



DYNAMIC MODELLING OF A SODIUM-COOLED FAST REACTOR DURING A LOSS-OF-FLOW EVENT

This case study describes how Flownex was used to simulate the dynamic behaviour of a Sodium-cooled Fast Reactor (SFR), including thermal-hydraulics, neutronics and feedback effects during a Loss of Flow Without Scram (LOFWOS) event.



Download the Paper

NUCLEAR & SMR

CHALLENGE:

Sodium-cooled Fast Reactors (SFRs) require accurate prediction of plant dynamics during transients like loss-of-flow events. These events involve strong coupling between sodium thermal-hydraulics, spatially varying temperatures, reactivity feedback and pump coast-down behaviour. Legacy system codes typically simplify several parts of the reactor, omit certain feedback paths or treat the steam-water side with boundary conditions, limiting their applicability for advanced safety studies.

BENEFITS:

Flownex was used because it can model the entire primary and secondary sodium circuits with realistic pressure, momentum and energy conservation while maintaining rapid execution. Temperature-dependent sodium properties, heat transfer within subassemblies, pump dynamics, intermediate heat exchanger behaviour and neutronic feedback could all be captured in one environment, enabling a unified and fast-running plant dynamics tool.

SOLUTION:

A full reactor layout was built in Flownex that included the core, upper and lower plenums, pipe loops, primary pumps and the intermediate heat exchanger. A kinetics model based on point-kinetics with temperature, density and structural feedback was implemented to capture reactivity changes. The model was validated against the well-documented Fast Flux Test Facility (FFTF) Loss of Flow Without Scram (LOFWOS) Test 13, where the predicted core power, temperatures and flow transients matched the experimental data, demonstrating that Flownex can effectively simulate complex SFR dynamics.

NUCLEAR & SMR

INTRODUCTION

Sodium-cooled Fast Reactors (SFRs) are known for their strong thermal-hydraulic coupling, fast transient response and reliance on inherent safety characteristics. Predicting their behaviour requires accurate modelling of liquid sodium, which undergoes significant temperature-dependent changes in density, heat capacity and thermal conductivity. In transients such as Loss of Flow Without Scram (LOFWOS), the reactor's power, coolant flow and fuel temperature interact through prompt kinetics and thermal feedback.

This study demonstrates how a complete plant dynamic model of a fast reactor can be created using Flownex. Instead of relying on segmented or simplified solvers, the reactor core, plenums, piping, pumps and heat exchangers were represented as an interconnected thermo-fluid network. The model was applied to the Fast Flux Test Facility (FFTF), a well-characterised sodium-cooled test reactor, enabling direct comparison with data from the LOFWOS Test 13 experiment.

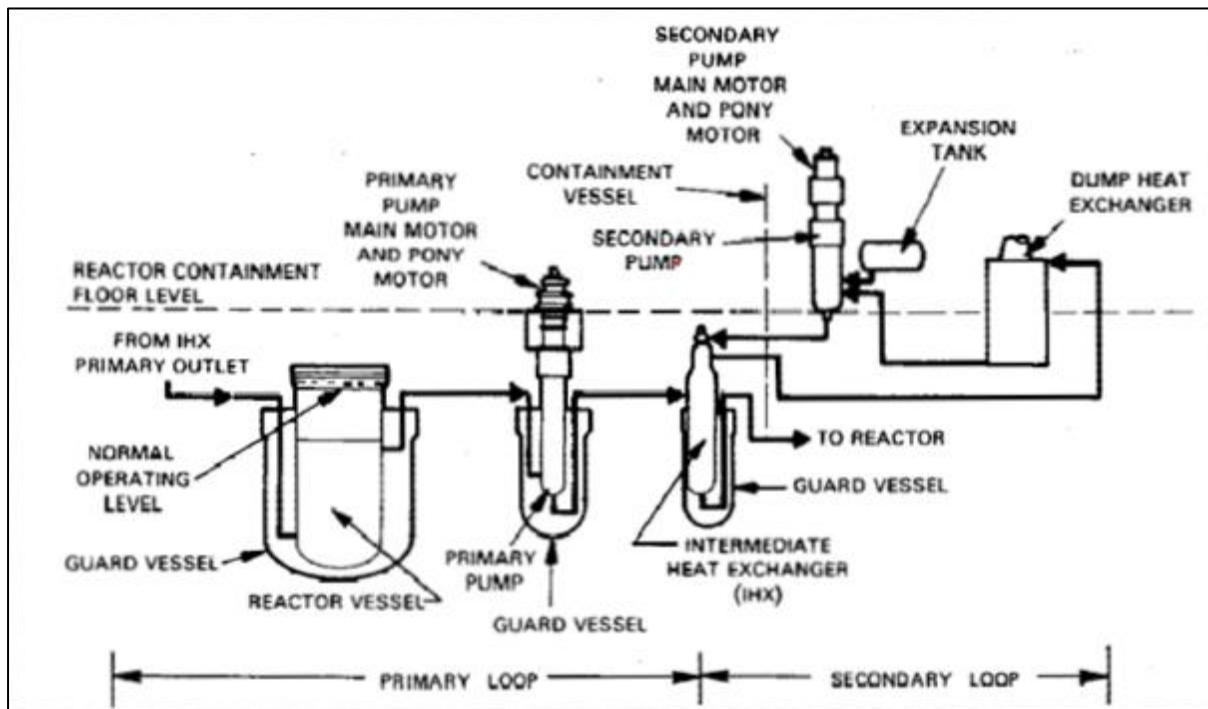


Figure 1: Loop-Type SFR Flow Diagram

MODELLING PHILOSOPHY

Developing an accurate SFR model required a modelling philosophy that captured the essential physics of the system without overcomplicating the workflow. In Figure 2, the core was represented in Flownex through a set of parallel channels that reflected the behaviour of different subassemblies, such as fuel, blanket and reflector positions. Each channel reproduced the heat generated along the fuel, this way the heat is transferred into the surrounding sodium. As temperatures rise, the coolant becomes less dense, its ability to remove heat changes, and these effects directly influence the reactor's power. Modelling these interactions in a continuous way was essential for reproducing the dynamics observed in real SFRs.

NUCLEAR & SMR

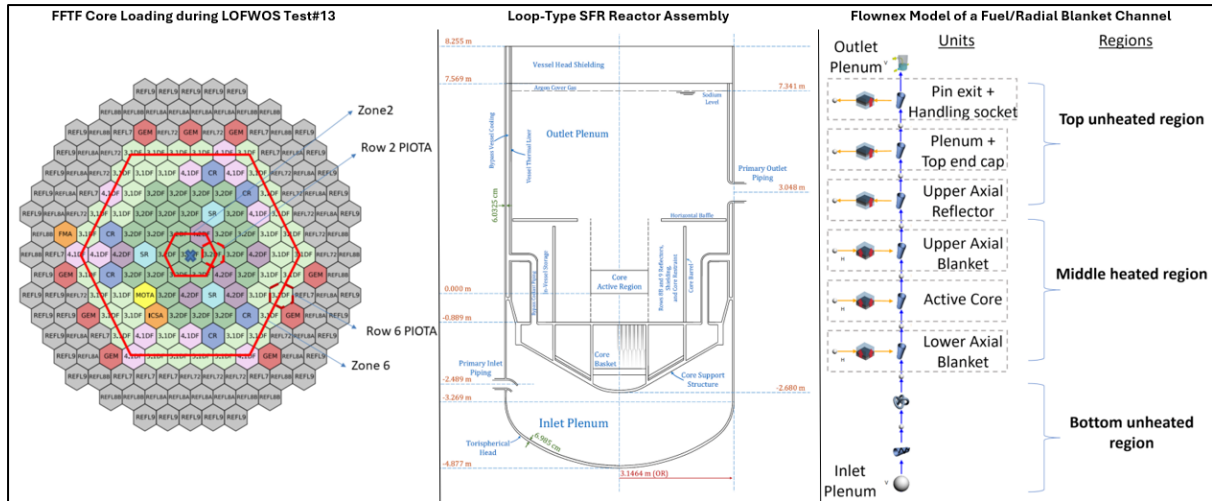


Figure 2: Reactor core loading, assembly and Flownex model

The primary system (Figure 3) was treated as an integrated network where the upper plenum, lower plenum, primary pipes and loop connections all contributed to the overall transient response. The Figure 3 and Figure 4 models are a single loop, representative of the multi-loop plant. Sodium can stratify, accelerate, stall or reverse direction depending on the event, so the model had to capture momentum changes realistically. During a loss-of-flow scenario, the pump coast-down creates rapid shifts in pressure and flow, and the model tracked these changes as they propagated through the entire circuit. Representing this hydraulic behaviour allowed the simulation to predict flow reduction, the onset of natural circulation and the stabilisation of temperatures after the transient.

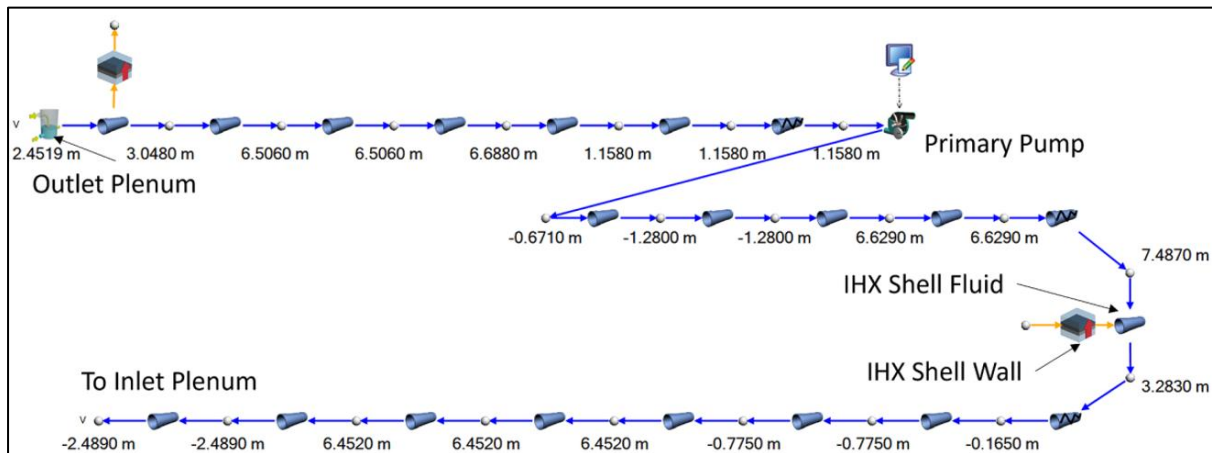


Figure 3: Flownex Model of the FFTF Primary Sodium Piping

NUCLEAR & SMR

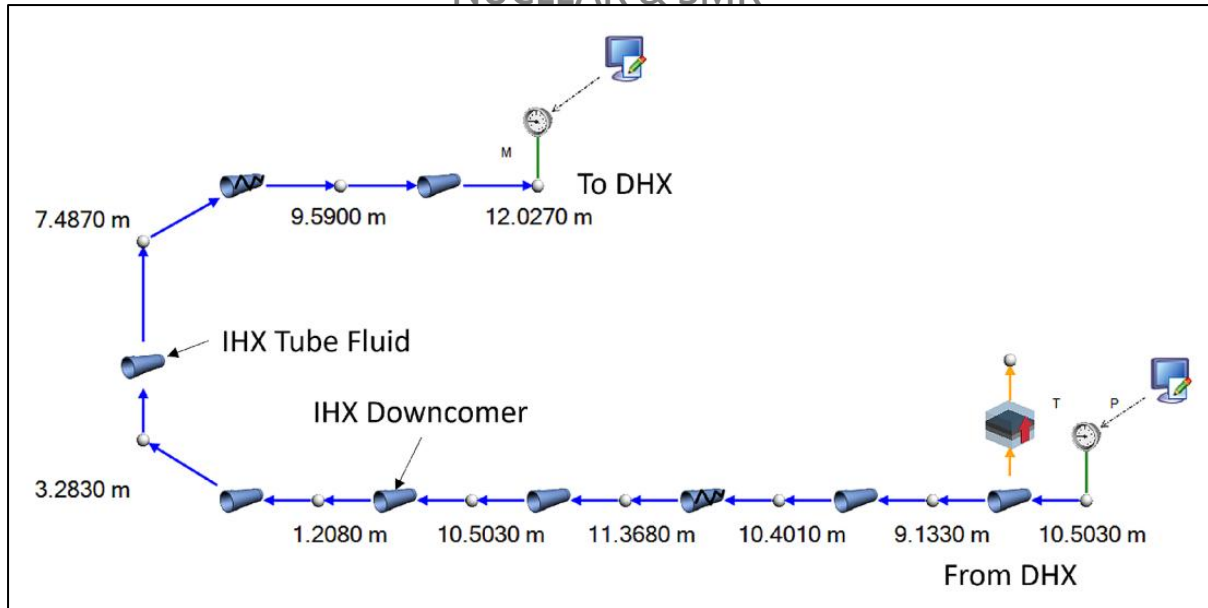


Figure 4: Flownex Model of the FFTF Secondary Sodium Piping

The dynamic response of the intermediate heat exchanger and primary pumps were incorporated in the model as well. The heat exchanger transferred energy between the primary and secondary sodium circuits (Figure 4) using temperature-dependent heat transfer relationships so that rising primary-side temperatures and decaying flow rates naturally produced the correct delay in heat rejection. Pump behaviour was captured through its characteristic head-flow relationship and its rotational inertia, allowing the model to simulate a realistic rundown when electrical power is lost.

A crucial part of the modelling philosophy was the integration of reactor kinetics into the thermal-hydraulic network. A point-kinetics model was used to calculate reactor power based on instantaneous changes in reactivity. As the coolant heated up and changed density and as the fuel temperature increased, these effects introduced feedback that altered the neutron population. By incorporating Doppler feedback, coolant temperature feedback and structural expansion effects, the model was able to respond to flow reductions exactly as a real SFR would.

Together, these modelling choices created a coherent representation of the reactor. Instead of relying on highly simplified assumptions or separating the thermal and neutronic behaviour into different tools, the entire system interacted naturally within one environment. This allowed the Flownex model to reproduce the characteristic power dip, temperature rise and eventual stabilisation seen in experiments such as the FFTF LOFWOS test, confirming that the modelling philosophy successfully captured the physics governing sodium-cooled fast reactor behaviour.

VALIDATION AGAINST FFTF LOFWOS TEST 13

The Flownex model was tested by simulating the LOFWOS Test 13 experiment. The simulation used a 1-second time step and ran for 900 seconds following the pump trip. The steady-state case completed in approximately 6 minutes, while the transient case took about 65 minutes on an Intel Xeon E5-2699A v4 @ 2.40 GHz (thin client) with 8 GB RAM. In this test:

- Pump power was rapidly reduced
- No emergency shutdown system operated
- The reactor relied solely on natural feedback mechanisms

NUCLEAR & SMR

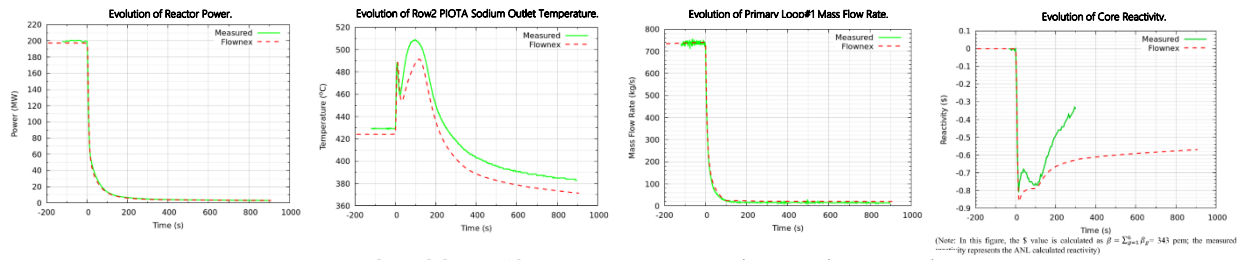


Figure 5: LOFWOS Test 13 experiment measured vs simulation results

Flownex reproduced the key transient behaviours observed in the FFTF LOFWOS Test 13 experiment:

- Rapid reduction in reactor power following the primary pump trip due to strong negative reactivity insertion
- Correct evolution of core reactivity associated with coolant density, Doppler and structural feedback mechanisms
- Sodium outlet temperature response in the core and primary loop
- Delay and magnitude of natural circulation onset following pump coast-down

The predicted reactor power showed close agreement with the measured data, reproducing the observed decay toward decay-heat-dominated conditions rather than exhibiting a distinct intermediate power rise. Overall, the comparison demonstrated that the Flownex model captured the dominant physical mechanisms governing the transient, thereby validating the modelling approach.

CONCLUSION

This case study shows that Flownex can effectively simulate the complex thermal-hydraulic and neutronic interactions within a SFR during challenging transients. By capturing core channel behaviour, reactivity feedback, pump rundown and heat exchange in a single model, Flownex provides engineers with a fast and accurate tool for evaluating plant dynamics, operational safety margins and design improvements.