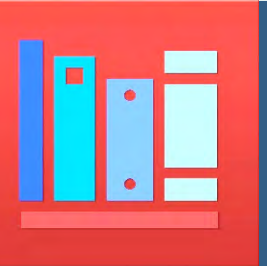


Advanced Reactor Developers Perspectives on Codes and Standards



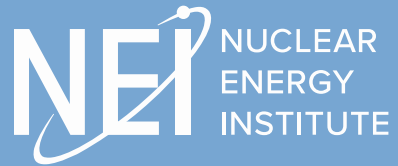
- **Moderator:** Mark Richter, Technical Advisor, Nuclear Energy Institute
- **Panelists/Speakers:**
 - Mark Richter (NEI)
 - J.J. Arthur (NuScale)
 - Steven Unikewicz (TerraPower)
 - Timothy Lucas (X-Energy)

Advanced Reactor Developers' Perspectives on Codes and Standards

2022 NRC Standards Forum

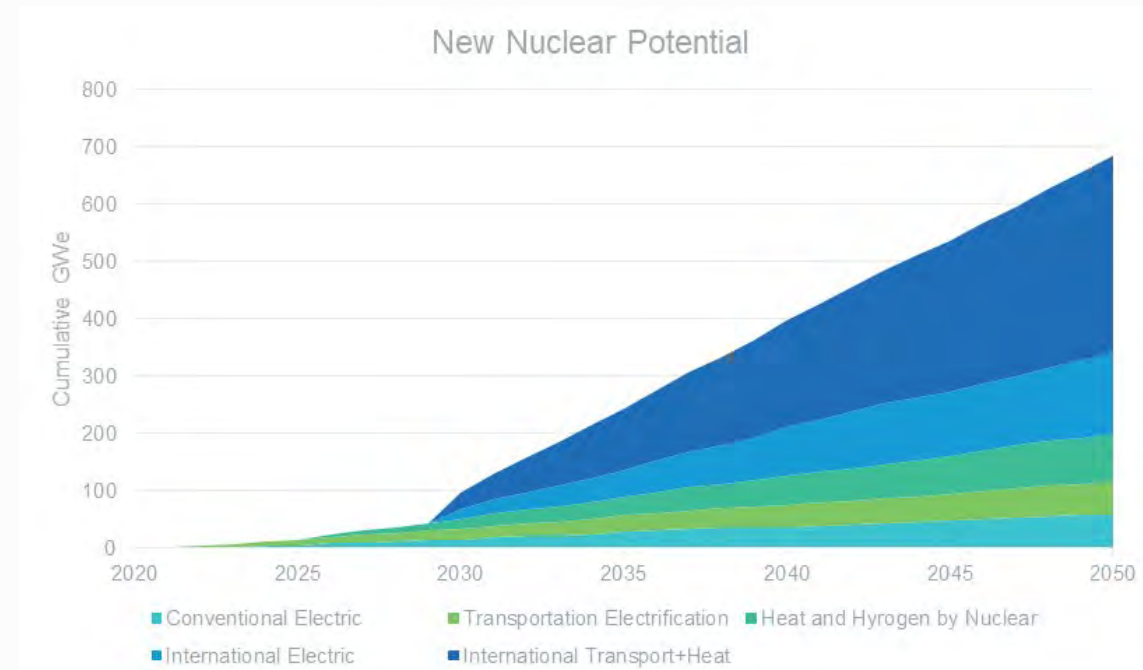
Mark Richter - NEI

September 28, 2022



Situational Context

- Increasing urgency for carbon reduction (electric and non-electric)
- Path to zero-carbon must be reliable and affordable
- Nuclear energy must be meaningful part of future energy portfolio
- Advanced reactor deployment plans increasing rapidly and more urgently
- License applications could be more than regulators can currently process



Codes and Standards: Important Role

- The EPRI North American Advanced Reactor Roadmap points to timely development of codes and standard as necessary enablers to the large-scale deployment of advanced reactors
- Collaboration and engagement among SDOs, reactor designers, regulators, and other interested stakeholders enables development of code and standards
- Advanced reactor developers are moving forward rapidly with initial licensing and design activities. Consensus standards are design enablers and must move forward to support aggressive timelines

Codes and Standards: Focus and Priority

- Perspectives from three advanced reactor developers will be shared today:
 - NuScale
 - Terra Power
 - X-Energy

- We'll have an opportunity for questions and open discussions following the presentation



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NuScale Perspectives on Codes & Standards

2022 NRC Standards Forum

September 22, 2022

J.J. Arthur, P.E.
Sr. Director, NSSS Engineering

Acknowledgement and Disclaimer

This material is based upon work supported by the Department of Energy under Award Number DE-NE0008928.

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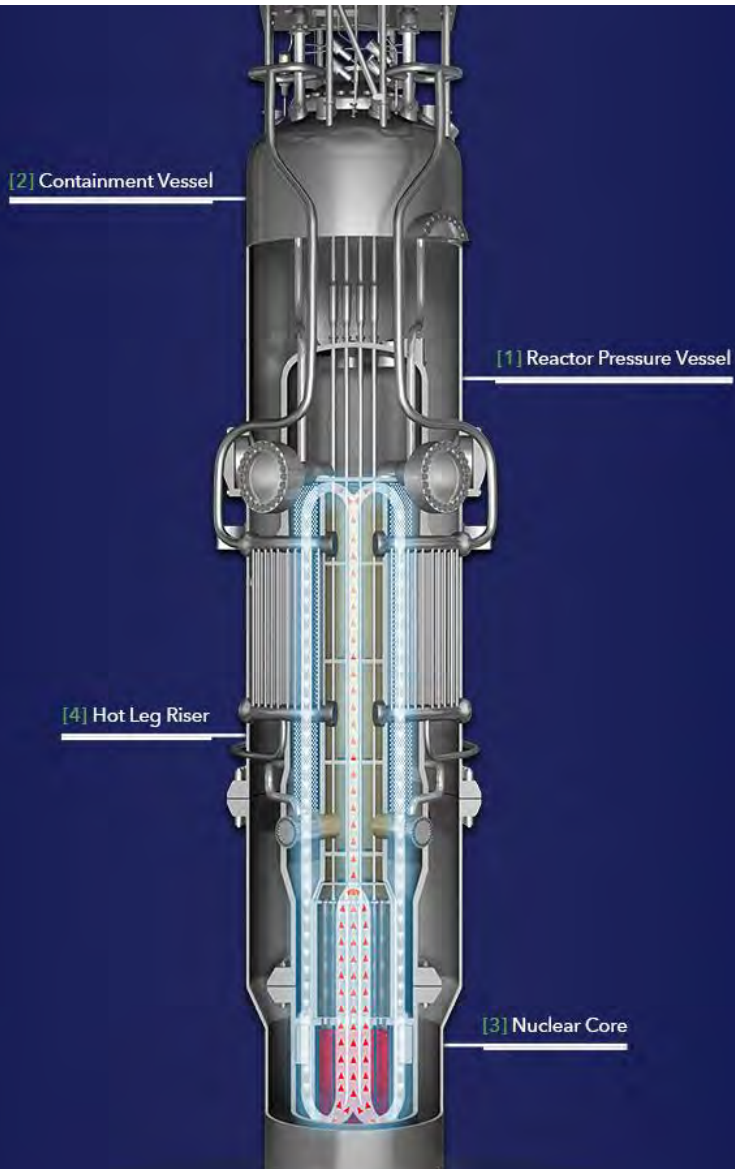


Who is NuScale Power?

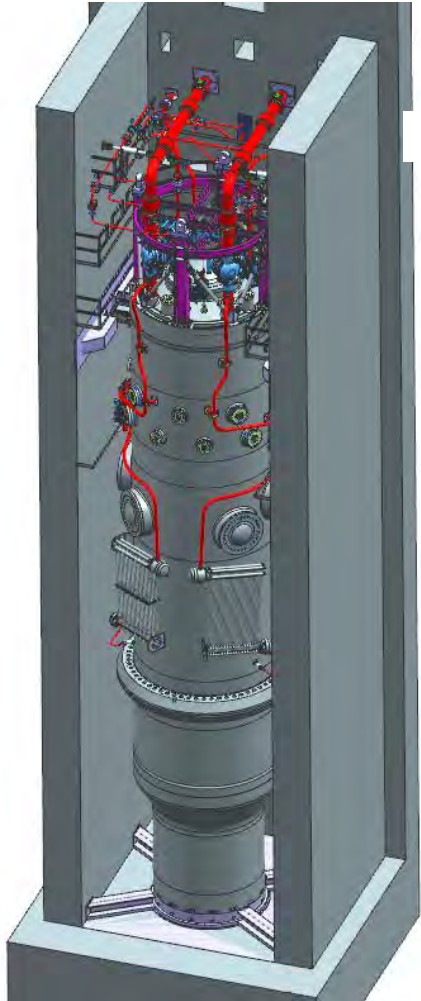
- NuScale Power Corporation is a public company trading on the New York Stock Exchange (NYSE) under the ticker symbols “SMR” and “SMR WS”.
- NuScale Power was formed in 2007 for the sole purpose of completing the design and commercializing a small modular reactor (SMR) – the NuScale Power Module.™
- Initial concept was in development and testing since the 2000 U.S. Department of Energy (DOE) MASLWR program.
- Fluor, global engineering and construction company, became lead investor in 2011
- 2013 - NuScale won a competitive U.S. DOE Funding Opportunity for matching funds, and has been awarded over \$400M in DOE funding since then.
- >500 employees in 5 offices in the U.S. and 1 office in the U.K.
- NuScale valued at \$1.9 B and merged with Spring Valley on May 2, 2022.
- **Investors include JGC, IHI and JBIC**
- 645 patents granted or pending in 20 countries; ASME N-Stamp.
- First project in Idaho (2029 COD); MOU’s with several potential customers worldwide.
 - Potential projects being pursued in U.S., UK, Canada, eastern Europe, Middle East, southeast Asia, and Africa.

Core Technology: NuScale Power Module

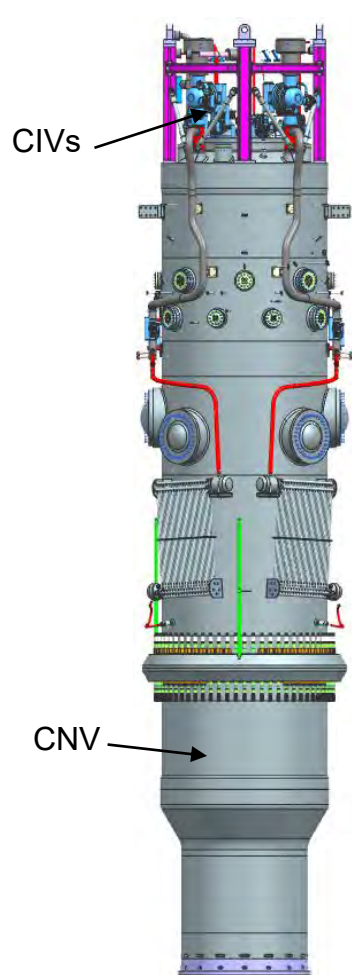
- A NuScale Power Module™ (NPM) includes the reactor vessel, steam generators, pressurizer, and containment in an integral package
- Simple design that eliminates reactor coolant pumps, large bore piping and other systems and components found in large conventional reactors
- Each module produces 250 MWt up to 77 MWe
 - Small enough to be factory built for easy transport and installation
 - Dedicated power conversion system for flexible, independent operation
 - Incrementally added to match load growth
 - 12 module plant – up to 924 MWe gross
 - 6 module plant – up to 462 MWe gross
 - 4 module plant – up to 308 MWe gross



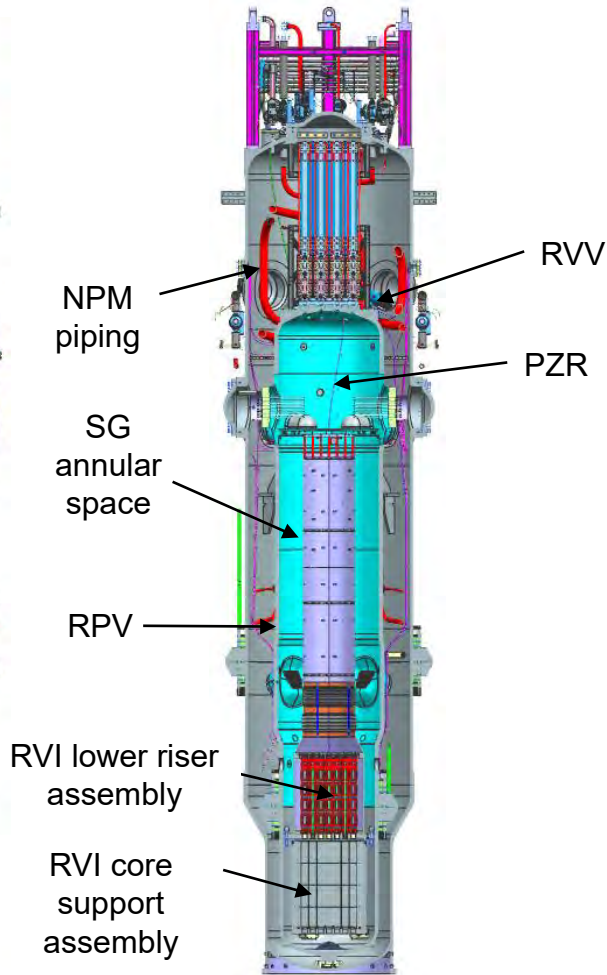
NuScale Power Module Arrangement



NPM in the bay



Front of the NPM



Section view of the NPM

- CIV = containment isolation valve**
- CNV = containment vessel**
- PZR = pressurizer**
- RPV = reactor pressure vessel**
- RRV = reactor recirculation valve**
- RVI = reactor vessel internals**
- RVV = reactor vent valve**
- RXM = reactor module**
- SG = steam generator**

Codes & Standards Needs

ASME BPV Code, Section XI

- New code rules need to be developed for IWB-3500 standards for application to austenitic vessel materials, dissimilar metal vessel material welds, and austenitic bolting material.
- New code rules need to be developed for Section XI, Mandatory Appendix VIII for application to austenitic vessel materials and dissimilar metal vessel material welds.

ASME O&M Code

- Need to resolve how to implement a single IST plan for multiple modules

ANS 30.3 – Light Water Reactor Risk-Informed, Performance-Based Design

- NRC Endorsement



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J.J. Arthur, P.E.
Sr. Director, NSSS Engineering
jarthur@nuscalepower.com

A large, stylized atomic symbol is positioned on the left side of the slide. It consists of a central green nucleus and several concentric green orbits with small green dots representing electrons.

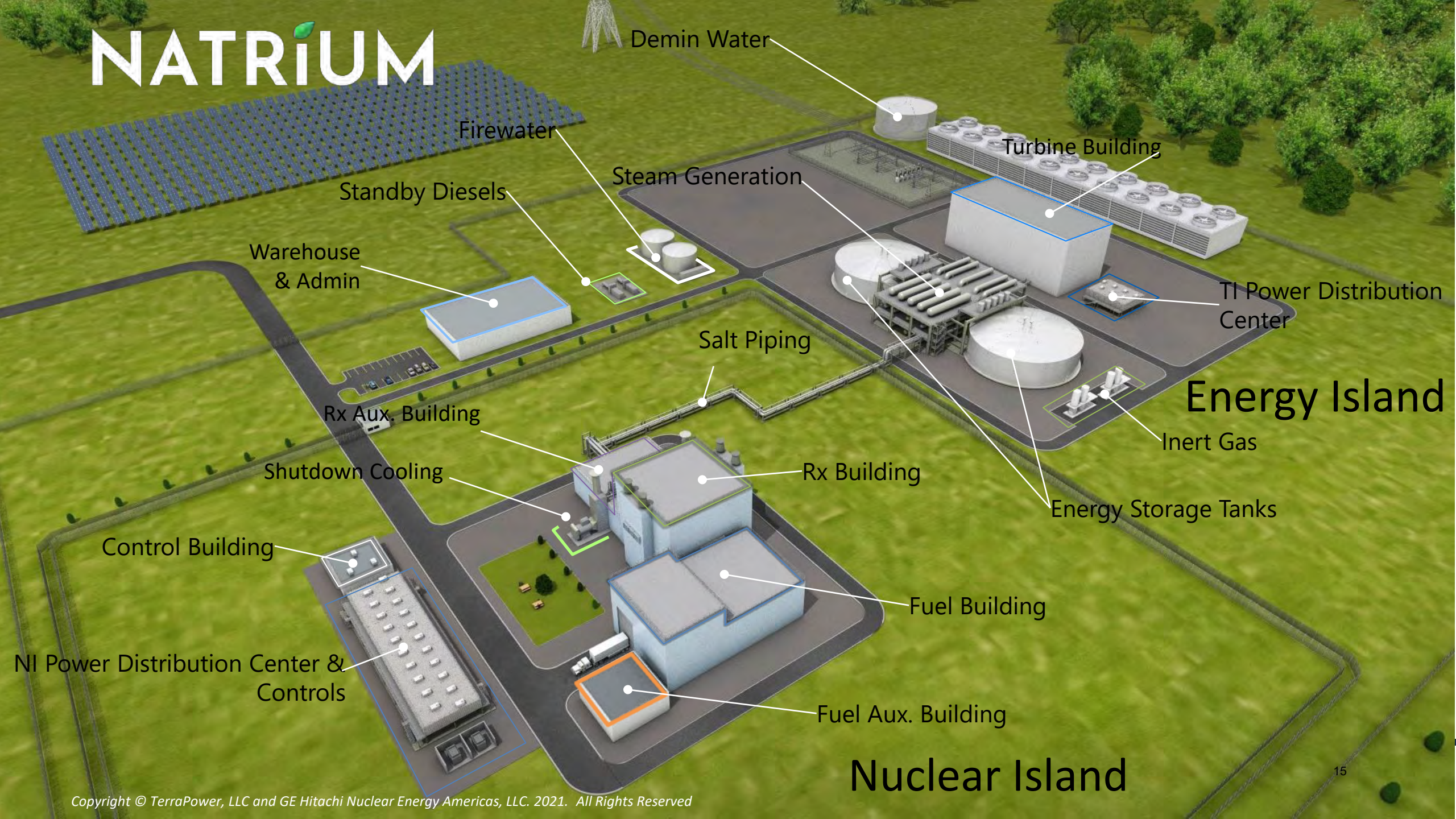
Plant Overview – NRC Adv Rx Forum

Steven Unikewicz

Terra Power Advanced Reactor Types

- Sodium Sodium Fast Reactor (SFR)
- Molten Chloride Reactor Experiment (MCRE)
- Molten Chloride Fast Reactor (MCFR)

NATRIUM



Demin Water

Firewater

Standby Diesels

Warehouse & Admin

Rx Aux. Building

Shutdown Cooling

Control Building

NI Power Distribution Center & Controls

Steam Generation

Salt Piping

Rx Building

Fuel Building

Fuel Aux. Building

Turbine Building

TI Power Distribution Center

Energy Island

Inert Gas

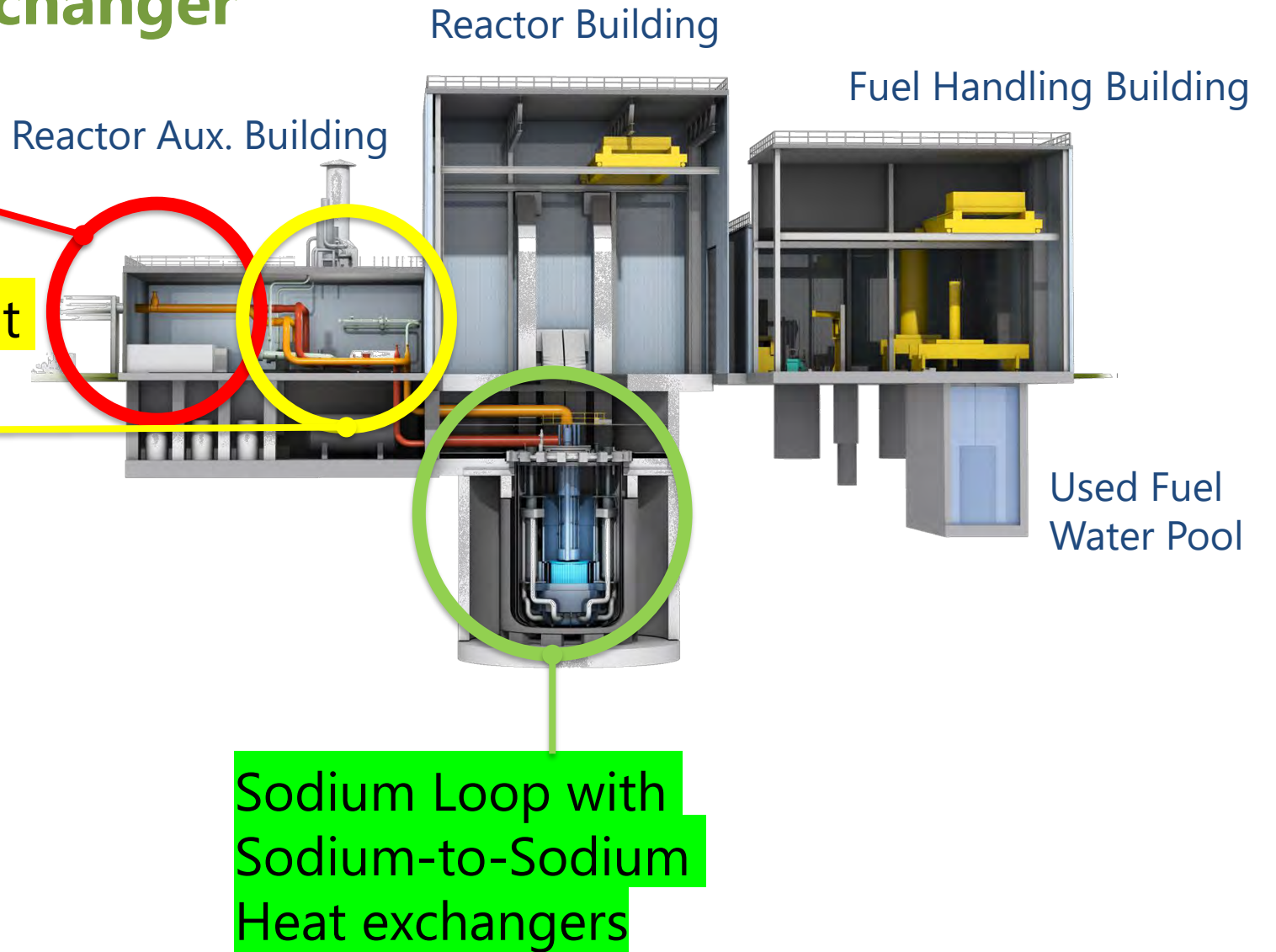
Energy Storage Tanks

Nuclear Island

Integrated Energy Storage Sodium-Salt Heat Exchanger Loop Tests

Salt loop w/ storage
and heat removal

Sodium to Salt heat
exchanger /
decoupling

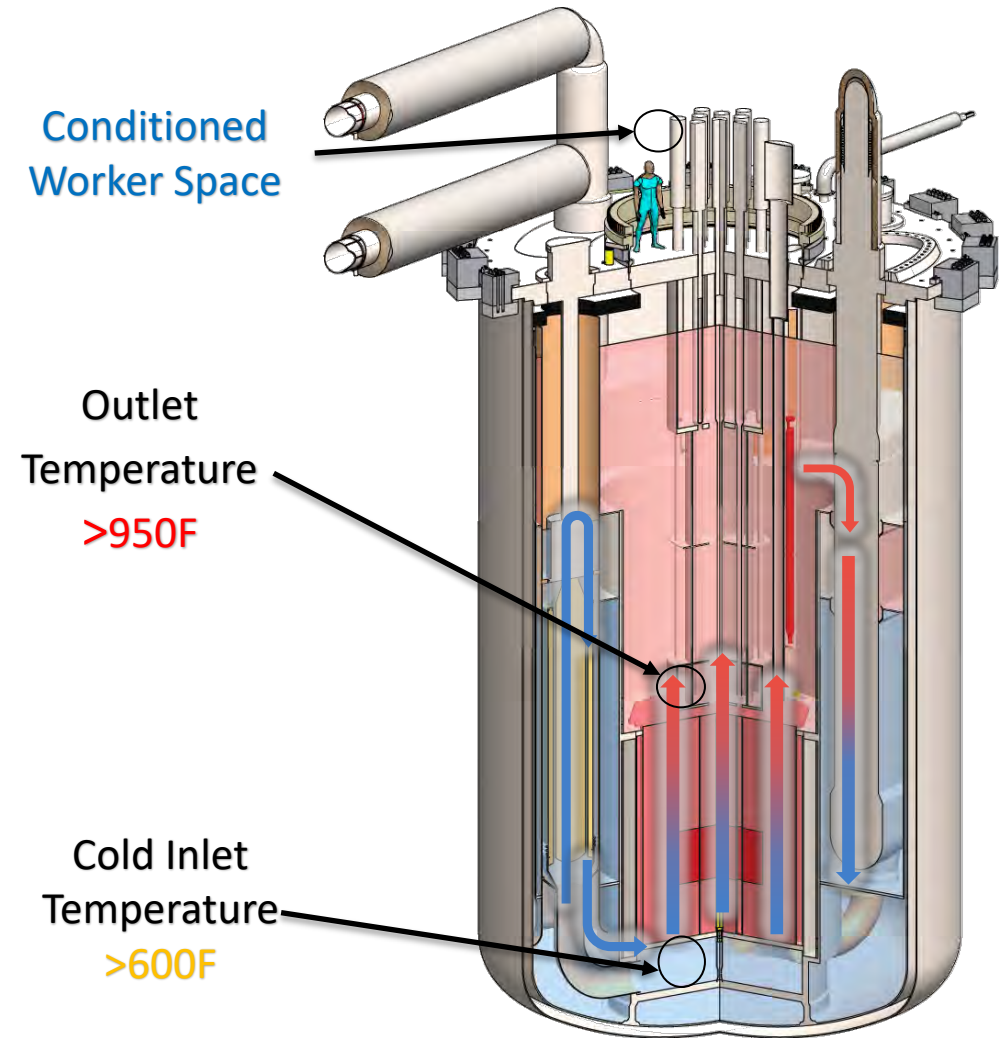


Natrium Profile

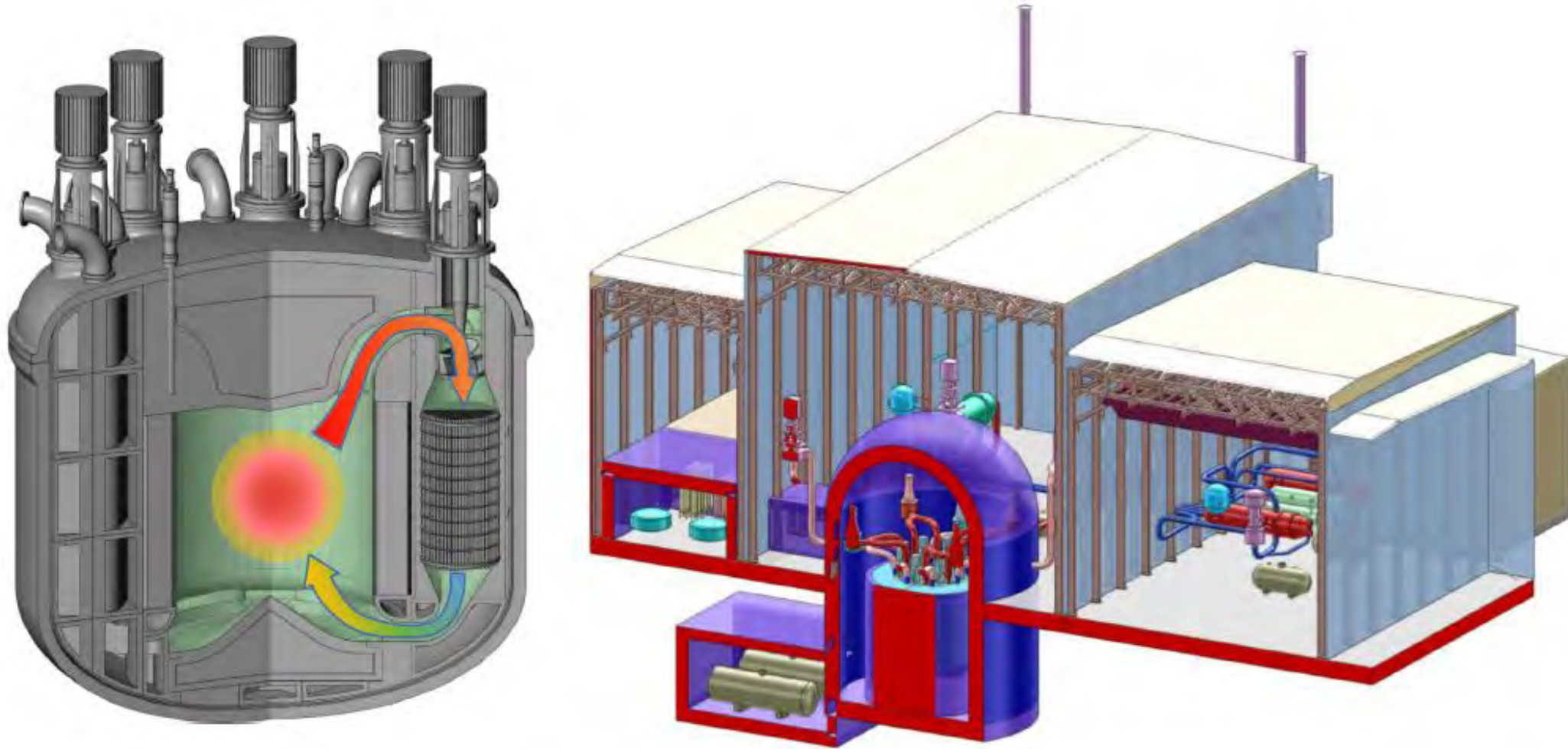
Reactor and Power Parameters

- Reactor Power Class: 840 MWt
- Reactor Type: Pool-Type Sodium Fast Reactor
- Reactor Coolant: Liquid Metal (Sodium)
- Reactor Fuel Type: Metal Uranium Fuel, Ferritic-Martensitic Cladding

- Turbine Power Class (Nom): 345 MWe
- Turbine Output: Variable (150%+ rated w/ Storage)
- Energy Storage Fluid: Molten Nitrate Salt
- Energy Storage Capacity: 5+ hours, depending on load



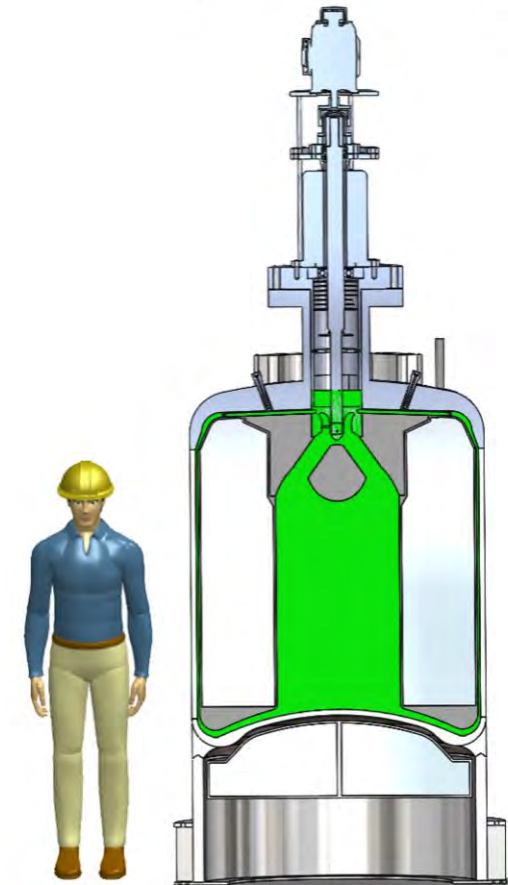
Molten Chloride Fast Reactor (MCFR) Demonstration Commercial



Credit: Jeff Latkowski

The Molten Chloride Reactor Experiment (MCRE) will be the first critical MCFR and will focus on reactor physics

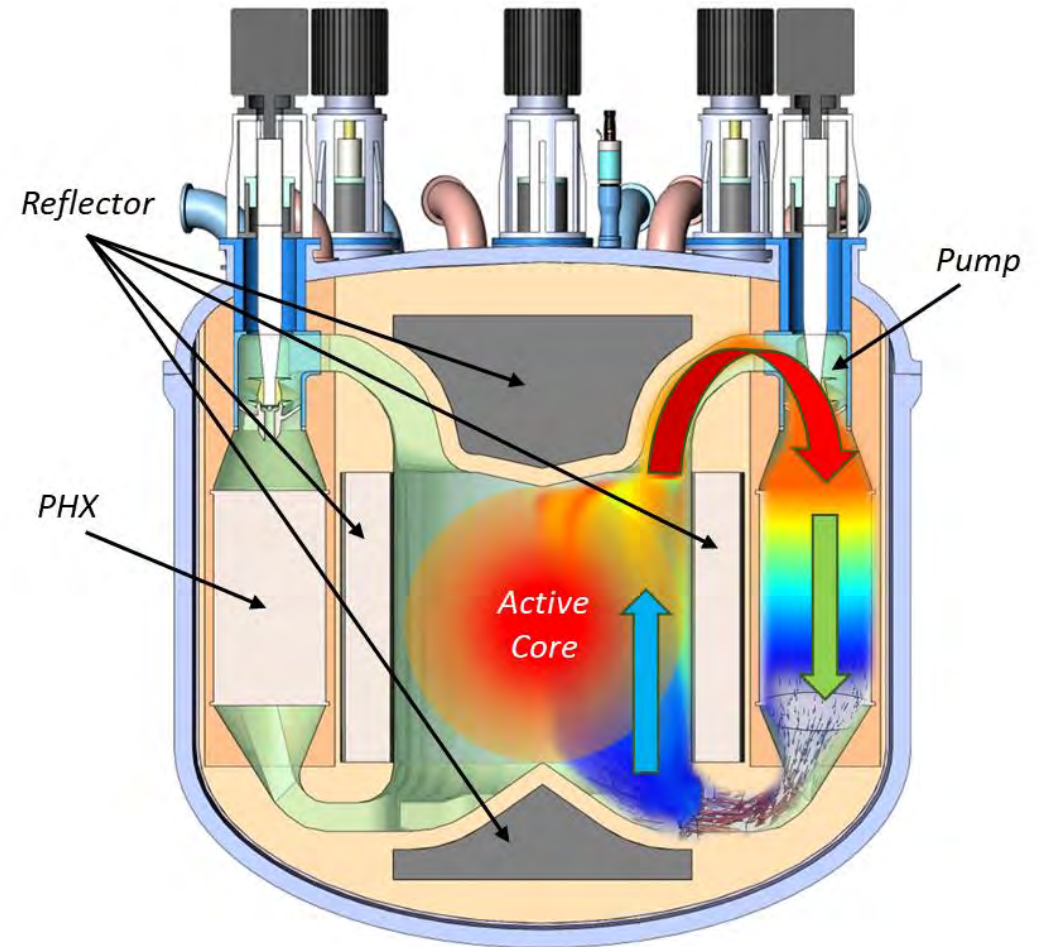
Parameter	MCRE
100% Thermal Power	200 kW
Nominal Temperature	1200°F
Nominal Pressure	37 PSI
Design Temperature	1300°F
Design Pressure	70 PSI
Time at Temperature	6000 hr
Time at Power	1000 hr (out of 6000 hr)



The MCFR is an advanced molten salt fueled reactor that operates in a breed & burn fuel cycle

MCFR: Molten Chloride Fast Reactor

- Pool design
- Fast spectrum
- Fuel salt: NaCl-UCl₃ eutectic
- Initial U enrichment of 11-13 wt%
- Feed depleted UCl₃
- PuCl₃ is bred up
- Fuel salt flows out of active core around 8 discrete flow paths
- 8 axial flow pumps
- 8 shell & tube PHXs



Codes and Standards Needs

- Sodium Fast Reactor applicability is not fully addressed by Codes and Standards currently endorsed and referenced by the NRC. Coordination with Standards Organizations and NRC is ongoing.
- Examples – ASME BPV – Section III Division 5
Section XI Division 2, Appendix 7, RIM
 - ASME OM-2
 - ASME QME-2
 - Certain IEEE Standards

Codes and Standards Activities

- Activities are ongoing to identify:
 - Consensus Codes and Standards or Code Cases intended for use with Advanced Reactors
 - Standards or Code Cases that have not been endorsed or previously accepted by the NRC
- The needs will be identified as the design progresses

Questions?



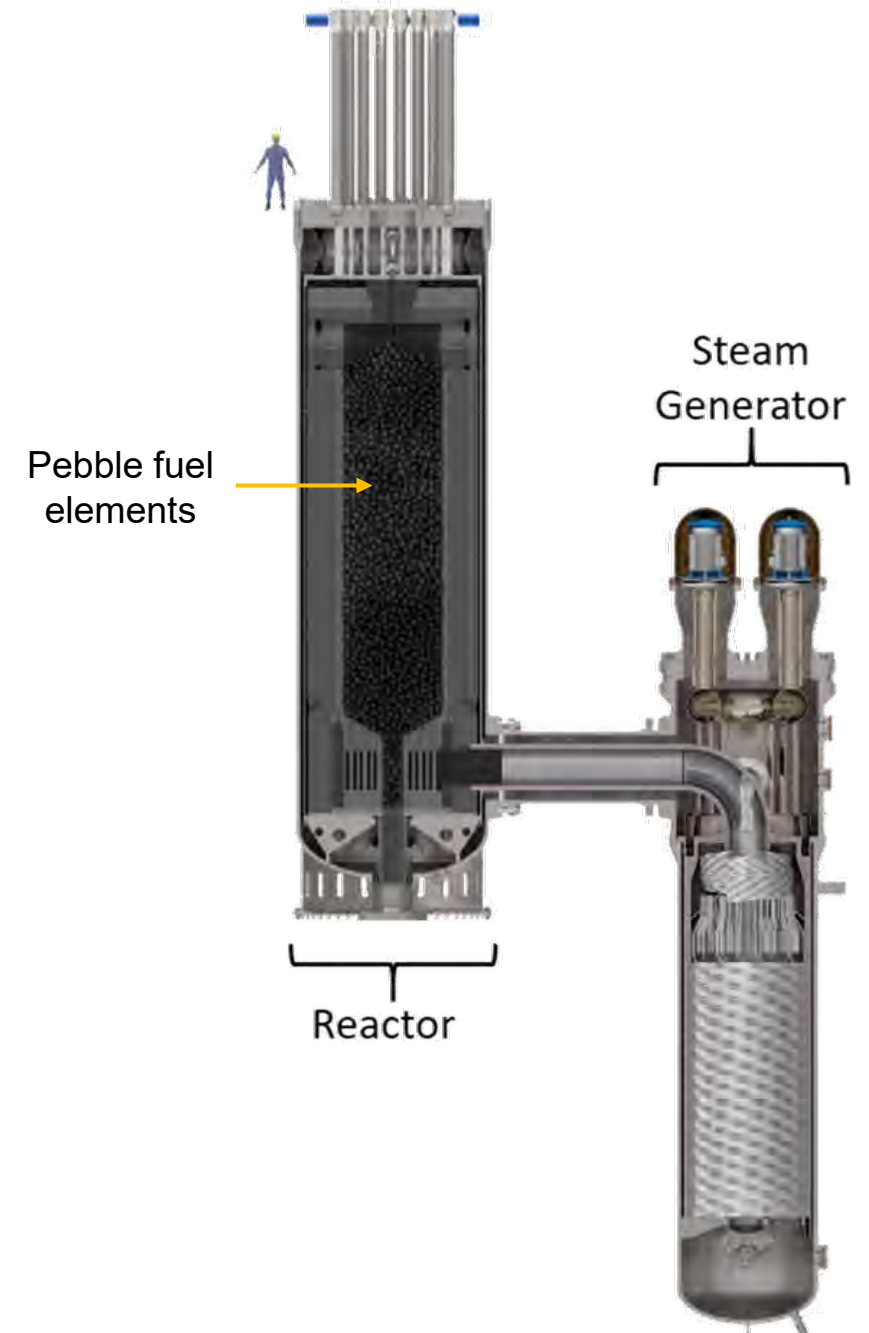
Code Overview – NRC

Dr. Timothy Lucas, *Main Power Systems Engineering Manager*

9/28/2022

- Introduction of the Xe-100 Pebble Bed Reactor
- ASME BP&V Section III-5 for RPV and Metallic Internals
- ASME BP&V Section III-5 for Graphite Structures
- Q&A

- 200 MWt, HTGR, Pebble Bed, Helium Heat Transfer Fluid coupled to a Helical Steam Generator
- Proven High Temperature Pebble Bed Reactor
- Derived from over 50 years of design and development to significantly reducing costs to enable competitive deployment
- Proven fuel technology (US DOE Advance Gas Reactor irradiation program)
- Versatile Nuclear Steam Supply System (NSSS) that can be deployed for electricity generation and/or process heat applications



Section III, Division 5 Scope

- Construction of High Temperature Reactors
- Pressure Boundary, Core Supports, and Supports Structures in an HTR
- Covers both high and low temperature service

** Construction, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.*

ASME Code does not address the classification of components, only the construction of components

- Historically covered by ANS Standards
- Addressed in Regulatory Guides

The Xe-100 Safety Classification

- NEI 18-04, “Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development”
- Endorsed by NRC Reg Guide 1.233

Section III, Division 5 Code Classes

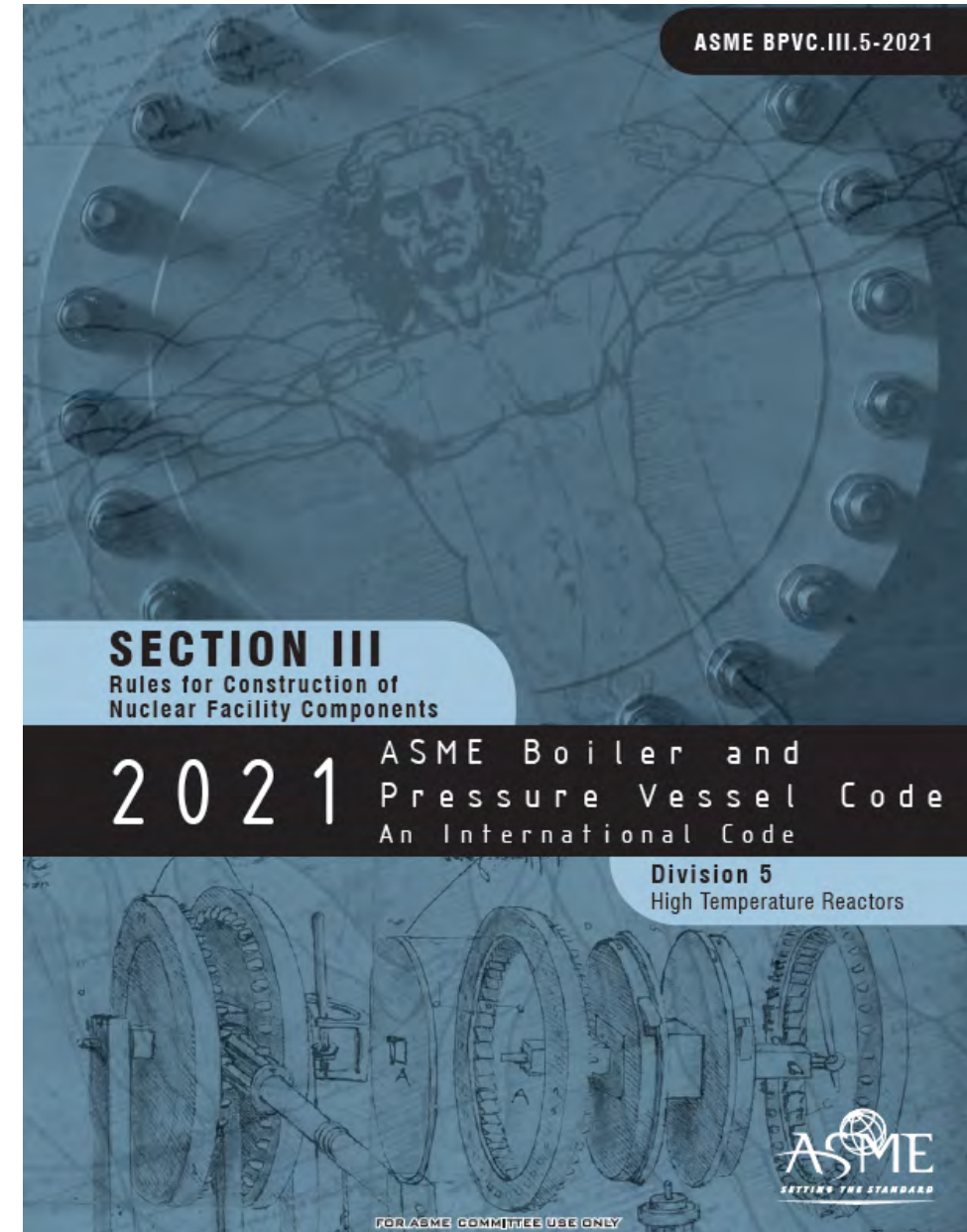
- Class A
- Class B

High Temperature Service

- Temperatures in the “creep regime”
- Ferritic materials > 375C, Austenitic and Inconel materials > 425C

Low Temperate Service

- Class A references Class 1 Rules
- Class B references Class 2 Rules



Reactor

- Pressure Vessel
- Reactor Internals
- Cross Vessel
- Safety Relief Valves
- Defuel Chute Vessel

Steam Generators

- Pressure Vessel
- Internal Structures
- Tubes, Tubesheets and Plenums
- Steam and Feedwater Piping within Isolation Valves
- MS and FW Isolation Valves

NEI 18-04 Risk Classification Process

- Determines AOO, DBE and BDBE based on risk consequence categorizations process
- Generally, structures that are needed to stay within the acceptable risk and consequence line for AOO and DBEs are designed to the ASME Code, Section III, Division 5

Xe-100 Risk-Consequence Model

- Does not require active cooling or retention of the coolant
- Does require that the core geometry be maintained

Pressure Retention is not a safety function

- Section VIII, Div 2 provides adequate assurance of a high-quality vessel for pressure retention
- Section III Design Rules address the unique needs related to nuclear service



X-energy submitted a White Paper to the NRC for comment

- Docket No. 99902071
- Submitted on July 13, 2020
- Requesting informal review and feedback
- Part of pre-submittal activities

White Paper summarized the proposed approach to design and construct the reactor pressure vessel:

- Construct and Stamp to Section VIII, for Design Condition
 - Design Pressure at Design Temperature and Deadweight
 - Material Specifications and Purchasing
 - Pressure Sizing
 - Quality Assurance
 - NDE and Testing
- Design and Analysis Section III, Division 5, Class A
 - Design Conditions
 - Material Requirements
 - Service Levels A, B, C and D
 - RPV Embrittlement

The CNSC and the USNRC reviewed the white paper and concluded that X-Energy's proposed approach for the design and fabrication of the Xe-100 RPV is viable, provided:

- X-Energy provides the full technical justification requested
- Address both regulators' observations documented in this report.

The proposed approach could be used to establish criteria for the Xe-100 design and fabrication of the RPV.



The main governing code of Concern is the ASME B&PV Code, Section III, Division 5, HHA and HAB.

The code provides standards and guidance on the:

- **Qualification of the Material**
 - Irradiated Material Properties Material being tested for qualification use must be representative
 - Historical Data must be shown to be applicable if used
 - Reporting Requirements for Material Data Sheets
 - Material Specification and use of ASTM standards
- **Design of Graphite Components and Assemblies**
- **Designer and Supplier Certification**
- **Machining, Examination, Shipping and installation**

The main question concerning this portion of the code is when the NRC will issue their formal endorsement?





Questions





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