TerraPower

April 13, 2023

TP-LIC-LET-0067
Project Number 99902100

U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
ATTN: Document Control Desk

Subject: SAS4A/SASSYS-1 As Evaluation Model for In-Vessel DBA and LBEs without Radiological Release Presentation Material

This letter provides the TerraPower, LLC presentation material for the upcoming Natrium™ advanced reactor[1] pre-application engagement meeting "SAS4A/SASSYS-1 As Evaluation Model for In-Vessel DBA and LBEs without Radiological Release" (Enclosures 2 and 4).

The presentation material contains proprietary information and as such, it is requested that Enclosure 4 be withheld from public disclosure in accordance with 10 CFR 2.390, "Public inspections, exemptions, requests for withholding." An affidavit certifying the basis for the request to withhold Enclosure 4 from public disclosure is included as Enclosure 1. Proprietary materials have been redacted from the presentation provided in Enclosure 3; redacted information is identified using [[ ]]$^{(a)(4)}$.

This letter and enclosures make no new or revised regulatory commitments.

If you have any questions regarding this submittal, please contact Ryan Sprengel at rsprengel@terrapower.com or (425) 324-2888.

[1] a TerraPower and GE-Hitachi technology.

Sincerely,

Michael Montecalvo

Michael Montecalvo
Manager of Licensing, Natrium
TerraPower, LLC

Enclosure:
1. TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))
2. "SAS4A/SASSYS-1 As Evaluation Model for Natrium In-Vessel DBA and LBEs without Radiological Release" Presentation Material – Open Meeting – Non-Proprietary (Public)
3. "SAS4A/SASSYS-1 As Evaluation Model for Natrium In-Vessel DBA and LBEs without Radiological Release" Presentation Material – Closed Meeting – Non-Proprietary (Public)
4. "SAS4A/SASSYS-1 As Evaluation Model for Natrium In-Vessel DBA and LBEs without Radiological Release" Presentation Material – Closed Meeting – Proprietary (Non- Public)

cc: Mallecia Sutton, NRC
William Jessup, NRC
Andrew Proffitt, NRC
Nathan Howard, DOE
Jeff Ciocco, DOE

ENCLOSURE 1

TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))

Enclosure 1
TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure
(10 CFR 2.390(a)(4))

I, George Wilson, hereby state:

1. I am the Vice President, Regulatory Affairs and I have been authorized by TerraPower, LLC (TerraPower) to review information sought to be withheld from public disclosure in connection with the development, testing, licensing, and deployment of the Natrium™ reactor and its associated fuel, structures, systems, and components, and to apply for its withholding from public disclosure on behalf of TerraPower.
2. The information sought to be withheld, in its entirety, is contained in Enclosure 4, which accompanies this Affidavit.
3. I am making this request for withholding, and executing this Affidavit as required by 10 CFR 2.390(b)(1).
4. I have personal knowledge of the criteria and procedures utilized by TerraPower in designating information as a trade secret, privileged, or as confidential commercial or financial information that would be protected from public disclosure under 10 CFR 2.390(a)(4).
5. The information contained in Enclosure 4 accompanying this Affidavit contains non-public details of the TerraPower regulatory and developmental strategies intended to support NRC staff review.
6. Pursuant to 10 CFR 2.390(b)(4), the following is furnished for consideration by the Commission in determining whether the information in Enclosure 4 should be withheld:
    a. The information has been held in confidence by TerraPower.
    b. The information is of a type customarily held in confidence by TerraPower and not customarily disclosed to the public. TerraPower has a rational basis for determining the types of information that it customarily holds in confidence and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application and substance of that system constitute TerraPower policy and provide the rational basis required.
    c. The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR 2.390, it is received in confidence by the Commission.
    d. This information is not available in public sources.
    e. TerraPower asserts that public disclosure of this non-public information is likely to cause substantial harm to the competitive position of TerraPower, because it would enhance the ability of competitors to provide similar products and services by reducing their expenditure of resources using similar project methods, equipment, testing approach, contractors, or licensing approaches.

I declare under penalty of perjury that the foregoing is true and correct.
Executed on: April 13, 2023

George Wilson

George Wilson
Vice President, Regulatory Affairs
TerraPower, LLC

ENCLOSURE 2

“SAS4A/SASSYS-1 As Evaluation Model for Natrium In-Vessel DBA and LBEs without Radiological Release”
Presentation Material – Open Meeting

Non-Proprietary (Public)

SAS4A/SASSYS-1 As Evaluation Model for Natrium In-Vessel DBA and LBEs without Radiological Release

a TerraPower & GE-Hitachi technology

NAT-3365

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

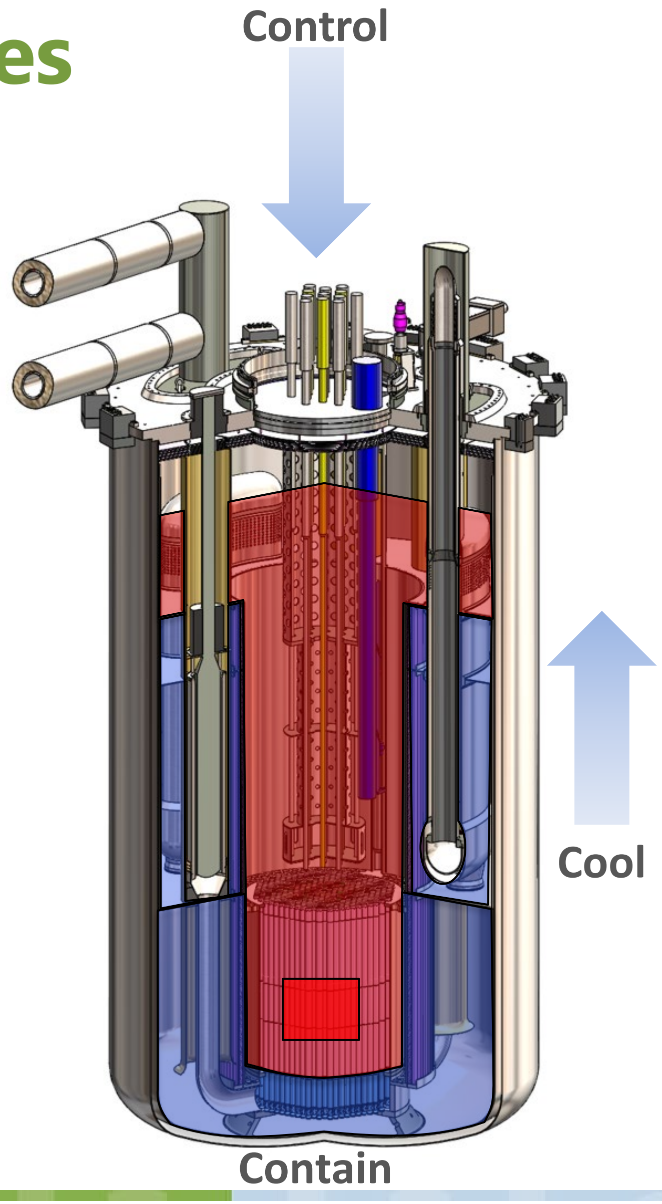
Natrium™ Reactor Overview

- The Natrium project is demonstrating the ability to design, license, construct, startup and operate the Natrium reactor.

- Pre-application interactions are intended to reduce regulatory uncertainty and facilitate the NRC's understanding of the Natrium design and its safety case.

Natrium Safety Features

- Pool-type Metal Fuel SFR with Molten Salt Energy Island
  - Metallic fuel and sodium have high compatibility
  - No sodium-water reaction in steam generator
  - Large thermal inertia enables simplified response to abnormal events
- Simplified Response to Abnormal Events
  - Reliable reactor shutdown
  - Transition to coolant natural circulation
  - Indefinite passive emergency decay heat removal
  - Low pressure functional containment
  - No reliance on Energy Island for safety functions
- No Safety-Related Operator Actions or AC power
- Technology Based on U.S. SFR Experience
  - EBR-I, EBR-II, FFTF, TREAT
  - SFR inherent safety characteristics demonstrated through testing in EBR-II and FFTF



Control

- Motor-driven control rod runback and scram follow
- Gravity-driven control rod scram
- Inherently stable with increased power or temperature

Cool

- In-vessel primary sodium heat transport (limited penetrations)
- Intermediate air cooling natural draft flow
- Reactor air cooling natural draft flow – always on

Contain

- Low primary and secondary pressure
- Sodium affinity for radionuclides
- Multiple radionuclides retention boundaries

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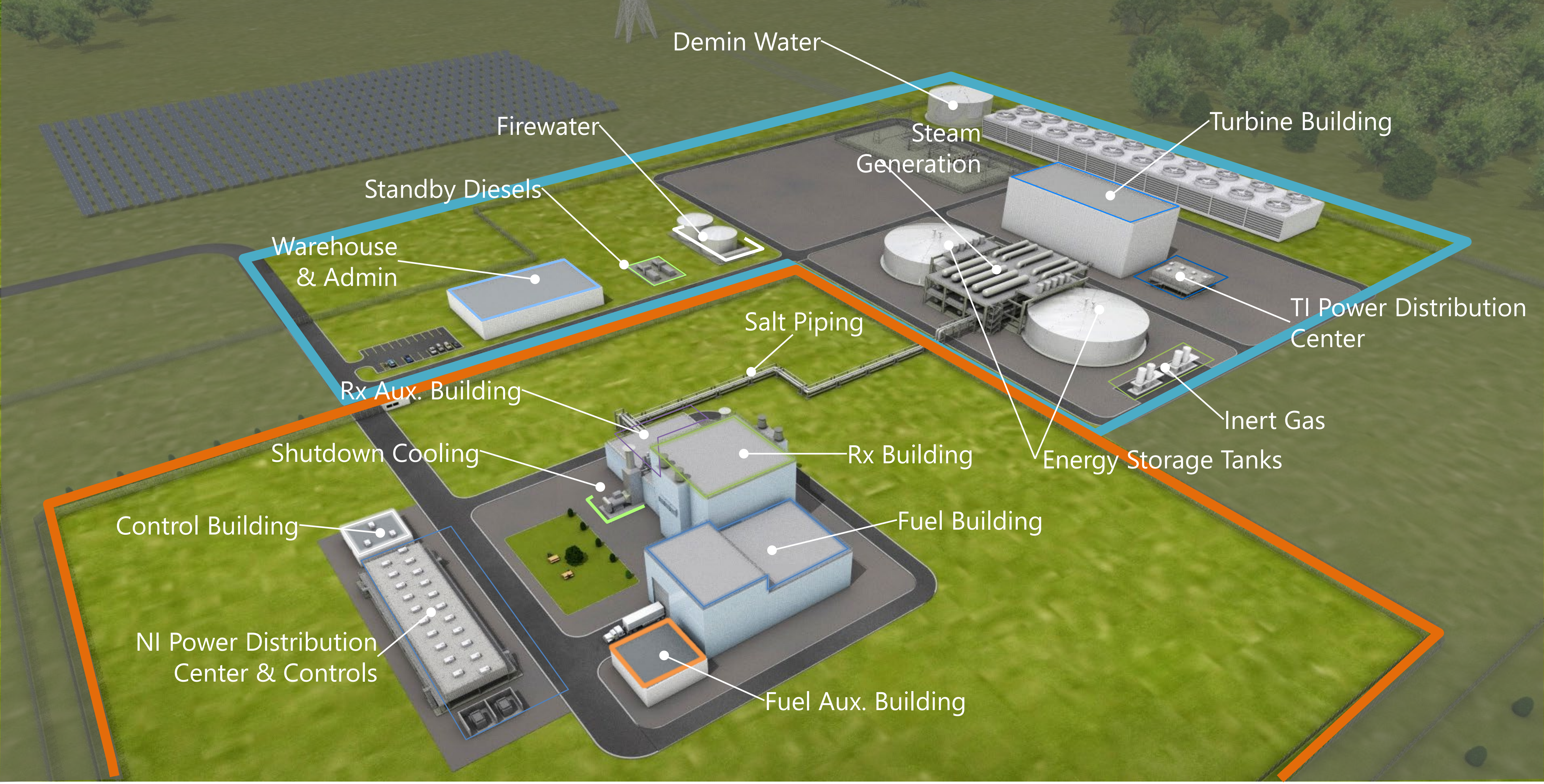
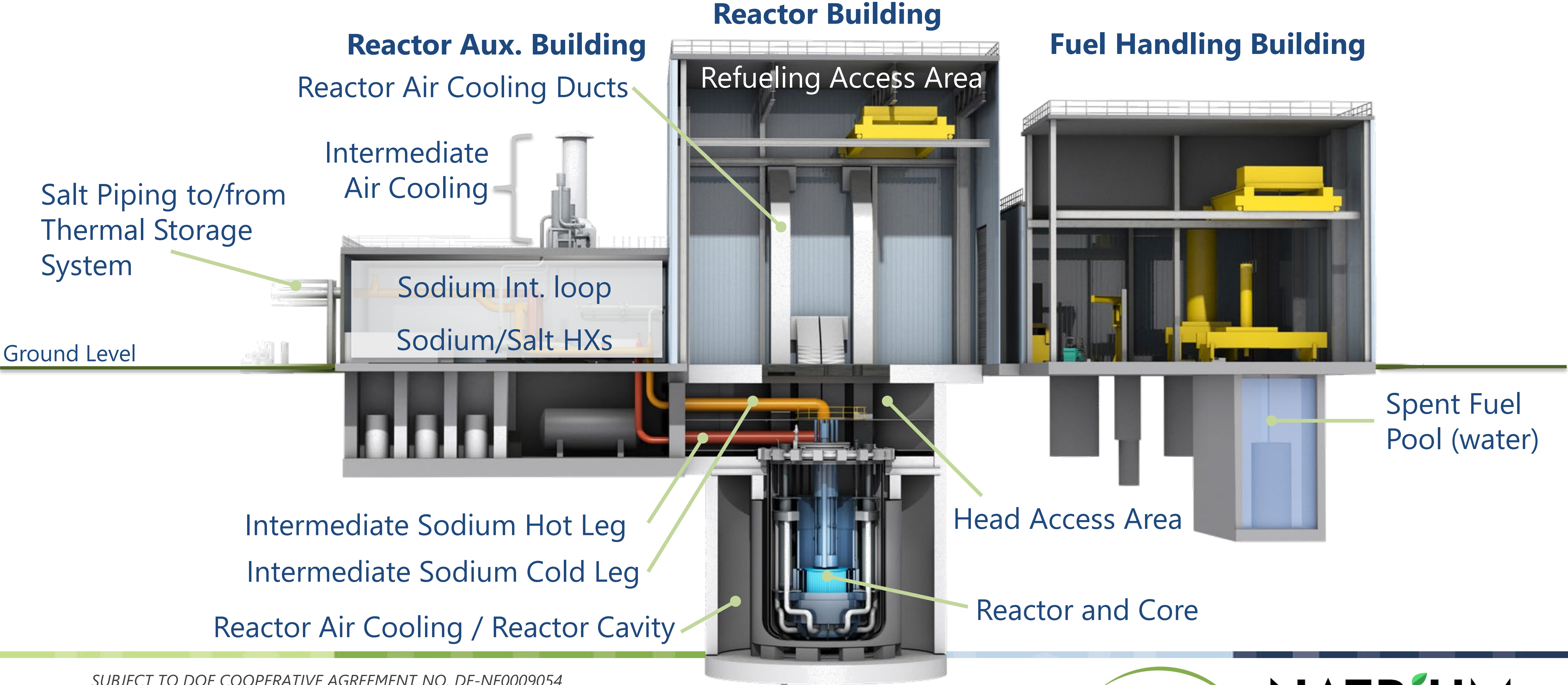

Demin Water
Firewater
Steam
Generation
Turbine Building
Standby Diesels
Warehouse
& Admin
Salt Piping
TI Power Distribution
Center
Rx Aux. Building
Inert Gas
Shutdown Cooling
Rx Building
Energy Storage Tanks
Control Building
Fuel Building
NI Power Distribution
Center & Controls
Fuel Aux. Building

Plant Overview



TerraPower NATRIUM

Presentation Objectives

- To share what has been done and what is planned for the SAS4A/SASSYS-1 EM:
  – Summary of Code Capabilities, Documentation, Quality Assurance, etc.
  – Selection for analysis of in-vessel LBEs and DBAs without fuel failure.
- To receive comments on EM to date:
  – Appropriateness of complying with RG 1.203 (EMDAP) and NUREG-1737
  – TerraPower evaluation of the EM
  – Activities taken to support code adequacy

Agenda

- Code Background and History
- Code Documentation, Structures, Models and Correlation
- Code Quality Pedigree in ANL
- Code Benchmarks

SAS4A/SASSYS-1 Background and History

- SAS4A/SASSYS-1 computer code is developed by ANL for LMR transient analysis
  - Originally developed to support CRBRP licensing
  - SAS4A: Consequence assessment in severe accidents
  - SASSYS-1: Safety margin assessment in DBA and ATWS scenarios
- Development continued during the Integral Fast Reactor program (metallic fuel)
- Heavy liquid metal coolant options added during the Advanced Accelerator Applications program
  - Water versions developed in NPR and international programs
- Modeling validated by applications to testing data from TREAT, EBR-II, and FFTF
- Previous version (2.0) has been exported: Germany, Japan, France, Italy, Russia; additional validation with CABRI test data
- Current version is 5.6.0, future releases are planned

Summary of Code Capabilities

Core Channel Model
Single – Subchannel

Fast Steady-State Solver

Transients
AOO – DBA – ATWS

Plant Control System

Liquid Metal Coolants
Na, NaK, LBE, Pb

Point Kinetics
Live Decay Heat

3D Reactivity Feedback
Doppler
Coolant Density
User-Defined
Axial Fuel Expansion
Axial Clad/Duct Expansion
Radial Expansion
Grid Plate Expansion
CRDL Expansion
Vessel Expansion
Plant Control

Primary Coolant System
Pipes – Pumps – Valves

Inlet – Outlet Plena
with or without cover gas

Coupling with CFD

Decay Heat Removal Systems

Reactor Vessel Cooling

Intermediate Coolant System
Pipes – Pumps – Valves

Component-to-Component Heat Transfer

Pumps
Homologous – Electromagnetic

Intermediate Heat Exchangers
Table Lookup – Detailed

Steam Generators
Table Lookup – Detailed

Fuel Restructuring

In-Pin
Fuel Melting / Relocation

Cladding Failure

Ex-Pin
Fuel Relocation / Freezing

Molten Clad (oxide)
Relocation – Freezing

Sodium Boiling

Code Documentation

Part I: Using SAS4A/SASSYS-1	
	1. Introduction
	2. SAS4A/SASSYS-1 User's Guide
Part II: Whole-Plant Analysis	
	3. Core Thermal-Hydraulics
	4. Reactor Point Kinetics, Decay Heat, and Reactivity Feedback
	5. Primary and Intermediate Loop Thermal Hydraulics Module
	6. Control System
	7. Balance of Plant

Part III: Fuel Performance	
	8. DEFORM-4: Steady-state and Transient Pre-Failure Pin Behavior
	9. DEFORM-5: Metallic Fuel Cladding Transient Behavior Model
	10. SSCOMP: Pre-Transient Characterization of Metallic Fuel Pins
	11. FPIN2: Pre-Failure Metal Fuel Pin Behavior Model
Part IV: Failure Modeling	
	12. Coolant Voiding
	13. CLAP: Cladding Motion Model
	14. PLUTO2: Non-Voided Channel Fuel Motion Analysis
	15. PINACLE: In-Pin Pre-Failure Molten Fuel Relocation Module
	16. LEVITATE: Voided Fuel Motion

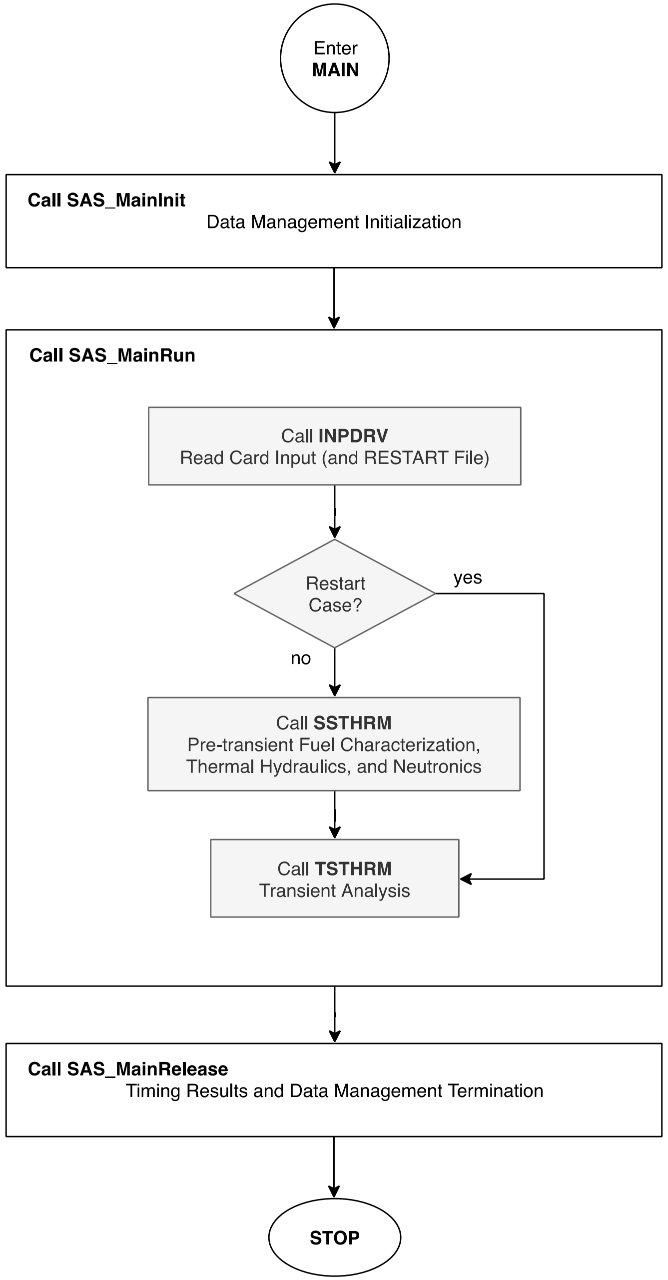
Other Supportive Code Documentation

- ANL/NSE-22/11, Rev. 2, SAS4A/SASSYS-1 Validation with EBR-II Tests Performed During the SHRT Testing Program, 2023
- ANL/NSE-22/15, SAS4A/SASSYS-1 Acceptance Testing Report for Sodium Fast Reactor Applications, 2023.
- ANL/NSE-22/16, SAS4A/SASSYS-1 Commercial Grade Dedication Example Report for a Generic Sodium Pool Fast Reactor Application, 2023.
- NL/NSE-22/17, Rev. 1, SAS4A/SASSYS-1 Validation with the FFTF Tests, 2023
- IAEA TECDOC 1703, Benchmark Analyses on the Natural Circulation Test Performed During the Phenix End-of-Life Experiments, 2013
- IAEA-TECDOC-1819, Benchmark Analysis of EBR-II Shutdown Heat Removal Tests, 2017
- "Modeling of Safety Basis Events in the VTR," T. Sumner, et al., *Nuclear Science and Engineering,* (196) 2022.
- "Multiscale Modelling of the Phénix Dissymmetric Test Benchmark," H. J. Uitslag-Doolaard, et al., *Nuclear Engineering and Design, (356) 2019.*
- SAS-SQAP-1 Rev. 1, Software Quality Assurance Plan SAS4A/SASSYS-1 (Argonne internal), 2022

TerraPower NATRIUM

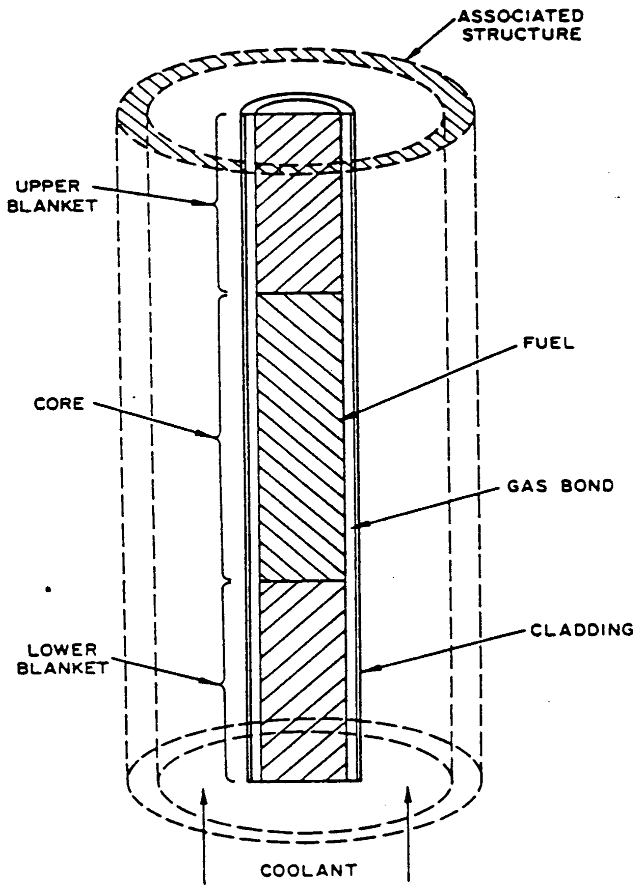
Code Structure, Models, and Correlations

- Coupling of the core with the heat transport system (PRIMAR-4)
- Main program flow:
  - Initialize
    - Input Processing and Memory Allocation
  - Solve
    - Steady State (SS): Core then PRIMAR-4 then Control
    - Transient (TR): Reactor Power then Control then PRIMAR-4 then Core
  - Clean up
- Program structure mirrors program flow
  - Memory structure is a mix of common blocks and allocated data structures
  - Modules and procedures are organized by physics/systems



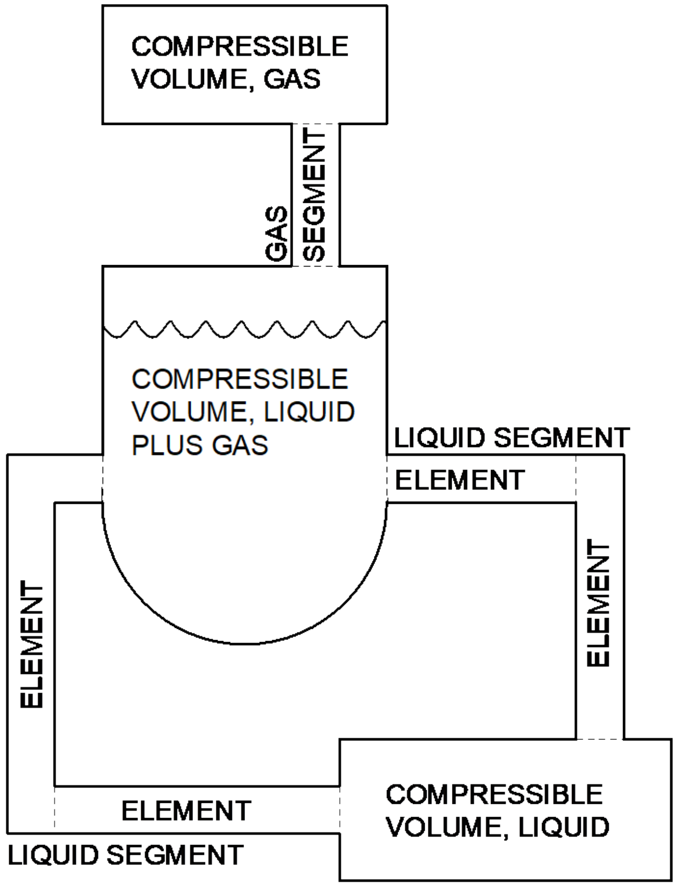
Core Channel Model

- Core channel is single-pin representation of one or more assemblies in the core
- One-dimensional, radial heat transfer at many axial locations
- Radial conduction through the fuel and cladding; conduction and radiation across the fuel/cladding gap
- Convective boundary condition to the axially flowing coolant from the cladding and the structure
- Initial, steady state conditions for the coolant mass flow and the axially-dependent channel power
- Steady state channel pressure drop in all channels adjusted to match the peak channel pressure drop with addition of a channel-dependent inlet orifice coefficient
- Transient channel flows computed from time-dependent inlet-to-outlet plena pressure drop



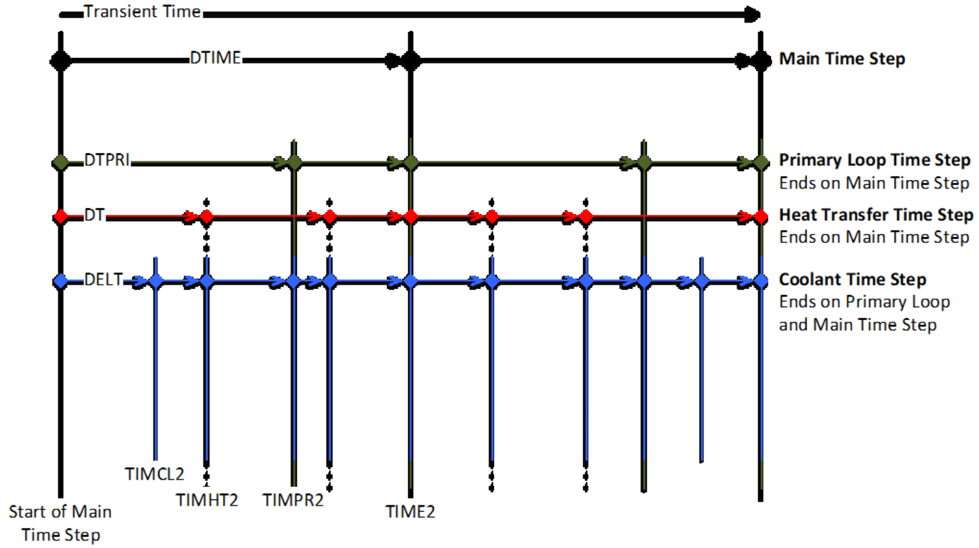
PRIMAR-4 Coolant Systems Model

- Thermal and hydraulic model for primary, intermediate, and decay heat removal systems
  - Forced and natural circulation
- General arrangement of volumes connected by segments
  - Volumes are perfectly mixed, compressible liquid with or without cover gas
  - Flow segments divided into elements for hydraulics simulation and into temperature groups for heat transfer
- Element models for pipes, pumps, valves, heat exchangers, steam generators, air dump heat exchangers, and more…
- Steam cycle modeling optional



Multi-level Time Steps

- All time steps in SAS synchronize on the main (power or reactivity) time step
  - Point kinetics predicts power over the next main time step
  - Heat transfer routines predict temperatures based on power
  - Hydraulic routines predict coolant flow and pressure drop



Single-phase Average Channel Hydraulics (SS/TR)

Momentum equation over the length of the channel:

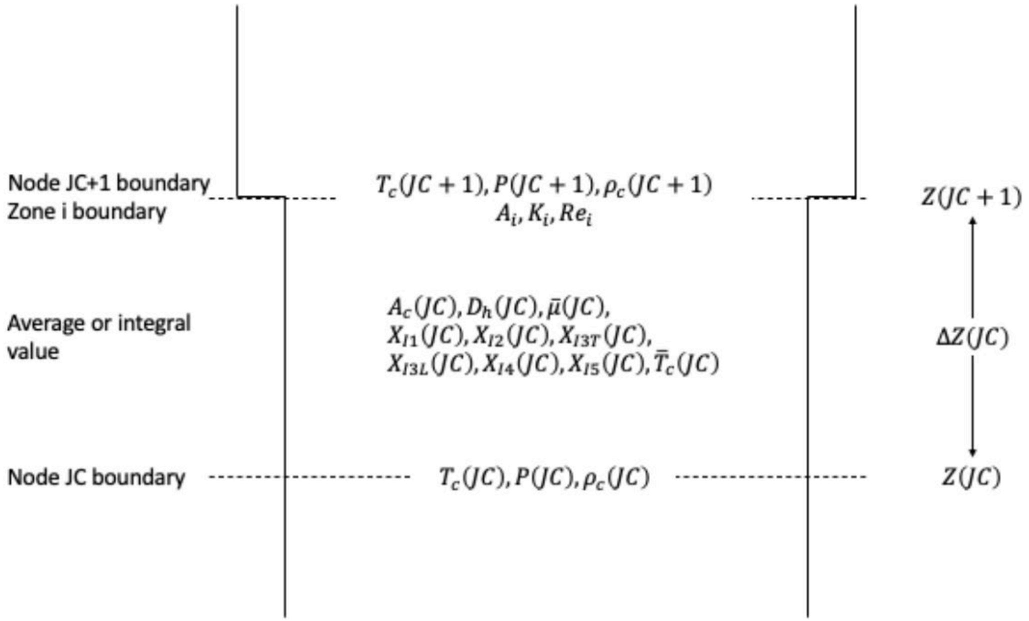
$$\frac{1}{A_c}\frac{\partial w}{\partial t}+\frac{\partial p}{\partial z}+\frac{1}{A_c}\frac{\partial (wv)}{\partial z}=-\left(\frac{\partial p}{\partial z}\right)_{fr}-\left(\frac{\partial p}{\partial z}\right)_{K}-\rho_c g$$

Solution approach:

$$\frac{\Delta w}{\Delta t}=\theta_1 f(w)+\theta_2 f(w+\Delta w)$$

User-defined friction factor correlations:

$$f=\begin{cases} A_{fr}(Re)^{b_{fr}}, & Re > Re_{TR} \\ \frac{A_{fl}}{Re}(1-\psi)^{C_1}(1-\psi^{C_2})+A_{fr}(Re)^{b_{fr}}\psi^{C_3}, & Re_L \le Re \le Re_{TR} \\ \frac{A_{fl}}{Re}, & Re > Re_L \end{cases}$$



Available orifice options:

$$K_{or}(JC)=\begin{cases} K_F(JC), w \ge 0 \\ K_B(JC), w < 0 \end{cases}$$

$$K_i(Re_i)=\begin{cases} C_1 + C_2 {Re_i}^{C_3} \\ C_1 + C_2 exp(Re_i C_3) \end{cases}$$

Steady State Single-phase Average Channel Temperature

Axial coolant temperature:

$$w_c \frac{\partial T}{\partial z} = Q(z) A_c$$

$$Q(z) = Q_{fuel}(z) + Q_c(z) + Q_{sc}(z)$$

Radial boundary condition:

$$Q_{fuel}(z) = h_c\big(T(NE') - T(NC)\big)\frac{2\pi r(NE')}{A_c}$$

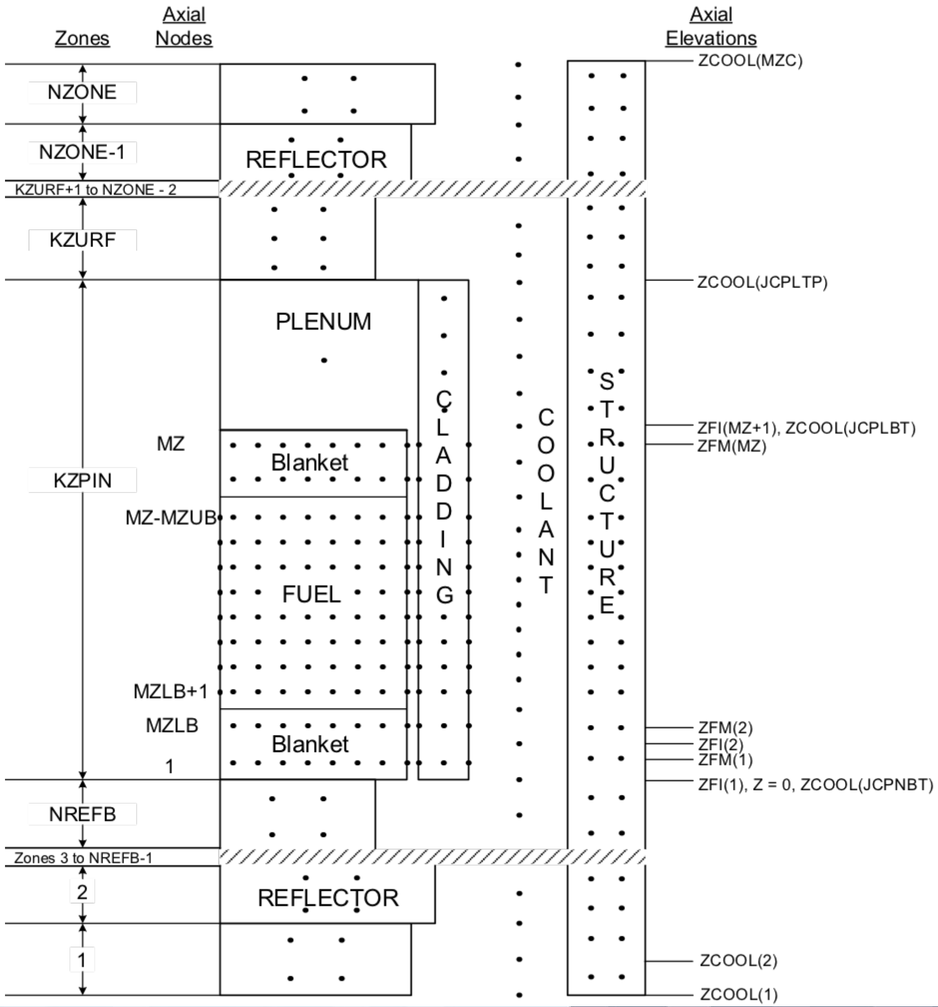
$$Q_{sc}(z) = h_c\big(T(NSI) - T(NC)\big)\frac{S_{st}}{A_c}$$

User-defined heat transfer coefficient:

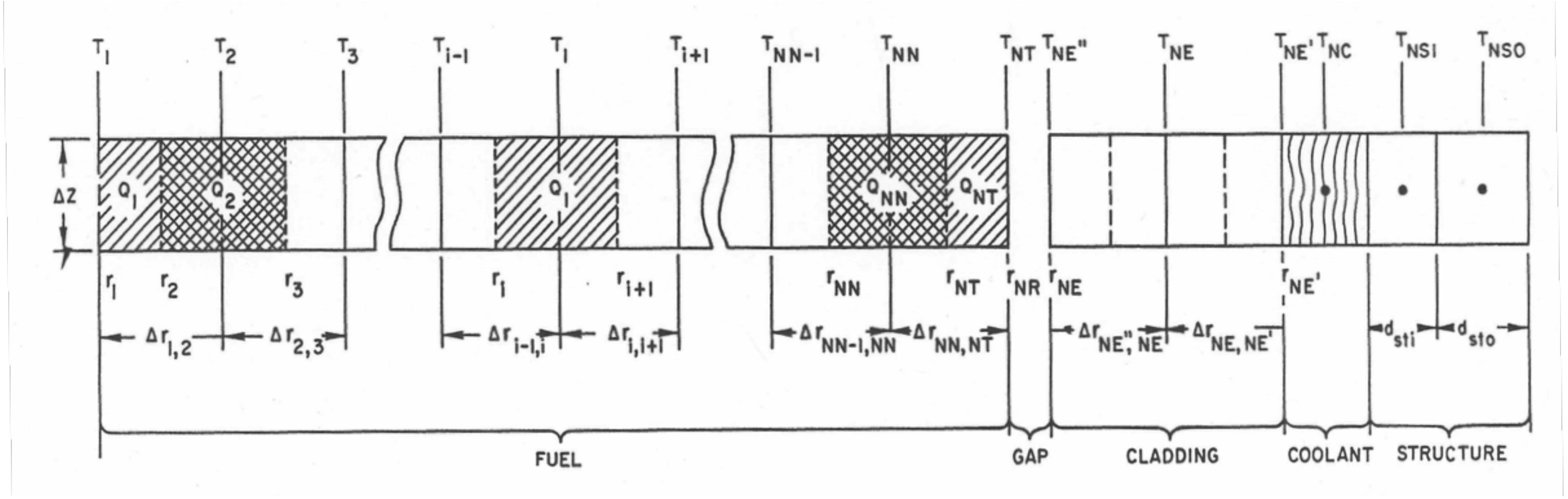
$$h_c = \frac{k}{D_h}\left(C_1\left[\frac{D_h w c}{k\ A}\right]^{C_2} + C_3\right)$$

Radial fuel/clad temperature:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) = -Q(r,z)$$



Core Channel Transient Temperature



Energy equation:

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) + Q$$

Solution method:

$$\frac{\partial T}{\partial t} = \frac{T(t+\Delta t) - T(t)}{\Delta t}$$

$$\frac{\partial T}{\partial r} = \theta_1 \frac{T(t, r+\Delta r) - T(t,r)}{\Delta r} + \theta_2 \frac{T(t+\Delta t, r+\Delta r) - T(t+\Delta t, r)}{\Delta r}$$

PRIMAR-4 Segment Hydraulics

Momentum equation over the length of the segment:

$$\frac{1}{A}\frac{\partial w}{\partial t}+\frac{\partial p}{\partial z}+\frac{1}{A}\frac{\partial (wv)}{\partial z}=\left(\frac{\partial p}{\partial z}\right)_{pump}-\left(\frac{\partial p}{\partial z}\right)_{fr}-\left(\frac{\partial p}{\partial z}\right)_{K}-\left(\frac{\partial p}{\partial z}\right)_{valve}-\rho g$$

Solution method:

$$\frac{\Delta w}{\Delta t}=\theta_1 f(w)+\theta_2 f(w+\Delta w)$$

Friction factor correlation:

$$f=\begin{cases}0.0055\left[1+\left(20000\frac{\epsilon(k)}{D_H(k)}+\frac{10^6}{Re}\right)^{\frac{1}{3}}\right] & Re \geq 1082 \\ \frac{64}{Re} & Re < 1082\end{cases}$$

Available orifice options:

$$K_{or}(E)=\begin{cases}K_{or}(E), w \geq 0 \\ K_{or}(E), w < 0\end{cases} \qquad K_i(Re_i)=\begin{cases}C_1+C_2 {Re_i}^{C_3}, Kind=1 \\ C_1+C_2 exp(Re_i C_3), Kind=2\end{cases}$$

Pipe-Like Element Temperatures

Semi-implicit Lagrangian formulation:

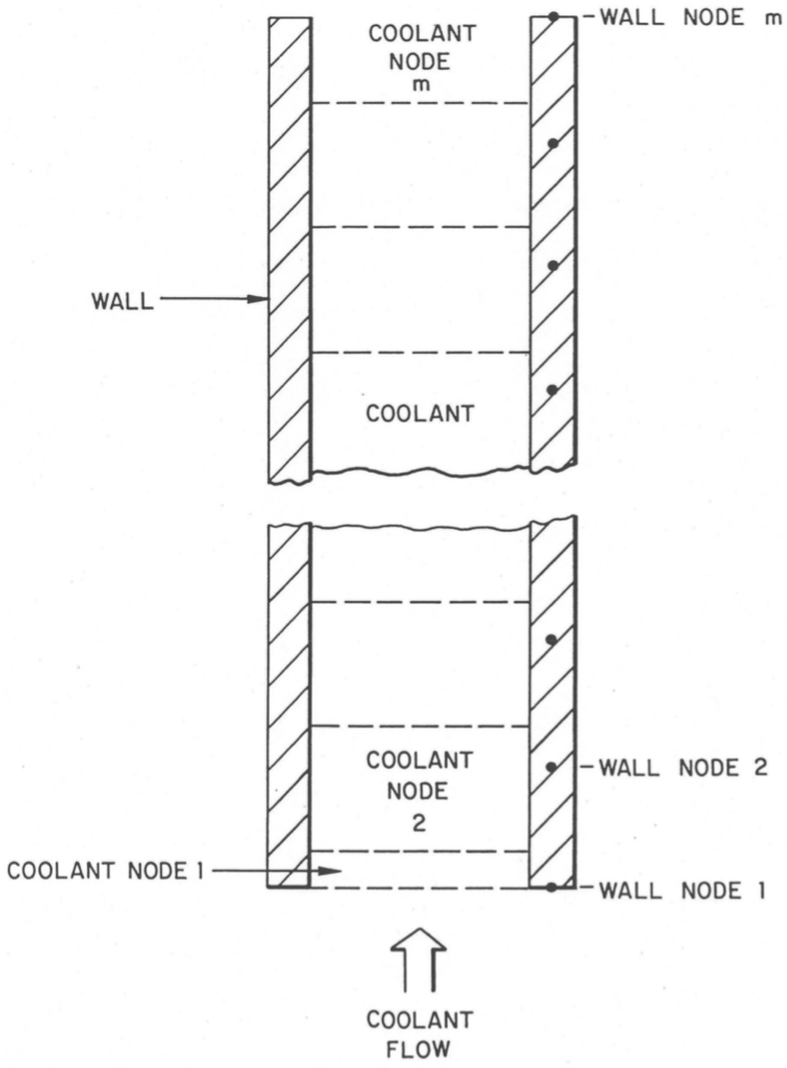
$$\rho c \frac{\partial T_c}{\partial t} = P_{er} h_{wc}(T_w - T_c) + q'_c$$

$$M_w c_w \frac{\partial T_w}{\partial t} = P_{er} h_{wc}(T_c - T_w) + (hA)_{snk}(T_{snk} - T_w) + q'_w$$

User-defined heat transfer coefficient:

$$h_{wc} = (h_c^{-1} + h_w^{-1})^{-1}$$

$$h_c = \frac{k}{D_h}\left(C_1 \left[\frac{D_h w c}{k\ A}\right]^{C_2} + C_3\right)$$



SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Heat Exchanger Element

Semi-implicit Eulerian formulation:

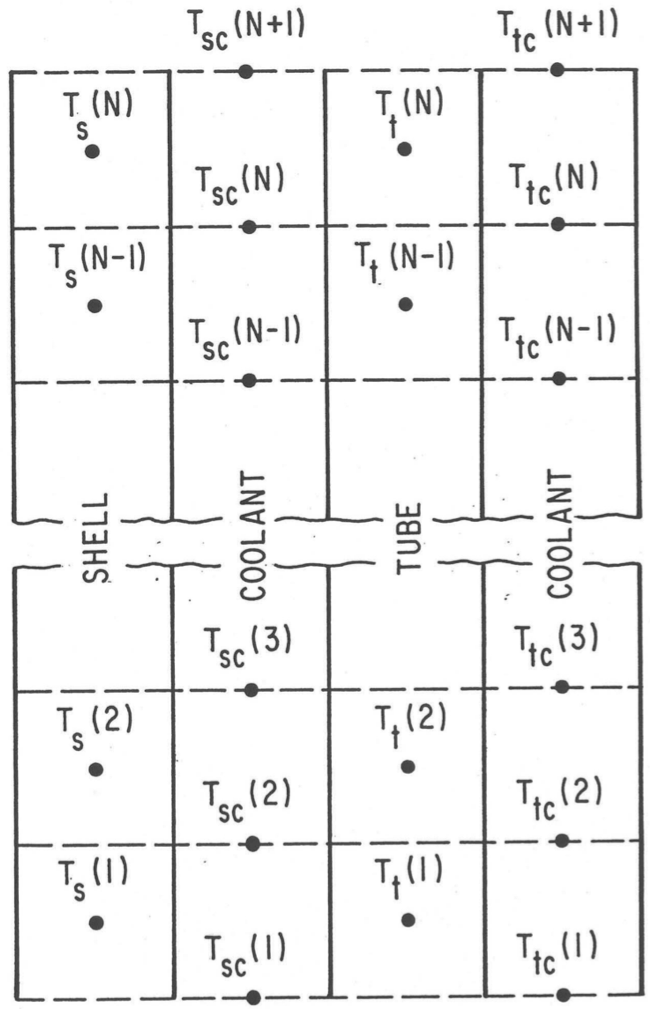
Equations omitted for brevity

Effective heat transfer coefficient:

$$H_s = \left(h_{cs}^{-1} + \left(\frac{2k_{sh}}{d_{sh}}\right)^{-1} + h_{fs}^{-1}\right)^{-1}$$

User-defined heat transfer coefficient:

$$h_{cs} = \frac{k}{D_h}\left(C_1 \left[\frac{D_h w}{\mu A}\right]^{C_2} \left[\frac{c\mu}{k}\right]^{C_4} + C_3\right)$$

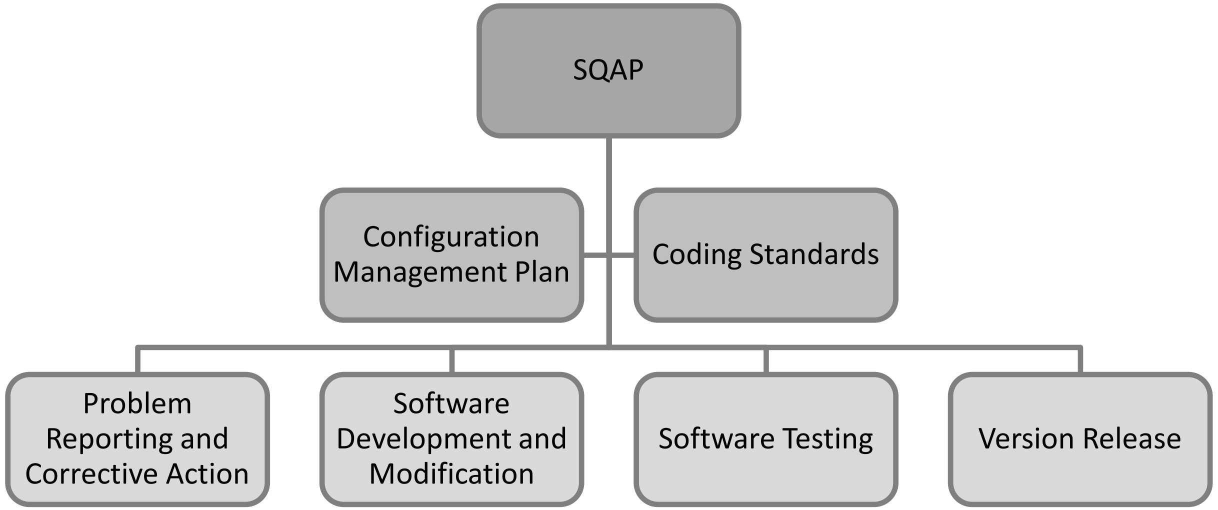


Quality Pedigree in ANL

- Formal SQA Program implemented in 2018 in ANL
- Targets NQA-1-2008/2009 and DOE O 414.1D requirements
- Includes standard software lifecycle elements and development best practices:
  - Configuration management
  - Software requirements, design, testing, review/approval
  - Procedural workflows for new developments, problem reporting and corrective actions, version releases, acceptance testing
- SQA best practices informally utilized since 2012
  - Version control, acceptance/regression testing
  - Majority of historical development efforts accompanied by V&V

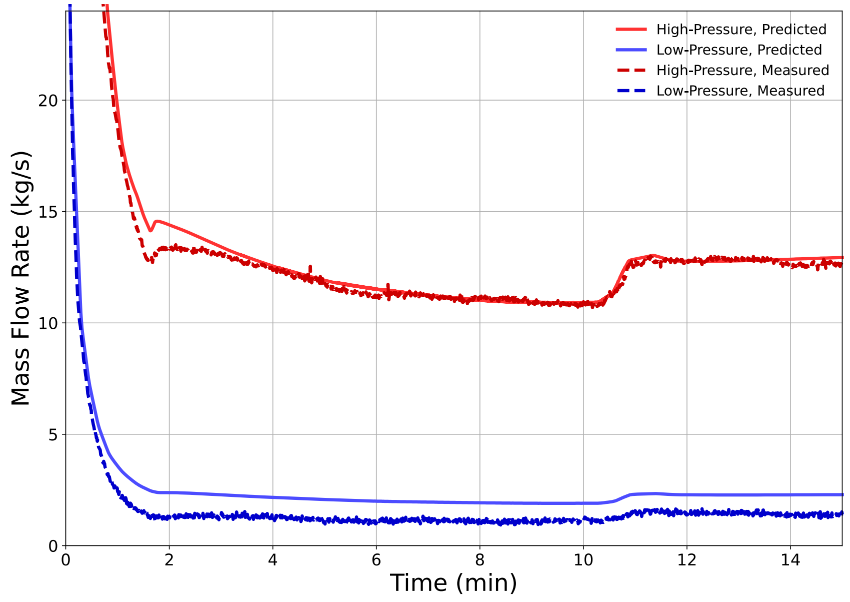
Quality Pedigree in ANL

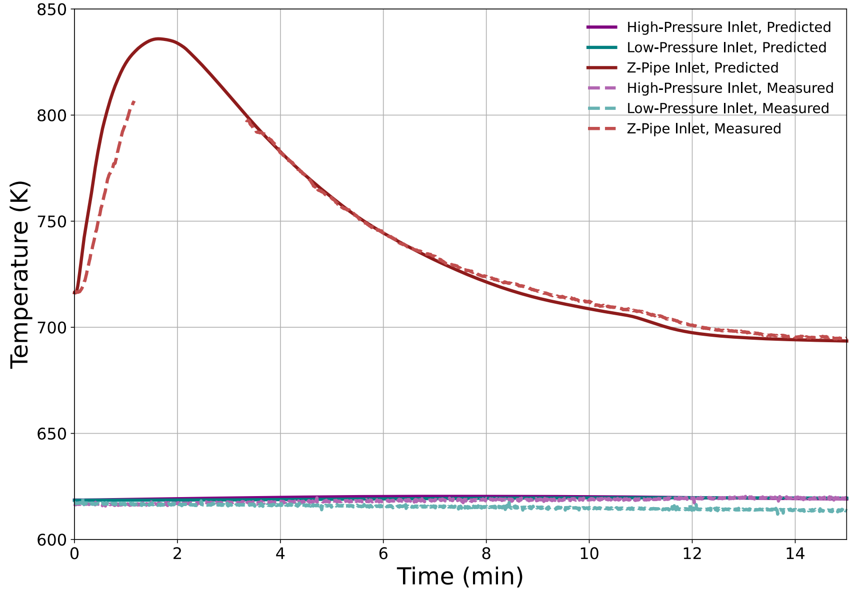
- SAS SQAP addresses all aspects of software life cycle with exception of retirement



Code Benchmarks: EBR-II

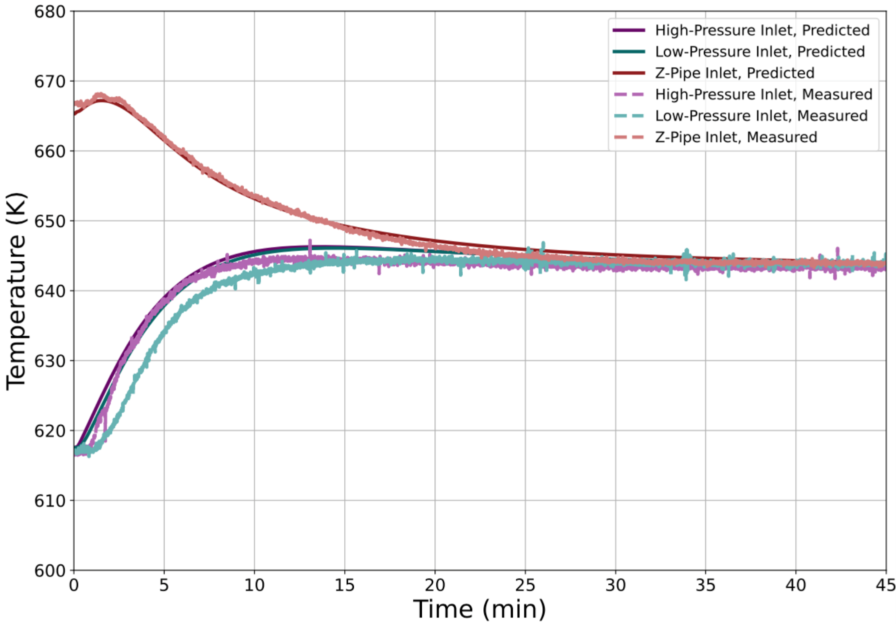
- SHRT-17
  - Most severe Protected Loss of Flow
  - Demonstrated how natural phenomena can protect the reactor by maintaining adequate flow during protected accidents (e.g. thermal expansion of sodium & thermal inertia of the pool)
- SHRT-45R
  - Most severe Unprotected Loss of Flow
  - Demonstrated how natural phenomena can shut down the fission process during unprotected accidents (e.g. thermal expansion of the core)
- SAS Validation Results
  - Flow rates are well-predicted for both tests
    - Modeling of pump locking is key
  - Temperatures well-predicted for both tests
  - For SHRT-45R, with reactivity feedback and point kinetics models activated, agreement with measured data is still good
  - Reasons for discrepancies with measured data are well understood

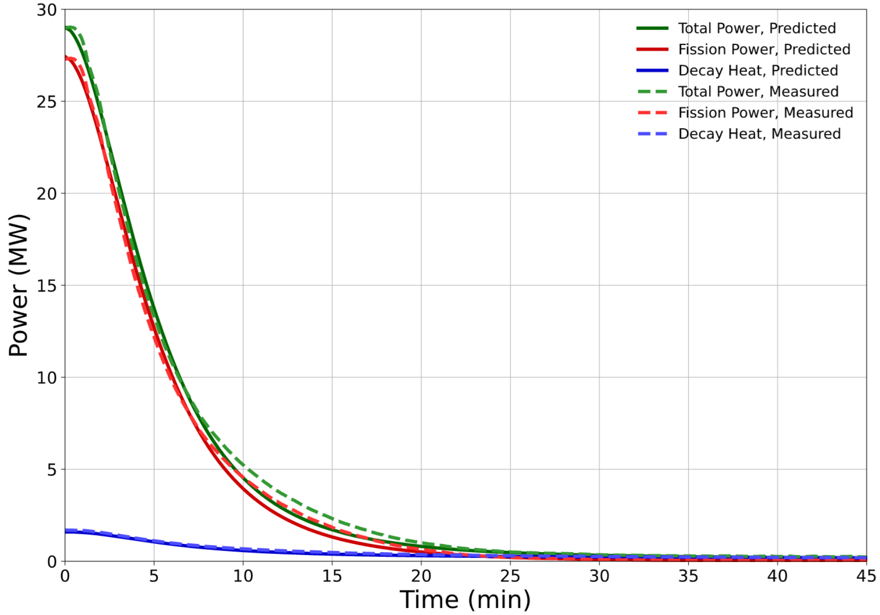




Code Benchmarks: EBR-II

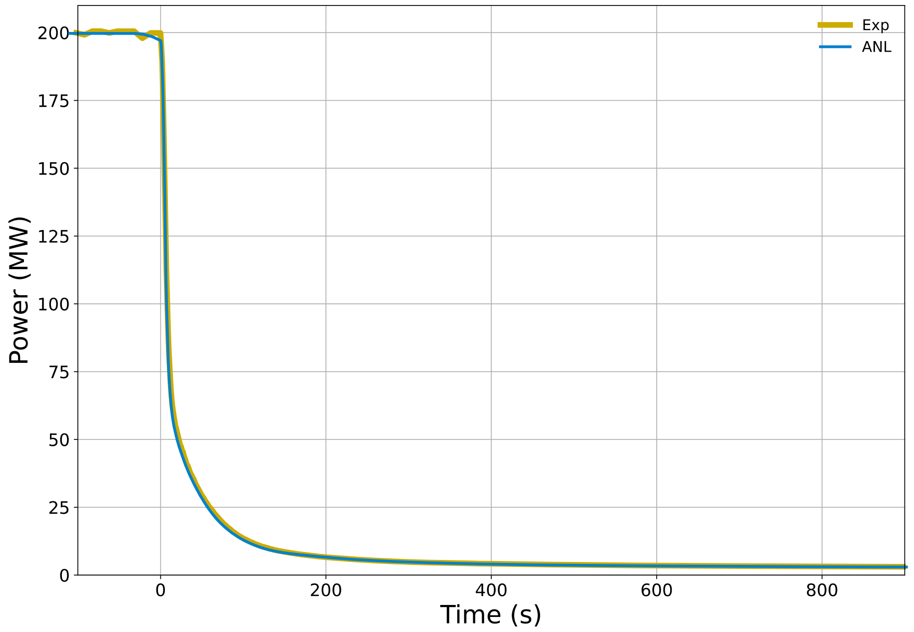
- BOP-301
  - Half power Unprotected Loss of Heat Sink
- BOP-302R
  - Most severe Unprotected Loss of Heat Sink
- Evaluated to validate model for different transient conditions
  - SHRT-45R driven by changing core flow while core inlet temp remained relatively constant
  - BOP tests driven by changing for inlet temp while core flow remained constant
- SAS Validation Results
  - Very good agreement achieved between simulation predictions and measured data
  - Capturing cold pool mixing with 0D volumes was key

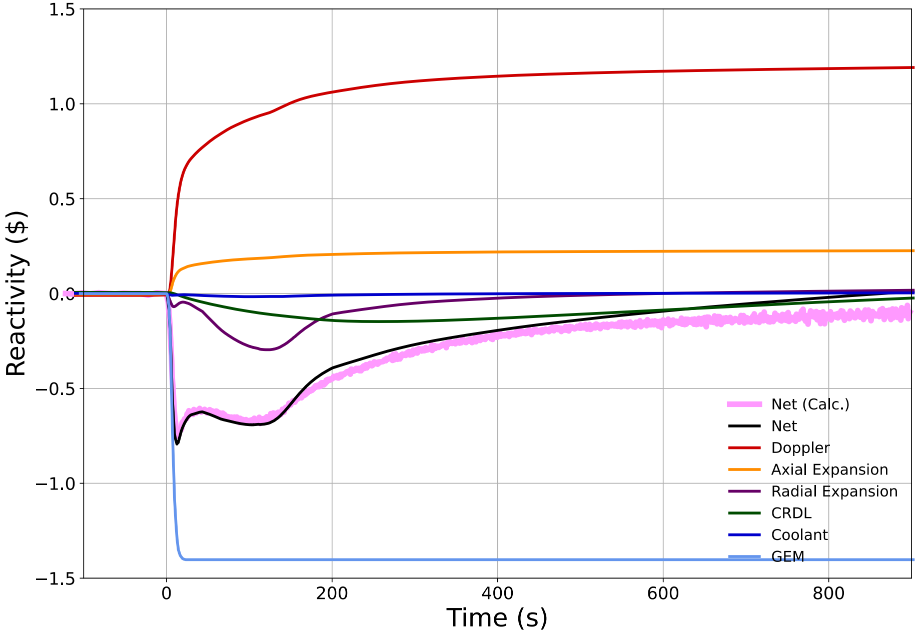




Code Benchmarks: FFTF

- Series of Unprotected Loss of Flow tests
  - LOFWOS Tests #10-13
  - Test #13 is subject of soon-to-be-completed IAEA CRP
- Demonstrated the effectiveness of:
  - GEMs as a shutdown device
    - Important for oxide fueled core
  - Limited free bow core restraint system
- SAS Validation Results
  - Final predictions for power (total, fission, decay heat) agree very well with measured/reference data
  - Flows during coastdown and natural circulation well predicted
  - Temperatures also well predicted by the model, especially in proximity to the core
    - Temperature discrepancies investigated and well understood





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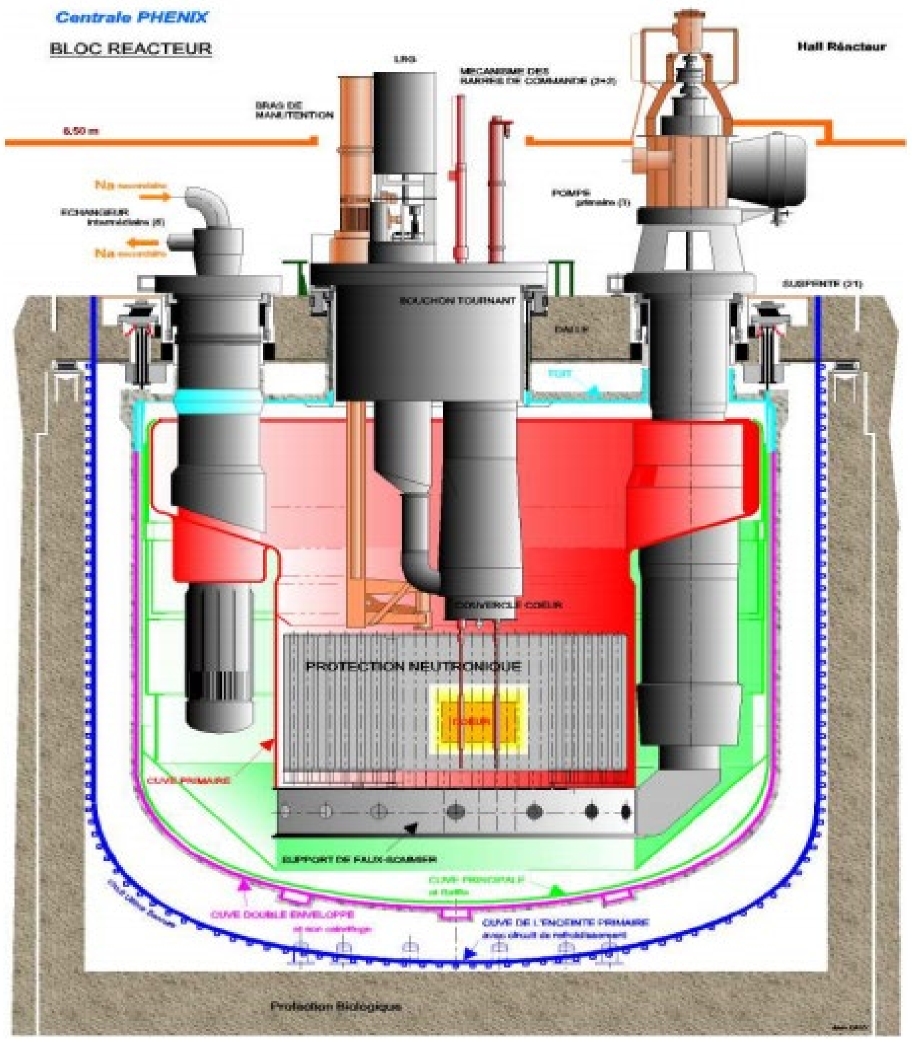
Code Benchmarks: Phénix

- Natural Circulation test conducted in 2009, scenario similar to a protected loss-of-heat sink event, with an extended period before scram to demonstrate the negative reactivity feedback features of the core
- SAS captured system temperature trends well (primary pump inlet, IHX primary inlet/outlet, average core outlet)
  - Discrepancies due to inability of system codes to capture localized effects (e.g. IHX outlet window stratification, recirculation at core exit)

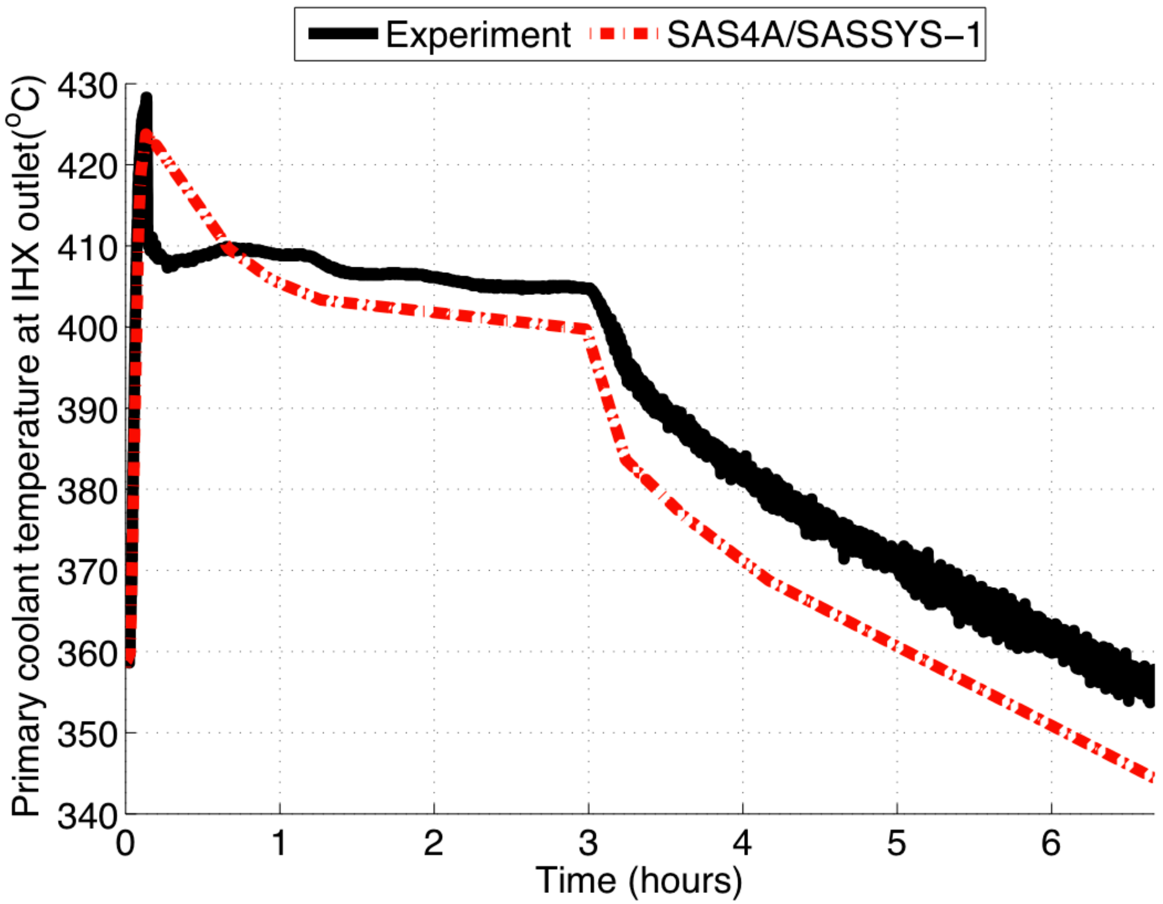


TerraPower NATRIUM

Code Benchmarks: Phénix

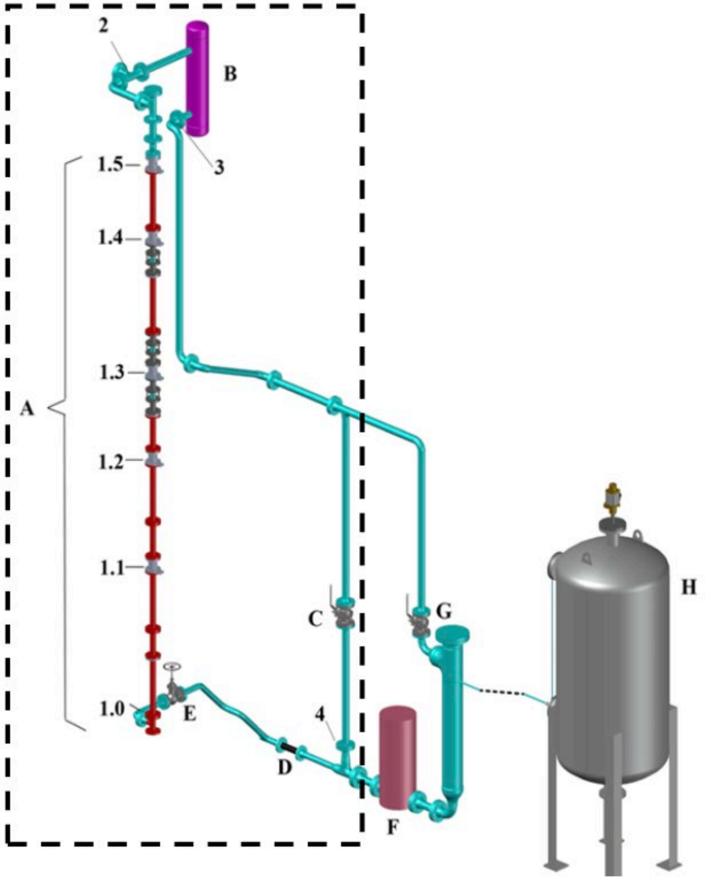
IHX Primary Outlet Temperature

- Measurements show a sudden drop of ~20 C soon after the pump trip
  - Not predicted by the model
- May be due to thermal stratification of sodium in the IHX outlet window.
  - The thermocouple is located in the bottom of the window, with the coolest sodium
  - The model only predicts the mean value



Code Benchmarks: UIUC

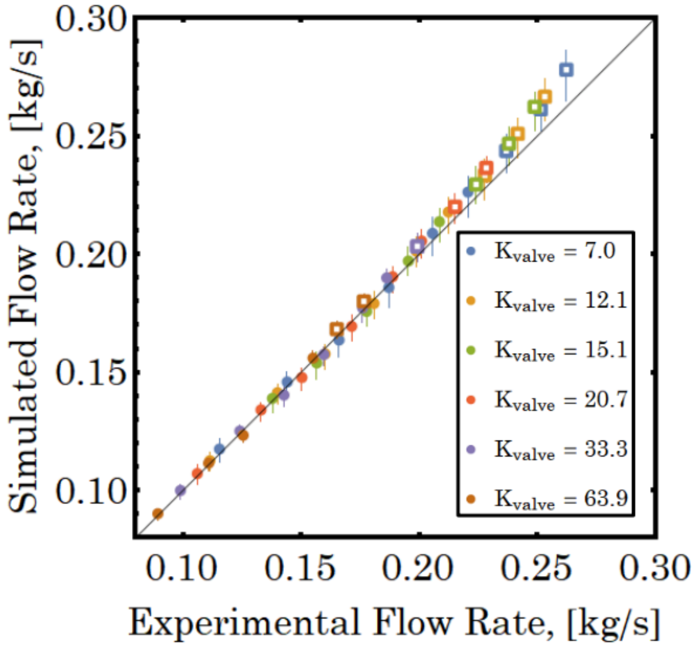
- SS Single-Phase Natural Circulation Tests
- Steady-state, single-phase water loop designed to demonstrate natural circulation under various conditions with well-characterized hydraulic losses and experimental uncertainties
  - 47 tests
  - Measurements include flow rate, pressure, fluid temperature at several locations. Visual inspection used to confirm single-phase conditions
  - Boundary conditions include power and ball valve position



Code Benchmarks: UIUC

Comparative Results:

- Discrepancies between simulations and measured data are well-bounded by maximum experimental uncertainty
- Tests are differentiated for cases where nucleation was observed at end of heated section (represented by open markers in figure)



Parameter	Mean Relative Discrepancy [-]	
	Condition #1-33	Condition #34-47
Mass flow rate	1.33%	3.41%
Fluid temperature, Port 5	0.78%	0.43%
Absolute pressure, Port 5	0.04%	0.05%
Pressure drop, Port 4 to Port 5	0.15%	0.13%

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References

- T. H. Fanning, A. J. Brunett, and T. Sumner, eds., The SAS4A/SASSYS-1 Safety Analysis Code System, ANL/NE-16/19, Nuclear Engineering Division, Argonne National Laboratory, March 31, 2017.
- T. Sumner, “SAS4A/SASSYS-1 Validation with EBR-II Tests Performed During the SHRT Testing Program,” ANL/NSE-22/11 Rev. 1, 2022.
- R. Thomas, T. Sumner, and A. Moisseytsev, “SAS4A/SASSYS-1 Validation with the FFTF LOFWOS Tests #10-12,” ANL/NSE-22/17, 2022.
- C. S. Brooks, T. Zhang, and T. H. Fanning, “Validation of SAS4A/SASSYS-1 for Steady-State Single-Phase Natural Circulation,” ANL/NSE-22/53, 2020.
- J. W. Thomas, et al., “Analysis of the Phénix End-of-Life Natural Convection Test with SAS4A/SASSYS-1,” *Proceedings of ICAPP ’12*, Chicago, 2012.

Questions?

TerraPower NATRIUM

Acronym List

AAA - Advanced Accelerator Applications
ANL - Argonne National Laboratory
AOO - Anticipated Operational Occurrence
ATWS - Anticipated Transients without Scram
BDBE - Beyond Design Basis Event
BOEC - Beginning of Equilibrium Cycle
CIP - Cabri International Project
CGD - Commercial Grade Dedication
CRBRP - Clinch River Breeder Reactor Plant
CRDM - Control Rod Drive Mechanism
DBA - Design Basis Accident
DBE - Design Basis Event
DID - Defense in Depth
DR1 - Design Reference One
EBR - Experimental Breeder Reactor
EM - Evaluation Model
EMDAP - Evaluation Model Development and Application Process
F-C - Frequency-Consequence
FFTF - Fast Flux Test Facility
GEM - Gas Expansion Model
GV - Guard Vessel
HX - Heat Exchanger

IAC - Intermediate Air Cooling
IET - Integral Effect Test
IFR - Integral Fast Reactor
IHT - Intermediate Heat Transport System
IHX - Intermediate Heat Exchanger
ISP - Intermediate Sodium Pump
LBE - Licensing Basis Event
LMR - Liquid Metal Reactor
LOFWOS - Loss of Flow without Scram
LOOP - Loss of Offsite Power
NI - Nuclear Island
NQA - ASME Nuclear Quality Assurance
NSS - Nuclear Island Salt Heat Transport System
NSTF - Natural Convection Shutdown Heat Removal Test Facility
PHT - Primary Heat Transport System
PIRT - Phenomena Identification and Ranking Table
PLOF - Potected Loss of Flow
PRA - Probabilistic Risk Assessment
PRISM - Power Reactor Innovative Small Module
PSP - Primary Sodium Pump

RAC - Reactor Air Cooling System
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RWAP - Rod Withdrawal at Power
RX - Reactor
SET - Separate Effect Test
SFR - Sodium-Cooled Fast Reactor
SHRT - Shutdown Heat Removal Tests
SHX - Sodium Heat Exchanger
SQA - Software Quality Assurance
SQAP - Software Quality Assurance Program
SS - Steady State
SSC - Structures, Systems, and Components
TI - Turbine Island
TR - Transient
TREAT - Transient Reactor Test Facility
UIUC - University of Illinois at Urbana-Champaign
ULOF - Unprotected Loss of Flow
VTR - Versatile Test Reactor

ENCLOSURE 3

"SAS4A/SASSYS-1 As Evaluation Model for Natrium In-Vessel DBA and LBEs without Radiological Release"
Presentation Material – Closed Meeting

Non-Proprietary (Public)

SAS4A/SASSYS-1 As Evaluation Model for Natrium In-Vessel DBA and LBEs without Radiological Release

a TerraPower & GE-Hitachi technology

NAT-3367

Portions of this presentation are considered proprietary and TerraPower, LLC requests it be withheld from public disclosure under the provisions of 10 CFR 2.390(a)(4).

Nonproprietary versions of this presentation indicate the redaction of such information using [[ ]]$^{(a)(4)}$.

Application in Natrium™ Design

- Evaluation of Quality Pedigree and Commercial Grade Dedication
- Evaluation of Code Capabilities and Documentation
- Evaluation of Code Assessment Base
- Nodalization and Modeling of Natrium Plant
- Sample Results for Representative Transients

Evaluation of SAS Code Quality Pedigree

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Commercial Grade Dedication

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Evaluation of SAS Code Capabilities

- SAS includes a wide range of capabilities that have been benchmarked on legacy test facilities, and used to model SFRs during various transients.
- Code-to-code comparison, such as the IAEA reports, indicates that SAS can model important phenomena and can reasonably predict the transient and behaviors when compared to other system computer codes.
- Potential code enhancements have been identified for Natrium applications. Examples include detailed metallic fuels, versatile control functions, expanding material properties, etc.
- Further assessment base development, including new IET and SET(s), is planned to assess code adequacy for Natrium applications and address the important phenomena identified in the PIRT.

Evaluation of SAS Code Documentation

- The current SAS Code Documentation provides detailed information on code capabilities, user's guidance, code structures, models and correlations, input/output parameters, etc. The documentation is effectively used to support SAS code use in Natrium applications with further support from ANL
- The existing SAS code documentation is expected to be revised and enhanced to include the elements as identified in RG1.203 in Appendix B:
  - Theory Manual
  - Models and Correlations
  - User's Manual
  - Programmer's Manual
  - Developmental Assessment Manual

Evaluation of SAS Code Assessment Base

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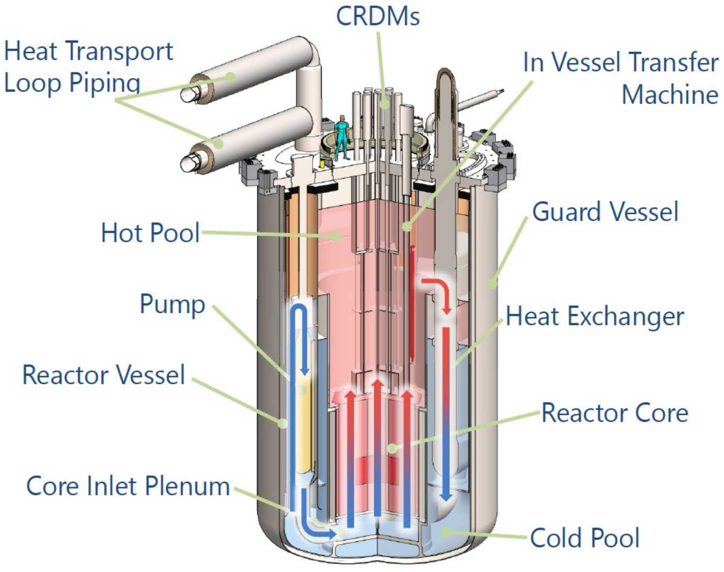
Natrium Modeling in SAS



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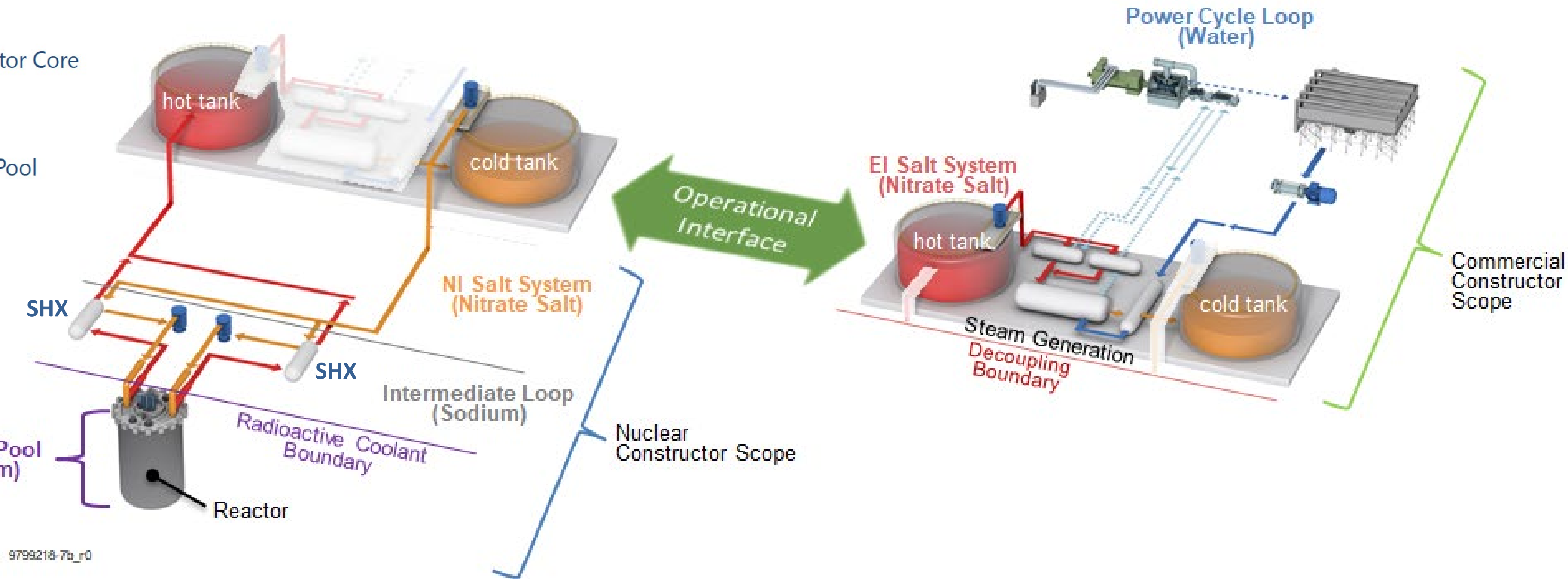

Natrium Plant Model Nodalization

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Natrium Core Model Nodalization

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Sample Transient Analysis

- The following slides present initial transient analysis results from the preconceptual DR1 phase of the Natrium design
  - Single rod withdrawal at power - short term response
  - Loss of offsite power – long term response
  - Loss of SHX

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Sample Transient Analysis – Uncontrolled Rod Withdrawal (Short Term Response)

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Uncontrolled Rod Withdrawal (Short-Term Response)

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Uncontrolled Rod Withdrawal (Short-Term Response)

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Uncontrolled Rod Withdrawal (Short-Term Response)

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Uncontrolled Rod Withdrawal (Short-Term Response)

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Uncontrolled Rod Withdrawal (Short-Term Response)

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Sample Transient Analysis – Loss of Offsite Power (Long Term Response)

- Event sequence (long term response):

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Loss of Offsite Power (Long Term Response)

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Loss of Offsite Power (Long Term Response)

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Loss of Offsite Power (Long Term Response)

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Loss of Offsite Power (Long Term Response)

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Loss of Offsite Power (Long Term Response)

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Sample Transient Analysis – Loss of SHX

- Event sequence (long term response):

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Loss of SHX

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Loss of SHX

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Loss of SHX

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