Computational fluid dynamics simulations in support of nuclear reactor safety

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Introduction

One of the conceptual Generation IV nuclear power reactors is the Sodium-cooled Fast Reactor (SFR), which uses sodium as a coolant in place of water. This poses significant safety risks due to the chemical volatility of sodium when exposed to air and water. The following investigation uses ANSYS Fluent to predict single-phase and two-phase flow behaviours of sodium through different geometries. This work is a continuation of Lebel 2016 and is a collaborative research project under the auspices of the International Atomic Energy Agency (IAEA).

Methodology

The geometry modelled was the Intermediate Heat Exchanger (IHX) which is part of the roof slab of the SFR as seen in Figure 1. The geometry and mesh of the IHX, shown in Figure 2, were built by L. Lebel and are used in both the single-phase and multi-phase cases.

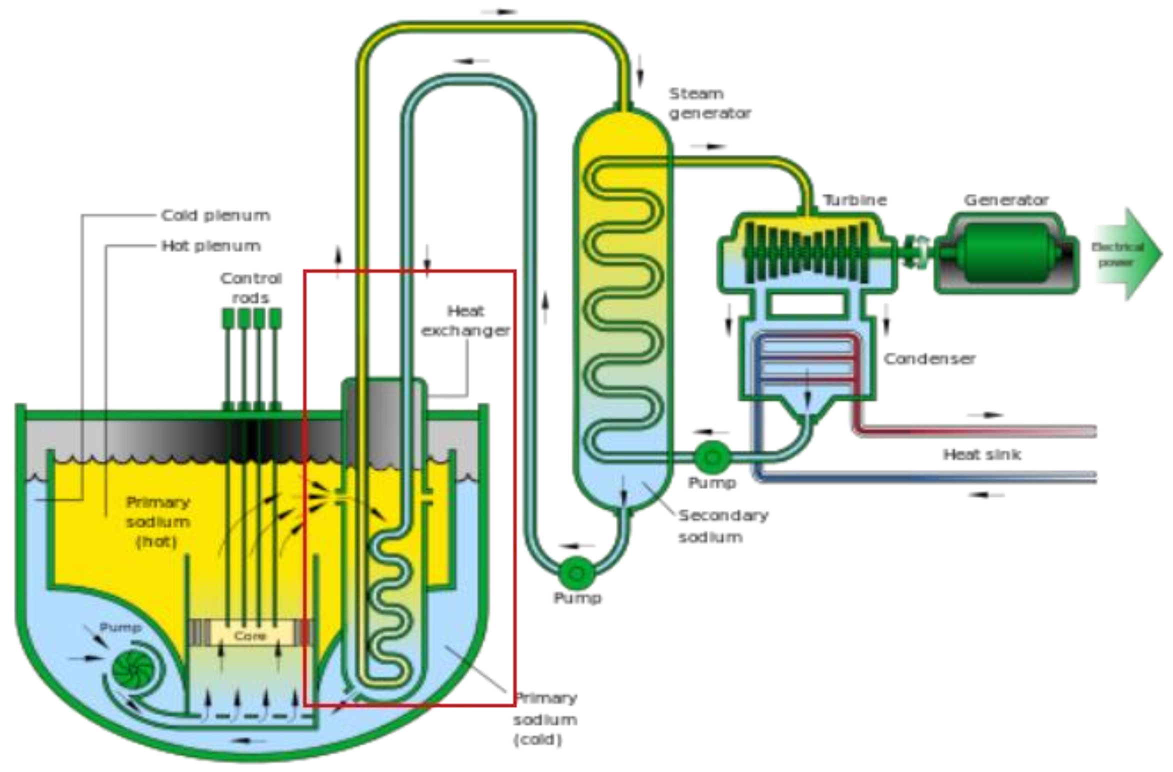

Figure 1 – SFR schematic with IHX component highlighted in red

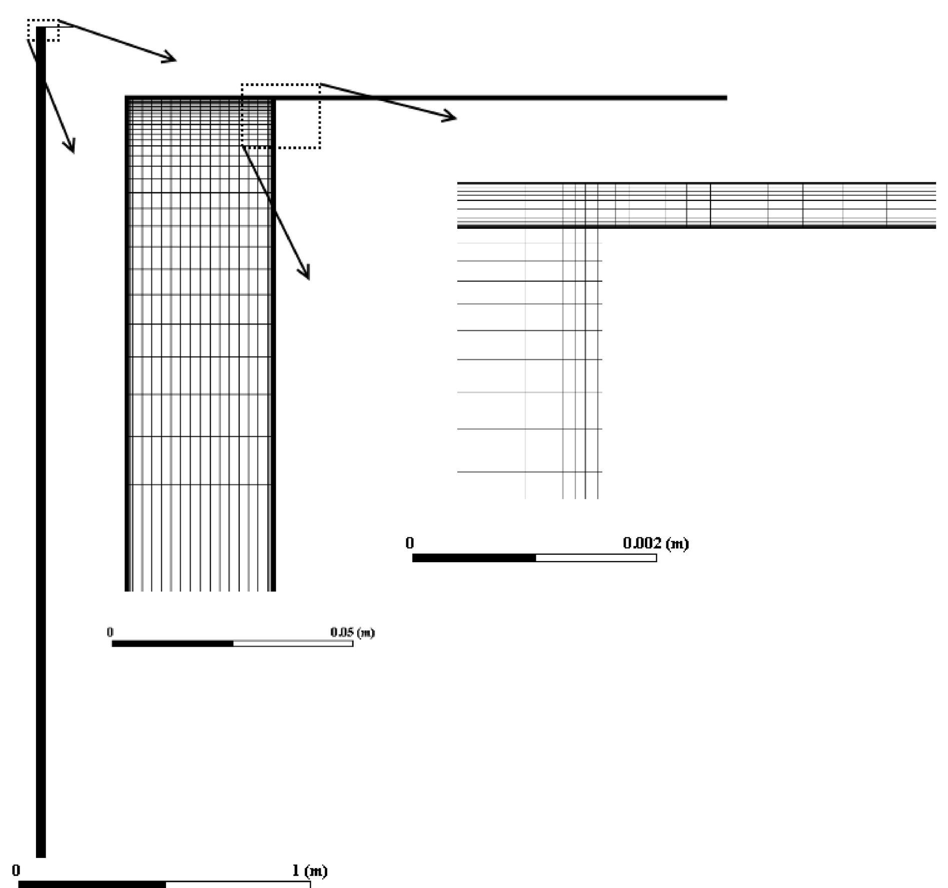

Figure 2 – Geometry and mesh displayed in ANSYS Fluent

Boundary Conditions

SFRs use argon as a cover gas for the sodium coolant. The inlet boundary condition of this problem is modelled as a pressure transient and is shown in Figure 3.

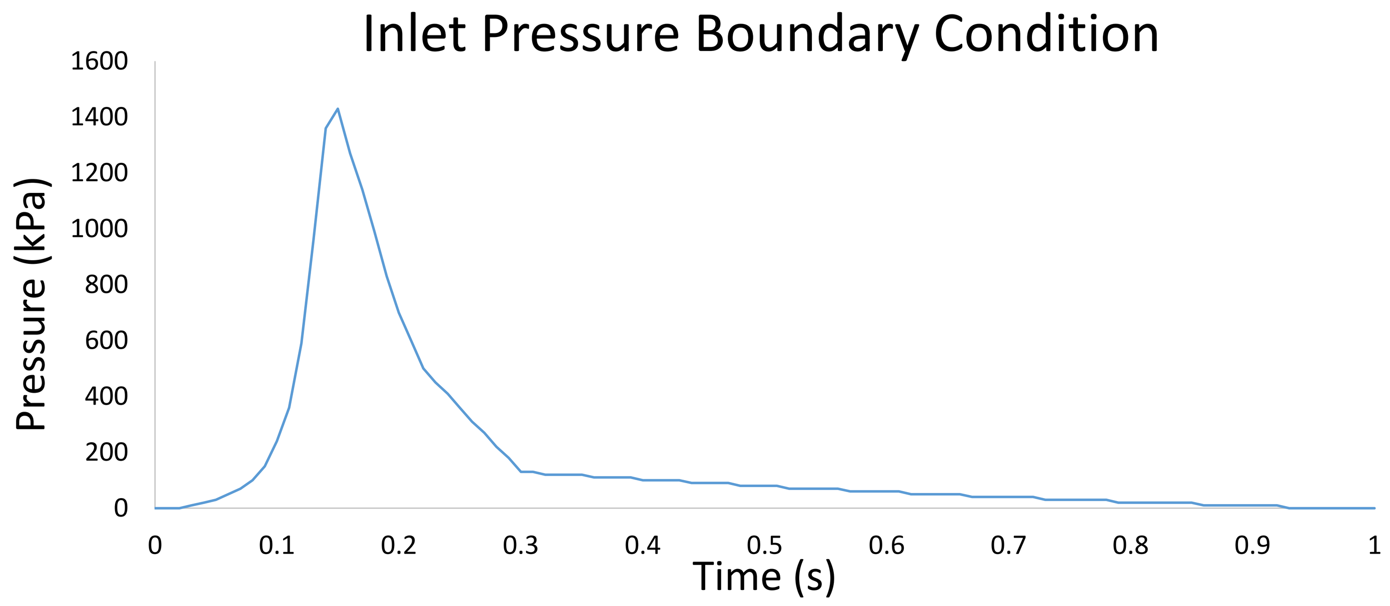

Figure 3 – Cover gas pressure profile to 1 s.

Single-Phase Flow Results

In the single-phase case, it is assumed that the entire geometry is filled with molten sodium prior to the start of the transient. As seen in Figure 4, the profile of the velocity of the sodium is very similar to the pressure profile of the cover gas with both plots increasing to a maximum just before 0.2 s. Figure 5 shows the cumulative mass of sodium ejected during the single-phase simulation through the entire IHX component.

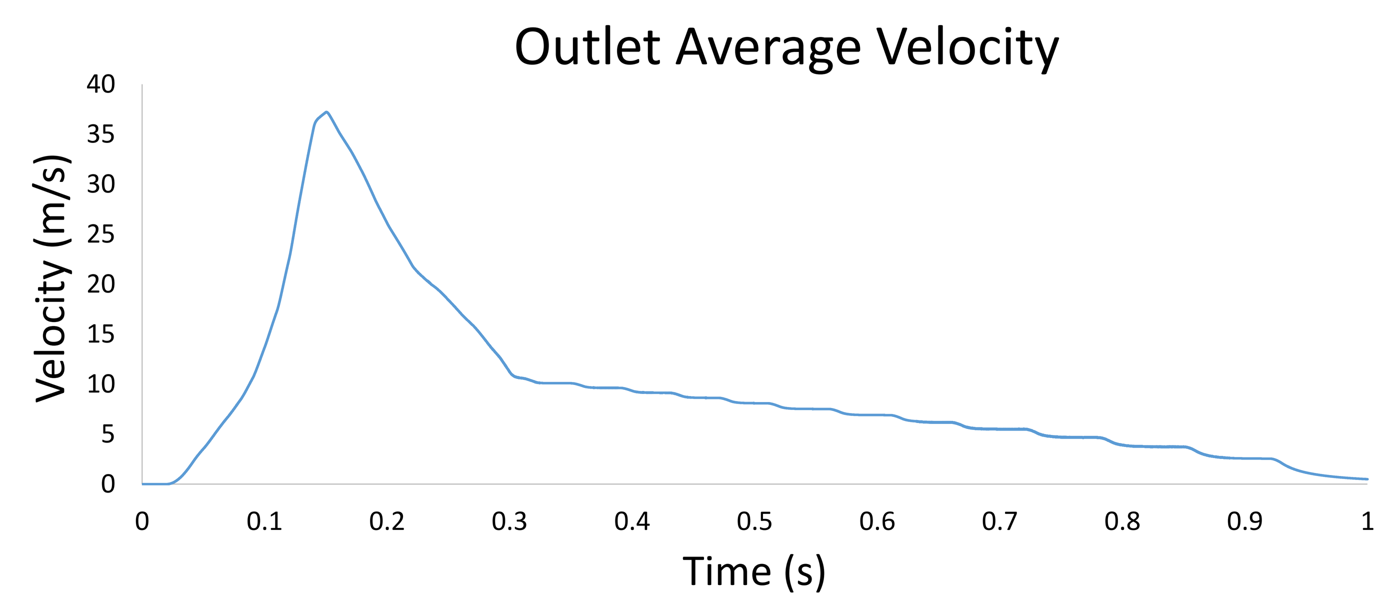

Figure 4 – Area weighted avg. velocity of sodium at the outlet

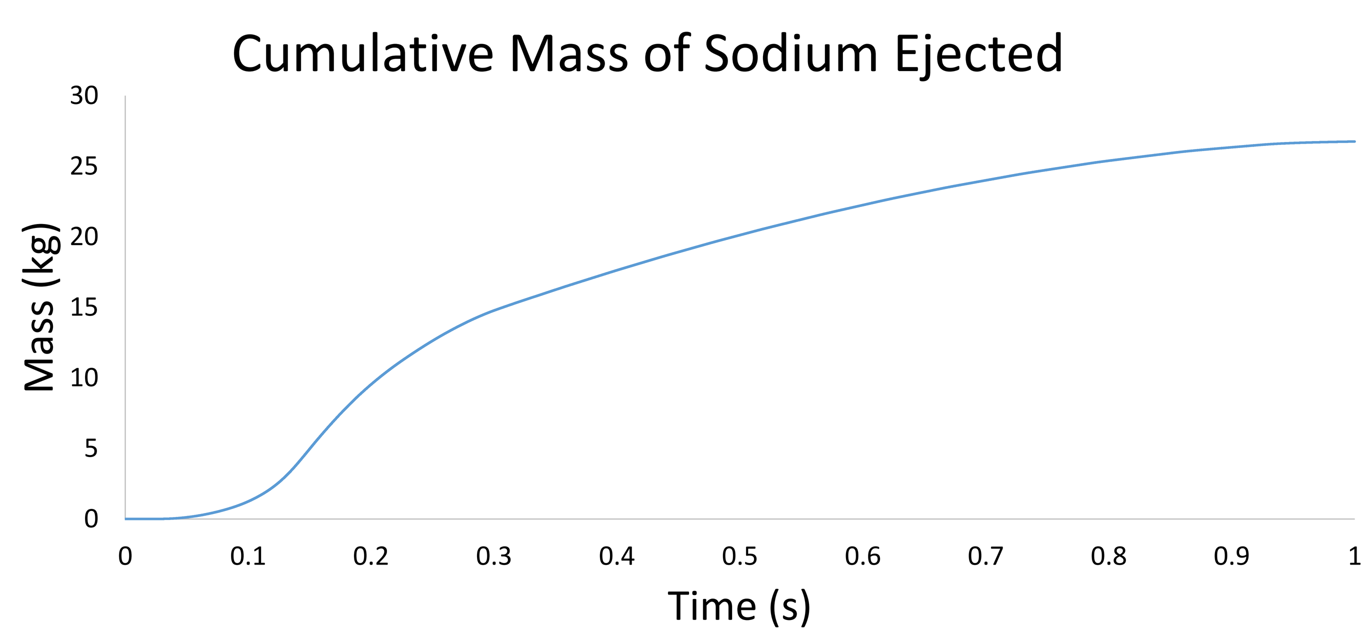

Figure 5 – Cumulative mass of sodium ejected in the single phase case.

Two-Phase Flow Results

The two-phase flow case predicts the behaviours of both sodium and argon with the initial volume filled entirely with argon prior to the start of the transient. This case is still a work in progress and it has only been successfully simulated to about 0.2 s. However, as seen in Figure 6, the flow of sodium roughly resembles the fully developed region of a laminar flow velocity profile. Further work is needed to investigate the flow behaviours as the sodium approaches the L-bend of the geometry.

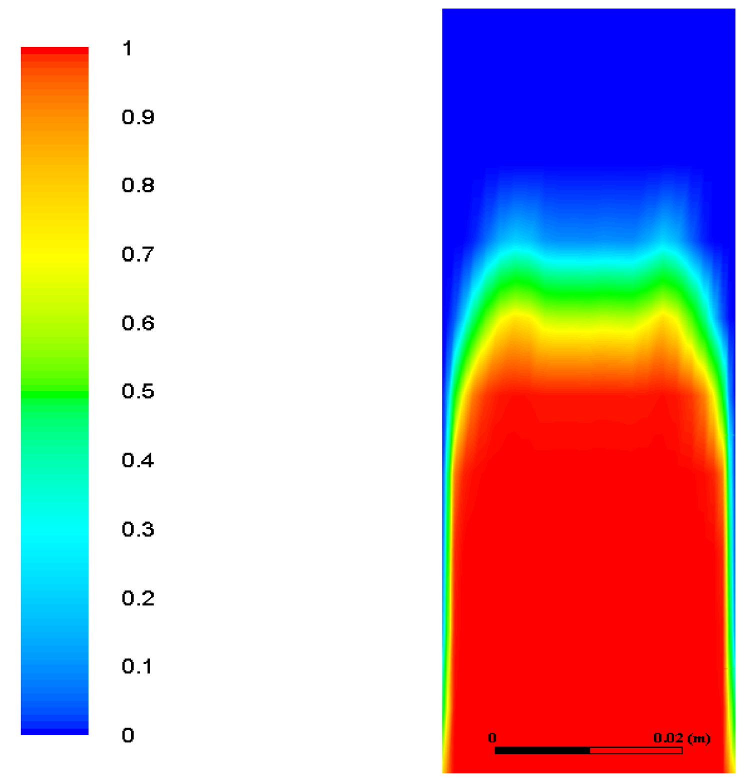

Figure 6 – Two-phase evolution of sodium flow within the leak path at 0.15 s. Argon is represented by blue and sodium is represented by red.

Hydra Simulation

In a parallel effort, an on-going investigation is underway with Hydra to simulate the flow by-pass effect in a CANDU fuel channel under in-reactor conditions. This is due to diametrical creep of the pressure tube and is illustrated in Figure 7.

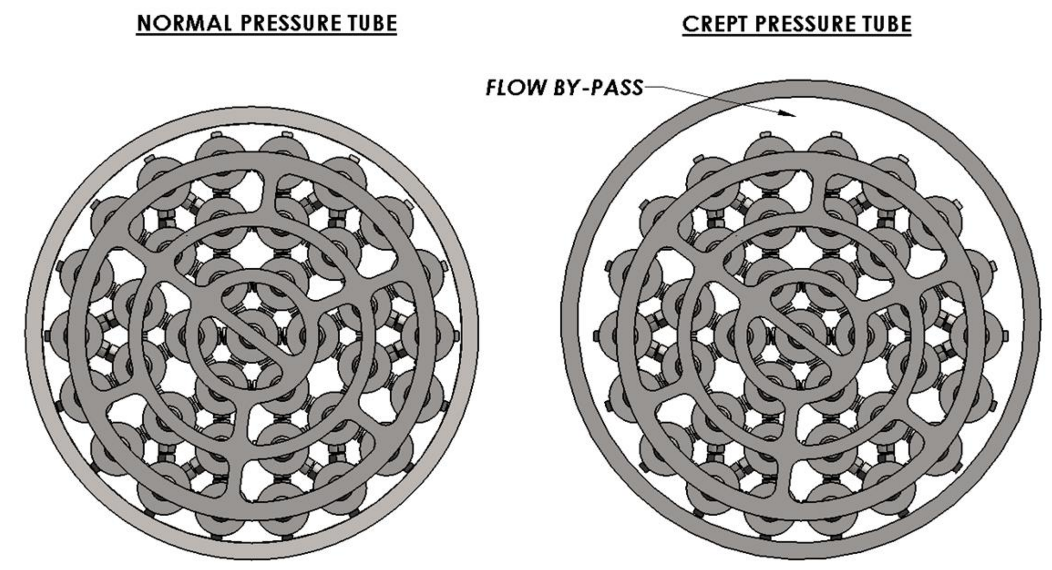

Figure 7 – Comparison of a normal and crept pressure tube with a flow By-Pass, taken from M.H.A. Piro, et al. 2016.

The open-source nature of Hydra permits large scale simulations on SHARCnet and Graham to use higher fidelity turbulence models to increase the accuracy of simulation and improve the understanding of this phenomenon.

Conclusion

With the push for new reactor technologies such as the SFR, and the on-going CANDU refurbishments at both Darlington and Bruce Power, the need for reactor safety driven simulations are extremely important. Improving the understanding of sodium flow through different geometries and the effects of flow by-passes on fuel cooling are both beneficial to the nuclear industry's safety culture.

Acknowledgments

This research was undertaken, in part, thanks to funding from the Canada Research Chairs program of the Natural Sciences and Engineering Research Council (NSERC) of Canada and the NSERC Undergraduate Student Research Fellowship.

L. Lebel, "Rates of Sodium Ejection during a Core Disruptive Accident", Institut de Radioprotection et de Sûreté Nucléaire Report (2017).
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