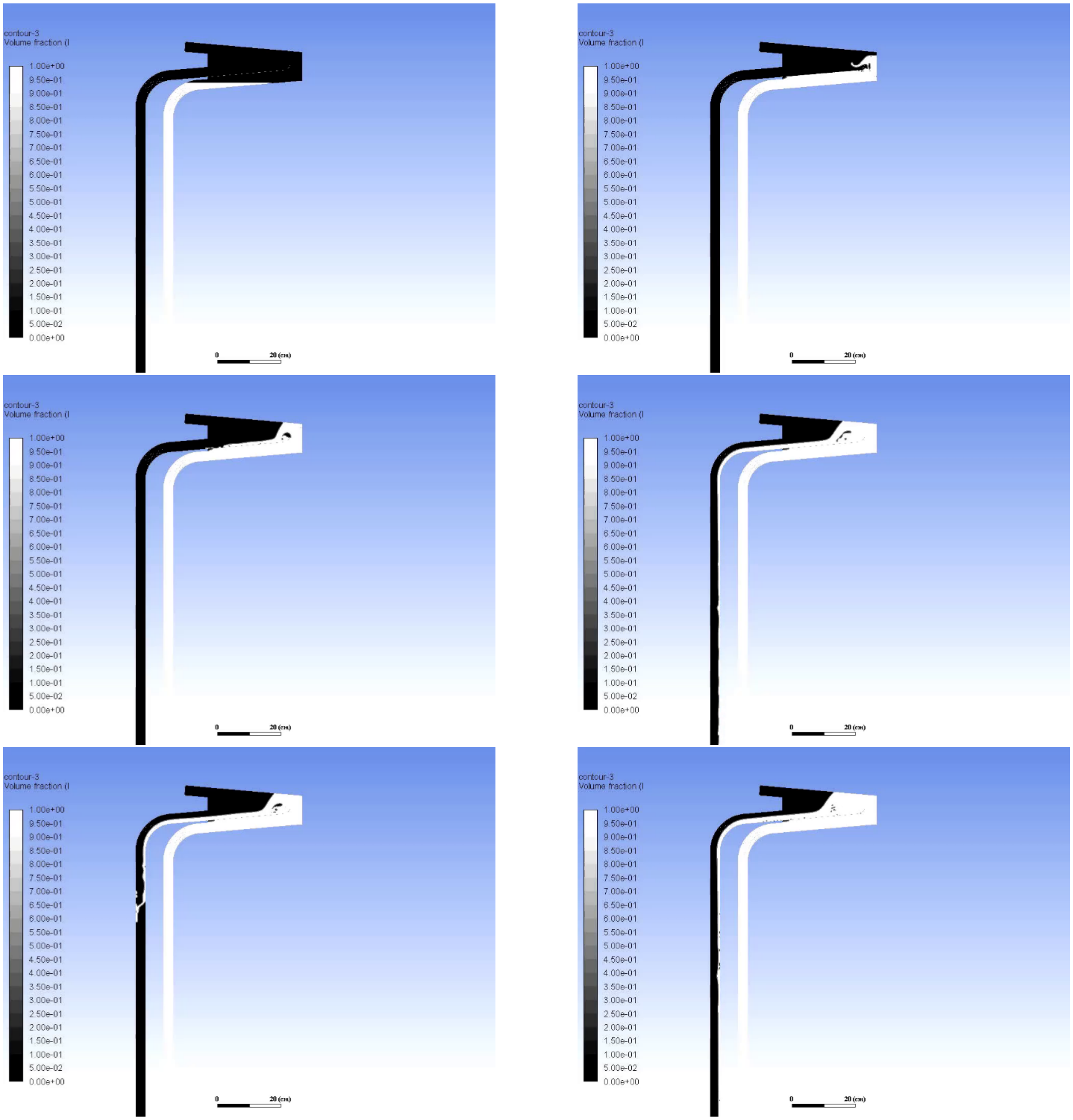


Figure 6. Still frames extracted from a video of the converter model flow. Top left is the initial condition, followed by sequential development of the flow.

Quartz Flow Visualization Model

LANL designed and fabricated a quartz replica of the converter. This was tested first with water at LANL, then at Niowave with LBE. The replica and some results are shown in the figures below. The similarity between the model and the analysis is excellent, evident even in the detail of flow separation or small void region just below the lip of the waterfall.

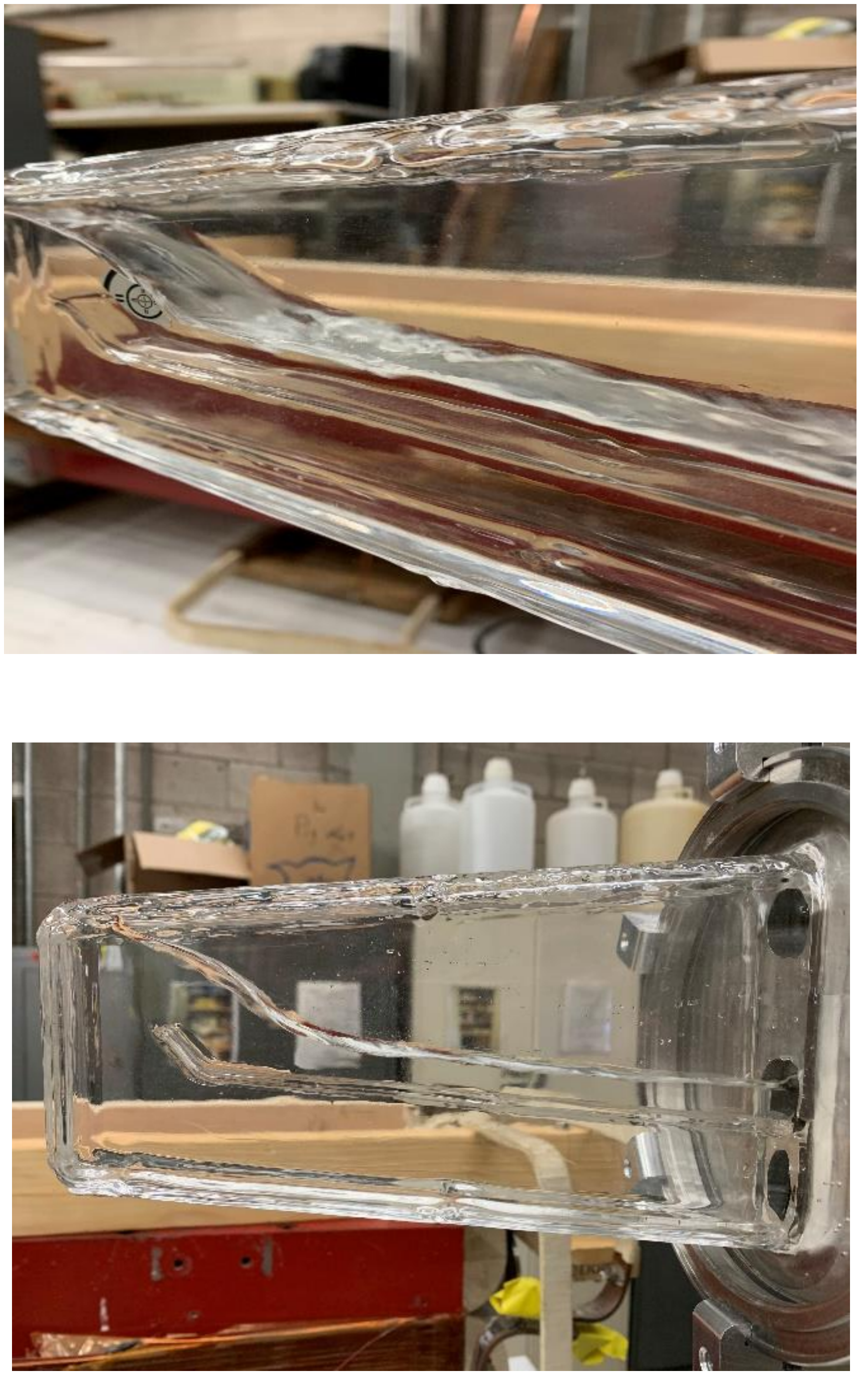


Figure 7. Quartz model, pretested with water.

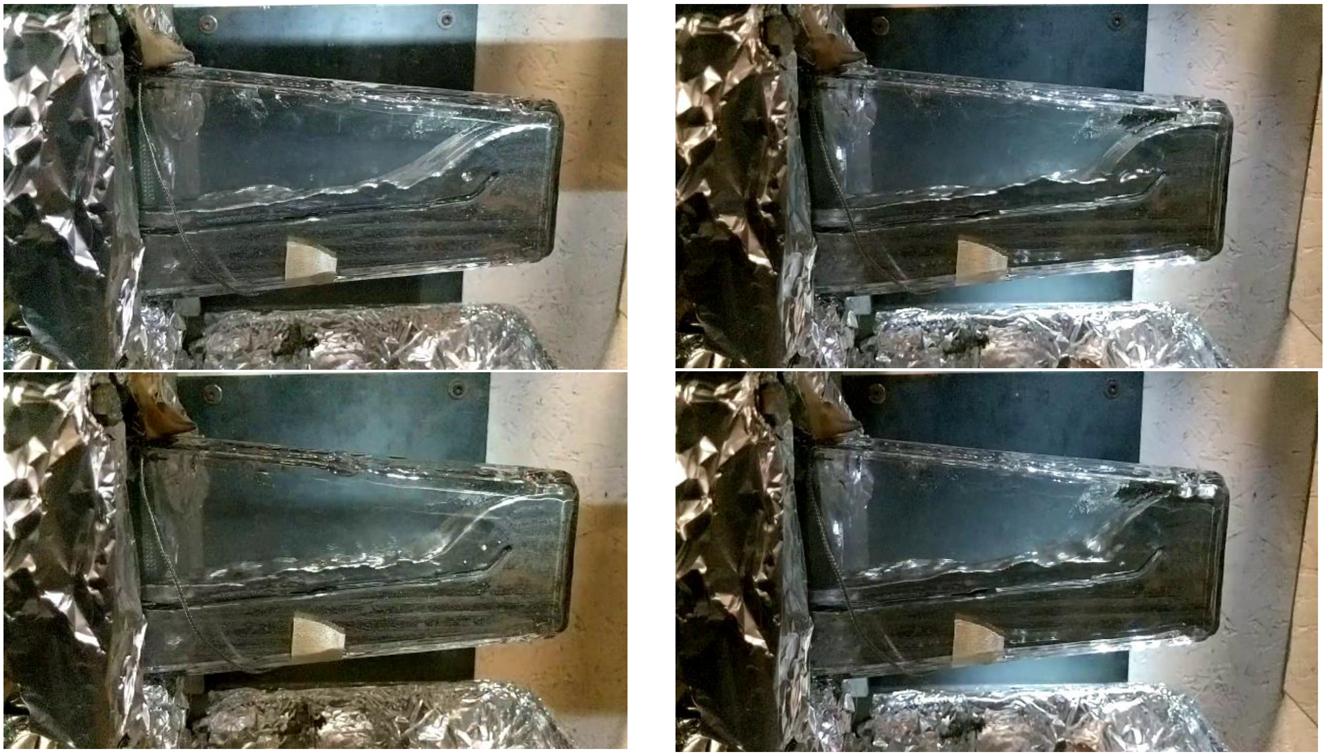


Figure 8. Quartz model with flowing LBE indicating stable LBE layer at the location of the beam penetration. The second frame, top right, clearly shows the void in the recirculation region.

Summary

Niowave has designed and built a LBE neutron converter, now in use experimentally in an electron accelerator. LANL contributed free surface finite element modeling and a physical transparent model made of quartz for flow visualization. Modeling and visualization are in good agreement, and the device is performing as expected in beam.