U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

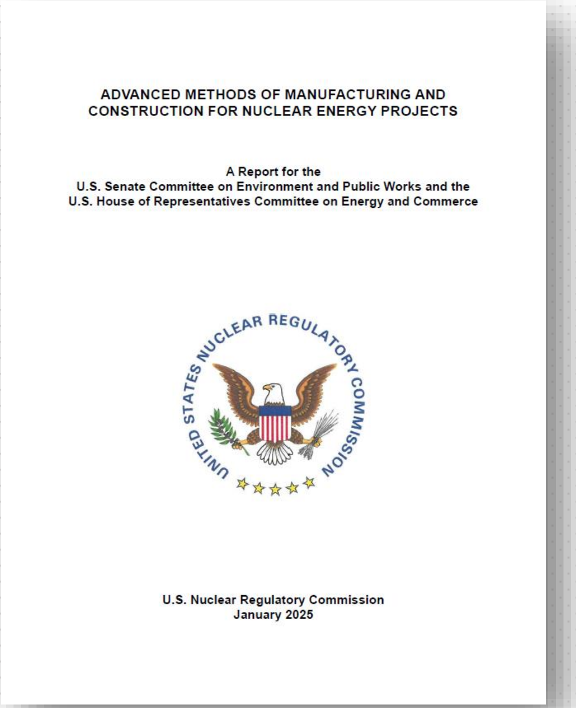
Public Meeting on Accelerated Material Qualification

Christian Araguas, Director
Division of Engineering
Office of Regulatory Research

May 6, 2025

ADVANCE Act Section 401

Advanced Methods of Manufacturing and Construction for Nuclear Energy Projects (ML24292A171)


ADVANCED METHODS OF MANUFACTURING AND CONSTRUCTION FOR NUCLEAR ENERGY PROJECTS

A Report for the
U.S. Senate Committee on Environment and Public Works and the
U.S. House of Representatives Committee on Energy and Commerce

UNITED STATES NUCLEAR REGULATORY COMMISSION

U.S. Nuclear Regulatory Commission
January 2025

Table 3 – potential action DD4

Develop guidance on accelerated material qualification

Meeting Objective

Hear from the technical community on activities related to the near- and mid-term deployment of new materials for advanced reactor designs.

No licensing or regulatory decisions are being made at today's meeting.

Meeting Agenda, Early Afternoon

Time	Topic	Speaker (and *Affiliation*)
1:00 PM	Welcome and Introduction	Meredith Neubauer (*NRC*)
1:05 PM	Opening Remarks	Christian Araguas (*NRC*)
1:10 PM	AMMT's Perspectives on Accelerated Material Qualification for Advanced Reactors	Meimei Li (*DOE-NE*)
1:30 PM	Accelerating the Deployment of Materials and Advanced Manufacturing Methods for Nuclear Applications	Marc Albert and Chris Wax (*EPRI*)
1:45 PM	Material Qualification for the eVinci® Microreactor	Zefeng Yu (*Westinghouse*)
2:00 PM	Kairos Power: An Iterative Approach for Reactor Materials	Craig Gerardi (*Kairos*)
2:15 PM	Break	

Meeting Agenda, Late Afternoon

Time	Topic	Speaker (and Affiliation)
2:30 PM	Aalo's Advanced Manufacturing and Qualification Approach for Intermediate Heat Exchangers	Luke Andrew (*Aalo*)
2:45 PM	Metallic Materials Development for the Natrium Advanced Reactor	Bridgette Hannifin (*TerraPower*)
3:00 PM	Qualification of Metallic Materials for Kaleidos	Parker Buntin (*Radiant Nuclear*)
3:15 PM	Discussion	*Moderator: NRC* *Discussion Participants: DOE, EPRI, Industry Representatives*
4:40 PM	Public Q&A	*Public*
4:50 PM	Closing Remarks	*NRC*

Advanced Materials and Manufacturing Technologies (AMMT) Program

Perspectives on Accelerated Material Qualification for Advanced Reactors

Meimei Li, National Technical Director, Argonne National Laboratory

Dirk Cairns-Gallimore, Federal Program Manager, DOE Office of Nuclear Energy

AMMT Program: Mission, Vision, Goals

Mission

Accelerate the development, qualification, demonstration, and deployment of advanced materials and manufacturing technologies in support of U.S. leadership in a broad range of nuclear energy applications.

Vision

Expansion of reliable and economical nuclear energy enabled by advanced materials and manufacturing technologies.

Goals

- Develop advanced materials & manufacturing technologies.
- Establish and demonstrate a rapid qualification framework.
- Evaluate materials performance in nuclear environments.
- Accelerate commercialization through technology maturation.

AMMT Program: Technical Areas

Advanced Materials & Manufacturing

- Advanced Metallic Materials
- Advanced Manufacturing Technologies
- Traditional Manufacturing & System Integration

Rapid Qualification

- Rapid Qualification Framework
- High-temperature Materials Qualification
- Advanced Manufacturing Qualification

Environmental Effects

- Neutron Irradiation & Post-irradiation Examination
- Accelerated Qualification for Radiation Effects
- Corrosion Effects in Nuclear Environments

Technology Maturation

- Component Fabrication & Evaluation
- Codes and Standards
- Regulatory Acceptance & Licensing

AMMT supports the development of a broad range of reactor concepts:

- Molten Salt Reactors (MSRs)
- Sodium-cooled Fast Reactors (SFRs)
- Gas-cooled Reactors (GCRs)
- Lead-cooled Fast Reactors (LFRs)
- Advanced Light Water Reactors (aLWRs)

AMMT's Perspective on Accelerated Material Qualification

Material Qualification

- "Qualification" refers to the entire process of transitioning materials from development to approval for nuclear applications.
- Material qualification addresses **temperature, stress, radiation, and corrosion effects**.
- Key aspects:
  - Baseline property testing and temperature effect evaluation
  - Performance testing in irradiation and corrosive environments
  - Predictive modeling of processing-structure-property-performance relationships
  - Development of Codes, Standards, and guidelines

Accelerated Material Qualification

- Goal: Faster, cost-effective qualification while maintaining the thoroughness and integrity of the qualification process.
- Acceleration is achieved through innovative testing techniques, advanced characterization, modeling and simulation, and AI/ML, enabling
  - Reduced dependence on extensive engineering property data
  - Rapid assessment of long-term material behavior in nuclear environments
  - Large time extrapolation factors
  - Utilization of non-standard or subscale specimen data

Advanced Materials & Manufacturing Development

Our materials development strategy is to develop advanced materials through integration with manufacturing processes.

- Apply advanced manufacturing to existing reactor materials
- Transition non-nuclear commercial materials for nuclear applications
- Develop innovative new materials

Materials

- Fe-based alloys (316, Alloy 709, G91, G92)
- Ni-based alloys (Alloys 617, 625, 244)
- Refractory alloys (Mo, Nb alloys)
- Innovative new materials (ODS, HEA, FGM)

Manufacturing Processes

- Advanced manufacturing (LPBF, DED, PM-HIP)
- Traditional manufacturing
- Hybrid manufacturing
- Joining techniques

Advanced materials and manufacturing development lays the groundwork for qualification.

Rapid Qualification Framework

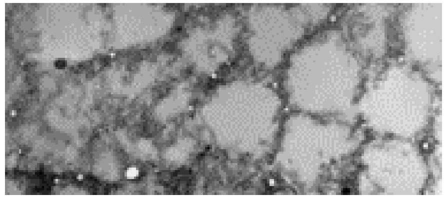
Integrate scientific understanding with engineering data to establish a physics-based, data-driven qualification methodology.

Establish **Processing-Structure-Property-Performance** relationships

A P-S-P-P based qualification framework requires a fundamental understanding of processing-structure-property-performance relationship to enhance the prediction of material behavior, design allowables, and performance limits in nuclear reactor environments.

Use integrated experimental, modeling and data-driven tools

Capitalize on the wealth of digital manufacturing data, integrated computational materials engineering (ICME) and machine learning/artificial intelligence (ML/AI) tools, and accelerated, high-throughput testing and characterization techniques.



Incorporate *in situ* process monitoring data into the qualification process

Monitor and analyze the printing process in real-time to ensure the quality and integrity of the fabricated part. Use *in situ* process monitoring data to detect defects and as a QA tool to assess part quality.

Demonstrate accelerated qualification methods through qualifying **LPBF 316H SS**

Laser powder bed fusion 316H stainless steel (LPBF 316H SS) serves as a test case for demonstration of a new qualification framework.

Rapid Qualification Approach

Advanced Experimental Methods

- Innovative testing methods and advanced characterization accelerate materials qualification by rapidly generating comprehensive datasets and providing detailed insights into material properties and performance.
  - Automated, fast NDE
  - Advanced characterization
  - Small-scale specimen testing
  - Accelerated testing tools

In-situ Process Monitoring

- In-situ process monitoring can play a crucial role in accelerating material qualification, particularly for advanced manufacturing techniques such as additive manufacturing.
  - Provide real-time insights
  - Improve quality control
  - Enable predictive modeling
  - Contribute to a digital thread

Computational Tools

- Computational tools accelerate materials qualification by providing predictive insights that complement experimental data.
  - Modeling Process-Structure-Property-Performance relationships
  - Extrapolation of long-term behavior
  - Sensitivity Analysis
  - Uncertainty Quantification

Rapid Qualification for Radiation Effects

Apply a science-driven licensing strategy, so called the **Licensing Approach with Ions and Neutrons (LAIN)** framework that combines neutron and ion irradiations with physics-based modeling to accelerate material qualification.

Neutron Irradiation

- Provide critical performance data in nuclear reactor environments
  - Neutron irradiation and post irradiation examination (PIE)
  - In-reactor experiments including combined irradiation and corrosion effects
- Ongoing and Planned Activities: ATR and HFIR irradiation and PIE of LPBF 316H and wrought Alloy 709.

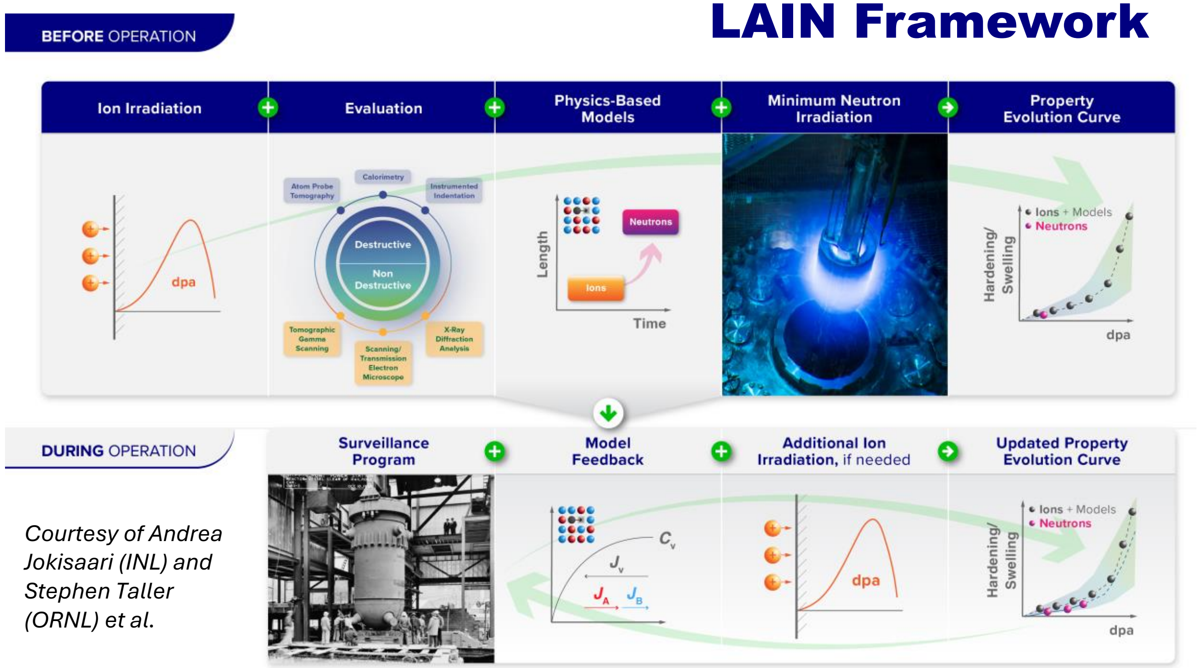
Ion Irradiation

- Use ion irradiation as an accelerated tool to provide complementary data to cover a wide parameter space
  - Metallurgical variables, e.g. heat variation, product form, heat treatment, etc.
  - Irradiation parameters, e.g. temperature, dose, dose rate, energy spectrum, transmutation, etc.

Modeling and Simulation

- Understand the underlying physics and predict material performance beyond testing conditions.

LAIN Framework



Courtesy of Andrea Jokisaari (INL) and Stephen Taller (ORNL) et al.

Material surveillance technology to monitor material degradation in service to enhance predictions and reduce uncertainties.

Evaluation of Corrosion Effects

Material interactions with coolants vary significantly across different reactor designs and environments, influenced by factors such as coolant chemistry and operating temperature.

Research Focus

- Understanding of corrosion processes in molten salt, liquid sodium, and helium environments.
- Evaluate corrosion behavior of additively manufactured (AM) materials focusing on their unique characteristics.

Ongoing Activities

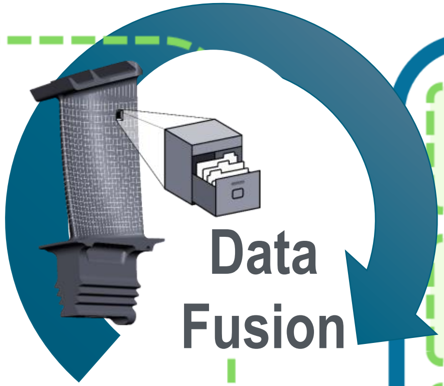
- **Testing in molten salts**
  - 316H, 709 SS, Alloys 625, 617, 244 Ni alloys (wrought and AM)
  - Evaluate corrosion and creep behavior in molten fluoride and chloride salts
  - Determine corrosion kinetics and speciation in molten $NaCl\text{-}MgCl_2$
  - Characterize corrosion behavior of LPBF 316H in molten $NaCl\text{-}MgCl_2$ and understand processing-structure-performance relationship
- **Testing in liquid sodium**
  - Wrought Alloy 709 and LPBF 316H
  - Performing sodium exposure tests in forced-convection loops
  - Evaluate sodium compatibility and effects on microstructural evolution and mechanical properties

Multi-Dimensional Data Correlation (MDDC) Platform

Digital Twin

Spatially Tracked Data

4 5 1 8
9 6 3 2

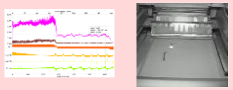


Manufacturing

Process Parameters

Feedstock Information

In-Situ Data



Post Processing

Characterization

Material Characterization

Non-Destructive Testing

Destructive Testing

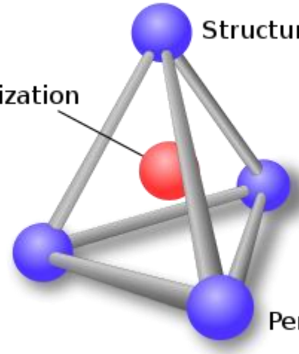
Lifetime & Performance

MDDC

- Twin 1
- Twin 2
- Twin 3
- …
- Twin n

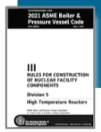
Toolkit

- Artificial Intelligence
- Machine Learning
- Data Analytics
- Process Models
- Materials Models
- Performance Models



Digital Twins and MDDC Toolkit Accelerates Development

Demonstrations	Digitally Aided Qualification	AI Based Design
3 years	5 years	10 years



Improve Performance, Reliability and Lifetime of Nuclear Components

Accelerated Qualification Strategy

- **Staged Approach:** Begin with statistical- or equivalence-based qualification and progressively transition to an advanced, accelerated qualification methodology.
- **Application Demonstration**: Use LPBF 316H SS as a case study to develop the accelerated qualification framework and demonstrate its applications to materials produced by various advanced and traditional manufacturing processes.

Codes and Standards Development

- New standards, such as material specifications and testing methods.
- LPBF 316H 100,000h Code Case in ASME Section III Division 5.
- Alloy 709 longer-term Code Cases (300,000 h and 500,00 h) in ASME Section III Division 5.
- Qualify additional product forms of Alloy 709, such as bar, pipe and forging.
- Introduce new materials and manufacturing processes in ASME Section III Division 5.

Design Requirements for Environmental Effects

- Provide data and insights to support the development of design guidelines that address the environmental effects of corrosion and irradiation.
- Identify alternative pathways to accelerate the adoption of advanced materials and manufacturing technologies.

Summary

- Material qualification addresses temperature, stress, irradiation, and corrosion effects in nuclear reactors.
- AMMT material qualification focus area
  - High temperature materials qualification
  - Advanced manufacturing qualification
- Rapid Qualification Framework
  - Integrates engineering data with scientific understanding of Processing-Structure-Property-Performance relationships
  - Leverage advanced characterization, high-throughput testing, modeling and simulation, and AI/ML
- Stakeholder Engagement
  - Understand and address their needs, requirements and expectations.
  - **Opportunities for further NRC guidance**
    - Acceptance of the rapid qualification framework
    - Digital-driven qualification with lifecycle data integration to qualify AM components
    - Incorporation of in-situ process monitoring data into the qualification process.
    - Rapid assessment of long-term material behavior in nuclear environments (e.g. LAIN framework)
    - Role of materials surveillance program in advanced reactors.
    - Utilization of non-standard or subscale specimen data
    - Large time extrapolation factors

Accelerating Deployment of Advanced Reactor Materials and Manufacturing Methods

NRC Public Meeting on Guidance Development for Accelerated Material Qualification

Marc Albert
Sr. Principal Team Lead – Advanced Manufacturing & Materials Qualification

Chris Wax
Sr. Principal Team Lead – Advanced Reactor Materials Reliability

May 6, 2025

Materials Deployment for Advanced Reactors

Code Qualification

Limited number of ASME Code Qualified alloys for high temperature service

Can take a DECADE to fully qualify a new alloy

$

Just because the material is **Code Qualified** doesn't mean it is **approved** for Nuclear Service

Environmental Effects

Owner/Operator has the responsibility to demonstrate to regional regulator that the effects on structural failure modes are accounted for in their specific reactor design

- Irradiation Data
- Corrosion Data
- Thermal Performance
- Environmental Testing

Supply Chain

Critical data and understanding required for informed fabrication and design of AR components

What does it take to deploy a material for ANLWRs?

an example

Code Data

- BPV III-Div. 5 code qualification up to 100,000 hrs of service
- BPV III-Div. 5 code qualification up to 300,000 hrs of service
- BPV III-Div. 5 code qualification up to 500,000 hrs of service

Environmental Effects

- Corrosion Rates in He
- Corrosion – EA cracking in He
- Corrosion Rates in salts
- Corrosion – EA cracking in salts
- Corrosion Rates in Na
- Corrosion – EA cracking in Na
- Corrosion Rates in Pb
- Corrosion – EA crackin in Pb
- Irradiation Assessment Data
- Irradiation Properties
- Combined Environmental Effects

Fabrication Data

- Weldment Optimization
  Tensile, high temp, creep, thermal fatigue
- Cyclic Stress Relaxation
- Heat to Heat Variability
- Feature Testing
- Multiple product forms
- Capable Suppliers and Fabricators

ASME Approval (for 12 years Operation)

ASME Approval (for 24 years Operation)

Regulatory Approval?

ASME Approval (for 60 years Operation)

?

Regulatory Approval?

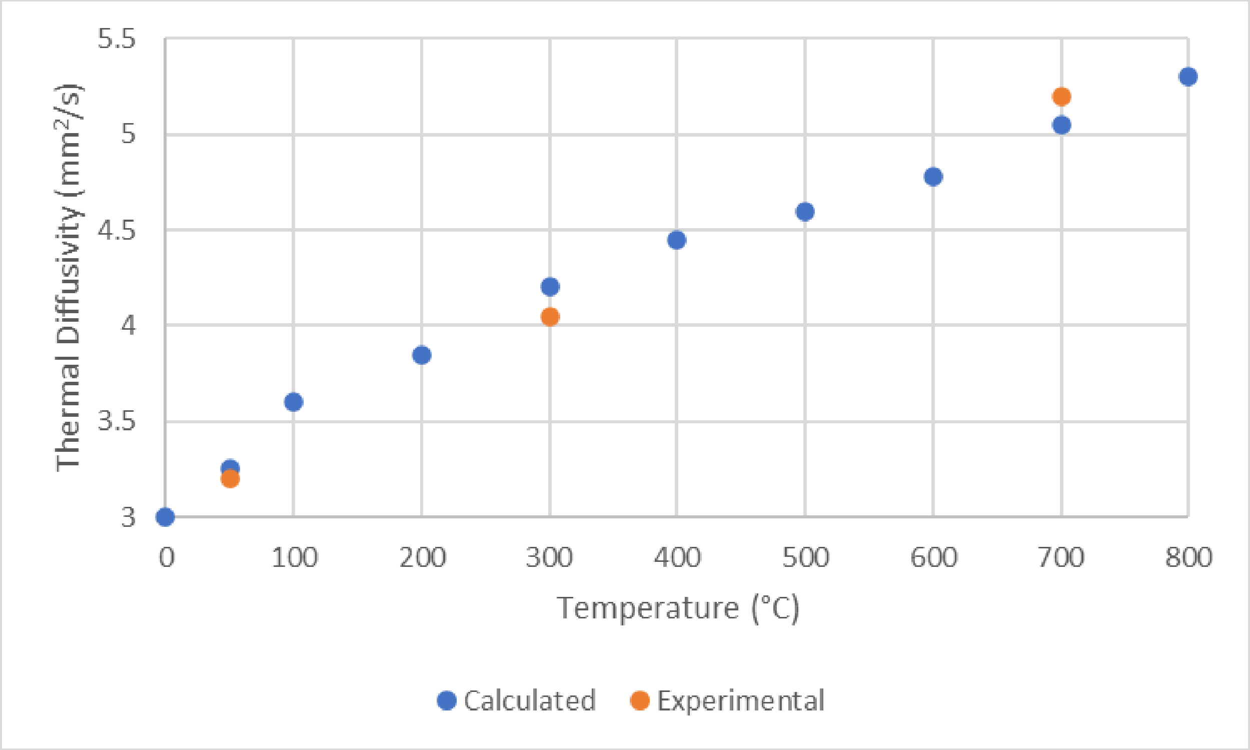
Confidence in Supply and Operation

Legend:

Needed
Complete
In-process
Not Needed or N/A

Reduction in Costly Experiments

- Regulatory agreement on key questions:
  - How many experiments does it take to verify a property?
    - Need to ensure inflection points are covered
  - What accuracy is needed to justify understanding of a property?
- Increased conservatism until additional data is captured
  - Increased Inspection & Monitoring
  - Larger error bars (uncertainty)
  - Fill in data gaps with modeling
- Target high-cost experiments?



Approaches for Accelerated Qualification of Materials

Approaches for Accelerated Qualification of Materials

Roadmap Strategic Gap Addressed:
1) Capture material data and close gaps necessary for deployment of Advanced Reactors

OBJECTIVE

- Qualification of new materials for nuclear applications is time consuming and expensive
  - Particularly for high temp applications (up to 10 years)
- Assess and develop accelerated qualification approaches
- Pilot the framework with codes & standards and regulatory bodies

STATUS

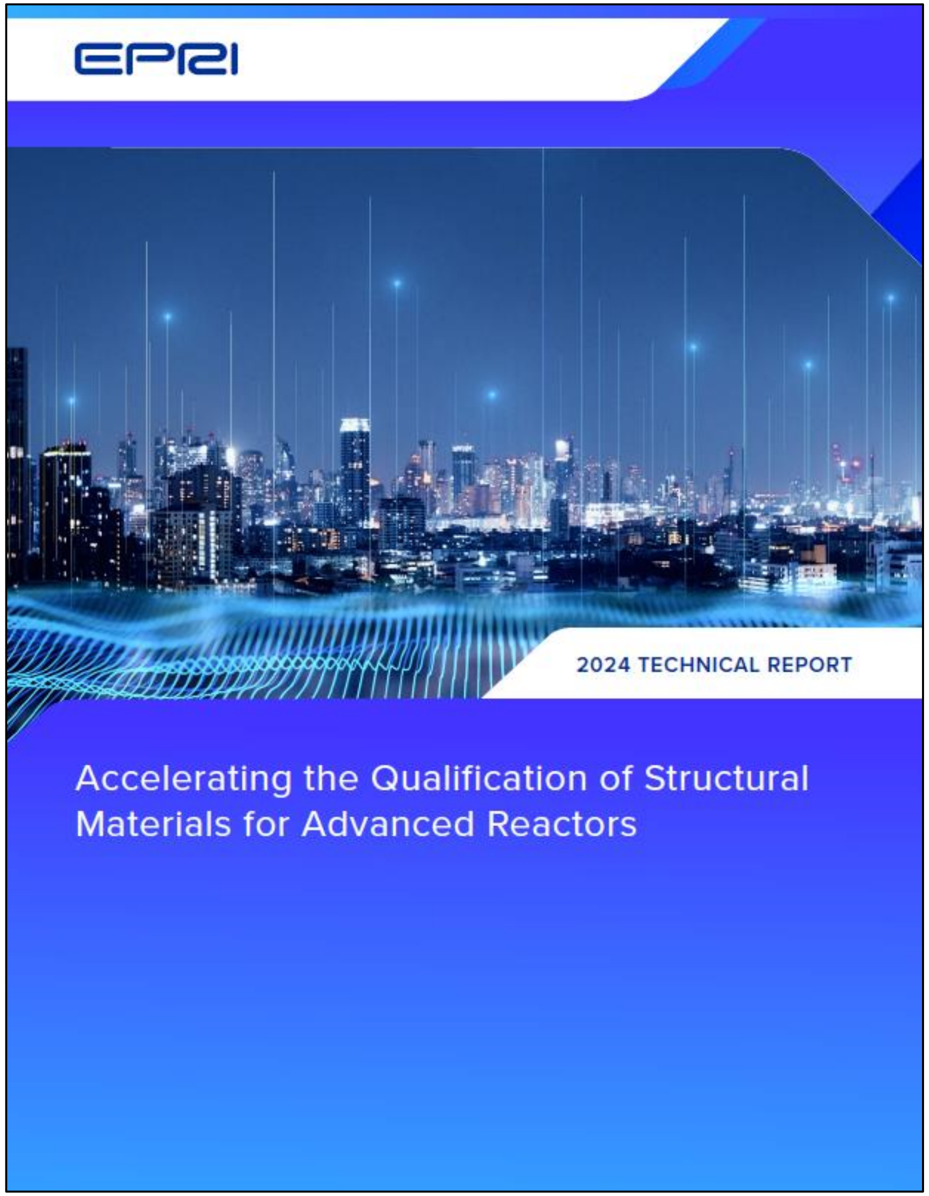
- 3002029265 published November 2024
- Assembled promising and most value-added methods
- Primer document outlining the advantages, disadvantages, and challenges of each approach
- Collaboration with Argonne National Lab

NEXT STEPS

- Integrate numerous approaches into a qualification framework
- Pilot framework with multiple approaches on known material (e.g., 316 variants)
- Continued collaboration with Argonne National Laboratory

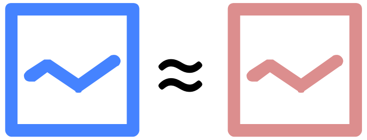
Phase I Activities

- Conducted survey to document methods that could potentially reduce ASME code qualification burden
- Collaboration with Argonne National Lab
- Various methods identified that might allow acceleration of the code process (primarily centered around long-term creep data)
- Report published in late 2024

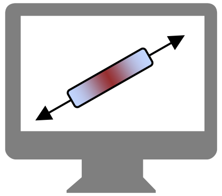


EPRI Report 3002029265, November 2024

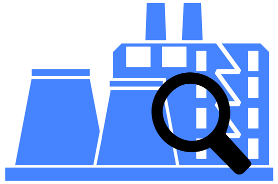
Potential Approaches to Accelerate Material Qualification



Qualification by Analogy



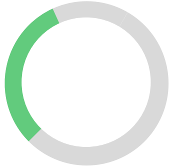
Physics-based Modeling



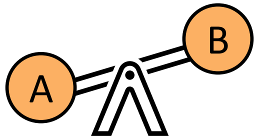
Material Surveillance

Staggered Qualification

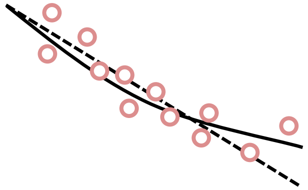
Accelerating qualification: Reduce the time required to conduct testing, analyze data, and secure approval for a new material compared to conventional approaches



Limited Design Scope



Alternate Code Classification



Improved Empirical Models

Next Steps – Accelerating Materials Qualification

Published "Primer Document" 3002029265

- Provides a **toolbox of approaches** to accelerating qualification
- Includes advantages, disadvantages, and specific research needed to deploy each given method

- Integrate multiple approaches into a qualification framework
- Continuing the collaboration with ANL

Phase 2 Underway

- Pilot framework with multiple approaches on known material (e.g., 316 variants)
- Looking to leverage pilot towards potential future materials

EPRI Proposed Approach for High Temperature Stress Allowables for DED Additive Manufacturing

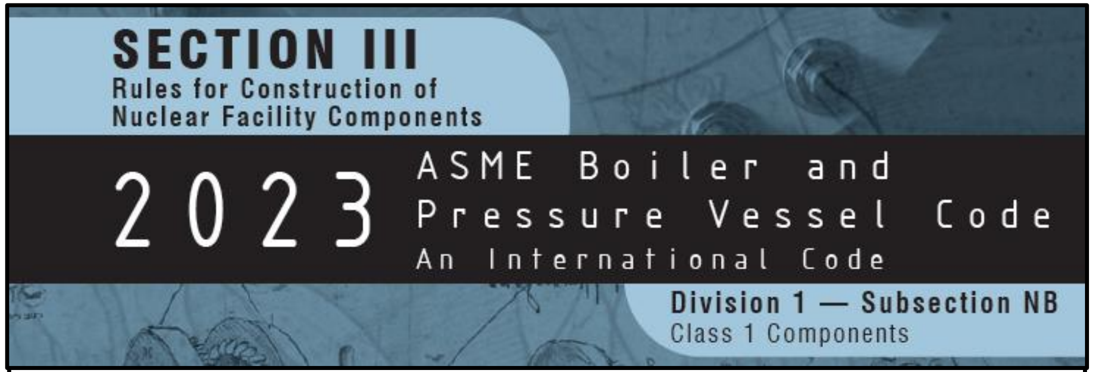
Gas Metal Arc–Directed Energy Deposition (GMA-DED)

Aka: wire arc additive manufacturing (WAAM), wire additive welding….

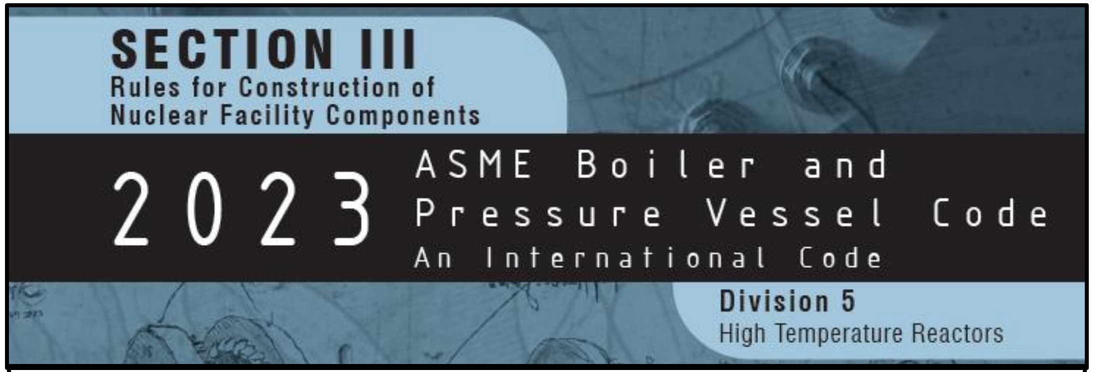
316LSi valve body, 1600 pounds (700 kg)

Collaborative effort between EPRI and Lincoln Electric Additive Solutions

Current Approach for GMA-DED within ASME Boiler and Pressure Vessel Code Section III

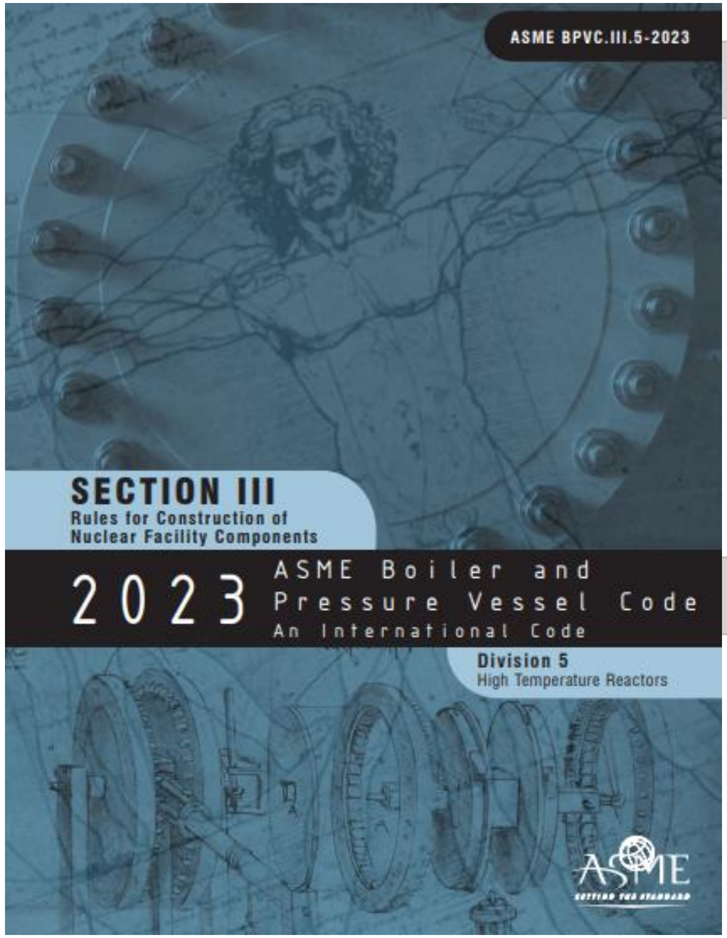


- Code Case nearing approval that builds off BPTCS/BNCS Special Committee on Use of Additive Manufacturing for Pressure Retaining Equipment
- Relies on bracketed qualification approach of AM process to permit use of design parameters from “corresponding material” for time-independent service



- No current actions specific to GMA-DED
- Recent focus has been on LPBF and PM-HIP for high temperature service
- Low temperature rules will likely mirror the Division 1 approach
- Extension to elevated temperatures is a gap (more on this later)

How are welds treated for high temperature applications?



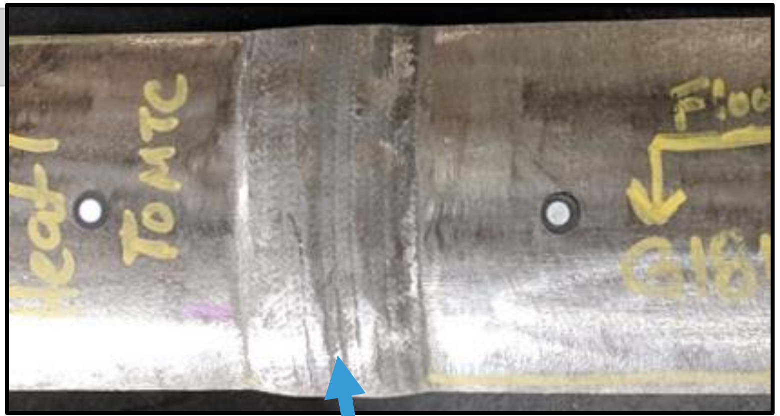
Conventional welded construction

- Base metal design curves
- "Knockdown" strength reduction factors applied to base material design stresses for welded construction

GMA-DED construction

- No existing design approach for high temperature nuclear service
- Treating DED as a "new" material will be very expensive + time consuming

316H piping girth weld (DOE-EPRI-FE31562)



316H Weld Material

316H GMA-DED build

316H weld material used in both cases, but no technical basis exists for high temperature GMA-DED designs rules

EPRI proposal for stress allowables in DED-AM components

ASME Section II Appendix 5

- Challenges
  - Section II Appendix 5 does not address AM processes and the possibility of different heat-treatments for the same material
  - If treated as a new material, each material + heat-treatment would require a prohibitive amount of long-term data for materials which are already well characterized in other product forms
  - Bracketed qualifications are not considered
  - Testing in multiple orientations not considered
- Important guidance
  - Consideration for service experience
  - Consideration for larger sample/feature testing (relevant data)

Alternative: AMSRF (Additive Manufacturing Strength Reduction Factor) Approach is Proposed

- **Using a combination of past available creep data on weld metals and new creep data on DED builds, use an approach similar to the WSRFs that used today for weldments to create stress allowables based on the wrought equivalent materials**
- **Validate the approach using lab or field data on relevant components**
- **In order to allow early adoption and field demonstration, use conservative factors until longer-term data are made available**

Alternative approach will help accelerate acceptance of DED-AM processes requiring stress allowables in the time-dependent regime

On-going Expanded 316H GMA-DED Work for ASME Code on Austenitic Stainless Steel

- Focus on GMA-DED for Section III elevated temperature service
- Compile data relevant to ASME qualification in the time-dependent regime (ETT, creep, creep-fatigue)
- Follow ASME time-independent qualification as much as possible to develop material for time-dependent testing and characterization
- Data package assembly and analysis for preliminary AM-SRF approach

Extensive database of wrought 316H creep rupture data enables comparisons with conventional product forms

Summary

- Large scale DED has reached commercial maturity and offers an attractive processing route to complement conventional methods of manufacturing
- ASME Code status:
  - Time-independent service: criteria have been established and are nearing adoption across multiple book sections. Qualification hinges on establishing material equivalency with wrought or cast products.
  - Time-dependent service: work is needed to establish the technical basis and qualification approach. Possible opportunity to leverage an equivalency approach with knockdown factors on time-dependent design parameters similar to how welds are treated today.
- On-going and future research activities are focused on two areas:
  - Fundamental R&D to understand process-structure-property-performance linkages
  - Applied R&D to establish and demonstrate a workable qualification approach

Materials Management

Environmental Compatibility

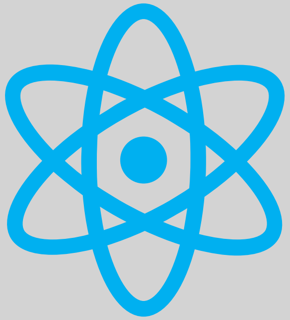
Regulatory Guidance for Advanced Reactor Materials

US Nuclear Regulatory Commission Interim Staff Guidance (DANU-ISG-2023-01)

- …Section III-5, HBB-1110(g) ASME Code rules do not provide methods to evaluate deterioration that may occur in service as a result of corrosion, mass transfer phenomena, radiation effects, or other material instabilities…non-LWR application to **review applicable design requirements including environmental compatibility, qualification and monitoring programs for safety-significant structures, systems, and components** (SSCs)…

High Temperature Materials Qualification

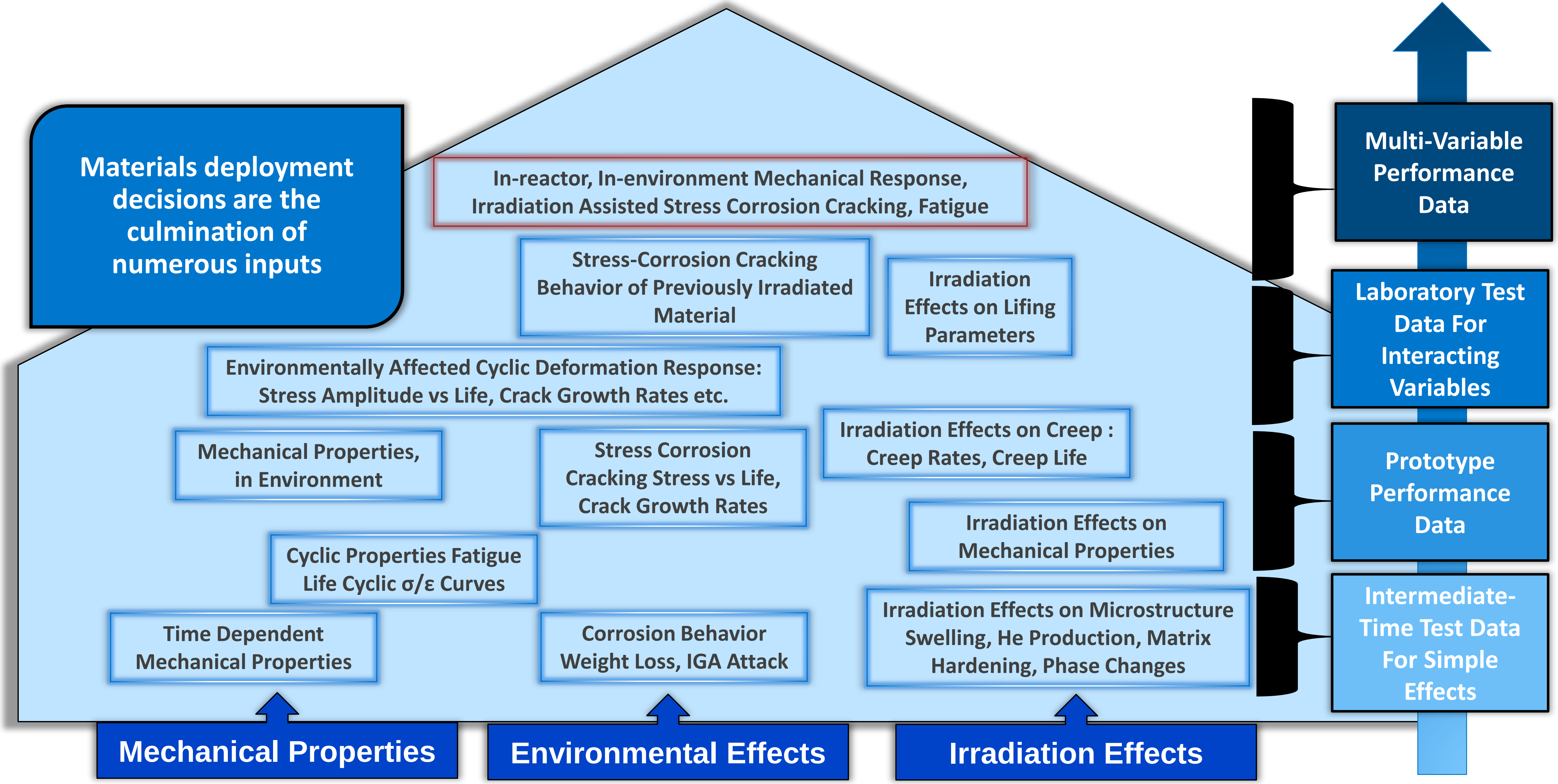
Materials Compatibility in New Reactor Environments



Materials Management Programs to Ensure Operational Integrity

EPRI

Materials Validation and Deployment



Materials Management – Post Material Selection

Identify applicable materials degradation for an AR environment

- Operating experience available?
- Research data available?
- Can the mechanism be modelled?

Assess impact of degradation

- Time-dependent or time-independent degradation?
- Critical/Detrimental to design integrity?

Can the degradation be designed out?

- Change geometries?
- Change materials?
- Change operating parameters/chemistry controls?
- SSC change, in general?

If not, then mitigate, monitor, or plan for replacement

- Cladding
- Peening
- Overlay
- New/Novel Mitigations
- Continuous monitoring
- Inspections
- Surveillance
- Plan for replacement

Design Phase

Materials TAG
Materials Degradation Matrices
Degradation Mechanism Screening and Assessment

Reactor developer decision making process – reasonable assurance for material deployment

Operational Programs

In-service inspection, monitoring, or surveillance
ASME Section XI, Division 2 - RIM

EPRI Advanced Reactor Materials Technical Advisory Group

AR Materials Technical Advisory Group (TAG)

Materials Gap Analyses

- **Molten Salt Reactors** 3002010726
- **Sodium Fast Reactors** 3002016949
- **High-Temperature Gas Reactors** 3002015815
- **Lead Fast Reactors** 3002016950

Advanced Reactor Materials Development Roadmap
3002022979

Materials Degradation Matrices
Materials, potential degradation mechanisms, and status of knowledge

- **Molten Salt Reactors MDM**
- **Sodium Fast Reactors MDM**
- **High Temp Gas Reactors MDM**
- **Lead-cooled Reactors MDM**

In Progress | Scoped | Future Project

AR Materials TAG
Key stakeholders to assist in direction setting and prioritization of needs concerning AR materials qualification and testing

Stakeholder engagement and alignment on industry deployment needs

- Code Qualification and Data Gaps
- Environmental Compatibility

Strategic direction setting and prioritization

- Advanced Reactor Materials Deployment Roadmap

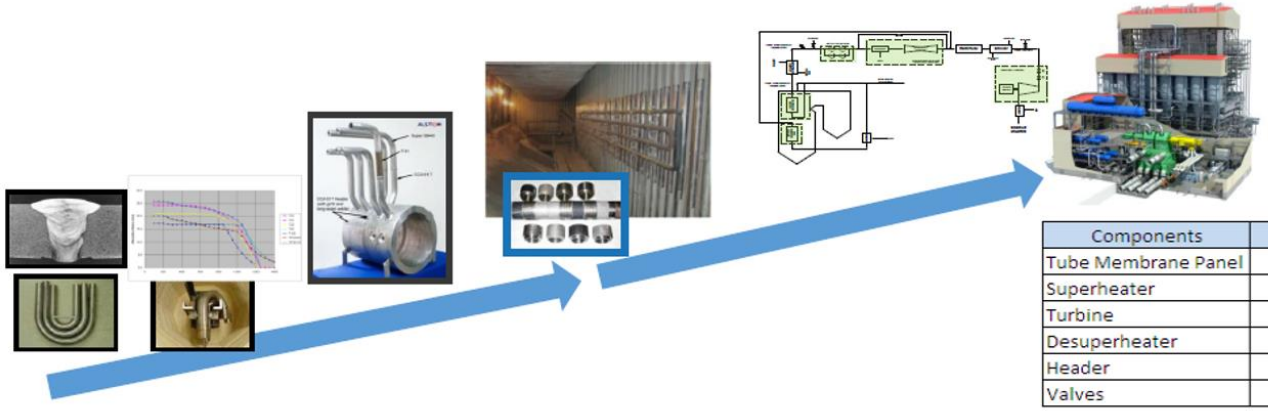
Develop & Execute Test Plans

Advanced Ultra-supercritcal (A-USC) Coal
Commercial Readiness

Inconel ® 740H® was the key enabling material for the U.S. DOE/OCDO A-USC Program

2001: Material Selection
2005: Material Optimization and Fabrication
2011: ASME Section I Code Case
2015: Field Testing Completed
2016-2020: Supply Chain Development & Small Pilots
2020-2023: First Large-Scale Pilot (sCO2) and Full-Size Components

Technology Readiness Levels			Roadmap to AUSC Demo	
Materials Evaluation (Nickel Superalloy Focus)	Component Mockup	Steam Loop at Plant Barry. Large forgings & castings	AUSC Component Test (ComTest)	AUSC Demonstration
Laboratory TRL 2-3	Proof of concept TRL 4	Component Test TRL 4-5	System TRL 4-7	Overall TRL 8-9



Components	TRL
Tube Membrane Panel	4
Superheater	5
Turbine	4
Desuperheater	4
Header	4
Valves	4

Recently completed DOE-sponsored projects achieved TRL = 4/5
AUSC ComTest will achieve TRL = 7 (ready for full scale demo)

Collaboration Across the Supply Chain is Critical

TOGETHER...SHAPING THE FUTURE OF ENERGY®

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eVinci® Microreactor

Material Qualification for the eVinci Microreactor

May 06, 2025

Westinghouse

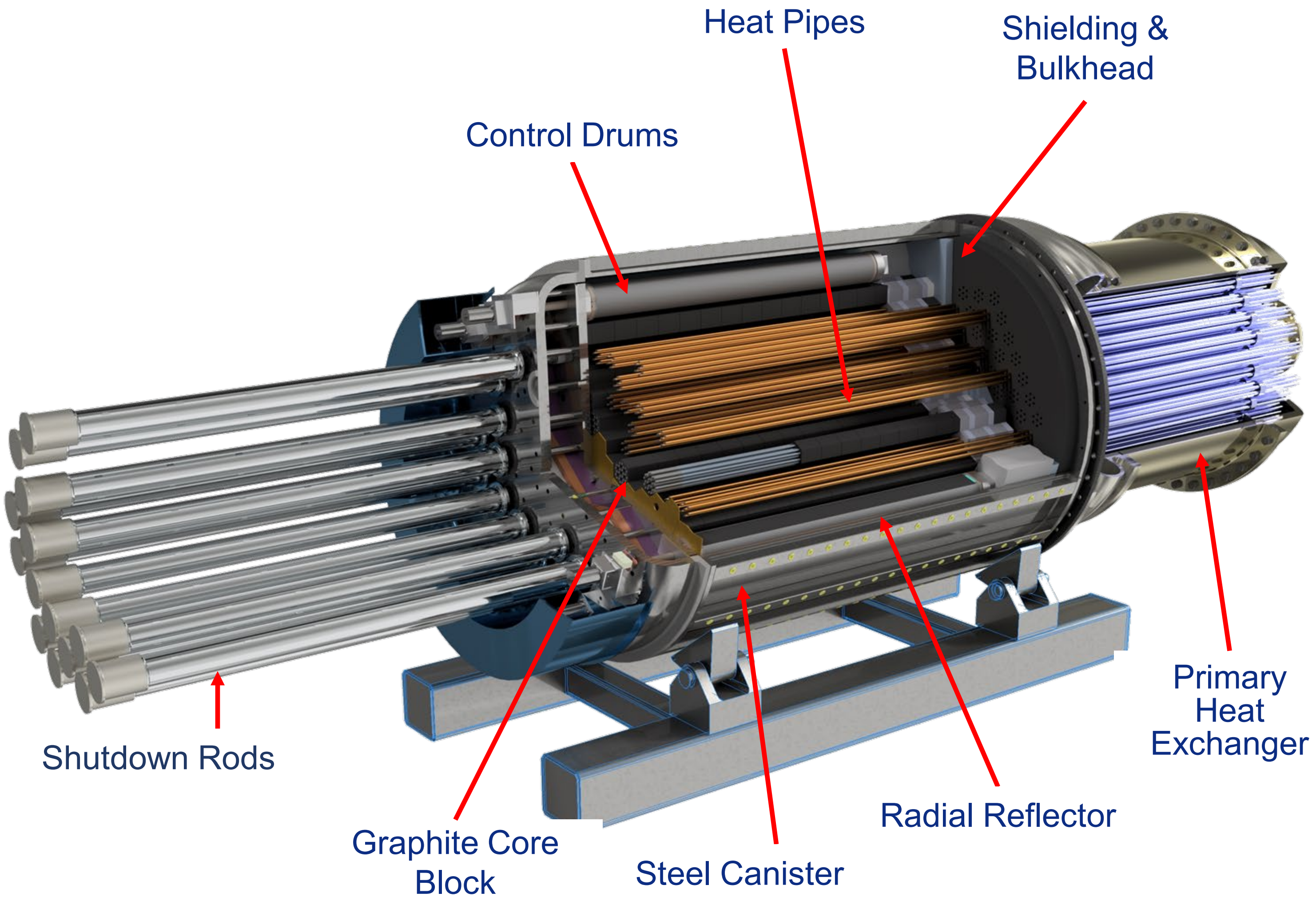
Agenda

- eVinci Microreactor Design Overview
- Overall Material Qualification Roadmap
- Metallic Qualification and Challenges
- Graphite Qualification and Challenges
- Ongoing Testing Programs
- eVinci Microreactor U.S. Nuclear Regulatory Commission (NRC) Pre-Application Engagement

eVinci Microreactor Design

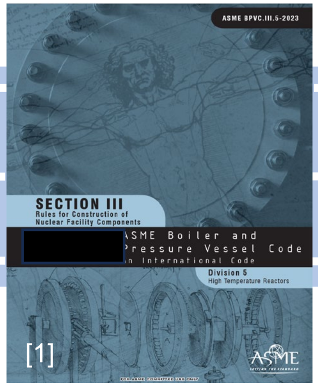
Safety through passive heat pipe technology, enabling a very low-pressure reactor

Parameter	eVinci Microreactor
Power	15 MWt
Fuel Cycle	8 years
Fuel (Enrichment)	Tri-structural Isotropic (TRISO) (19.75%)
Coolant	Heat Pipes
Reactor Pressure	~1 atm
Moderator	Graphite
Power Conversion	Open-Air Brayton
Efficiency	34%
Decay Heat Removal	Radial Conduction

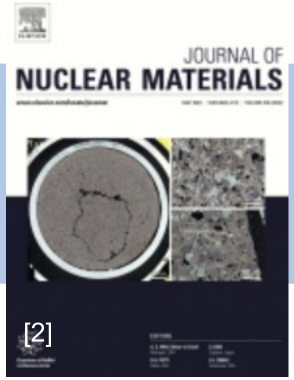


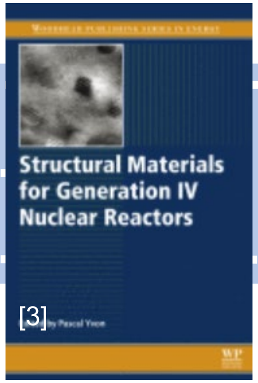
Overall Material Qualification Roadmap

(1) Qualification based on ASME Code + Reg Guide



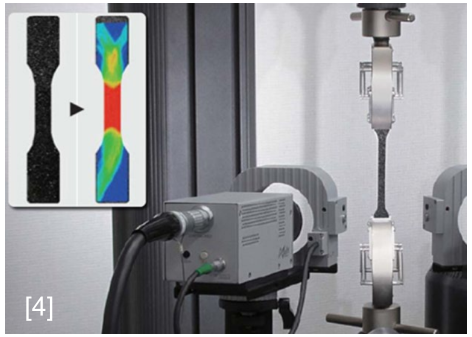
(2) Qualification of Existing Data from Literature





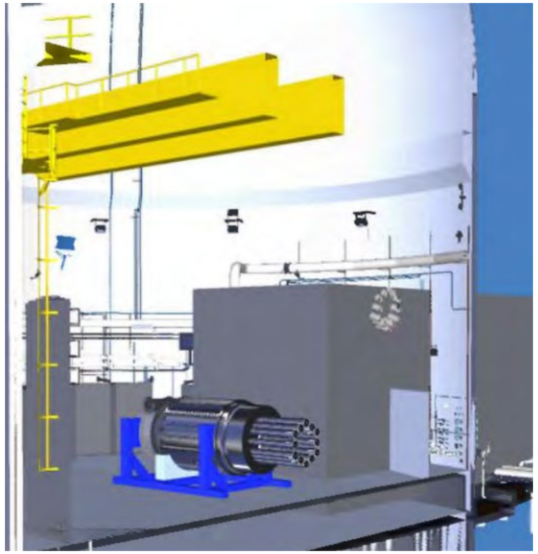
Identify Gaps

(3) Material Development + Confirmatory Testing



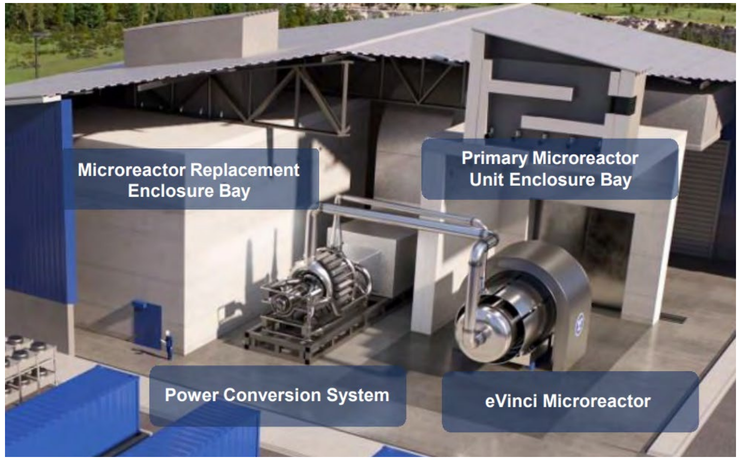
- Baseline properties
- Aging effects
- Irradiation effects
- Oxidation effects
- Material combability

(4) Design input to NTR through DOE



(5) Additional material property assessment, identify gaps, and testing.

(6) Design input to Commercial Reactor



[1] ASME BPVC.III.A-2023
[2] Journal of Nuclear Materials | Vol 578, May 2023 | ScienceDirect.com by Elsevier
[3] Structural Materials for Generation IV Nuclear Reactors (Woodhead Publishing Series in Energy): Yvon, Pascal: 9780081009062: Amazon.com: Books
[4] Material Testing – Photron

Metallic Qualification and Challenges

- eVinci microreactor metallic qualification guided by:
  - ASME BPVC Section III Division 5 (Div. 5)
  - ASME NQA-1–2024
  - DANU-ISG-2023-01
  - RG 1.87
- Use Div. 5 materials where possible based the allowable temperature ranges
- Div. 5, App. HBB-Y provides guidance for metallic material development & testing
  - Testing based on justified needs for design
  - Testing partners with universities, national labs, commercial vendors, internal testing labs
- Qualification of existing data based on NQA-1, Subpart 4.2.3
  - Qualification methods: quality assurance program equivalency, data corroboration, confirmatory testing, and peer review

Metallic Qualification and Challenges

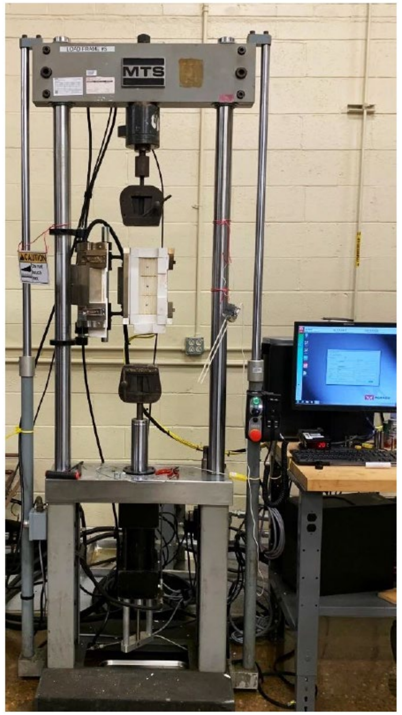
- **Challenges:**
  - Environmental effects (e.g., irradiation, oxidation, etc.) not explicitly addressed in Div. 5 for metals
  - Long-term high temperature testing to qualify “new materials”
    - Despite code permitting 3x or 5x extrapolation of creep data, several years of testing needed to obtain statistically significant creep data for new materials or to validate creep models
- **Ask:**
  - Although Div. 5 HBB-Y rules are for qualification of new materials into ASME code, rules can be used to qualify materials
    - Request NRC endorse Div. 5 HBB-Y for material qualification
    - Endorsement represents agreement that approach is acceptable without needing materials added to code first

Graphite Qualification and Challenges

- Div. 5, HHA-2200 provides guidance for graphite material qualification
  - Generate MDS including: 1) manufactured material properties, 2) irradiated material properties, and 3) oxidized material properties
- Div. 5 does not list permissible graphite grades like it does for metallic components
  - Westinghouse has comprehensive testing program to acquire manufactured material properties
- Gaps of irradiation data for graphite grades
  - Utilize DOE funded programs to access publicly available data on relevant graphite grades
  - Establish and implement statistical analysis methods to interpolate and extrapolate irradiated material behaviors
- **Ask**:
  - In TLR-RES/DE/REB-2022-1, material properties or parameterization developed using the graphite degradation models (thermo-mechanical model and oxidation model) were specifically for IG-110
  - Beneficial for NRC to expand application of these models for other graphite grades and provide corresponding parameterizations

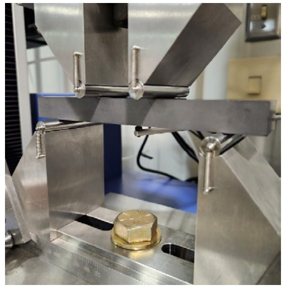
Ongoing Testing Programs

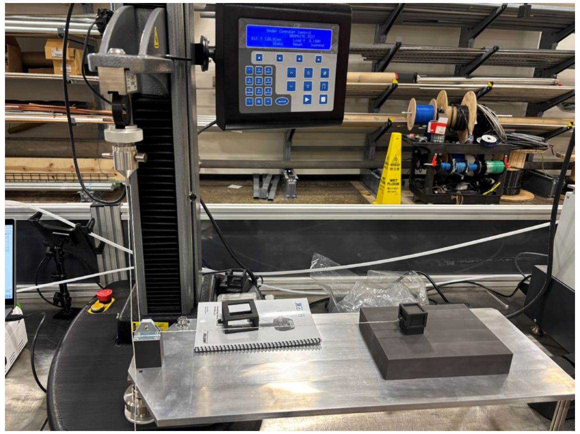
- Heat Pipe Testing
  - High Temperature Testing for time-independent and time-dependent material properties.



- Material Compatibility Testing
  - Long term and high temperature sodium compatibility with heat pipe tubing and wick materials.

- Graphite Testing
  - Room and High Temperature (>1000 °C) Mechanical Testing
  - Thermal Property Testing





Pre-Application Engagement – White Papers

Current Status:
https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities/evinci.html

#	Topic	Submittal Wave	#	Topic	Submittal Wave	#	Topic	Submittal Wave
1	Facility Level Design Description	Submitted - 1	13	Advanced Logic System®(ALS) v2	Submitted - 3	25	Inservice Inspection Program/Inservice Testing Program	Submitted – 5
2	Principal Design Criteria	Submitted - 1	14	Component Qualification	Submitted- 3	26	Post-Accident Monitoring System	Submitted – 5
3	Safety and Accident Analysis Methodologies	Submitted - 1	15	Emergency Plan Zone Sizing Methodology	Submitted - 3	27	Equipment Qualification	Submitted – 5
4	Licensing Modernization Project Implementation	Submitted - 1	16	Physical Security	Submitted - 3	28	Probabilistic Risk Assessment and Transportation Risk Assessment	Submitted – 5
5	Regulatory Analysis	Submitted - 2	17	Heat Pipe Design, Qualification, and Testing	Submitted - 3	29	Fire Protection	Submitted – 5
6	Deployment Model	Submitted - 2	18	Nuclear Design	Submitted - 3	30	Cyber Security	Submitted – 5
7	Safeguards Information Plan	Submitted - 2	19	U.S Transportation Strategy	Submitted - 3	31	Radiation Protection and Contamination Methodology	Submitted – 6
8	Test and Analysis Process	Submitted - 2	20	Phenomena Identification and Ranking Table (PIRT)	Submitted - 4			
9	Functional Containment and Mechanistic Source Term	Submitted - 2	21	Integral Effects and Transient Testing	Submitted - 4			
10	Composite Material Qualification and Testing	Submitted - 2	22	Refueling and Decommissioning	Submitted - 4			
11	Fuel Qualification and Testing	Submitted - 3	23	Seismic Methodology	Submitted - 4			
12	Code Qualification	Submitted - 3	24	Operations and Remote Monitoring	Submitted - 4			

Topical Reports

#	Report Title	Status
1	ALS v2 Platform	Approved (Mar. 2025)
2	ALS v2 Development Process	Approved (Mar. 2025)
3	Principal Design Criteria	Approved (Jan. 2025)
4	ALS v2 Platform Elimination of Technical Specification Surveillance Requirements	Submitted (Dec. 2023)
5	Nuclear Design Methodology	Submitted (May 2024)
6	Westinghouse TRISO Fuel Design Methodology	Submitted (Aug. 2024)
7	Composite Materials Qualification Methdology	
8	Testing Program	
9	Physical Security Design	
10	Functional Containment and Mechanistic Source Term Methodology	
11	Design Basis Analysis Methodology	
12	Metallic Materials	
13	Graphite Materials	
14	Heat Pipe Qualification Criteria	
15	Component Qualification Methodology	
16	Inservice Inspection	
17	Inservice Testing	

Westinghouse

Questions

Thank You

Westinghouse Electric Company

@WECNuclear

Westinghouse Electric Company

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Westinghouse

KAIROS POWER: AN ITERATIVE APPROACH FOR REACTOR MATERIALS

NRC PUBLIC MEETING: ADVANCE ACT - ADVANCED METHODS OF MANUFACTURING AND CONSTRUCTION FOR NUCLEAR ENERGY PROJECTS

6 MAY 2025

Kairos Power's mission is to enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

In order to achieve this mission, we must prioritize our efforts to focus on a clean energy technology that is ***affordable*** and ***safe***.

Background

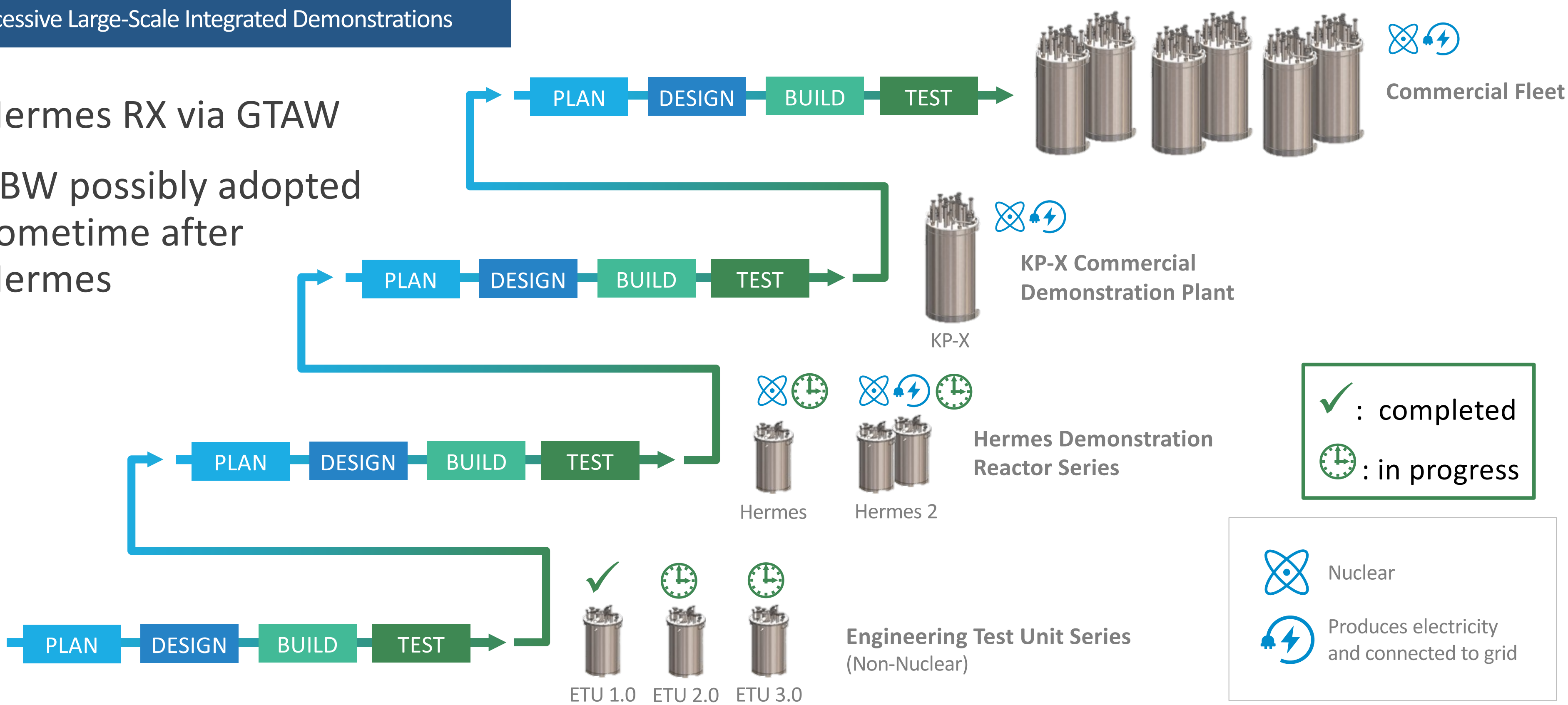
- KP-FHR Reactors operate 550-650°C at low pressure

	Key Points
Reactor Description	Pool-type, fluoride-salt cooled, high temperature reactor (FHR)
Core Configuration	Pebble bed core, graphite reflector, and enriched Flibe molten salt coolant
Primary Heat Transport System	Flibe Salt, 550°C-650°C, ~0.2 MPa, ~0.11-0.15 m/s T_{max} < 750°C
Materials for Safety Related Structures	316H 16-8-2 Weld Filler Metal Possible 316H Autogenous EBW
Lifetime	20 years for Power Reactor
End of Life Irradiation of Reactor Vessel	<0.1 dpa

Kairos Power Path to Commercialization

Successive Large-Scale Integrated Demonstrations

- Hermes RX via GTAW
- EBW possibly adopted sometime after Hermes



Topics of Interest to Kairos Power

- Extension of 16-8-2 filler metal to higher temperatures in Sec. III Div 5
  - Wrapping up internal testing program to justify
- Local vacuum electron beam welding
  - Technical assessment complete
  - Vetting test plan through ASME Allowable Stress Committee May 2025
  - May initiate materials testing in the near-future
- Combined effects testing
  - Utilizing MIT-R to assess molten salt + irradiation for graphite and 316H
- New alloys
  - 709 for improved creep resistance
  - ‘Hast-N’ type alloys for use in fluoride salts – in collaboration with ORNL (Dr. Murali Muralindharan)
  - Stainless steels that have increased resistance to helium embrittlement
- Solid state welding for head & vessel penetrations
- Additive manufacturing
  - 316H PM and wire arc additive
  - AM component performance in our Engineering Test Unit (ETU)

AALO'S ADVANCED MANUFACTURING AND QUALIFICATION APPROACH FOR INTERMEDIATE HEAT EXCHANGERS

Luke Andrew, PE

Aalo-X Program Technical Lead

OUTLINE

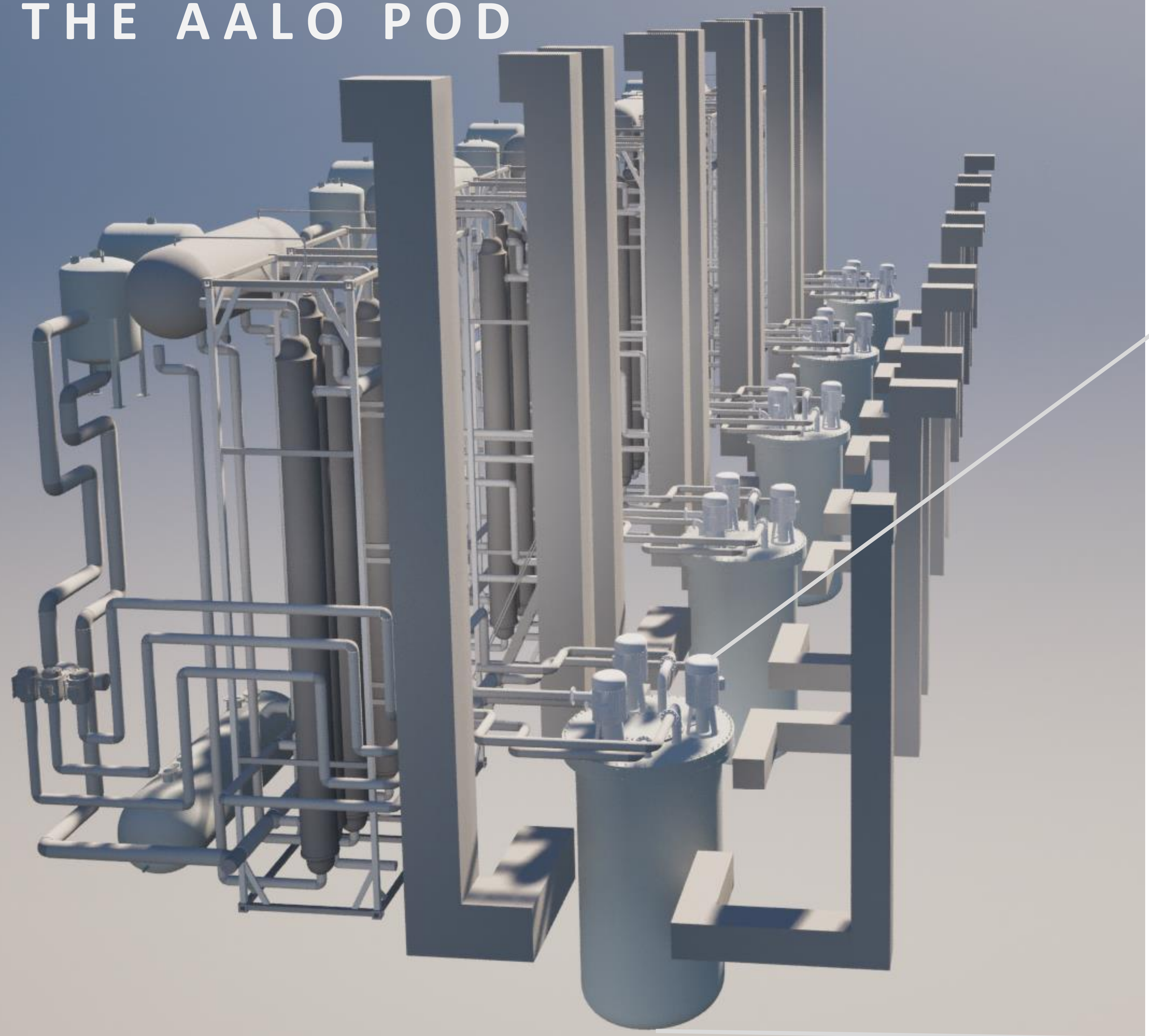
CURRENT NUCLEAR CONSTRUCTION TIME
1 GW = 10+ YEARS

At Aalo, we focus on Factory Manufacturing

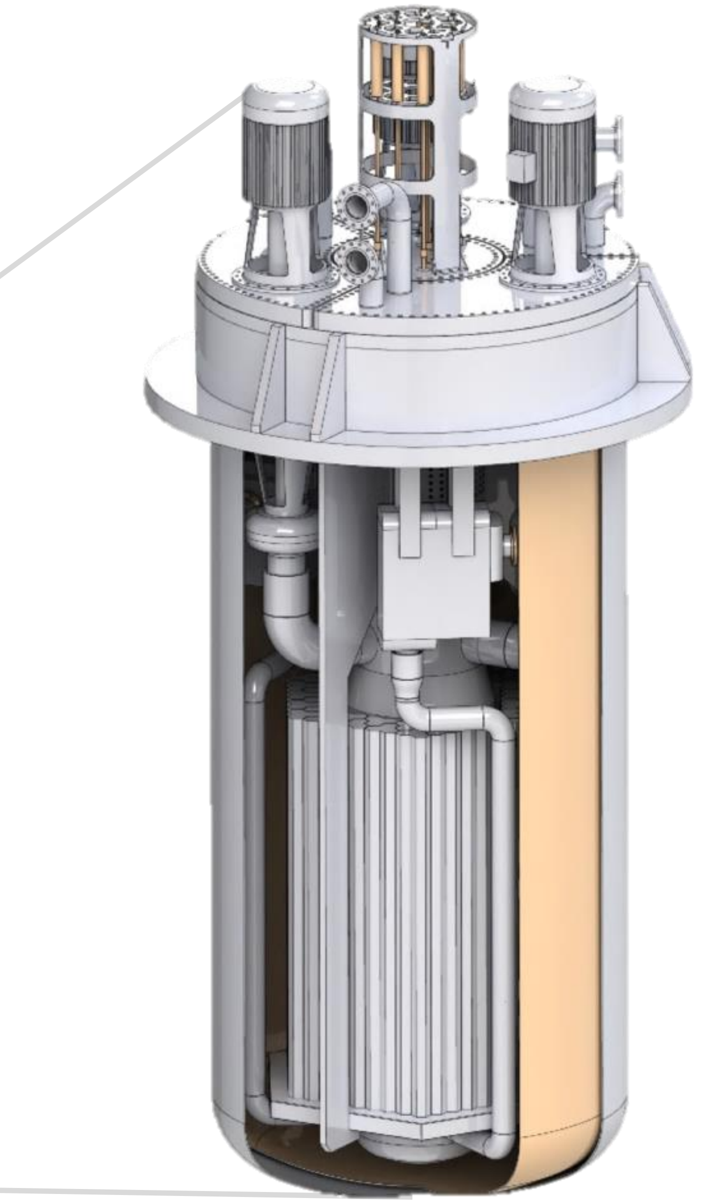
1 GW (100 reactors) / yr / factory

Austin, TX, USA

THE AALO POD



AALO-1 REACTOR



Aalo's Business Model

Rapid Deployment at Multiple sites with Multiple Pods

Unit Overview

Confinement

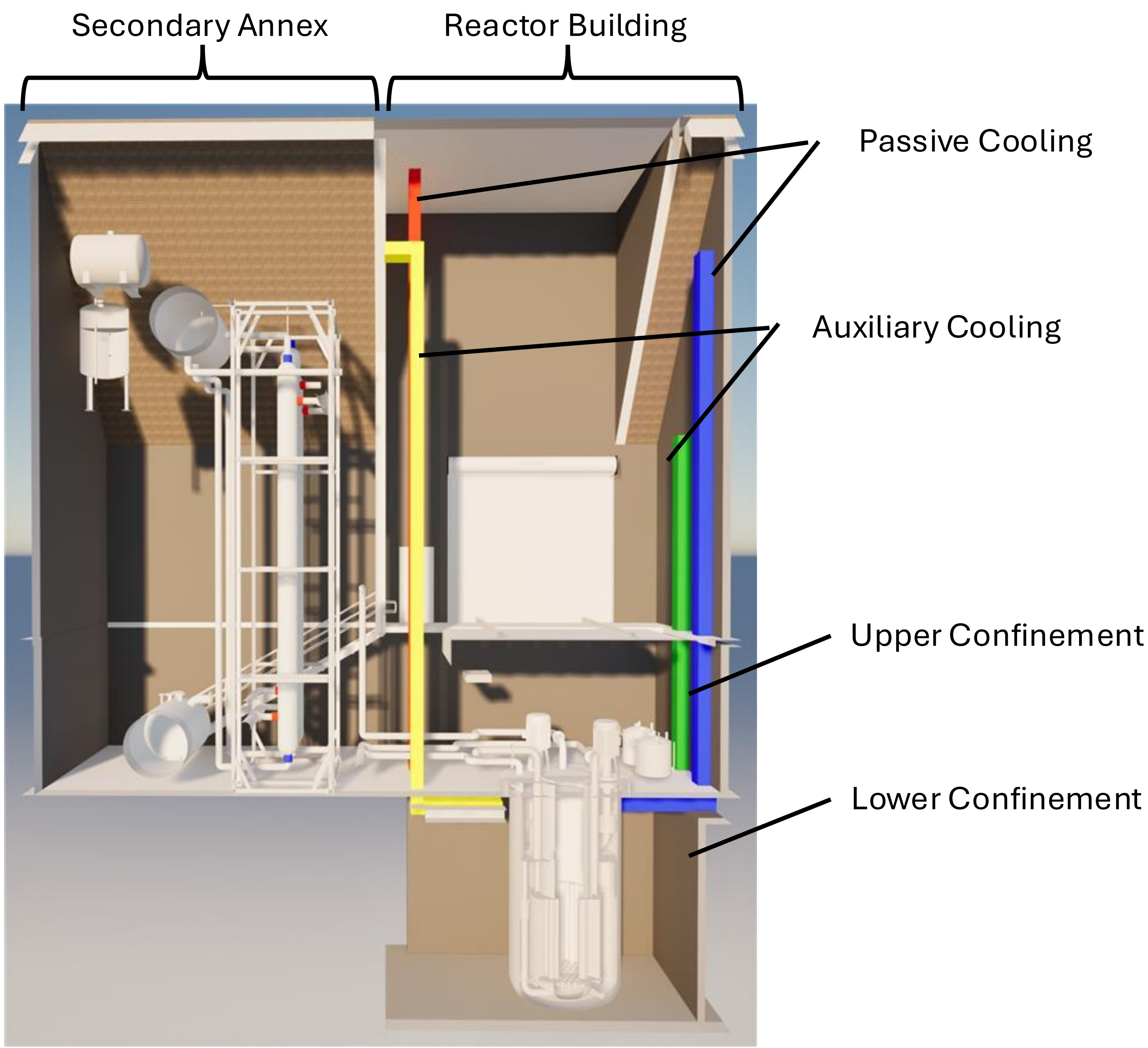
- Lower SC Module
- Upper SC Module

Structurally Independent

- Secondary Annex
- Reactor Building

Air-Based Cooling

- Auxiliary Cooling
- Passive Cooling



Safety Features

Control

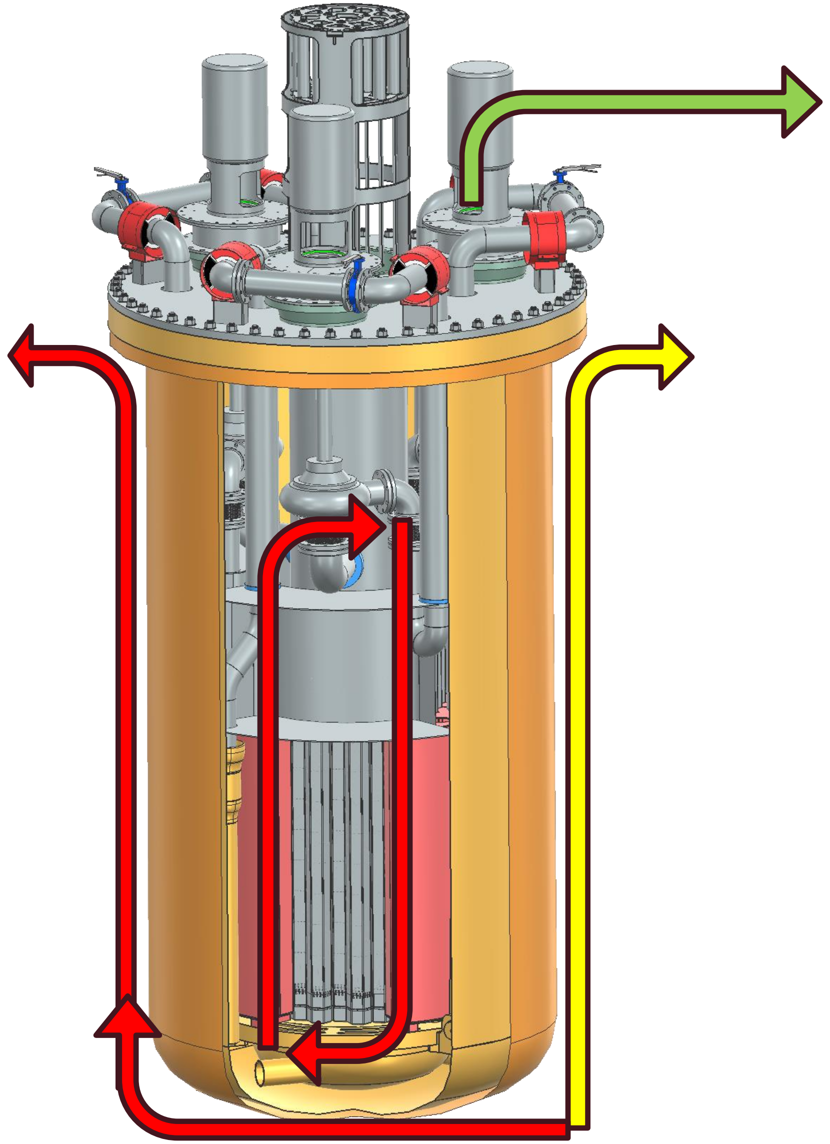
- Motor-driven control rod power reduction and scram
- Gravity-driven control rod scram

Contain

- Low pressure primary system
- No penetrations in reactor vessel wall
- Guard vessel for secondary containment

Cool

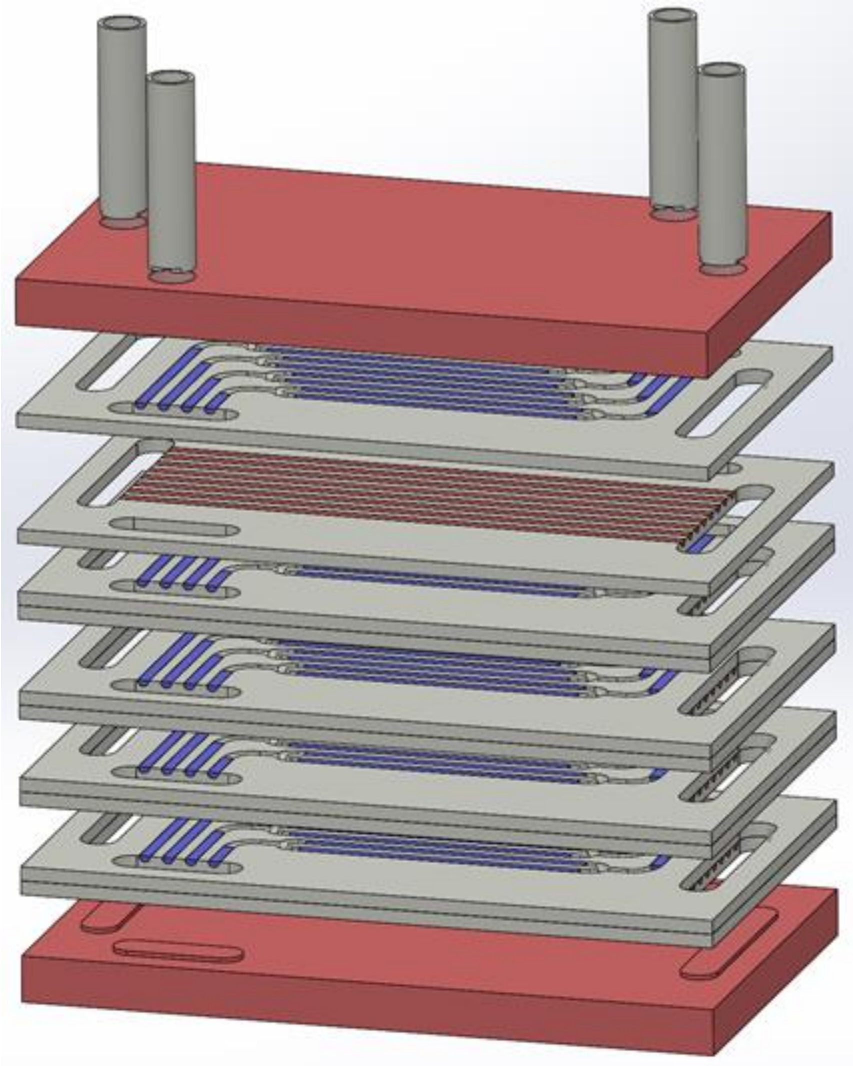
- Natural circulation within reactor
- Auxiliary air cooling through natural and forced circulation
- Passive air cooling through natural circulation “always operational”



IHX IN AALO-1 DESIGN

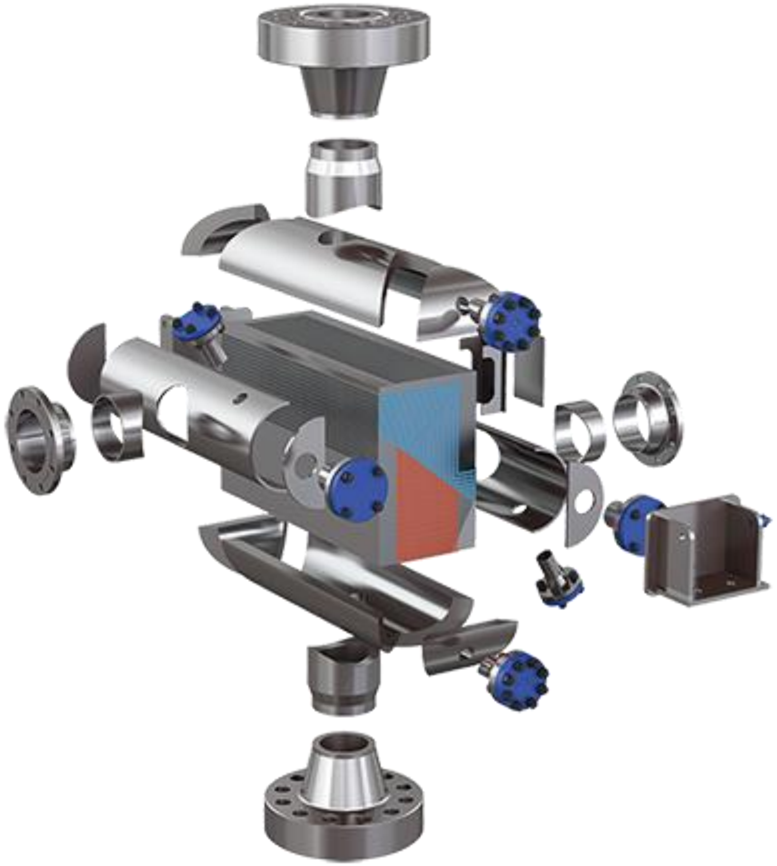
Printed Circuit Heat Exchanger

- Highly compact and efficient type of heat exchanger
  - Up to 85% smaller than equivalent shell & tube
- Used in high-temperature, high-pressure applications
  - Pressure capability: up to 1,000 bar (14,500 psi)
  - Temperature range: -270°C (-454°F) to 900°C (1650°F)
- Inherently robust design
  - High integrity plate type exchangers
- Flexible Implementation
  - No restrictions on fluid pressure drop



MANUFACTURING PROCESS

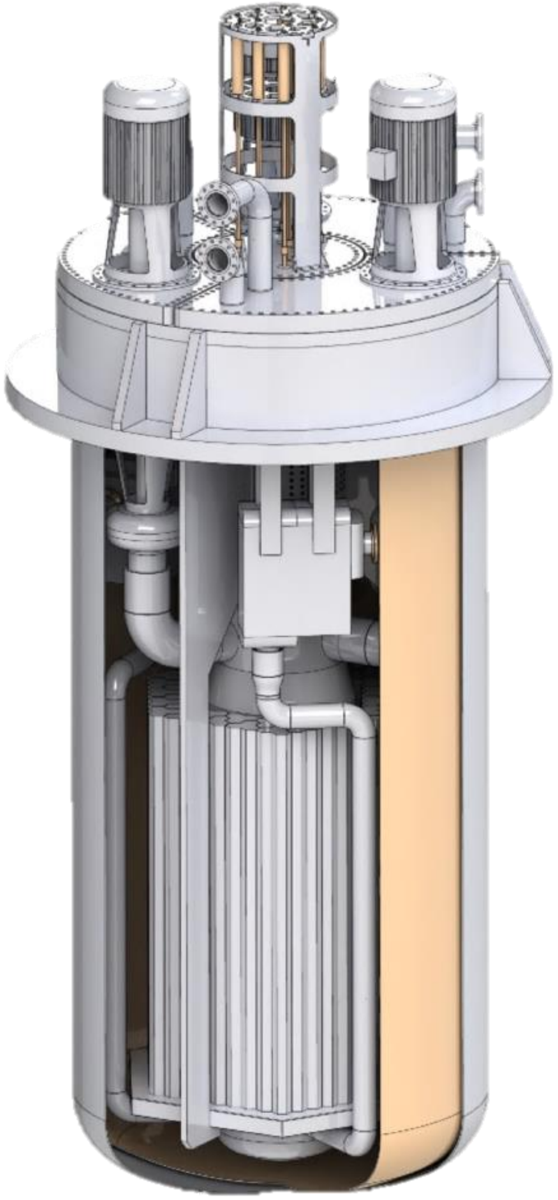
1. Plate material
   a) 316 L
2. Photolithographic Masking, Chemical Etching, or Milling of flow channels
3. Plate Stacking
4. Diffusion Bonding
   a) Vacuum hot press furnace under large pressure, temperature, and time
   b) atomic diffusion occurs across the plate interfaces
      a) creating a solid-state weld that forms a monolithic block with no joints or seals



PCHE ROLE IN AALO-1 DESIGN

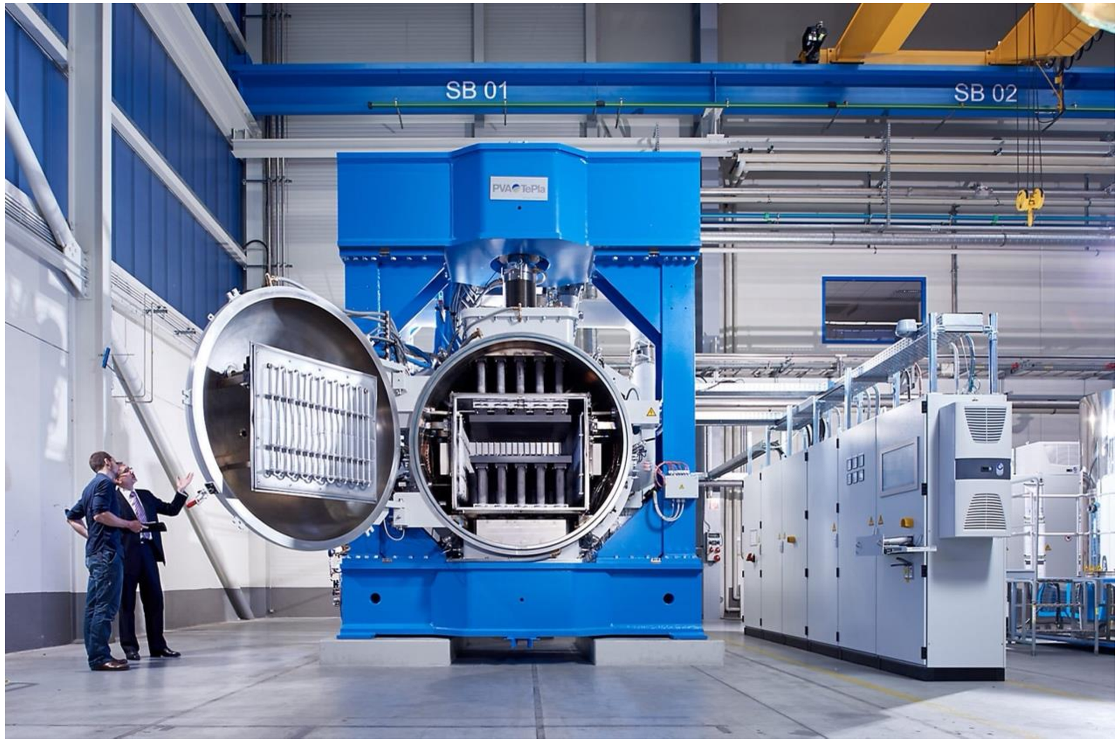
a) **Safety function for PCHE**
    a) **IHX isolates the secondary sodium used from the sodium in the primary system**
    b) **Leaks in the IHX would result in the transfer of Secondary sodium into the primary system**

b) **Critical characteristics for PCHE**
    a) **Ensure postulated leakage across the IHX interface is within acceptable limits consistent with radionuclide release design limits**
    b) **Capable to transfer its design heat load during normal operation**

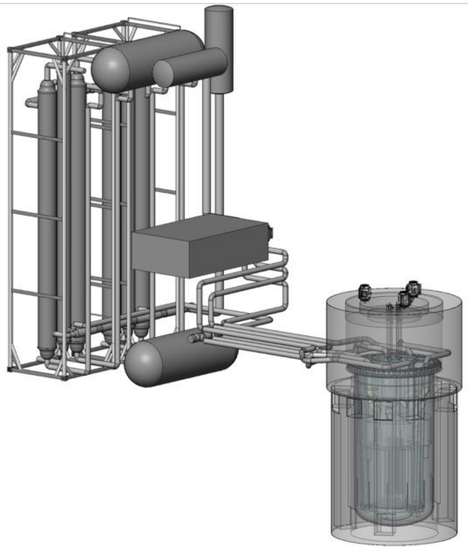


PCHE IMPLEMENTATION AT AALO

- Use ASME BPVC Section IX requirements for the qualification of Diffusion Welding (DFW)
  - Seeking Code Interpretation
- Use 316L for PCHE Fabrication
  - Code Case 2577 allows use of 316L at elevated temperatures for Section VIII.1 (time independent properties)
    - ASME BPVC Section II Part D Table 1A permits 304L and 316L to 1200 F and 304, 304H, 316, and 316H to 1500 F per Section VIII

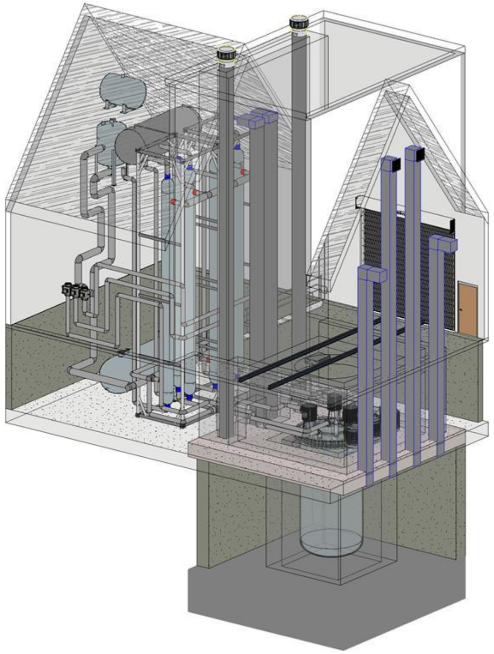


SYSTEMATIC TECHNOLOGY MATURATION



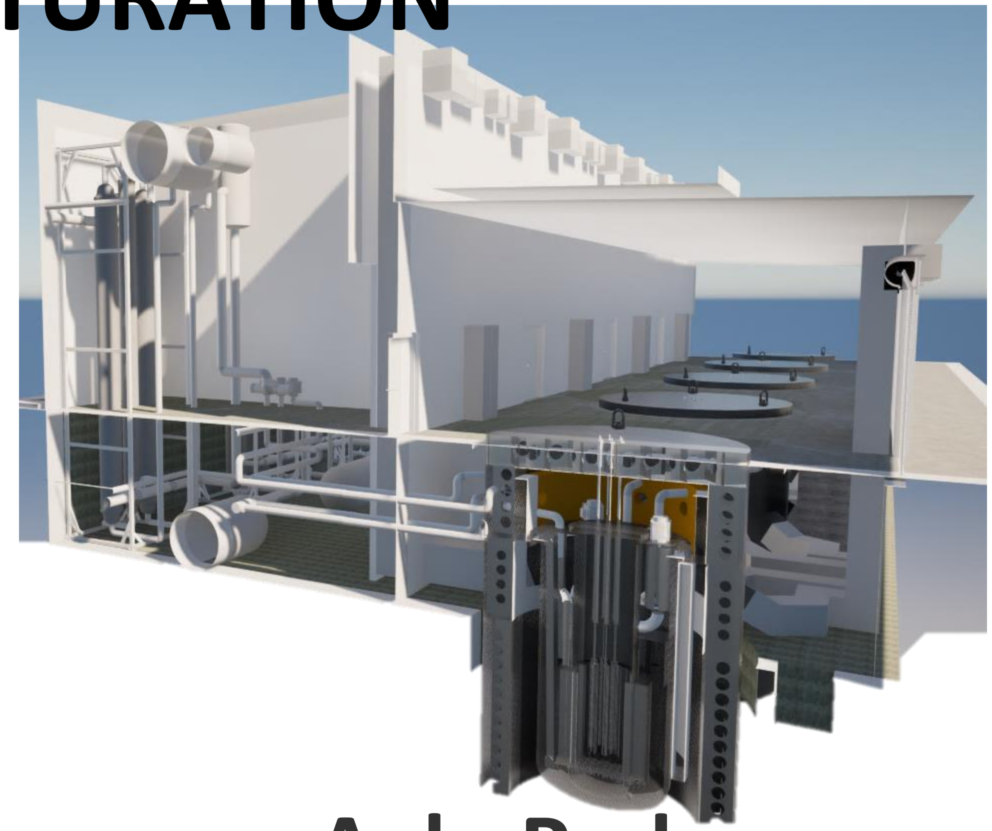
Aalo-0

Non-nuclear Systems Prototype (Separate Effects and Integrated Effects Testing)



Aalo-X

Experimental Reactor (Testing and demonstrating design features, and safety functions)

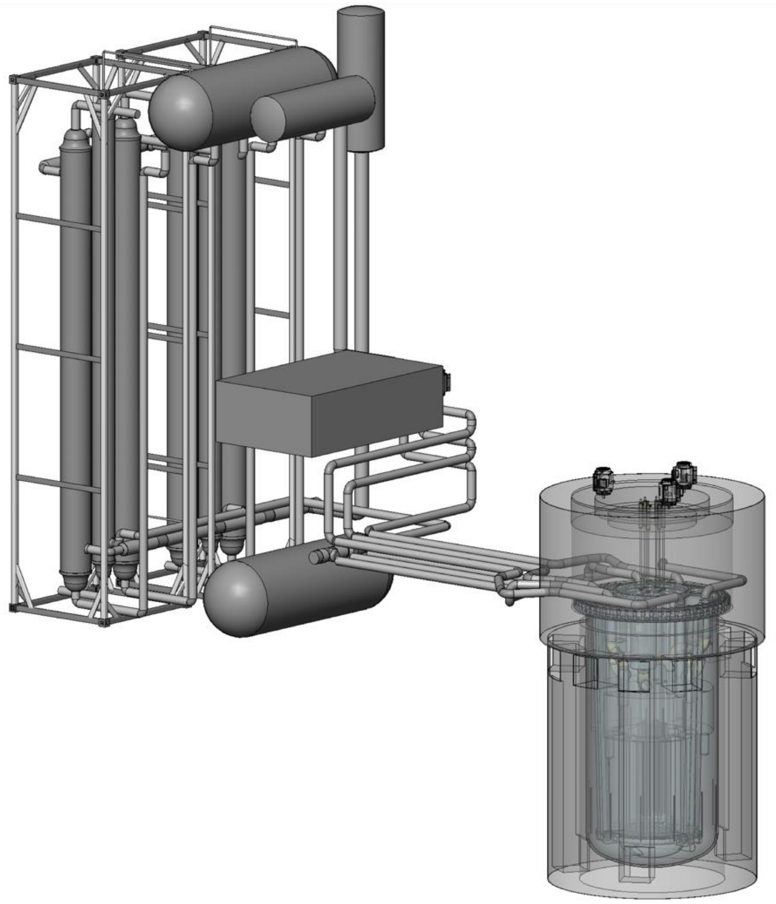


Aalo Pod

NRC Licensed Facility (Uses data and experience from Aalo-0 and Aalo-X)

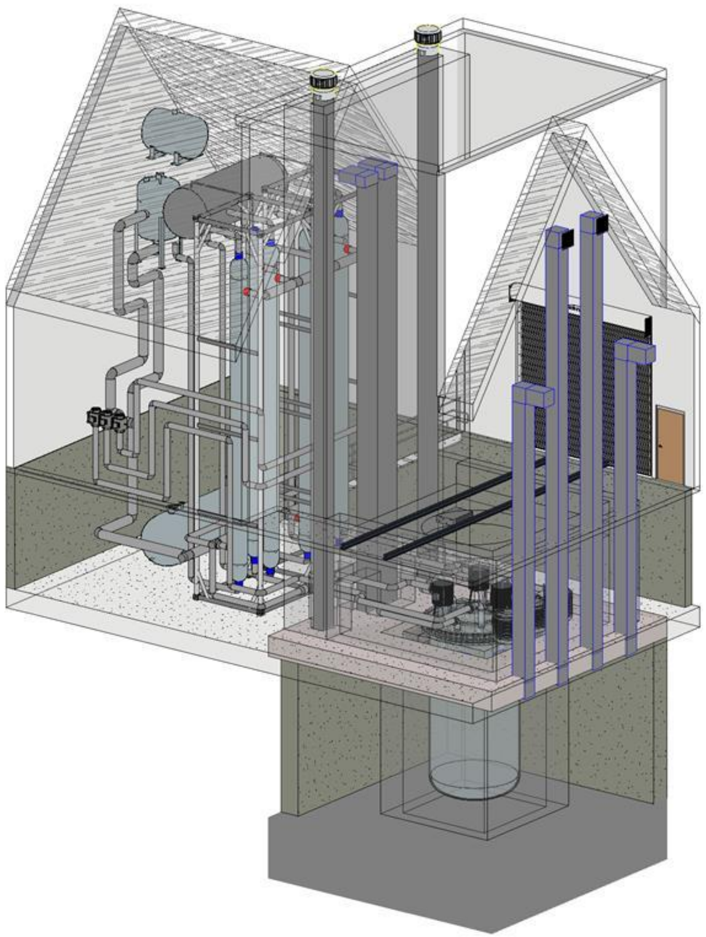
PCHE PERFORMANCE EVALUATION AT AALO-0

- Verify PCHE performs its intended functions.
- Demonstrate the operability and performance of the heat exchanger as a component and within its system
- Confirm structural and leak-tight integrity
- Verify heat transfer capability



PCHE PERFORMANCE EVALUATION AT AALO-X

- Verification of PCHE operation during Aalo-X operation
  - potentially through temporary configurations to test different design conditions
- Heat transfer capability
- Flow rates and inlet/outlet temperatures
- Structural and leak-tight integrity
- Functional Interfaces with connecting systems



WWW.AALO.COM

LUKE@AALO.COM

THANK YOU

Metallic Materials Development for the NATRIUM® Advanced Reactor

Bridgette Hannifin

May 6, 2025

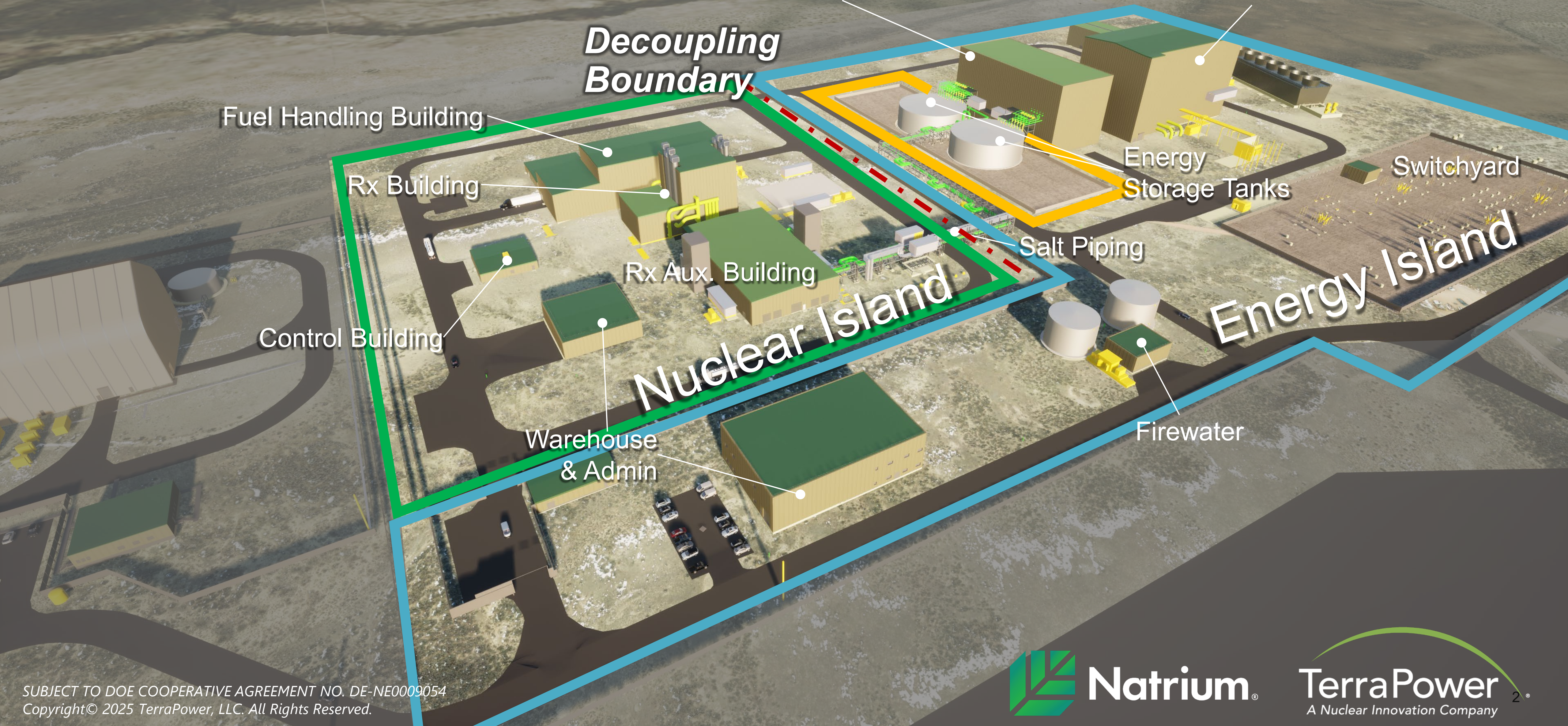
TerraPower

Natrium

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Natrium reactor is a TerraPower & GE Hitachi technology

Single Unit Site



Natrium
TerraPower
A Nuclear Innovation Company

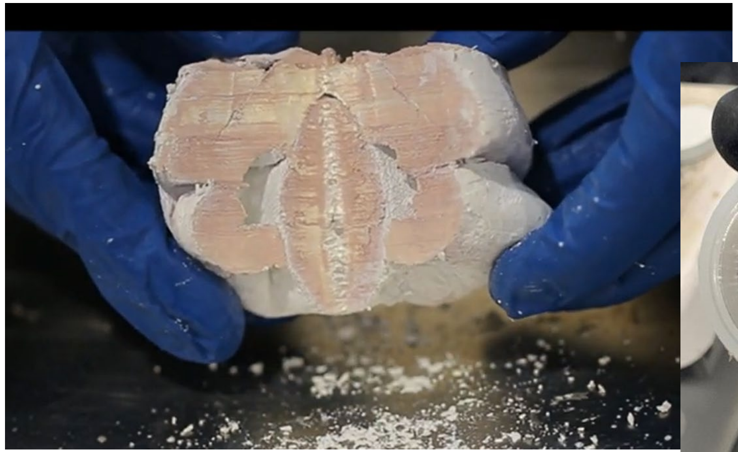
Sodium Coolant and Molten Salt Properties

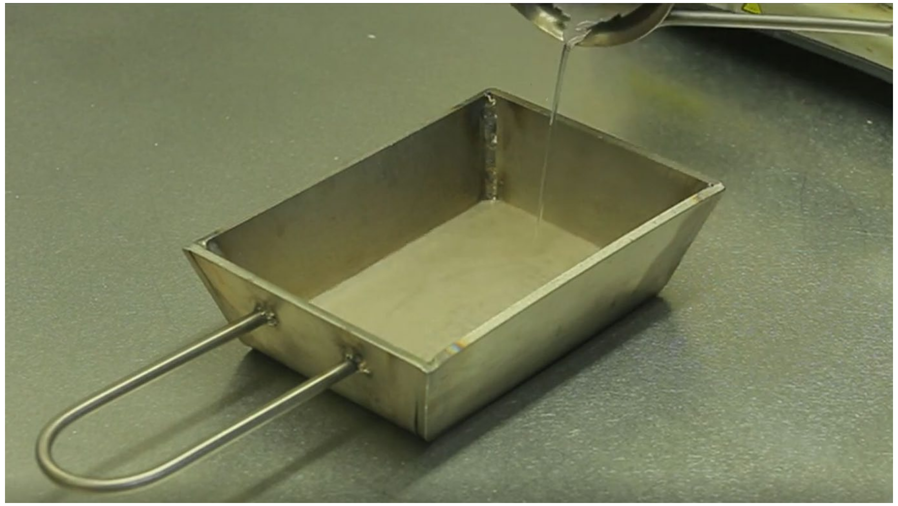
Liquid Sodium

- 730-1050°F (390-540°C) Reactor Coolant Operating temperature
- 98°C Melting Temperature
- Operates near atmospheric pressure

Molten Salt (60 $NaNO_3$- 40 KNO_3)

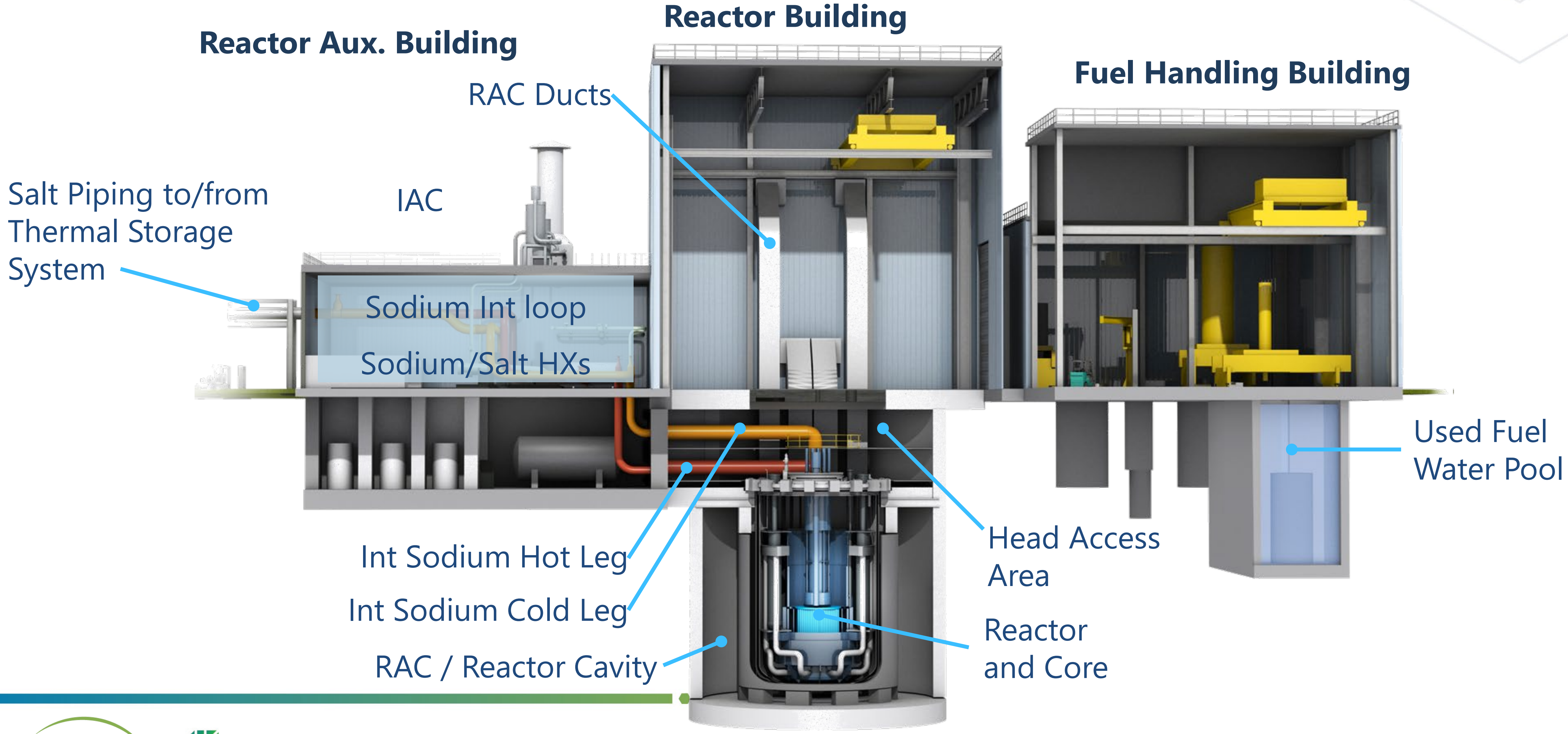
- Temperature range 460-1150 °F (238°C – 621°C)
- Commonly used for heat storage is the same as used for solar plants





SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

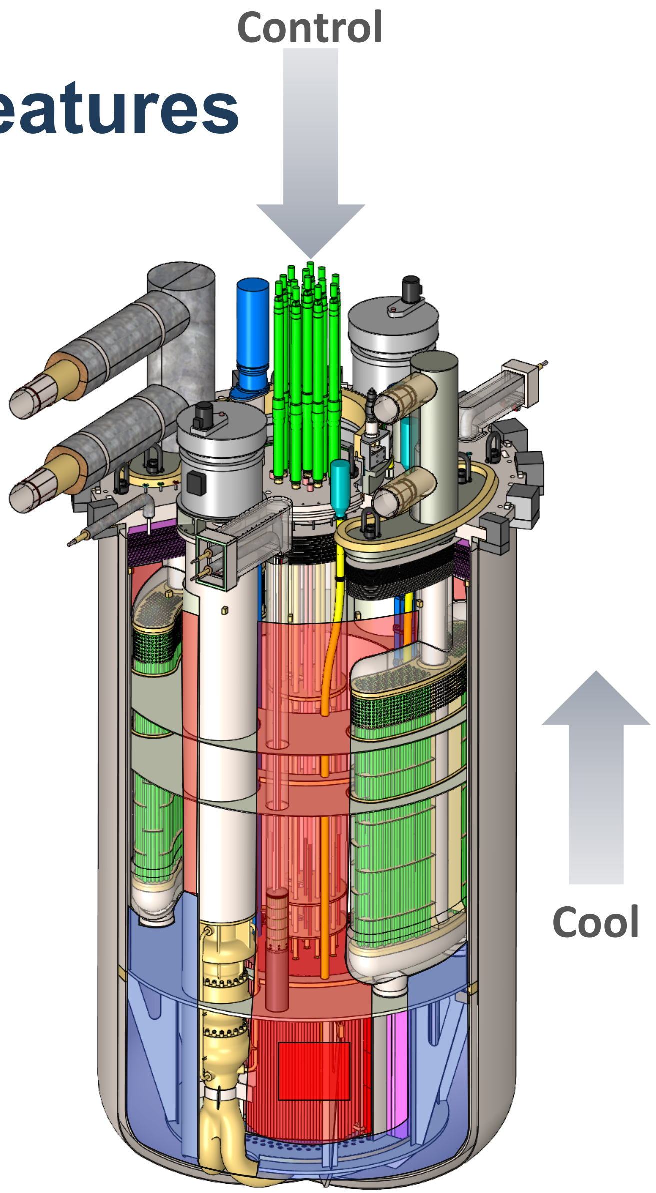
Key Technical Features of Natrium Reactor Buildings



SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Natrium Reactor 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

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Natrium® Program Roadmap

Qualification and testing of commercial technology occurs through advanced fuel and materials development using the Natrium reactor system as a platform.

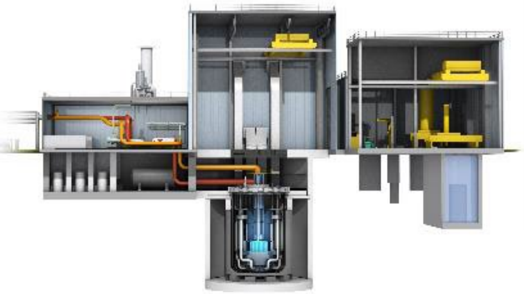
Technology

TWR

Product

Natrium Reactor

Demo project start April 1st, 2021



1980s-2019		2021-2030	2030+	2040+
U.S. legacy SFR experience, PRISM and TWR development	Pre-Demo Phase	Natrium Demonstration Project (345 MWe → 500 MWe) Commercial Plant Economics +Energy Storage & Peaking Capability	Natrium Commercial Series I (345 MWe → 500 MWe) 3 yr. Construction +Energy Storage & Peaking Capability	Commercial Series II+ (Up to GWe scale) Commercial Series I Benefits +DU Breed-and-Burn +Potential UNF Recycling +Potential Pu Disposition +Zero-Carbon Process Heat

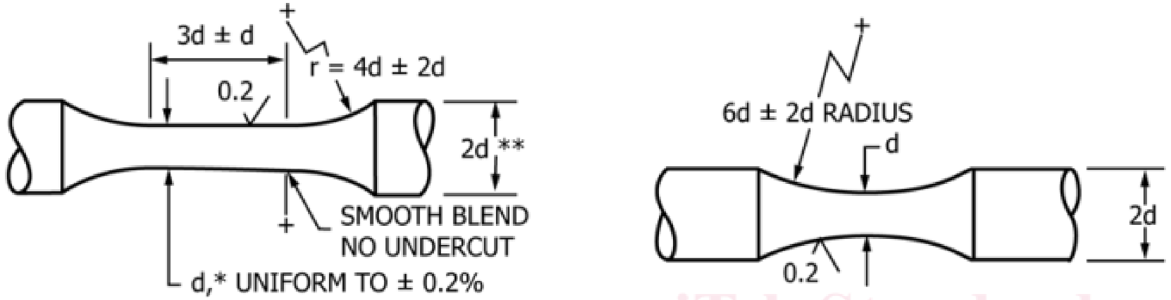
ASME BPVC Challenges for Section III Div 5

- Time-temperature gaps in the design properties for the six currently-qualified Class A materials
  - Section III, Div 5 covers 300,000 hrs. Code case required to extend to 500,000 hrs
  - Testing may be required to extend material properties to longer times and/or higher temps
- US NRC endorsements and potential restrictions
  - NRC reviewed the rules of ASME Section III, Division 5, 2017 edition and identified a set of material specific restrictions on the currently-qualified materials that could be mandated by the NRC as a condition of their endorsement of the ASME design approach
- The simplified design-by-elastic analysis rules for evaluating the Section III, Division 5 creep-fatigue and deformation limits criteria may have reduced accuracy in the temperature range where creep and plasticity become indistinguishable
- Does not provide reference inelastic constitutive models for use with the design by inelastic analysis method for evaluating the creep-fatigue and deformation limits
- The list of currently-qualified Class A and Class B materials may not be optimal for some advanced reactor concepts

Messner et al. 2021. ANL-21/27 Identifying Limitations of ASME Section III Division 5 For Advanced SMR Designs

Code Challenges: HBB-2800

- HBB-2800 stipulates a fatigue acceptance test on every *lot* of material
- HBB-2800 specifies ASTM E 606
  - Sample geometry as shown below where d=0.25 in
  - >0.5 in of material is needed for the sample
  - Push-pull test - thin or subsize specimens may buckle
  - Potentially limits applications/geometries where 304/316 SS can be used



(a) UNIFORM-GAGE TEST SECTION
(*SEE RECOMMENDATION OF FIGURE 5a)

(b) HOUR-GLASS TEST SECTION

HBB-2800 FATIGUE ACCEPTANCE TEST

(a) For 304 and 316 austenitic stainless steel components intended for service where conditions for Levels A, B, and C do not satisfy the limits of HBB-T-1324(a) and HBB-T-1324(b), a uniaxial fatigue acceptance test of each lot of material shall be performed.

(b) The fatigue test shall be performed in air at 1,100°F (595°C) at an axial strain range of 1.0% with a 1-hr hold period at the maximum positive strain point in each cycle. Test-specimen location and orientation shall be in accordance with the general guidance of SA-370, paras. 6.1.1 and 6.1.2 and the applicable product specifications. Testing shall be conducted in accordance with ASTM Standard E 606. The test shall exceed 200 cycles without fracture or a 20% drop in the load range.

(c) Failure to meet this requirement shall be cause for rejection of the lot for use in Class A elevated temperature components.

(d) The definition of "lot" shall be obtained from the material specification. Where more than one definition is provided by the specification, the definition used to establish the tensile properties shall govern. Either the Material Organization or N-Type Certificate Holder may perform the lot qualification test.

(e) Retesting is permitted. Two additional specimens shall be tested and both specimens must pass the cyclic life requirement. Further retests are not permitted.

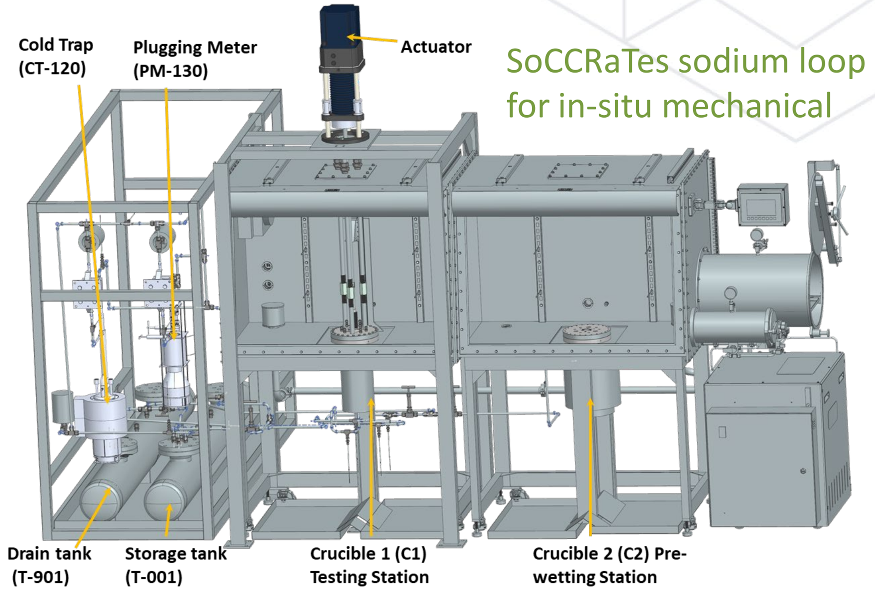
Environmental Testing in Sodium

<u>In-situ mechanical testing</u>

- SoCCRaTes Loop being fabricated at Oregon State University
- Mechanical properties testing in sodium using a load frame
- Facility for in-situ testing of mechanical properties using a miniature bellows system (GELS)

<u>Sodium exposure testing</u>

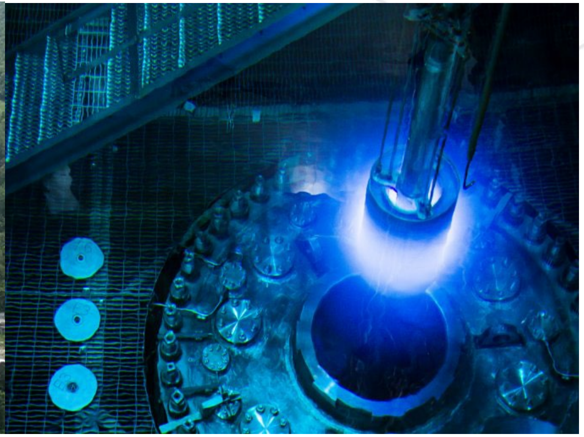
- SMT-3 loop fabricated and running at ANL
- Primary goal is to develop carburization/decarburization curves for core assembly materials (HT9 and Grade 92) to match published curve for Grade 91 (ANL-ART-190)
- Structural materials, welds, and coatings will be included
- Evaluations of mass loss, mass transfer, effects on mechanical properties, etc.



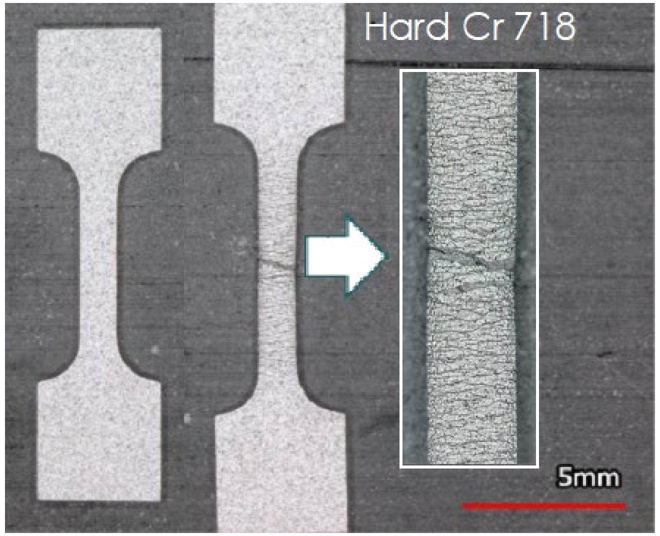
Environmental Testing-Neutron Irradiation

Neutron Irradiations in HFIR at ORNL

- Four campaigns
  - Structural materials
  - Welds
  - Coatings and surface treatments
  - Advanced fuel cladding materials



Material	Sample Type	Target Dose Range
316 SS	• Metallography, Tensile, Bend • Base, coated	0.6 – 2 dpa
316 H SS	• Metallography, Tensile, Bend, Fracture Toughness, Creep • Base, coated, welded, cold-worked, sensitized	0.5 – 10 dpa
Alloy 718	• Metallography, Tensile, Bend, Fracture Toughness, Creep • Base, coated	0.6 - 6 dpa
Grade 22	• Metallography, Tensile, Bend • Base, coated	0.5 dpa



Coated specimen of the type inserted into HFIR

Challenges in Developing Advanced Manufacturing for Metallics

- The qualification process for “new” materials is long compared to design and construction timelines.
- Neither nuclear nor industrial codes & standards address full environmental effects relevant to time-temperature dependent properties driving design of advanced reactors.
- In-Service Inspection in-situ is limited in pool type reactors, leading to increased consideration of monitoring technologies.

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

THANK YOU

To learn more, visit www.terrapower.com

Natrium reactor is a TerraPower & GE Hitachi technology

Qualification of Metallic Materials for Kaleidos

NRC Accelerated Material Qualification Meeting

Parker Buntin

5/6/2025

RADIANT

RADIANT

Kaleidos | Mass-Produced HTGR Microreactor

A climate-friendly alternative to diesel generators, the Kaleidos microreactor will make nuclear portable, bringing clean energy to remote areas.

1 MW
Powers microgrids, data centers, military bases, and emergency relief disaster areas.

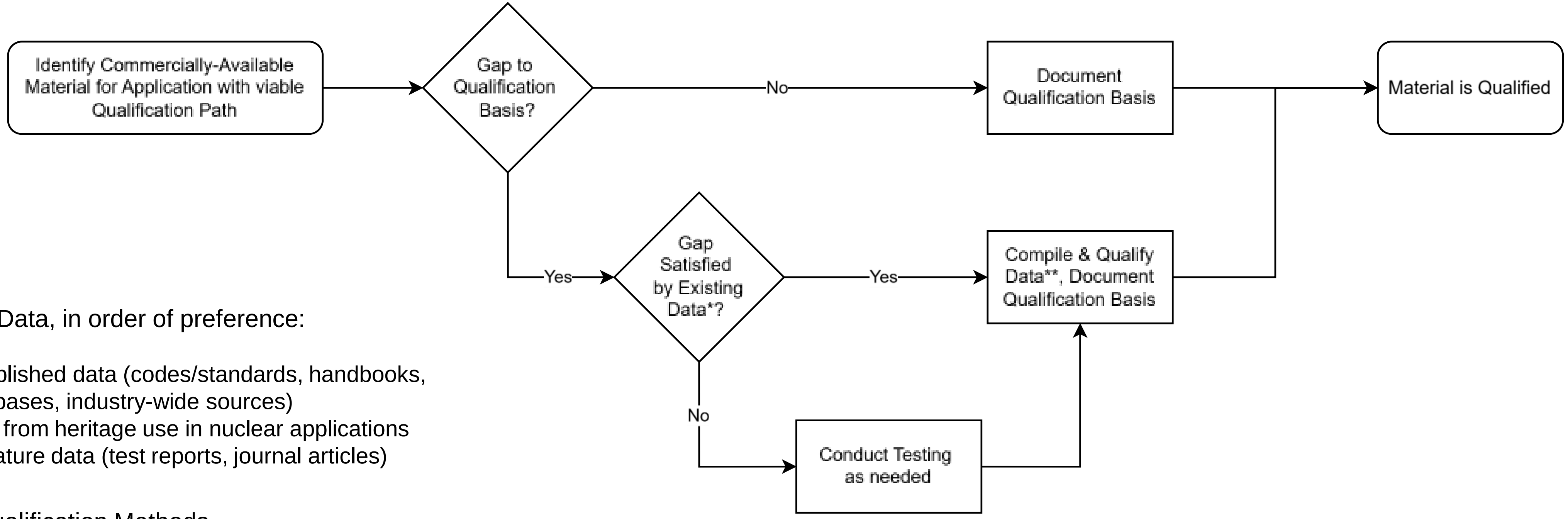
~1.9 MW
Thermal power byproduct can deliver facility heating water desalination.

48 hours
Delivery via truck, ship, or plane. Requires no site excavation or water lines and achieves full power the next day.

Zero waste
No permanent waste on-site. Shipped backed after 5-year use period for refueling and spent core storage off-site.

Radiant Material Qualification

Qualified Material: Sufficient technical basis for materials & components to fulfill design requirements for design life



*Existing Data, in order of preference:

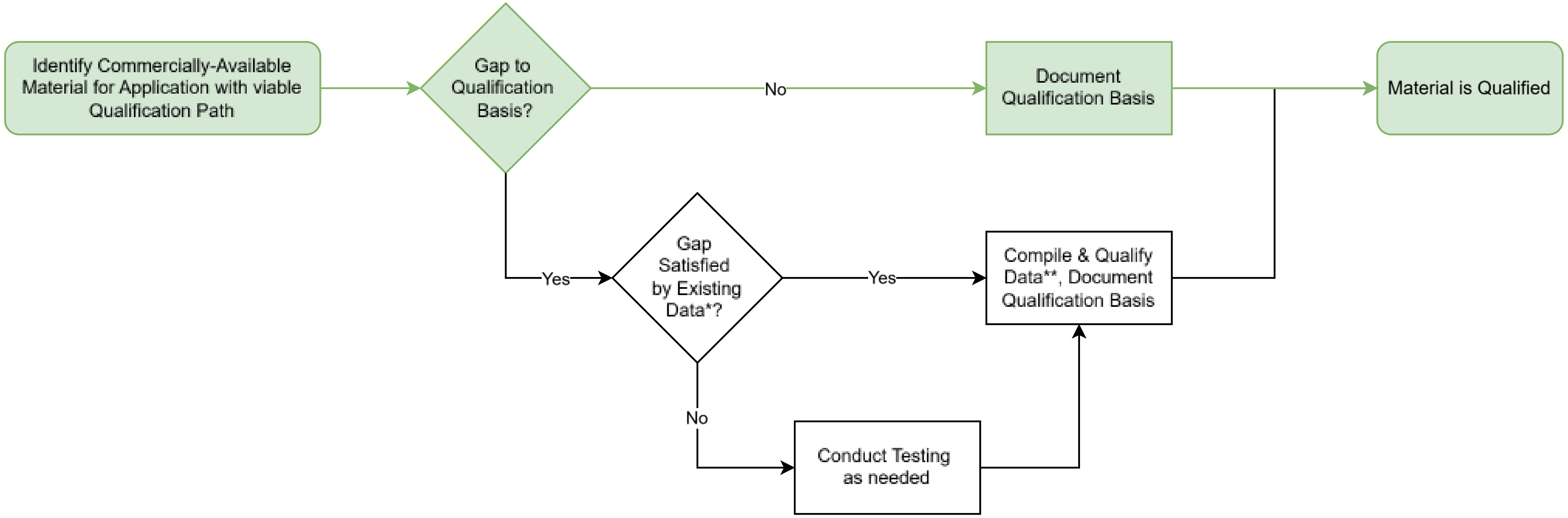
1. Established data (codes/standards, handbooks, databases, industry-wide sources)
2. Data from heritage use in nuclear applications
3. Literature data (test reports, journal articles)

**Data Qualification Methods

1. Quality Assurance Program Equivalency
2. Data Corroboration
3. Confirmatory Testing
4. Peer Review

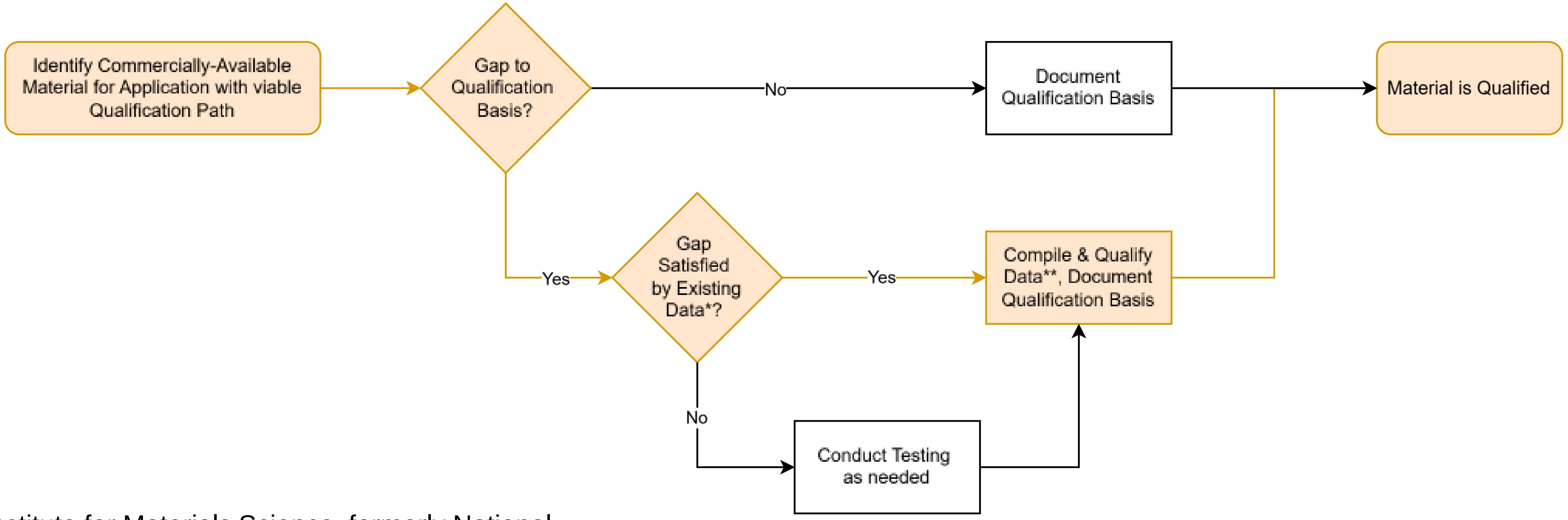
316H Stainless Steel Forging Material

- Austenitic stainless steel with high carbon for improved creep and strength performance at elevated temperatures
- Approved Class A material per BPVC III.5 HBB for elevated temperature service
  - Data available to 700 °C+
- Service conditions of applications vary but all within BPVC envelope
- Material ordered per ASME standards
  - Includes material test coupons for mechanical property testing in representative environments



A286 Bolting Material

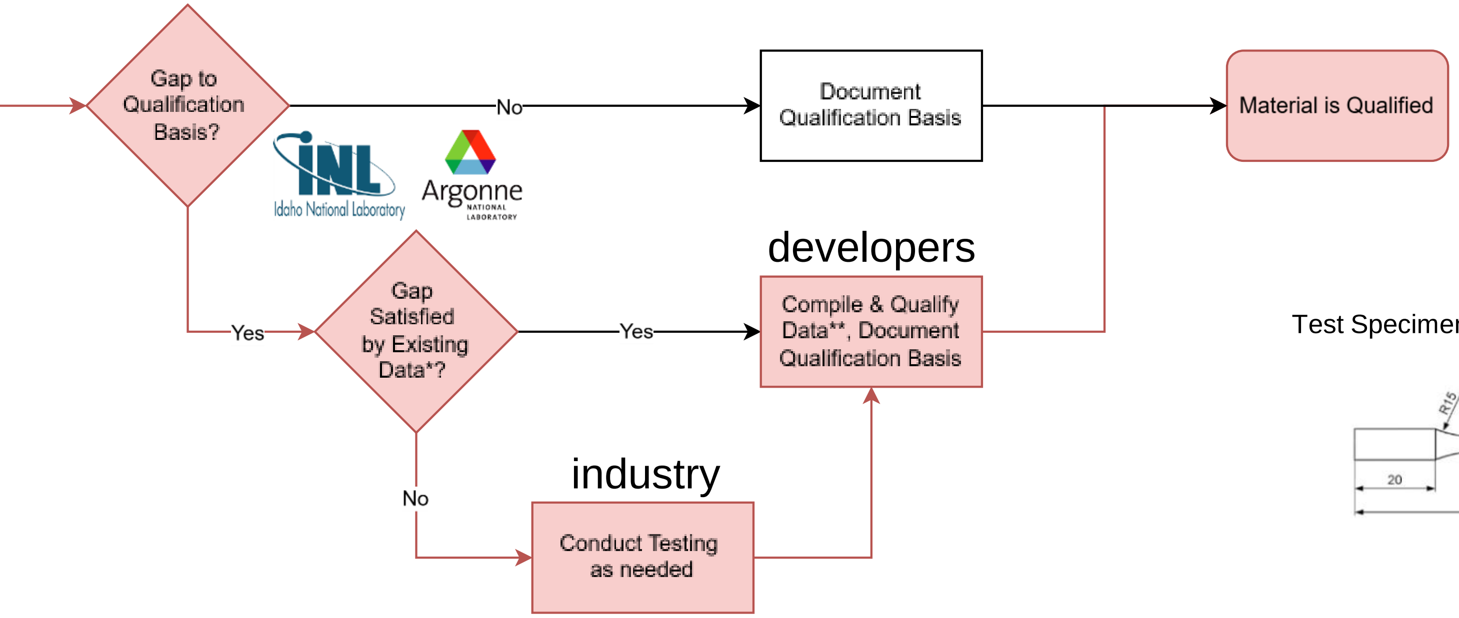
- Precipitation-hardened austenitic stainless steel (Alloy 660) with high strength and corrosion resistance
- Approved Class A bolting material per BPVC III.5 HBA for low temperature service (≤ 427 °C)
  - Not approved for elevated temperature service (≥ 427 °C)
  - Approved bolting material for non-nuclear applications per BPVC VIII.1 up to 538 °C
- Service conditions of applications bounded by 550 °C
- Collaboration with MPR Associates to use NIMS[1] database to prepare BPVC III.5 A286 bolting code case for service up to 100,000 hours & 550 °C
  - 3 month from project start to code case submission for comment & review at ASME Code Week May 11 – 16 2025



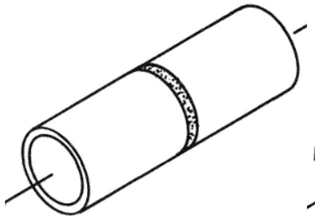
[1]NIMS = National Institute for Materials Science, formerly National Research Institute for Metals (NRIM)

A625 Wrought & Welded Material

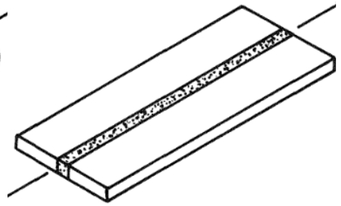
- Solid-solution strengthened nickel-based superalloy with high strength and corrosion resistance (Low Co)
- A625 material specifications in BPVC II-B, but not permitted in BPVC III.5
- Many reactor developers are considering use of Alloy 625 in primary system applications for elevated temperature service (core supports, primary pressure boundary)
- Collaboration with INL & ANL on white paper for gap analysis → identify testing required
- Leverage ASME Code Committees to organize industry collaboration on an Alloy 625 code case(s)
  - Kickoff meeting attended by 2 national labs, ASME representatives, 5 reactor developers, 1 metal supplier, 1 nonprofit organization
  - Reactor developers conduct test programs, determine the qualification envelope, and contribute to the technical basis for the code case
  - National labs, suppliers, and industry partners have an opportunity to support and contribute



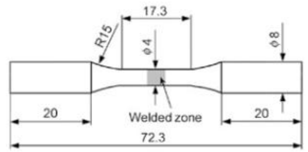
Welded Pipe



Welded Plate



Test Specimen from Weld Coupon



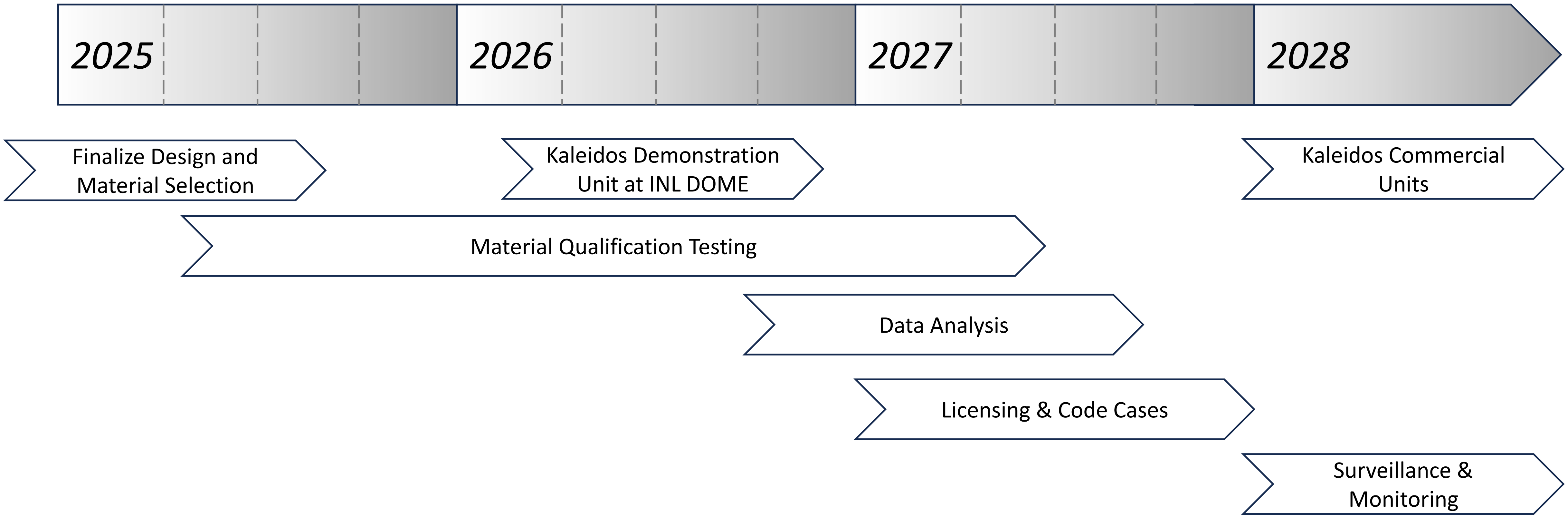
How to Accelerate Material Qualification

- Leverage existing codes and standards
  - Metallic Materials Properties Development and Standardization (MMPDS)
  - European Creep Collaborative Committee (ECCC)
  - NIMS databases (Japan)
  - National Laboratory Technical Reports and Handbooks
- Provide guidance and pathways to qualify many new materials at once, rather than one material at a time
  - e.g. “bulk” acceptance of materials from existing codes, standards, and databases instead of code case submissions for individual materials
- Reduce testing burden for developers
  - Reduce material qualification testing overhead for first-of-a-kind units with shorter lifetimes but increased monitoring
  - Encourage surveillance and monitoring of materials through non-destructive examination (NDE)

ADVANCE Act Title IV Sec. 401

(c) Contents.--
(1) In general.--The report shall--
(A) <<NOTE: Examination.>> examine any unique licensing issues or requirements relating to the use, for nuclear energy projects, of--
(i) advanced manufacturing processes;
(ii) advanced construction techniques; and
(iii) rapid improvement or iterative innovation processes;
(B) <<NOTE: Examination.>> examine--
(i) the requirements for nuclear-grade components in manufacturing and construction for nuclear energy projects;
(ii) opportunities to use standard materials, parts, or components in manufacturing and construction for nuclear energy projects;
(iii) opportunities to use standard materials that are in compliance with existing codes and standards to provide acceptable approaches to support or encapsulate new materials that do not yet have applicable codes and standards; and
(iv) requirements relating to the transport of a fueled advanced nuclear reactor core from a manufacturing licensee to a licensee that holds a license to construct and operate a facility at a particular site;

Timeline


2025
2026
2027
2028
Finalize Design and Material Selection
Kaleidos Demonstration Unit at INL DOME
Kaleidos Commercial Units
Material Qualification Testing
Data Analysis
Licensing & Code Cases
Surveillance & Monitoring

Acknowledgements

- This work was conducted (in part) using the Creep Data Sheets provided by the Materials Data Platform (MDPF) of the National Institute for Materials Science (NIMS), formerly National Research Institute for Metals (NRIM)."

Questions?