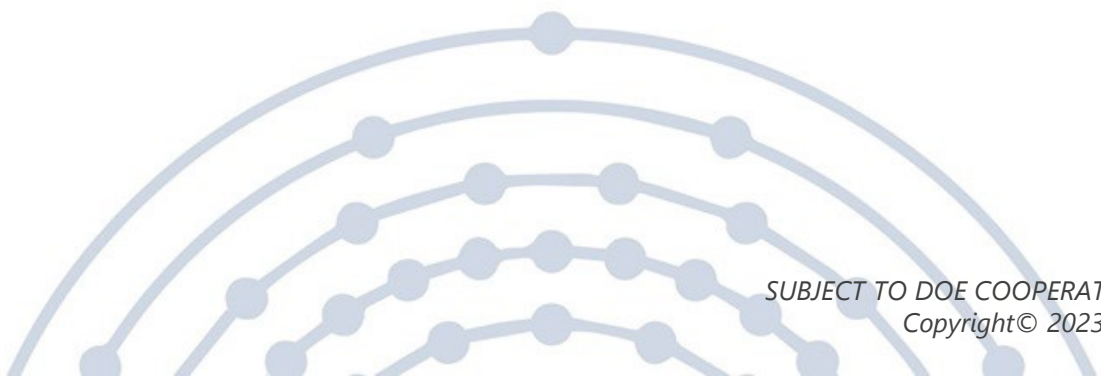




a TerraPower & GE-Hitachi technology

Material Qualification

TP-LIC-PRSNT-0021



*SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054
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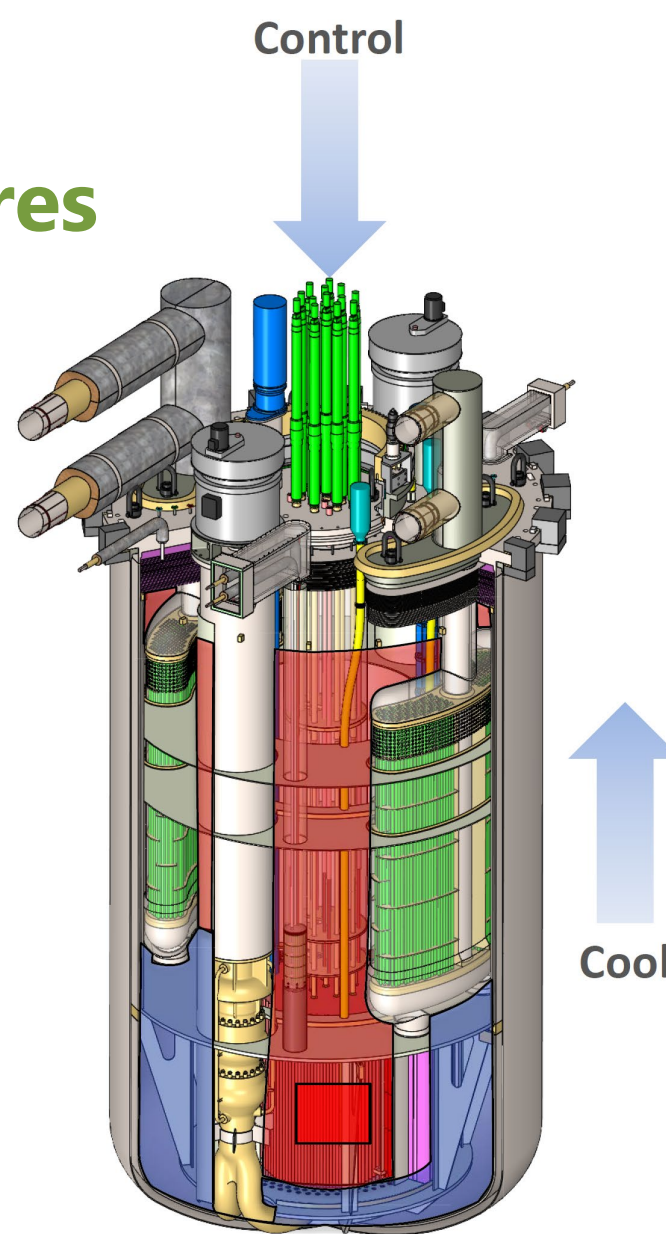
- Natrium™ Reactor Overview
- Material Qualification Overview
 - Summary of Materials in the Natrium Advanced Reactor
 - Material Test Process and Example
 - Identification
 - Planning
 - Test Execution
 - Qualification for Use

Natrium Reactor Overview

- The Natrium project is demonstrating the ability to design, license, construct, startup and operate a Natrium reactor.
- Pre-application interactions are intended to reduce regulatory uncertainty and facilitate the NRC's understanding of the Natrium design and its safety case.

Natrium Safety Features

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



Control

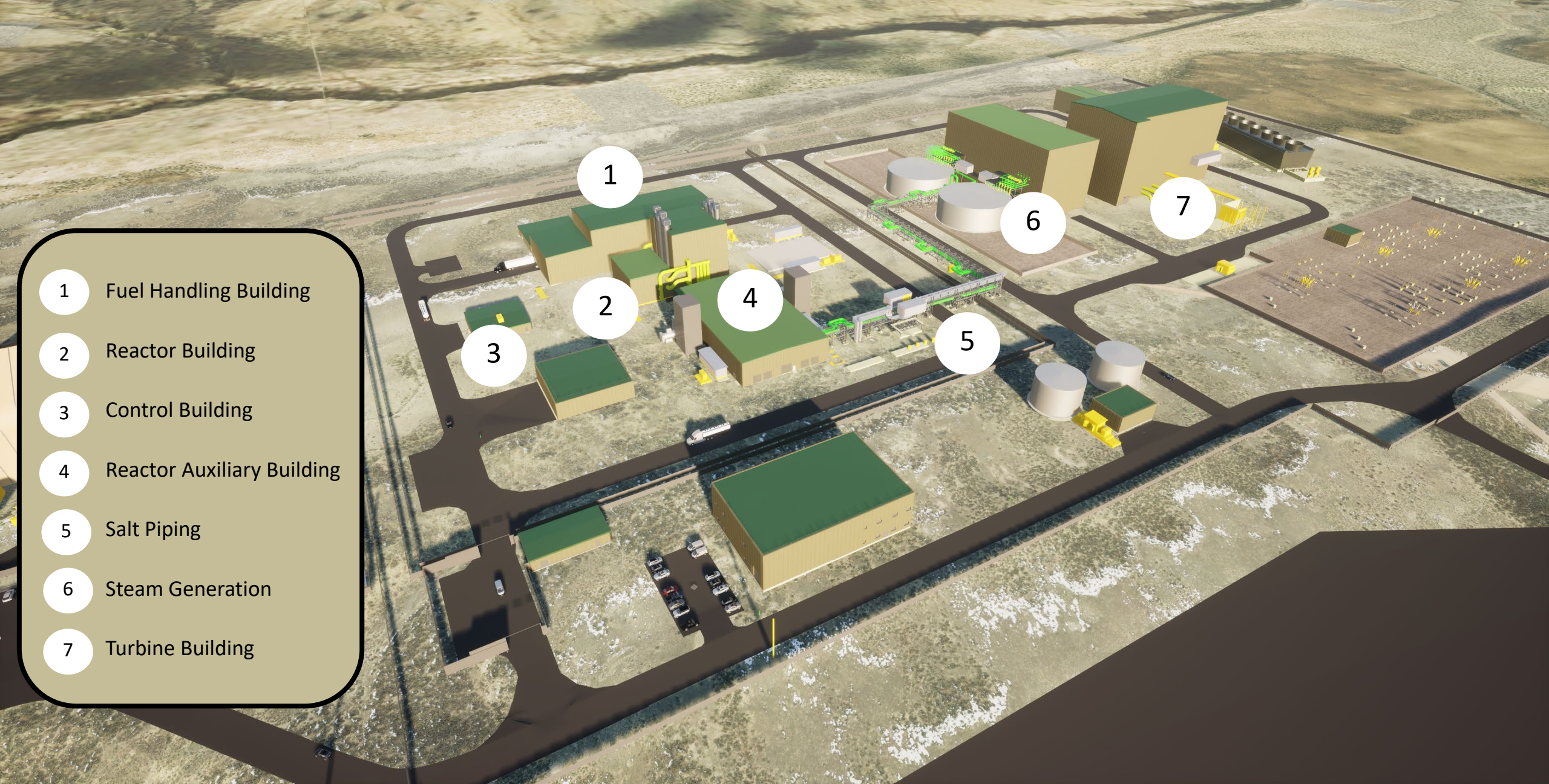
- Motor-driven control rod runback and scram follow
- Gravity-driven control rod scram
- Inherently stable with increased power or temperature

Cool

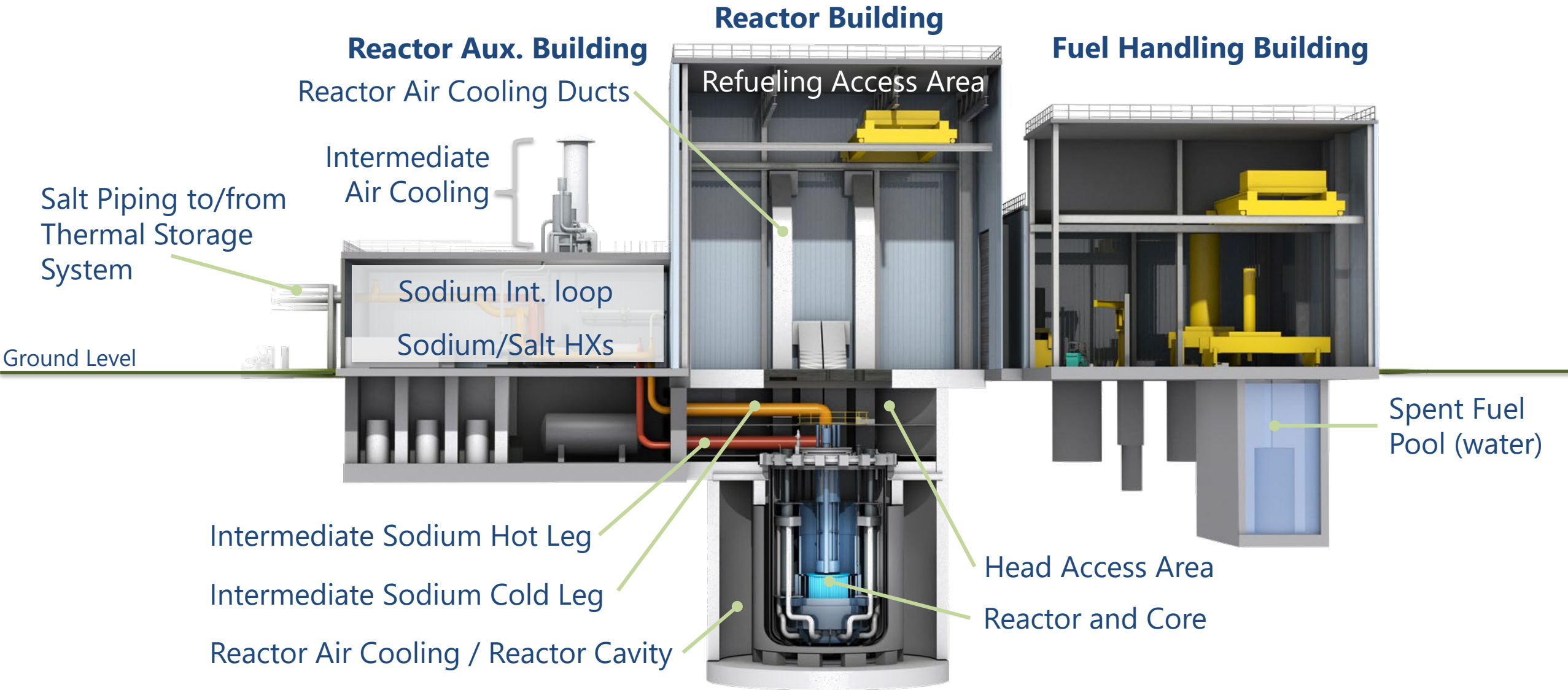
- In-vessel primary sodium heat transport (limited penetrations)
- Intermediate air cooling natural draft flow
- Reactor air cooling natural draft flow – always on

Contain

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



- 1 Fuel Handling Building
- 2 Reactor Building
- 3 Control Building
- 4 Reactor Auxiliary Building
- 5 Salt Piping
- 6 Steam Generation
- 7 Turbine Building



Materials Qualification Overview

Scoping

- NQA-1, Subpart 4.2.3: Qualification of Existing Data
- Prior Engagements
 - Overall codes and standards for the Sodium reactor have been provided via ML22269A445: Consensus Codes and Standards.
 - Design Specifications identify applicable codes and standards selections and are out of scope for Material Qualification discussion.
 - Fuel raw materials qualifications have been the subject of ML20316A038: Advanced SFR Fuel Assembly Qualification Plan and are not the focus of today's meeting.
 - Testing of Safety Features, focusing on component and equipment scale testing, was discussed in ML22273A073: Testing Programs White Paper.

ARCAP Guidance

o Material Qualification

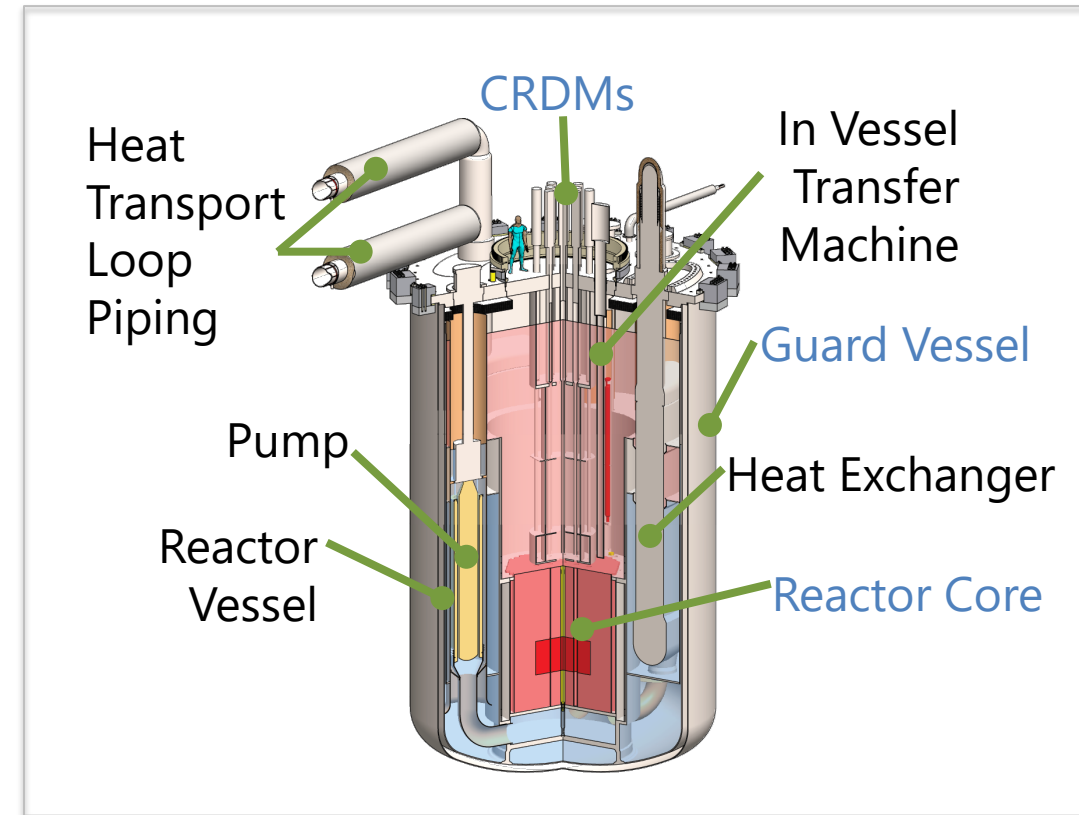
There is a significant lead time for materials testing. As such, a prospective applicant should engage with the NRC staff on materials qualification and the development of qualification plans, when necessary, for all materials used in safety-related or risk-significant applications. The methods of engagement, level of detail, maturity of testing programs, and, if needed, approval of qualification plans via topical report review, will vary depending on several factors, including the proposed application type (e.g., CP, COL, DC).

Robust material qualification plans generally have the following attributes:

1. The plan demonstrates how data is collected in accordance with the applicable endorsed ASME BPV Code (the Code), including any endorsement conditions
2. The plan addresses how appropriate environmental testing (i.e., coolant, environment, irradiation) was performed
3. Data encompasses operating and accident conditions, and
4. Data is provided to justify the use of non-Code qualified materials.

Summary of Materials in Sodium Advanced Reactor

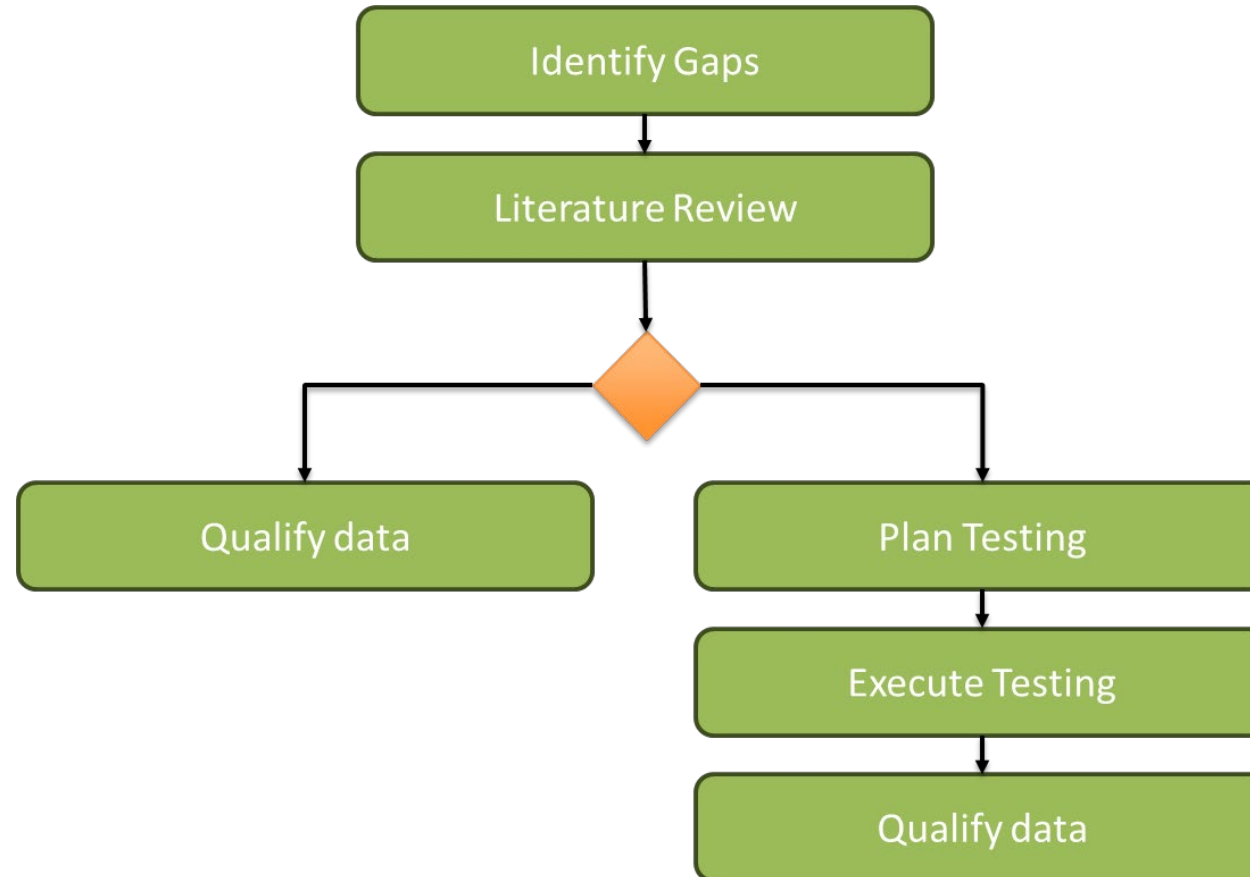
- Primary structural material in contact with sodium is austenitic stainless steel
 - H Grade where required by ASME High Temperature applications
- Where required by design, limited usage of additional materials is planned, including:
 - Austenitic stainless steels
 - Ferritic-Martensitic alloys
 - Nickel-Based Alloys
 - Structural Steels



Natrium Advanced Reactor Material Qualification

- Technology Heritage
 - Materials in Natrium Advanced Reactor are evaluated for applications and environments in context of both Sodium Fast Reactor and broader Nuclear service experience.
- Material Qualification is considered for environmental effects unique to Natrium Advanced Reactor, novel alloys, or novel applications such as:
 - Natrium Advanced Reactor environment
 - Corrosion
 - Wear
 - Irradiation
 - Novel Applications
 - Novel Alloys
- Material Qualification Testing discussed today is focused on coupon-level testing of materials and does not extend to Equipment Qualification or full-scale component testing.

Material Test Process – Outline



Parallels process outlined in ML22273A073: Testing Programs White Paper.

Material Test Process – Identify Gaps

- **Design Collaboration**
 - Technology Maturation Plans identify new or novel technologies or materials usages.
 - Development is reviewed at each design phase and design definition release as defined by internal procedures.
 - Test plans must anticipate design in early phases.
- **Literature Surveys**
 - Evaluation by materials engineers of existing knowledge and data:
 - Sodium Reactors
 - Other nuclear or industrial applications where relevant
 - **Testing is only planned if a gap is identified**

Data Qualification by Corroboration

- Sodium Advanced Reactor must define design values for established materials supplemental to published ASME values. Typical applications include environmental modifications and materials used in non-code applications.
 - Qualification of Existing Data is performed in accordance with TerraPower's Quality Program (TP-QA-PD-0001), implementing NQA-1 Subpart 4.2.3 non-mandatory guidance on Qualification of Existing Data.
 - Internal procedures control the process and documentation of the qualification.
 - **Established materials that can be corroborated are not tested.**
 - Qualifications are performed by Materials Data Management engineers.
 - Data used in order of Preference:
 1. ASME B&PVC where applicable
 2. Consensus Handbooks: Nuclear Systems Materials Handbook, Sodium-NaK Handbook
 3. TerraPower data or modeling
 4. DOE Published technical literature, including Gen IV Materials Database
 5. Other Technical Handbooks and Open literature

Material Test Process – Plan Testing

- **Plan Testing**
 - Input
 - Technology Maturation Plan
 - Test Requirements Document
 - Output and Qualification Requirements
 - Test Design Specification
 - Test Plan & Matrix
 - Multi-Disciplinary Engagement
 - Interdisciplinary Design Review with expert panel

Material Test Process – Execute Testing

- **Execute Testing**
 - Partner Collaboration
 - Materials Testing
 - Specimen level
 - Representative conditions
 - Test Procedures
 - Calibration in accordance with defined testing
 - Reviewed through QA program
 - Phased Testing Approach
 - Test Matrix defines testing per property/material
 - Gather data

Ongoing Testing Programs

- **Thermal Aging**

- Effective way to simulate irradiation effects in FM steels
- Aging program



Aging of HT9 and candidate FM steels up to 10kh, 30kh and 50kh at 360°C – 700°C at OSU



Post-aging microstructural characterization at OSU & SBU

- Post-aging mechanical testing



Plates of FM steel were encapsulated in stainless steel encasings, filled with Ar, and aged up to 50kh

- **Neutron Irradiation**

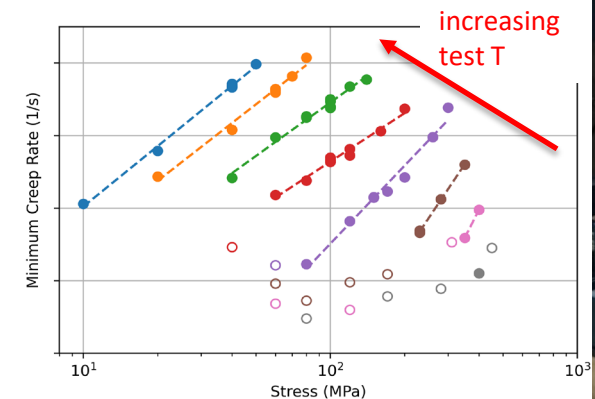
- Irradiation of HT9 and candidate FM steels in BOR-60 up to ~85 dpa



- Post irradiation examination and mechanical testing (tensile, three-point bend, pressurized tube, bar, TEM) planned

- **Thermal Creep Testing**

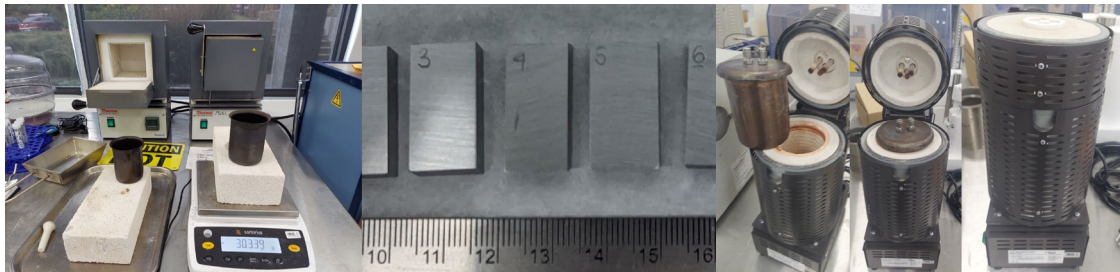
- Thermal creep testing up to 100kh (expected duration)
- Development of improved modeling and understanding of creep behavior of optimized HT9 (e.g., deformation mechanisms & behavior)



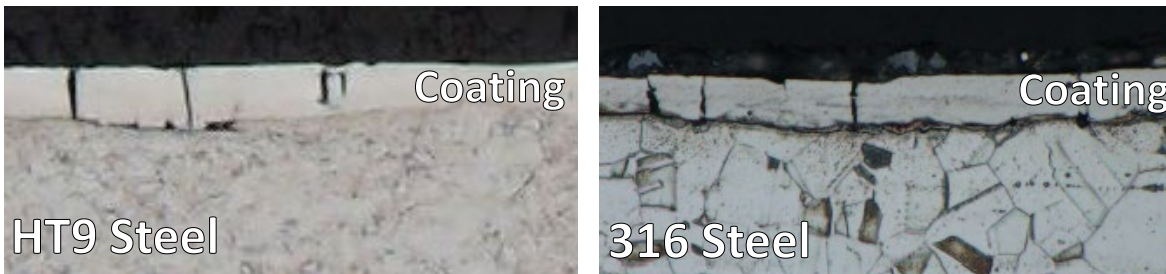
Ongoing Testing Programs

- **Solar Salt Studies**

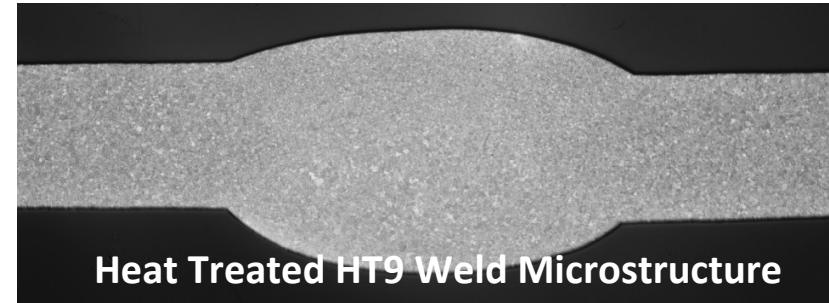
- Effect of Solar Salt decomposition on the corrosion of stainless steels in solar salts and the impact of formed oxide scales on tritium migration



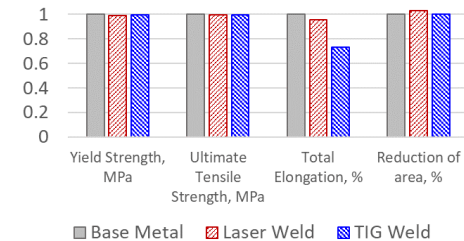
- **Hardface Coatings**



- **Weld development**



Normalized Mechanical Properties

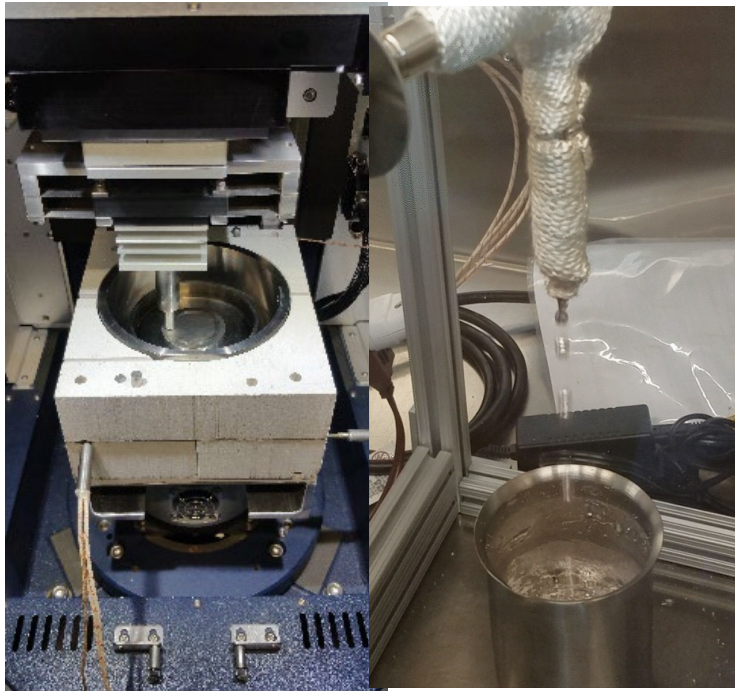


- **Long-term Compatibility of FM steels in a Spent Nuclear Fuel Pool**

Ongoing Testing Programs

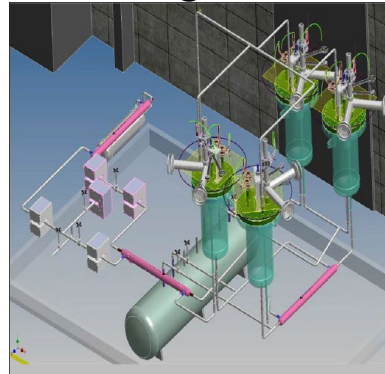
- **Tribology Testing**

- Sliding wear and short-term self-welding at TP
- Fretting wear and long-term self-welding at OSU

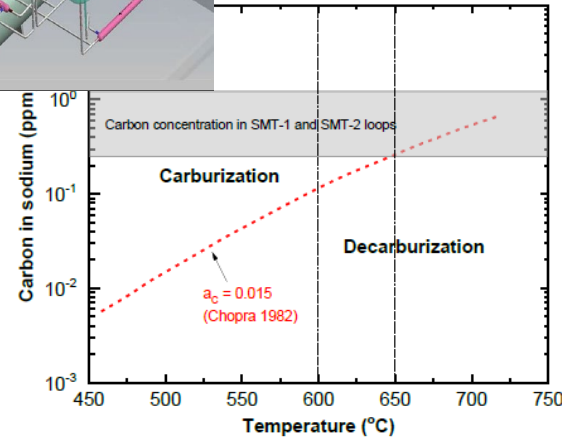


- **Corrosion Testing and Post-exposure Testing & Characterization**

- Established for FM steels at Argonne National Laboratory



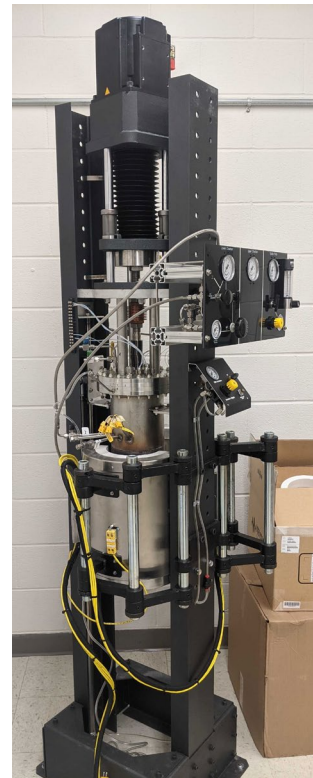
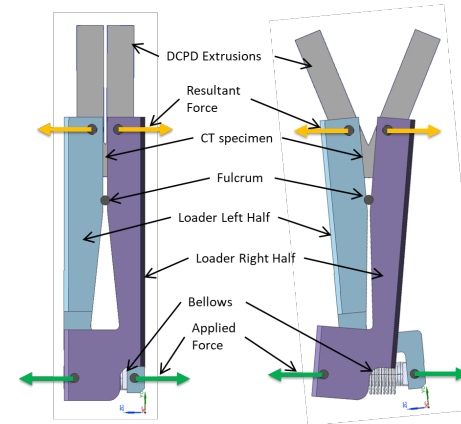
SMT-3: Four-vessel loop fabrication in progress at Argonne for sodium corrosion testing



- **In-situ Mechanical Testing**



Investigations of changes to mechanical properties in sodium at OSU



Material Test Process – Qualify Data for Application

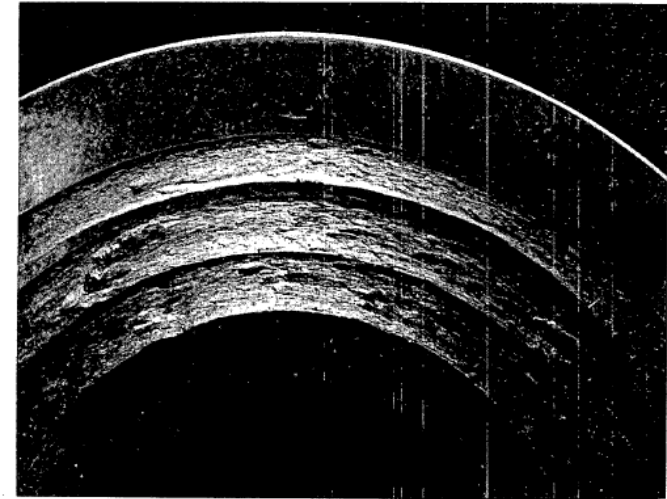
- **Finalize Material/Data for Application**
 - Validate test data
 - Generate Test Report
 - Reviewed by stakeholders, QA, technical team
 - Add final data to data storage system
 - Test results fed back into design

Tribology Example – Identify Gaps

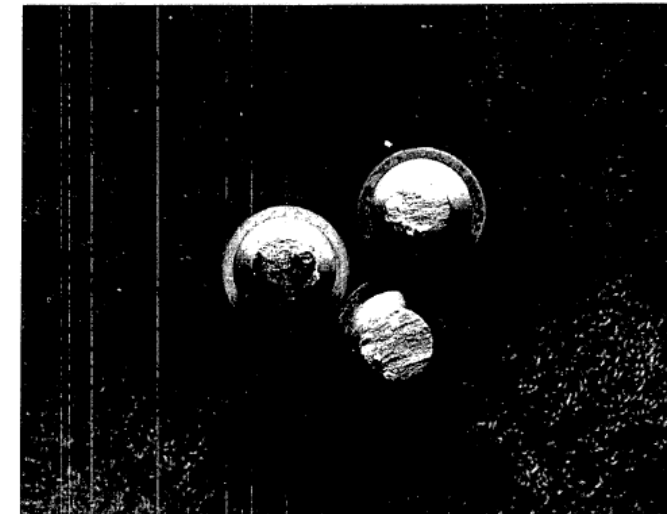
- In-Vessel Transfer Machine
 - Critical Technology Elements defined at TRL 3 at close of conceptual design
 - Identified components such as bearings, sliding splines, gears
- Technology Maturation Plan **identifies a need for tribological data at various interfaces within the system**
 - Tribological data in sodium and sodium vapor environments is limited
 - Concerns include **frictional data, wear, and self-welding behavior**
- Tribology testing contributes to increasing maturity up to TRL 5

Tribology Example – Literature Review

- **Limited quantity of literature** available for tribological testing in sodium environments
 - Novel testing conditions for Sodium reactor components
 - System property that needs to match
- **Poor data integrity** in available resources such as FFTF documentation
 - Primarily summary documents
 - Most testing is scoping in nature
 - Degradation to images
 - Missing key pieces of information
 - Raw test data
 - Post-test characterization



7694-1025



Liquid Metal Engineering Center, "Friction and Wear Screening Tests of Materials in Sodium," US Atomic Energy Commission, July 1970.

7694-1022

Tribology Example – Plan Testing

- Testing defined by Test Requirements Document
 - Includes objectives, assumptions, requirements, test matrix, pre-test validation
 - Materials to be tested are defined: austenitic stainless steels, hard facing coatings, diffusion coatings, nickel-based alloys
- Tribological testing is conducted at the **specimen level**
 - Tribology is a **system property**
 - Obtain friction, wear, and self-welding data for interacting components at the specimen level
 - Values that can be generated include **static and dynamic coefficient of friction, relative wear comparisons, and breakaway torque**

Tribology Example – Plan Testing

- Testing is conducted within the requirements of the TerraPower QA program
 - Instructions and procedures (test procedures, test design specification, ASTM standards)
 - Control of equipment
 - Calibrated thermocouples
 - Calibrated measurement devices (i.e., calipers, torque wrench)
 - Identification & control of items (unique test identifiers, data acquisition system outputs)

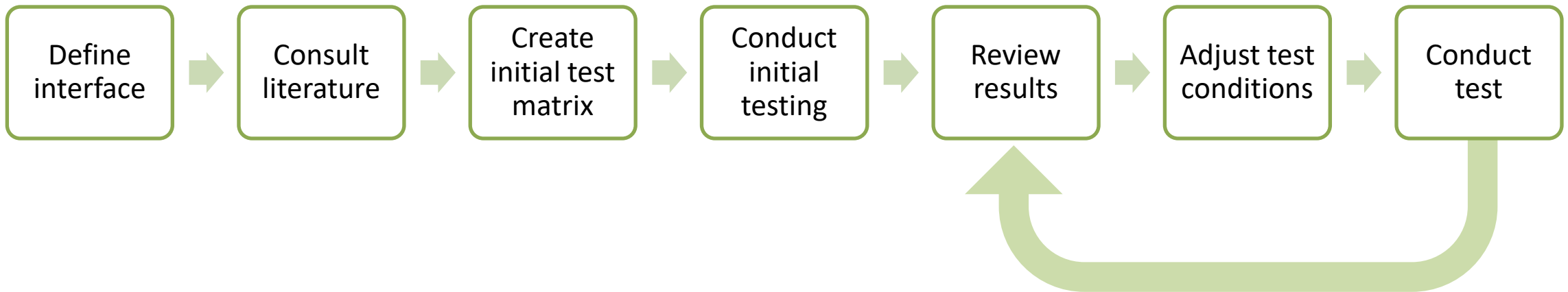
Tribology Example – Execute Testing

- Test procedures will be followed for all types of testing: sliding, fretting, self-welding
- **Testing conducted in representative environments**
 - Elevated temperature low oxygen liquid sodium
 - Sodium vapor
- Testing conditions will **mimic interface as much as possible within the bounds of a specimen level test**
 - Materials/coatings, load, temperature, duration, type of motion
- Evaluate various materials and coatings under representative tribological conditions as defined in test plan/matrix
 - Type of testing is appropriate for component expected state
 - Iterative testing approach



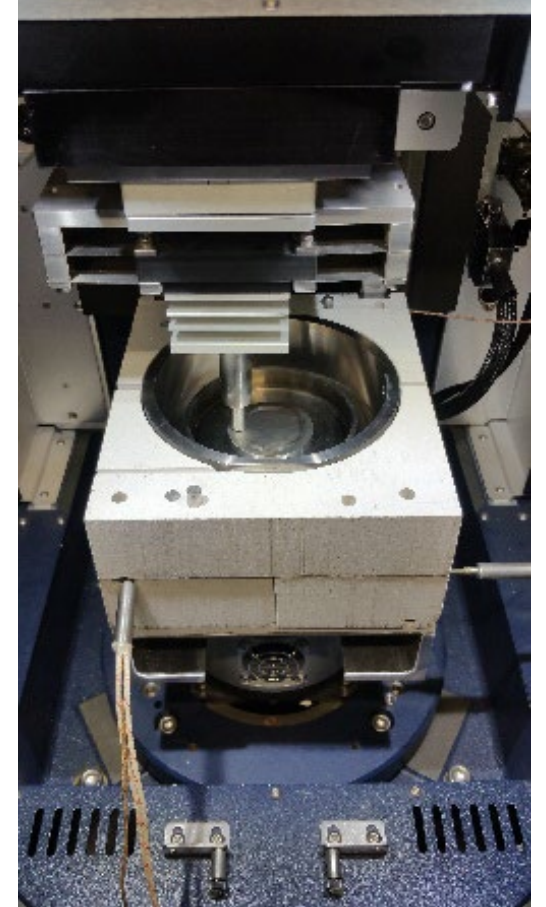
Tribology Example – Execute Testing

- Tribology testing is iterative in nature since it is a **system property**
- **Imperative to have a test that is as representative as possible**



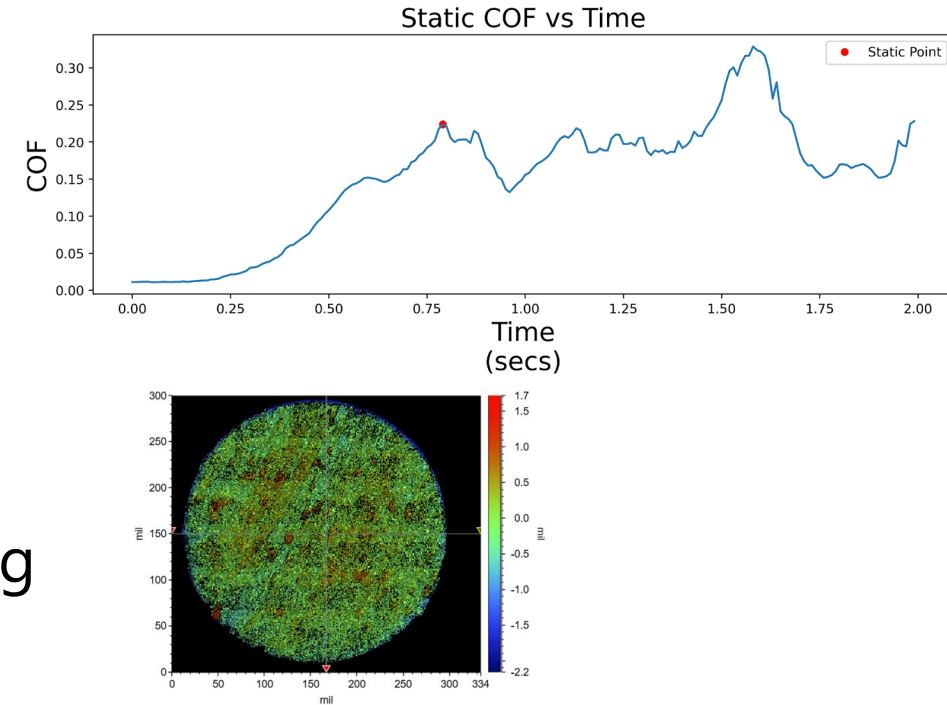
Tribology Example – Qualify Data

- Validate test data
 - ASTM standards (i.e., G99, G115)
 - Ensure control of equipment was met and maintained
 - Test conditions were maintained throughout testing
 - Results make sense with known information



Tribology Example – Qualify Data

- Final Report
 - Test results
 - Static and dynamic coefficient of friction
 - Relative wear comparison
 - Breakaway torque from self-welding testing
 - Data can be used in models
 - Data can inform material selection, component design, and more complex testing





Questions?

Acronym List

ARCAP – Advanced Reactor Content of Application Project
ARDC – Advanced Reactor Design Criteria
ARDP – Advanced Reactor Demonstration Program
ASTM – American Society for Testing and Materials
CFR – Code of Federal Regulations
DID – Defense-in-Depth
EBR – Experimental Breeder Reactor
FFTF – Fast Flux Test Facility
FM – Ferritic-Martensitic
GDC – General Design Criteria
LBE – Licensing Basis Event
LMP – Licensing Modernization Project
PDC – Principal Design Criteria
PSAR – Preliminary Safety Analysis Report
QA – Quality Assurance
RIPB – Risk-Informed, Performance-Based
SFR – Sodium Fast Reactor
SSC – Structures, systems, and components
TEM – Transmission Electron Microscope
TICAP – Technology Inclusive Content of Application Project
TREAT – Transient Reactor Test
TRL – Technology Readiness Level