Advanced Reactor Stakeholder Public Meeting

September 14, 2023

Microsoft Teams Meeting
Bridge line: 301-576-2978
Conference ID: 791 911 650#

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United States Nuclear Regulatory Commission
Protecting People and the Environment

Time	Agenda	Speaker
10:00 – 10:10 am	Opening Remarks	NRC
10:10 – 10:15 am	Advanced Rx. Integrated Schedule	NRC
10:15 – 10:45 am	Computer Code Readiness for Advanced Reactor Applications	NRC
10:45 – 11:15 am	Quality Assurance Program Reviews for Advanced Reactor Applications	NRC
11:15 – 11:25 am	Public Comments	Public
11:25 – 11:30 am	Planning for the Next Meeting and Closing Remarks	Adjourn

Advanced Reactor Integrated Schedule of Activities

The updated Advanced Reactor Integrated Schedule

is publicly available on NRC Advanced Reactors website at:

https://www.nrc.gov/reactors/new-reactors/advanced/integrated-review-schedule.html

Advanced Reactor Program
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Advanced Reactor Integrated Schedule of Activities

Advanced Reactor Program - Summary of Integrated Schedule and Regulatory Activities*

Strategy	Description
Strategy 1	Knowledge, Skills, and Capability
Strategy 2	Computer Codes and Review Tools
Strategy 3	Guidance
Strategy 4	Consensus Codes and Standards
Strategy 5	Policy and Key Technical Issues
Strategy 6	Communication

Legend

Concurrence (Division/Interoffice)	● EDO Concurrence Period
Federal Register Publication	Commission Review Period**
Public Comment Period	▼ ACRS SC/FC (Scheduled or Planned)
Draft Issuance of Deliverable	External Stakeholder Interactions
Final Issuance of Deliverable	↓ Public Meeting (Scheduled or Planned)

Version 9/7/23

Present Day

Strategy	Regulatory Activity	Commission Papers	Guidance	Rulemaking	NEIMA	Complete	2022 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2023 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Development of non-Light Water Reactor (LWR) Training for Advanced Reactors (Adv. Rxs) (NEIMA Section 103(a)(5))					x																								
	FAST Reactor Technology				x	x																								
	High Temperature Gas-cooled Reactor (HTGR) Technology				x	x																								
	Molten Salt Reactor (MSR) Technology				x	x																								
	Competency Modeling to ensure adequate workforce skillset					x																								
	Identification and Assessment of Available Codes					x																								
	Development of Non-LWR Computer Models and Analytical Tools																													
	Code Assessment Reports Volume 1 (Systems Analysis)					x																								
	Reference plant model for Heat Pipe-Cooled Micro Reactor					x																								
	*Reference plant model for Sodium-Cooled Fast Reactor (update from version 1 to 2)****																													
	*Reference plant model for Molten-Salt-Cooled Pebble Bed Reactor (update from version 1 to 2)****					x																								
	Reference plant model for Monolith-type Micro-Reactor																													
	*Reference plant model for Gas-Cooled Pebble Bed Reactor (update from version 1 to 2)****					x																								
	*Reference plant model for Molten-Salt-Fueled Thermal Reactor (update from version 1 to 2)****																													
	Code Assessment Reports Volume 2 (Fuel Perf. Anaylsis)					x																								
	FAST code assessment for metallic fuel					x																								
	FAST code assessment for TRISO fuel					x																								
	Code Assessment Reports Volume 3 (Source Term					x																								
	Non-LWR MELCOR (Source Term) Demonstration Project					x									↓															
	Reference SCALE/MELCOR plant model for Heat Pipe-Cooled Micro Reactor					x																								
	Reference SCALE/MELCOR plant model for High-Temperature Gas-Cooled Reactor					x																								
	Reference SCALE/MELCOR plant model for Molten Salt Cooled Pebble Bed Reactor					x																								
	Reference SCALE/MELCOR plant model for Sodium-Cooled Fast Reactor					x																								

https://www.nrc.gov/reactors/new-reactors/advanced/integrated-review-schedule.html

NRC Readiness for Advanced Reactor Systems Analysis

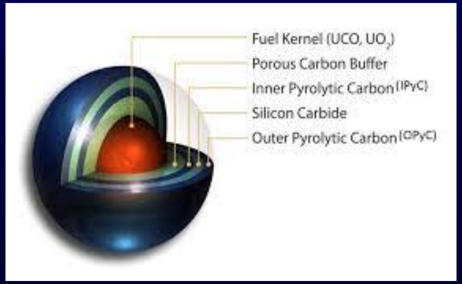
Stephen M. Bajorek, Ph.D.
Senior Technical Advisor for Thermal-Hydraulics
Office of Nuclear Regulatory Research
United States Nuclear Regulatory Commission

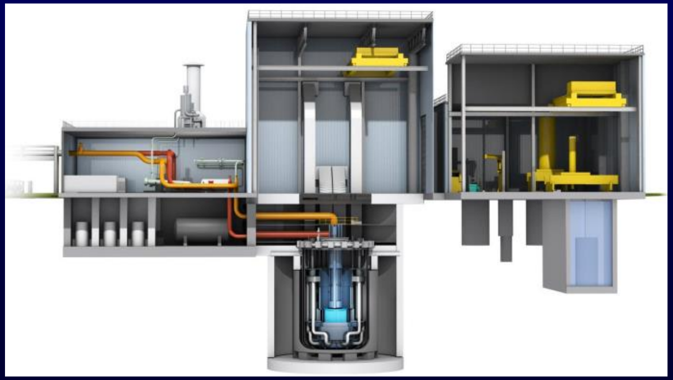
Advanced Reactor Stakeholder Meeting

September 14, 2023

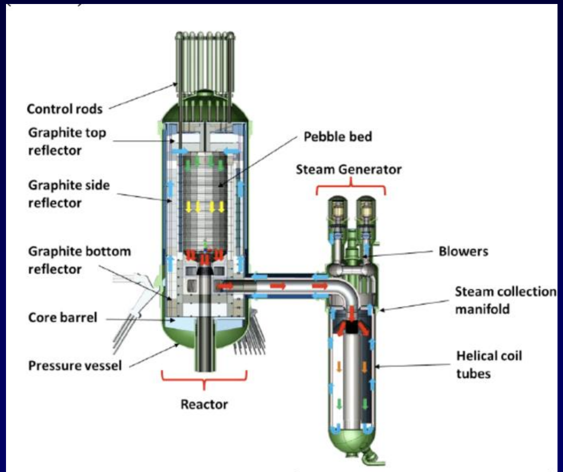
Exciting Times for Nuclear

- ✓ Many designs under development.
- ✓ Multiple technologies.

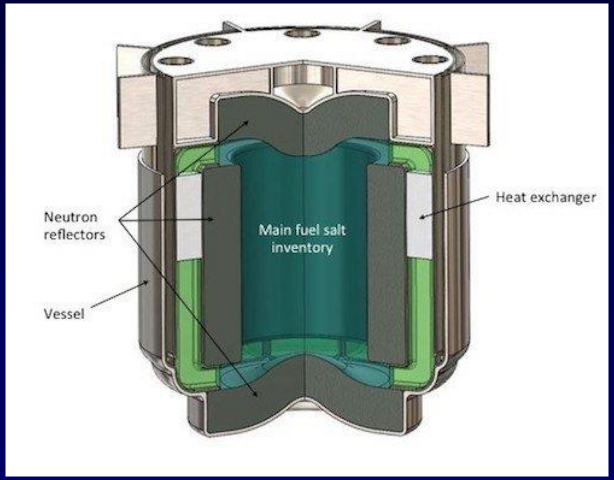


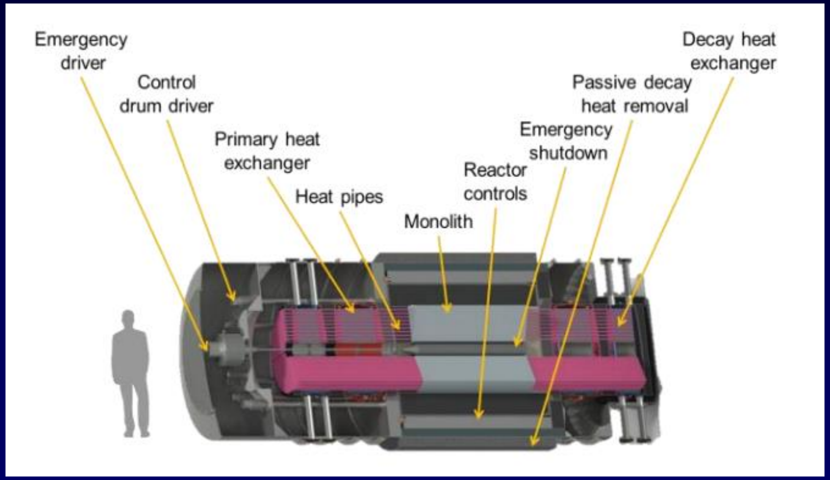


Key mission for NRC is to be prepared . . . for any & all.



Xe-100 Reactor System Configuration (Courtesy of X-energy, with permission)





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NRC's Integrated Action Plan (IAP) for Advanced Reactors

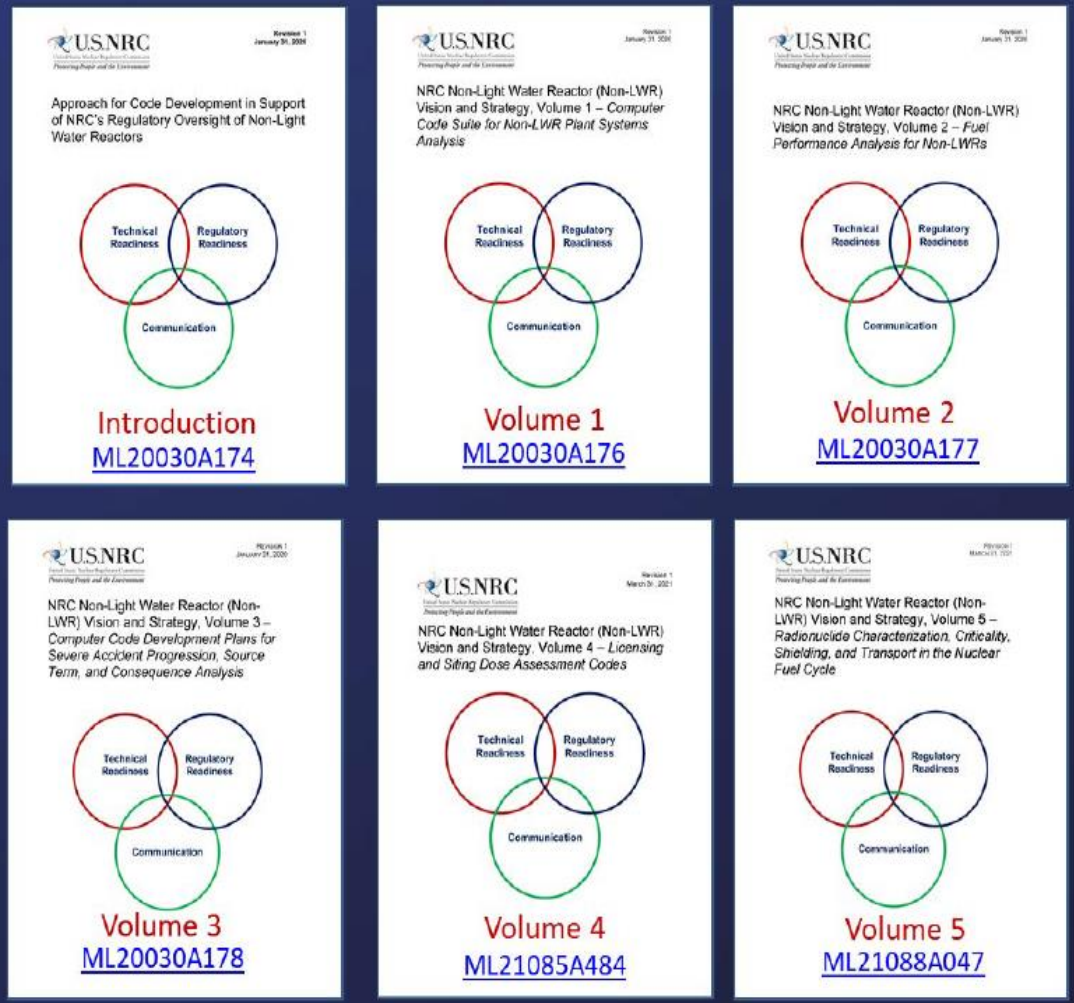
Near-Term Implementation Action Plan

- **Strategy 1** – Knowledge, Skills, and Capacity
- **Strategy 2** – Computer Codes
- **Strategy 3** – Flexible Review Process
- **Strategy 4** – Industry Codes and Standards
- **Strategy 5** – Technology Inclusive Issues
- **Strategy 6** – Communication

Independent Analysis Capability

Advanced Reactor Code Development Reports

- These Volumes outline the specific analytical tools to enable independent analysis of non-LWRs, technical “gaps” in capabilities, V&V needs.
- Gaps in experimental data are currently being identified.



Volume 1: Systems Analysis and Design Basis Event Simulation

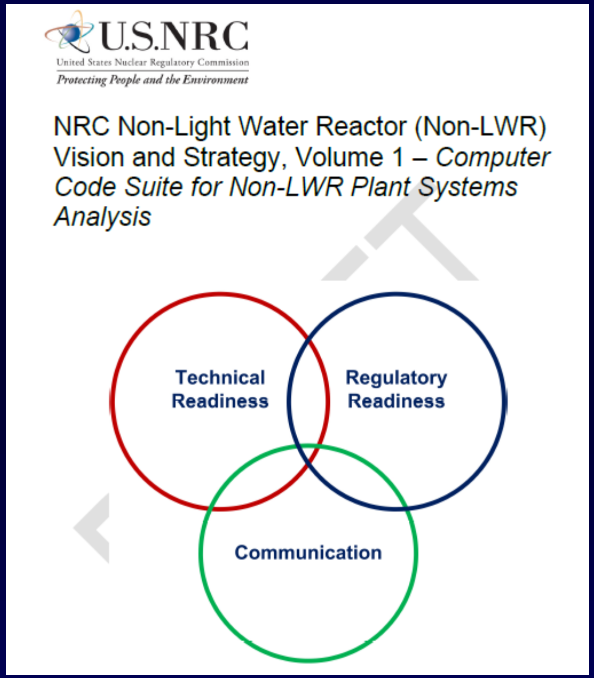
– Volume 1 activities are designed to:

1. Identify analysis codes and code development needs for non-LWRs. Address known deficiencies.

2. Develop a set of “reference plant models” that :

   A. Test the capability of analysis codes (i.e. find flaws now)
   B. Generate models that can be quickly modified to represent the “real design.”

3. Perform a range of “design basis” simulations.
   - Unprotected Loss of Flow (ULOF)
   - Unprotected Loss of Heat Sink
   - Design specific (i.e. Heat Pipe Failure)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NRC Non-Light Water Reactor (Non-LWR) Vision and Strategy, Volume 1 – *Computer Code Suite for Non-LWR Plant Systems Analysis*

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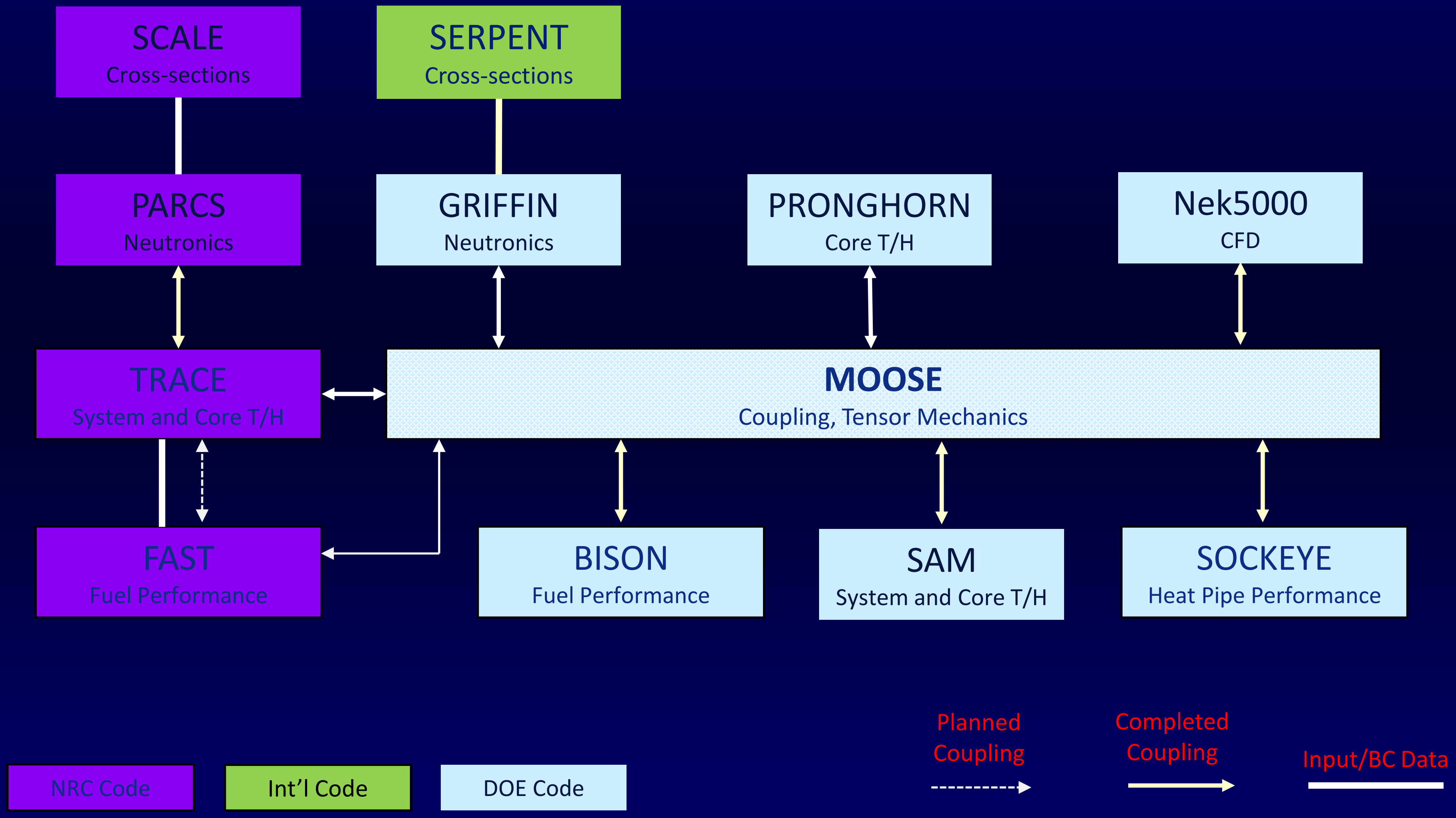
"Comprehensive Reactor Analysis Bundle"
BlueCRAB



Current View; Sept 2023

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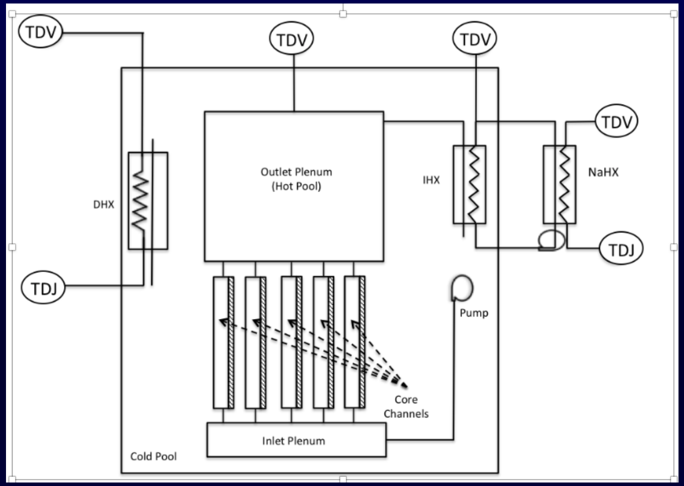
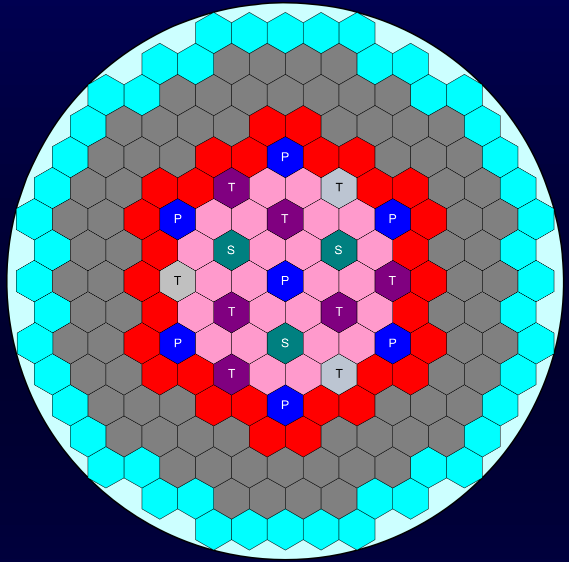
Multiphysics Coupling

SAM: System Level Thermo-Fluids



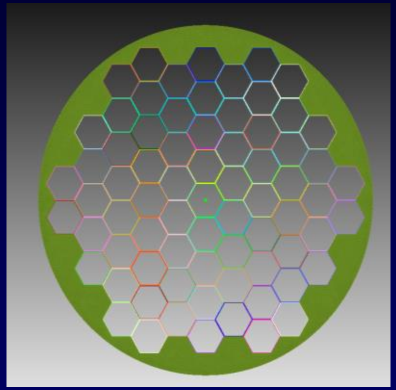
Griffin: Reactor Kinetics



Temperatures & Densities

Power

Temperatures



Displacements

Tensor Mechanics Module

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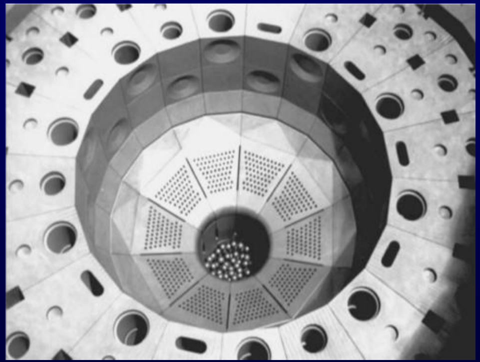
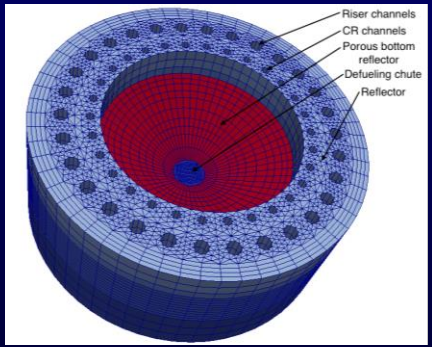
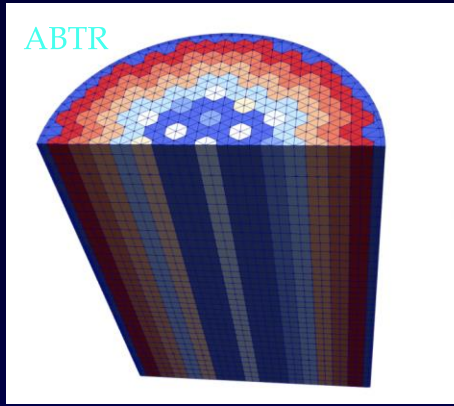
Reference Model Development

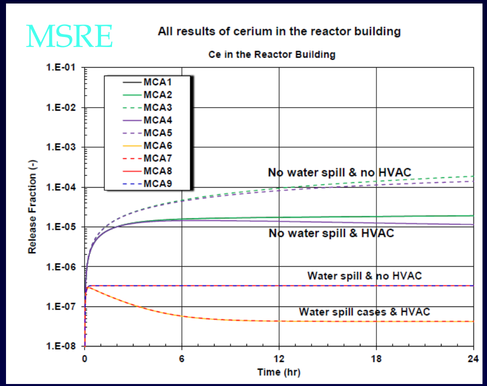
- Reference Models - Generic representation of a design type, based on publicly available information.
- Scenarios “of interest” are selected (loss-of-flow, loss-of-heat sink, rapid reactivity insertion).
- Simulations performed to demonstrate code capabilities and identify deficiencies before licensing reviews begin.

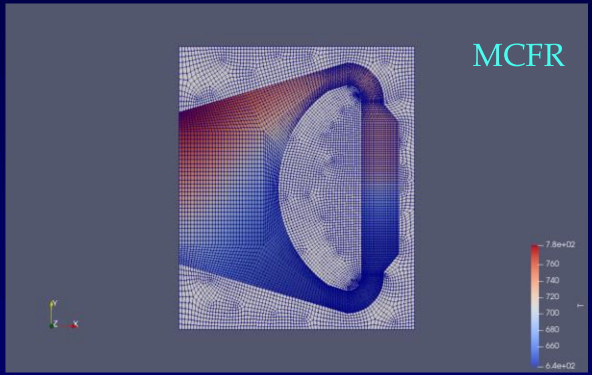


HTR-10









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Advanced Reactors
Three-Phased Approach for Confirmatory Models

Stage 1 – Generic Readiness for a Reactor Technology	Code infrastructure development, reference plant model/source term demonstration, generic models that benefit all non-LWR designs (IAP Strategy 2 Volumes)
Stage 2 – Readiness for a Specific Application	Model build of a preapplication based design)
Stage 3 – Model build, Analysis, and Review of a specific application under licensing review	Conduct confirmatory analysis, generation of RAIs, and input to SER

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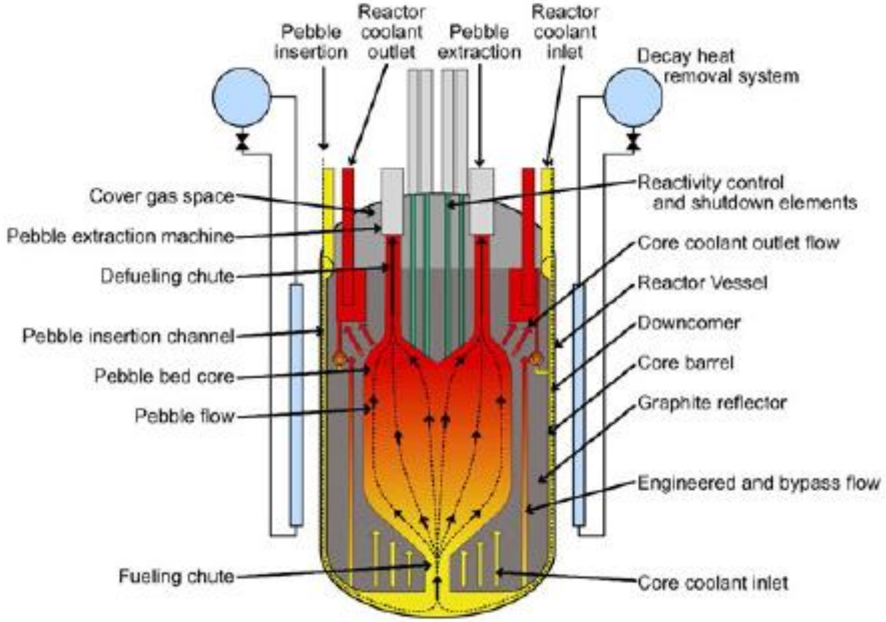
Reference Plant Models: Quick Status

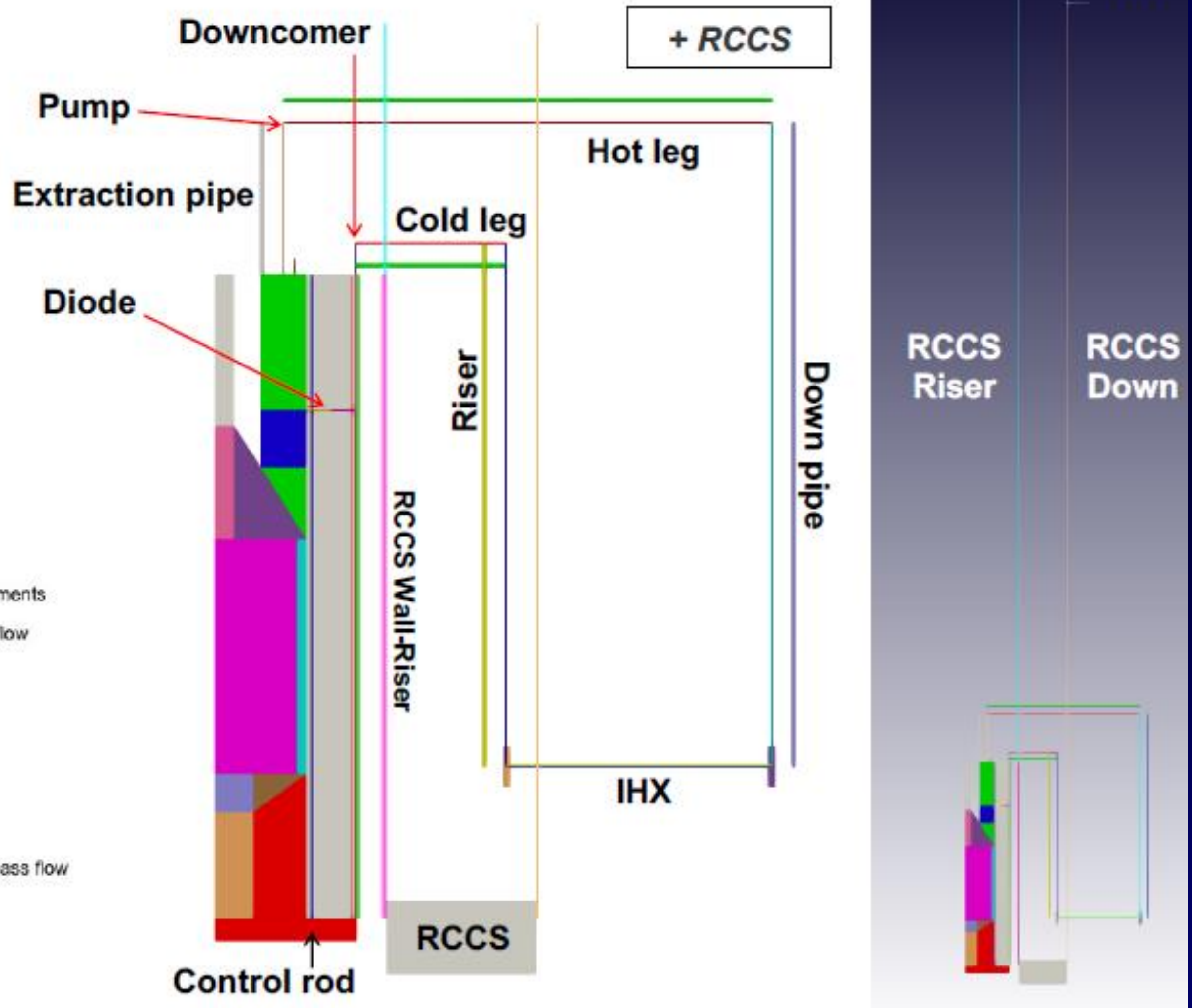
Design Type	Reference Model	Comment
Gas-Cooled Pebble Bed	HTR-PM	Coupled Neutronics/Thermal-Fluid
Sodium Fast	ABTR	Coupled Neutronics/Thermal-Fluid/Structural
Molten Salt Cooled	PB-FHR	Coupled Neutronics/Thermal-Fluid
Molten Fuel Salt (Thermal)	MSRE	Coupled Neutronics/Thermal-Fluid
Molten Fuel Salt (Fast)	EVOL	2D “Slice” Coupled Neutronics/Thermal-Fluid
Microreactor (Vertical)	SPR “Design A”	Neutronics/Thermal-Fluid/Structural
Microreactor (Horizontal)	“eVinci – like”	Coupled Neutronics/Thermal-Fluid

Reference Plant Models: Example

PB-FHR Reference Plant SAM Model

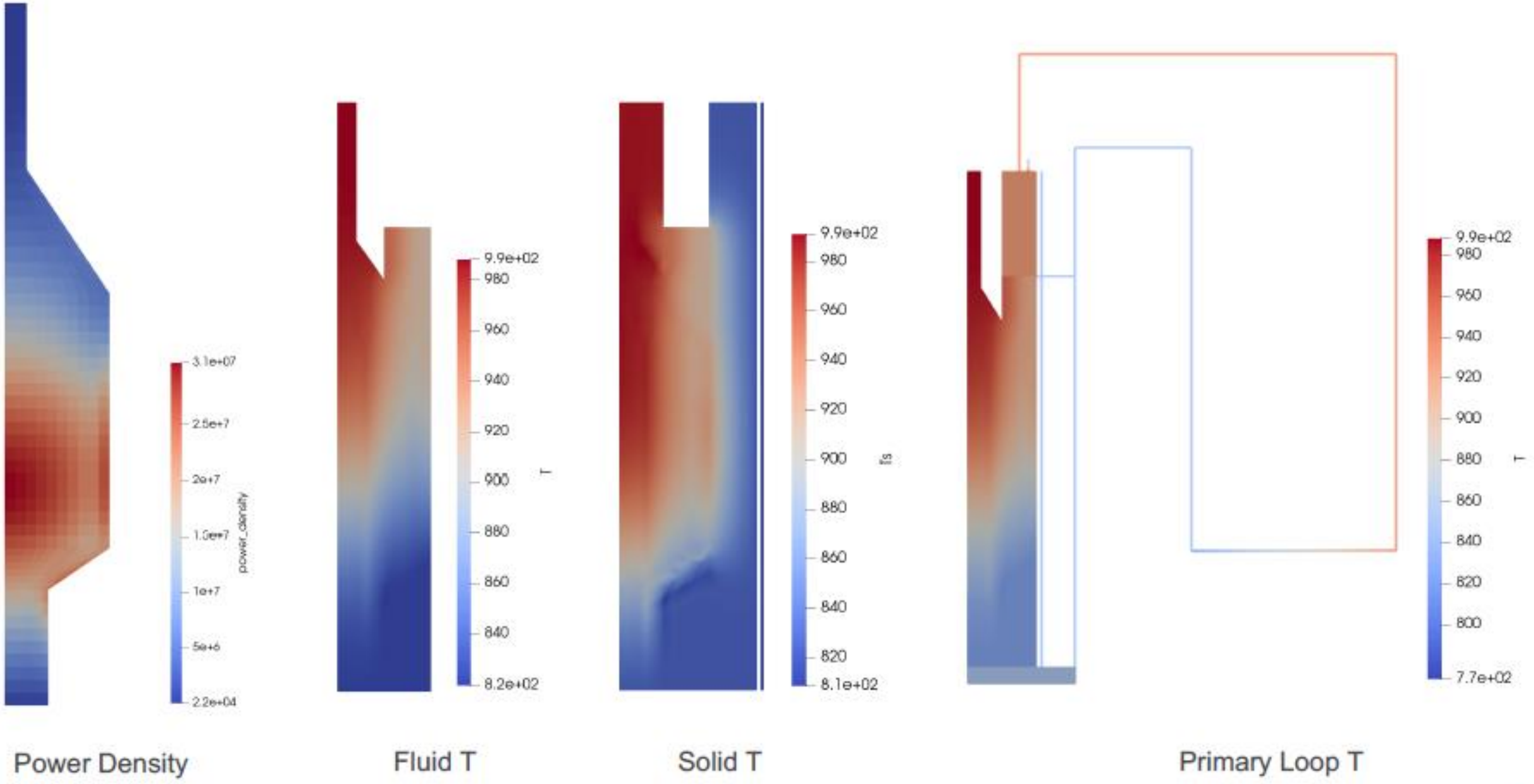
- Reactor cavity cooling system (RCCS) included as a candidate decay heat removal system
  - Heat transfer: **Radiation (vessel wall)**
  - Working fluid: **Water**
  - Heat rejection: **Air (atmosphere)**





Reference Plant Models: Example

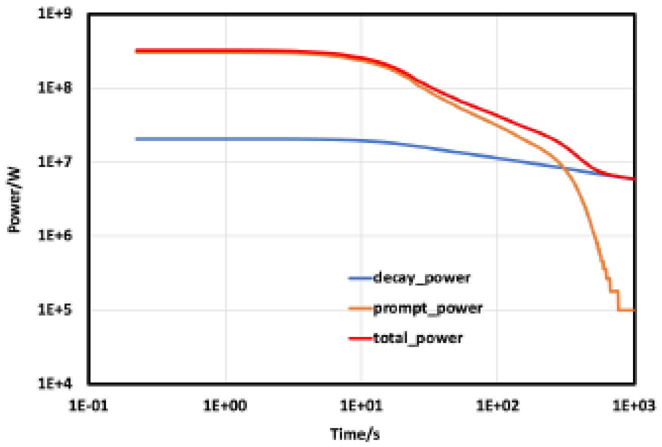
STEADY STATE RESULTS

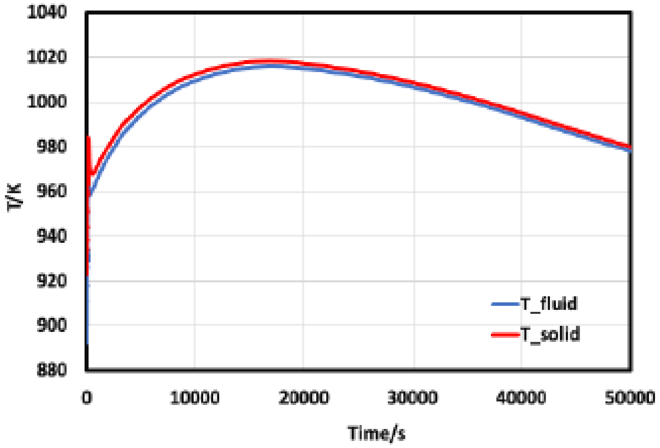


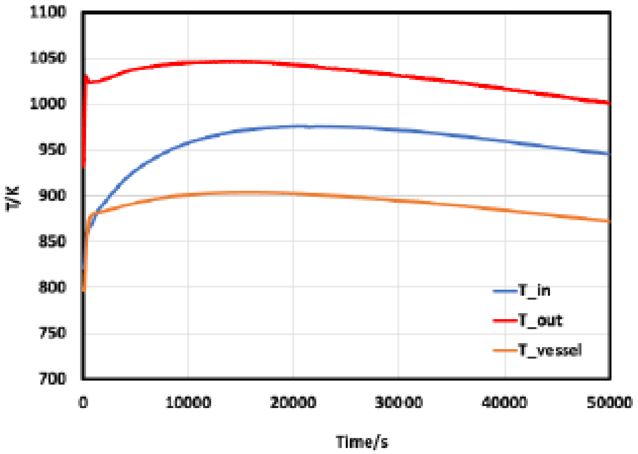
Reference Plant Models: Example

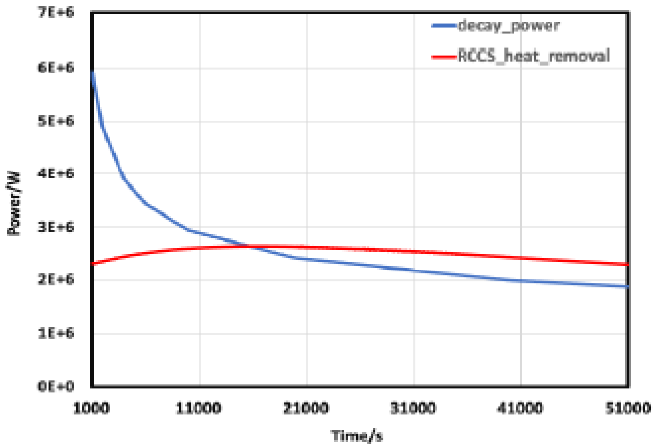
ULOF TRANSIENT

- After 1000 s, the power is from decay heat and then only SAM standalone simulation is performed to speedup the simulation.
- The heat transferred to RCCS system will be larger than the decay heat in ~ 5 hrs.





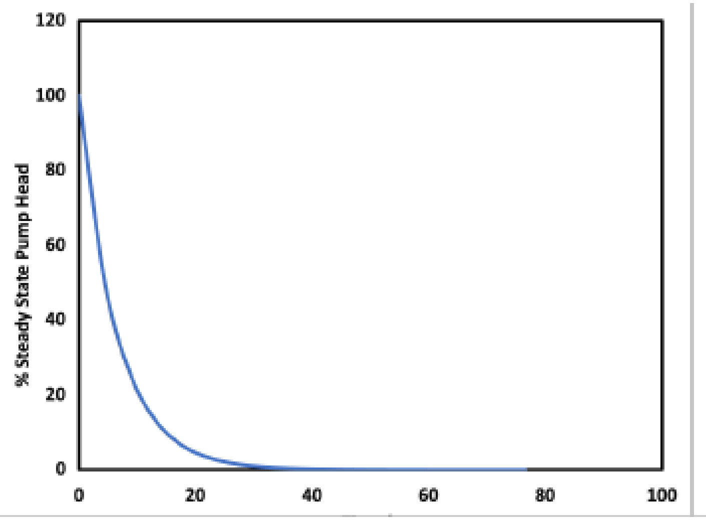


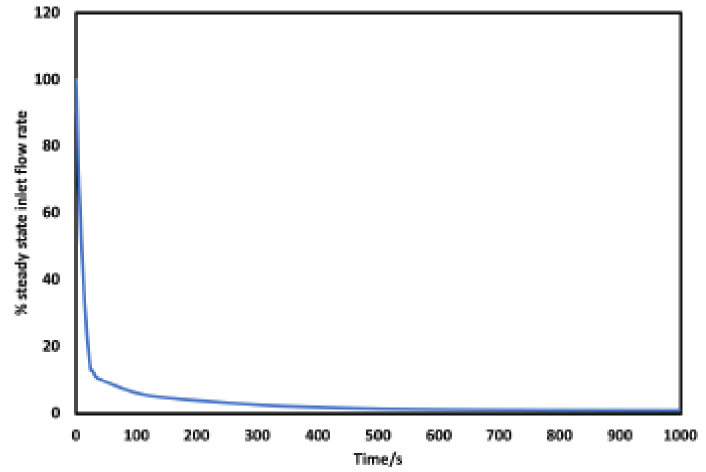


Reference Plant Models: Example

ULOF TRANSIENT

- In the ULOF transient, the primary pump head is decreased following a coast down curve with a halving-time of 4.5 seconds.
  - About approximately 75 seconds the pump head is assumed to be completely lost.
  - The fluid diode is open after ~25 seconds.
- It is assumed there is no reactivity control mechanisms active to shut down the reactor
  - The reactor replies entirely on its internal reactivity feedback mechanisms to reach approximate shutdown state.
- A natural circulation with ~1% steady state inlet flow rate is established during the transient.





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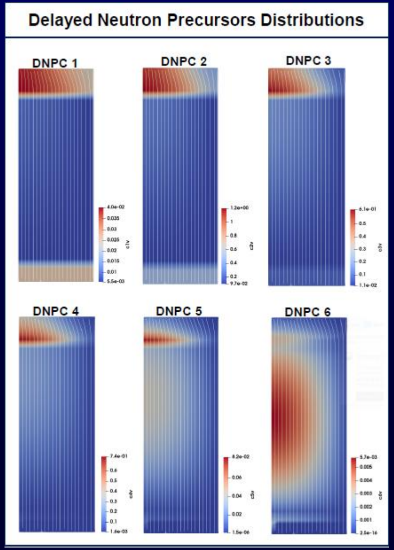
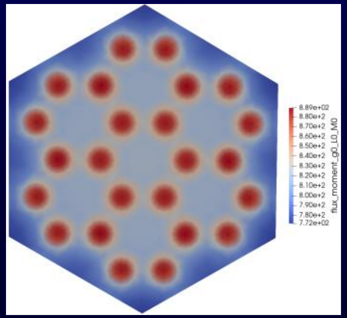
Improvements & Capabilities

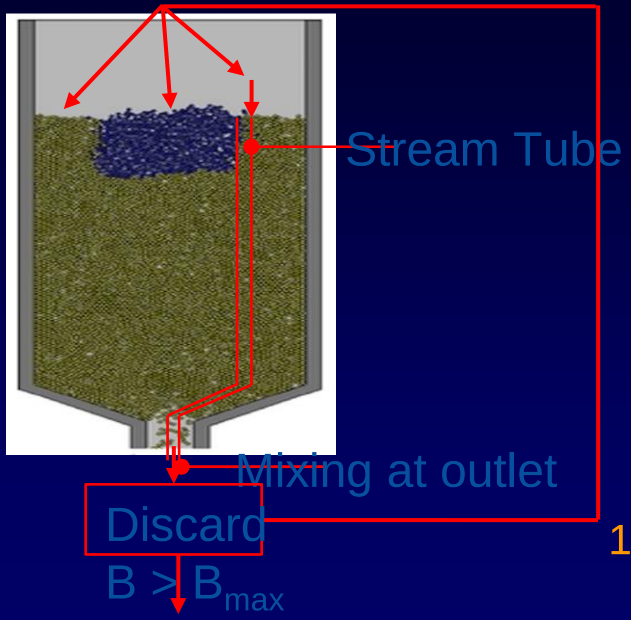
- Exercise of BlueCRAB codes and simulation of events has helped develop several important capabilities.

- Notable are:

1. Coupled pre-cursor tracking (molten fuel salts)
2. Equilibrium core calculation (Pebble tracking and depletion)
3. Coolant solidification
4. Multiple computation platforms (GovCloud, INL HPC, MacBooks)
5. Demonstration of coupled neutronic / tensor mechanics (fast spectrums)
6. “MOOSE – Mesh” for common geometries to speed input prep.
7. Heat Pipe Models (Superconductor - - SAM Component - - Sockeye)
8. Improvements in Multiphysics code coupling.







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Still Under Consideration . . .

- Phenomena that are significant and "new" with increased importance for non-LWRs relative to conventional LWRs include but are not limited to:
  - Thermal stratification and thermal striping
  - Thermo-mechanical expansion and effect on reactivity
  - Large neutron mean-free path length in fast reactors
  - Transport of neutron pre-cursors (in fuel salt MSRs)
  - Solidification and plate-out (LMRs and MSRs)
  - 3D conduction / radiation (passive decay heat removal)
  - Molten salt thermophysical properties
  - Secondary / tertiary loop modeling
  - Modeling of RCCS and DHRS
  - Heat Pipe performance and transient behavior

Evaluation Model

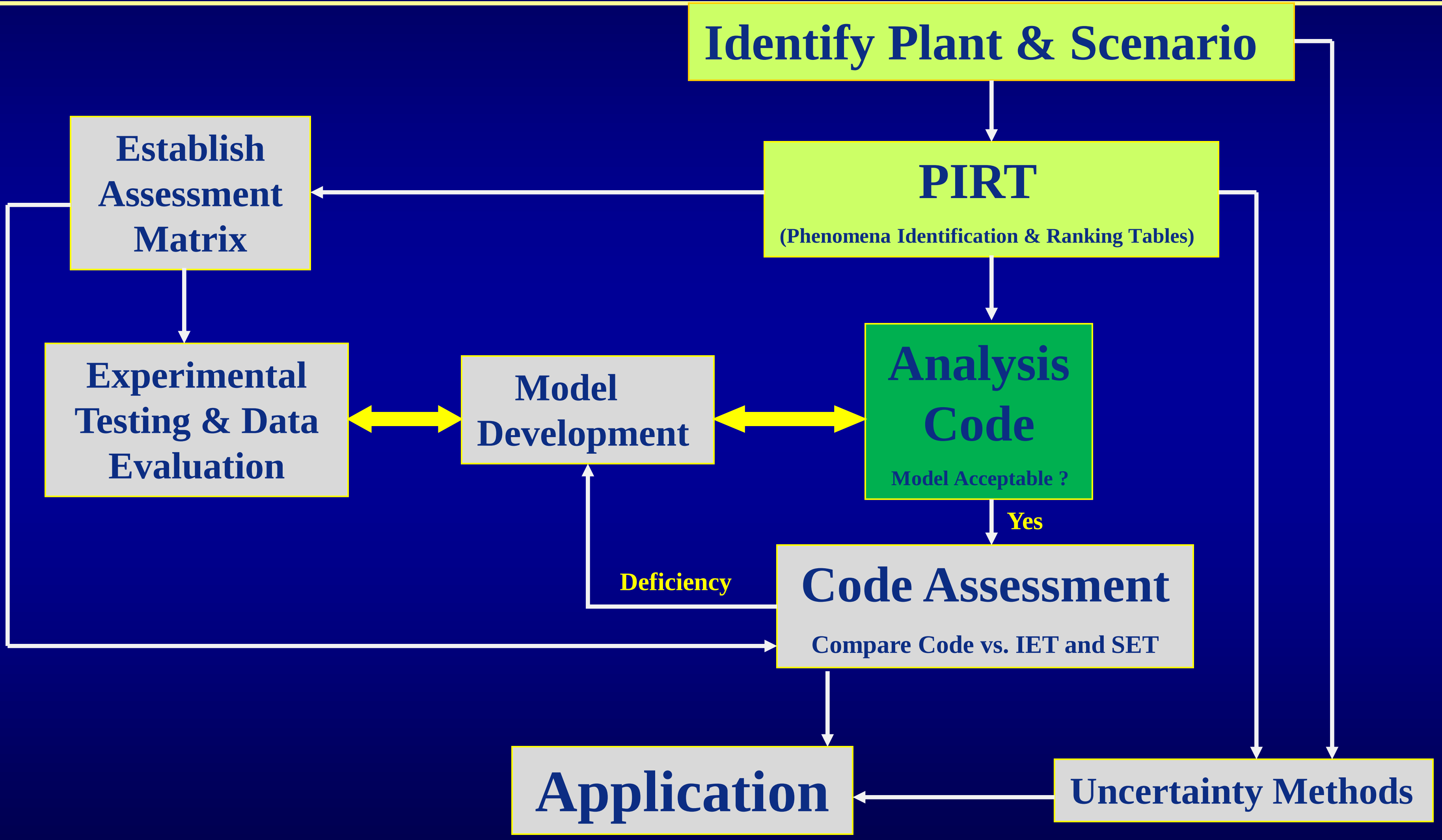
- Regulatory Guide 1.203 defines the “Evaluation Model” concept & process (EMDAP).

“An evaluation model (EM) is the calculational framework for evaluating the behavior of the reactor system during a postulated transient or design-basis accident. As such, the EM may include one or more computer programs, special models, and all other information needed to apply the calculational framework to a specific event … “

- Elements of EMDAP include:

1. Determine requirements for the evaluation model.
2. Develop an ***assessment base*** consistent with the determined requirements.
3. Develop the evaluation model.
4. ***Assess the adequacy*** of the evaluation model.
5. Follow an appropriate ***quality assurance*** protocol during the EMDAP.
6. Provide comprehensive, accurate, up-to-date documentation.

Reg Guide 1.203 Code Development



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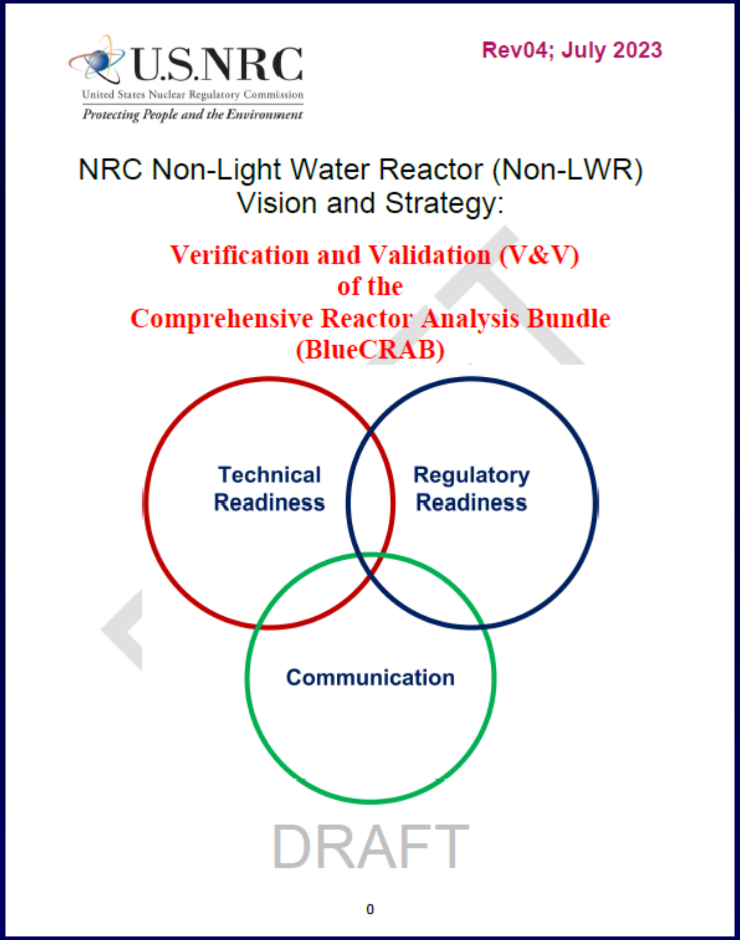
BlueCRAB V&V Report Contents

- Introduction and Code Summary
- Verification
  - Regression Testing and Coverage
  - Verification of Code Coupling
- Evaluation Model Development
  - Expected Scenarios
  - Design Types Considered
  - PIRTs
- Validation
  - Gas-Cooled
  - Liquid Metal Cooled
  - Molten Salt Reactors
  - Microreactors
  - General Neutronics
  - Components
  - Appendix: Brief Description of Tests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Rev04; July 2023

NRC Non-Light Water Reactor (Non-LWR)
Vision and Strategy:

**Verification and Validation (V&V)
of the
Comprehensive Reactor Analysis Bundle
(BlueCRAB)**

DRAFT

0

BlueCRAB V&V Report

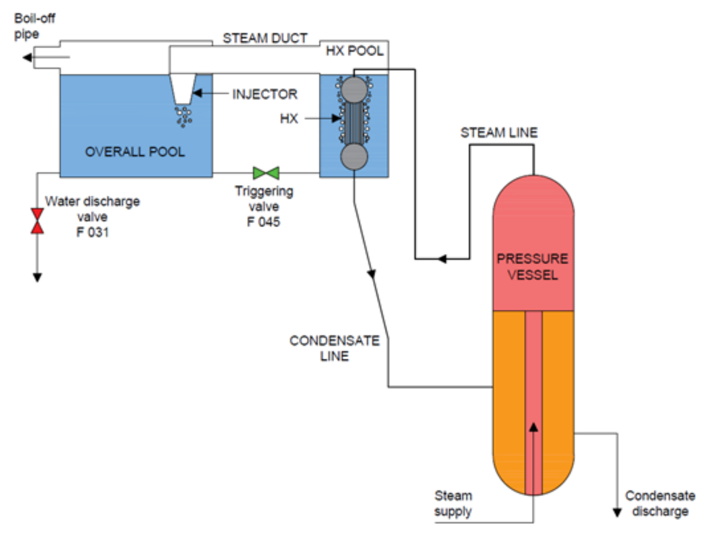
- BlueCRAB V&V Report Objectives:

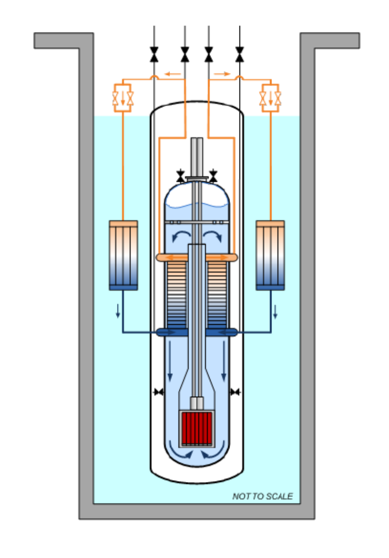
1. Provide documentation that verification and validation exists and is being performed for codes that are part of BlueCRAB.
2. Summarize validation that is applicable (and probably necessary) for common design types.
3. Identify “gaps” in either the assessment base or available experimental database – to the extent possible prior to applicant submittals.

Assessment of individual codes does not necessarily satisfy EMDAP requirements. But it is an important first step.

SMRs (LWRs with Passive Cooling)

- Independent analysis of SMRs performed with “conventional” codes (TRACE, FAST, PARCS, MELCOR).
- Previous work for AP600, AP1000, ESBWR provided initial validation and data.
- Additional validation performed as needed, with experimental data provided by applicant, from international collaboration (ATLAS, PKL, PANDA, PERSEO) or by NRC (RBHT).





Summary

- There remain several physical processes that need to be understood better for non-LWR analysis.
- Reference Models for most designs are now available and are being used & improved.
- For non-LWR system analysis and design basis type accident scenarios . . . **We Are** (*cautiously*) **Ready**.
  - Design specific information is necessary to develop independent analysis models.
  - Validation must be identified and shown sufficient and scaled to a particular design.


Questions?

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Quality Assurance Program Reviews for Advanced Reactor Applications

SEPTEMBER 14, 2023

FRANKIE VEGA

REACTOR OPERATIONS ENGINEER

NRR/DRO/IQVB

Purpose/Outcome

Present NRC staff expectations for advanced reactor developer quality assurance programs to support high-quality topical reports and applications.

Present issues encountered during staff's reviews and cover lessons-learned from these reviews.

Outline

- Regulatory Framework
  - Pre-application Activities
  - Regulatory Requirements
  - Regulatory Guidance
  - Staff review approach/guidance – Standard Review Plan
- Issues encountered
  - QAPD Reviews
- Lessons learned
  - Staff’s recommendations

Quality Assurance Program Description

- The QAPD is the top-level document that establishes the manner in which quality is to be achieved and presents overall philosophy regarding achievement and assurance of quality.

- The QAPD provides for control of activities that affect the quality of safety-related nuclear plant structures, systems, and components (SSCs) and include all planned and systematic activities necessary to provide adequate confidence that such SSCs will perform satisfactorily in service.

- The QAPD describes the methods and establishes quality assurance (QA) and administrative control requirements that meet 10 CFR 50.34, Appendix B to 10 CFR Part 50 and 10 CFR Part 52, as applicable.

- QAPDs should be developed considering the intended application of the QAPD (e.g., ESP, COL, construction phase, operations, or all).
  - For CP application the QAPD should address design and construction QA activities
  - For DC applications the QAPD should address design QA activities in support of a DC
  - For COL applications the QAPD should address all phases of a facility's life, including design, construction, and operation

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Regulatory Framework (QA Reviews)

- **10 CFR Part 50 Process**
  - Construction Permit – 50.34
  - Operating License – 50.34
- **10 CFR Part 52 Processes**
  - Early Site Permit – 52.17
  - Design Certification & SDAs – 52.47 and 52.137
  - Combined License – 52.79
  - Manufacturing Licenses (52.157)

Applicable regulatory guidance associated with QAPDs (power reactors)

- NUREG-0800, "Standard Review Plan (SRP) for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 17.5, "Quality Assurance Program Description - Design Certification, Early Site Permit and New License Applicant"
- NRC Regulatory Guide (RG) 1.28, "Quality Assurance Program Criteria (Design and Construction)," Rev 5
- NRC Regulatory Guide 1.33, "Quality Assurance Program Requirements (Operation)," Revision 3
- RG 1.164, "Dedication of Commercial-Grade Items for Use in Nuclear Power Plants," Revision 0
- RG 1.231, "Acceptance of Commercial-Grade Design and Analysis Computer Programs Used in Safety-Related Applications for Nuclear Power Plants," Revision 0.
- RG 1.234, "Evaluating Deviations and Reporting Defects and Noncompliance Under 10 CFR Part 21," Revision 0.

Applicable regulatory guidance associated with QAPDs (non-power reactors)

NUREG-1537, Part 1, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Format and Content,” dated February 1996

NUREG-1537, Part 2, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Standard Review Plan and Acceptance Criteria,” dated February

Regulatory Guide 2.5, “Quality Assurance Requirements for Research and Test Reactors,” Revision 1, dated June 2010

ANSI/ANS-15.8-1995, “American National Standard for Quality Assurance Program Requirements for Research Reactors,” dated May 10, 2013.

Issues encountered during staff's QAPD reviews

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1. QAPDs are often generic and are applied to multiple applications
2. Scope/Applicability section of the QAPD does not clearly specify the application the QAPD will be supporting
3. QAPDs don't clearly state that an evaluation was performed against the SRP
   - NUREG-0800 SRP 17.5
4. QAPDs lack statements with commitment to compliance with specific NQA-1 "Quality Assurance Requirements for Nuclear Facility Applications," requirements
5. Applicants (non-licensees) must submit changes to an approved QAPD in accordance with 10 CFR 50.4(b)(7(ii) (vs 10 CFR 50.54(a) for licensees)
6. Regulatory Commitments are often vague and do not address specific RGs and its exceptions or clarifications

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Issues encountered during staff's review (cont.)

7. QAPDs, when referencing NEI 14-05-A, "Guidelines for the Use of Accreditation in Lieu of Commercial Grade Surveys for Procurement of Laboratory Calibration and Testing Services", often don't include all the conditions approved by the staff in the SE (ADAMS ML20322A019) (RG 1.28 Rev. 5)
8. QAPDs often don't include commitments to the most recent revision of RGs and generic letters (SRP 17.5 Section V)
9. Training and qualification requirements for inspection and test personnel typically are not included in QAPDs (SRP Section 17.5, Subsection II.T; Criterion II, NQA-1 Requirement 2 Section 302)
10. QAPDs referencing COL activities lack specific QA requirements for operation phases (SRP 17.5) and often don't include commitments to RG 1.33.

Issues encountered during staff's review (cont.)

11. Relying on industry programs such as ASME and NUPIC as input or the basis for supplier qualification is not appropriate for most applicants
12. Roles and Responsibilities for quality related activities during each of the phases (i.e., design, construction and operation) should be clearly described

Lessons Learned

Applicants are encouraged to:

- Engage with NRC staff during pre-application phase
- Clearly state what applicants want to achieve with the QAPD
- Submit a complete, accurate, and comprehensive submittal
- Be familiar with Regulations, SRPs and RGs associated with QA
- Reference documents that reflect latest revision issued or endorsed
- Be familiar with issues identified with previous QAPDs reviews

Questions or Comments?

Contact Information	
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Future Meeting Planning

- The next periodic stakeholder meetings in 2023 are scheduled for October 25, and December 7.

- Potential topics for our next meeting include seismic design, use of standard design approvals for construction permit and operating license applications, and metallic fuel qualification.

- If you have suggested topics, please reach out to Ramachandran Subbaratnam at Ramachandran.Subbaratnam@nrc.gov.

How Did We Do?

- Click link to NRC public meeting information:

  https://www.nrc.gov/pmns/mtg?do=details&Code=20230271

- Then, click link to NRC public feedback form: