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

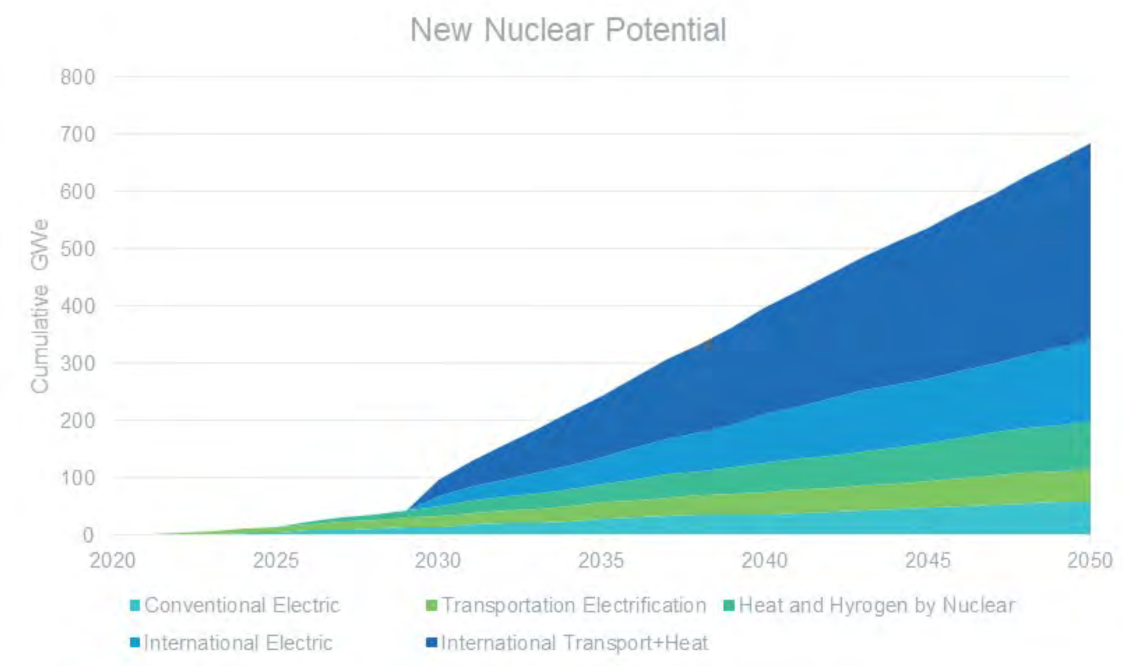
Mark Richter - NEI

September 28, 2022

NEI NUCLEAR ENERGY INSTITUTE

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

NuScale Perspectives on Codes & Standards

2022 NRC Standards Forum

September 22, 2022

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

Acknowledgement and Disclaimer

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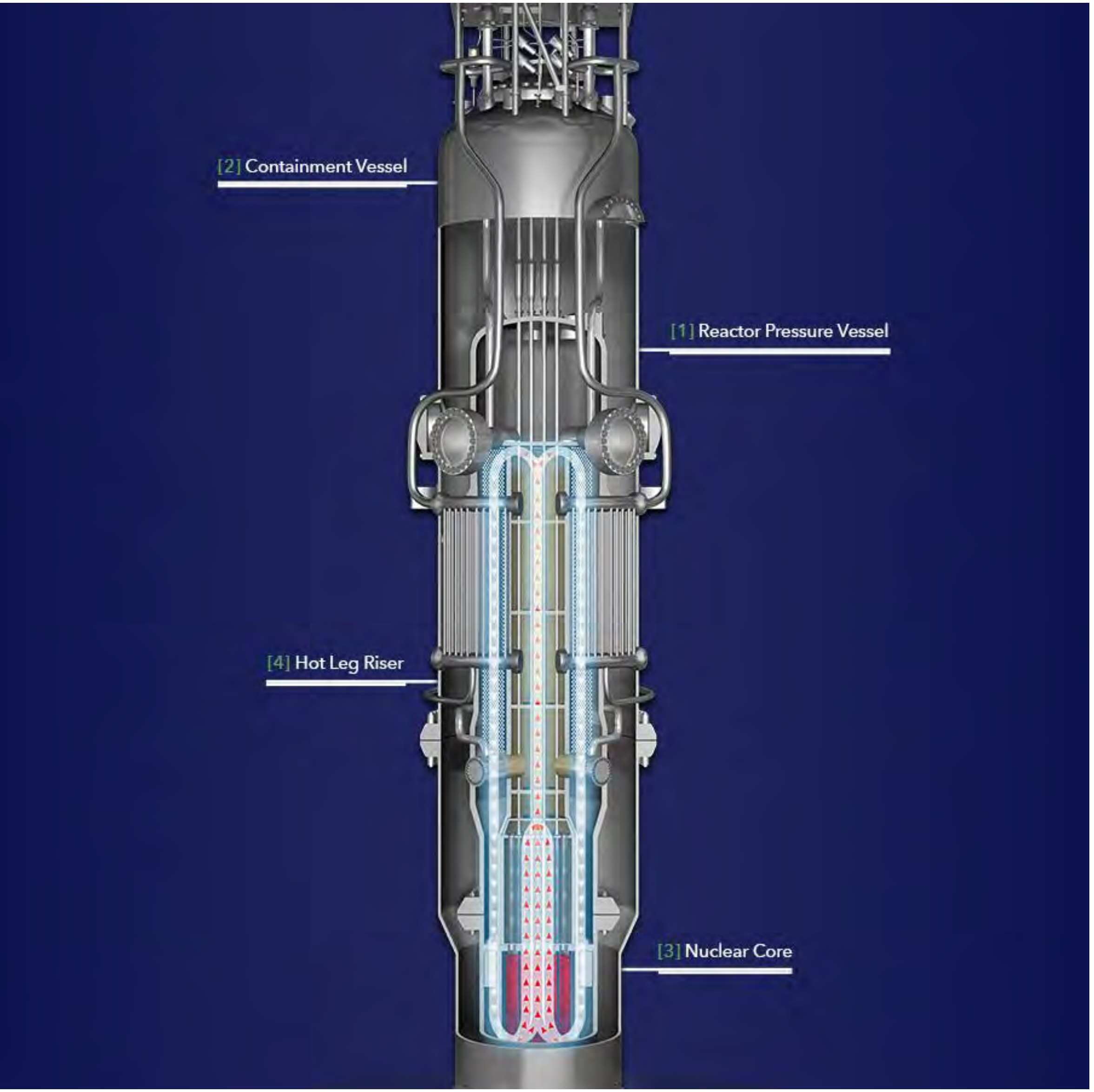
Who is NuScale Power?

- 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.

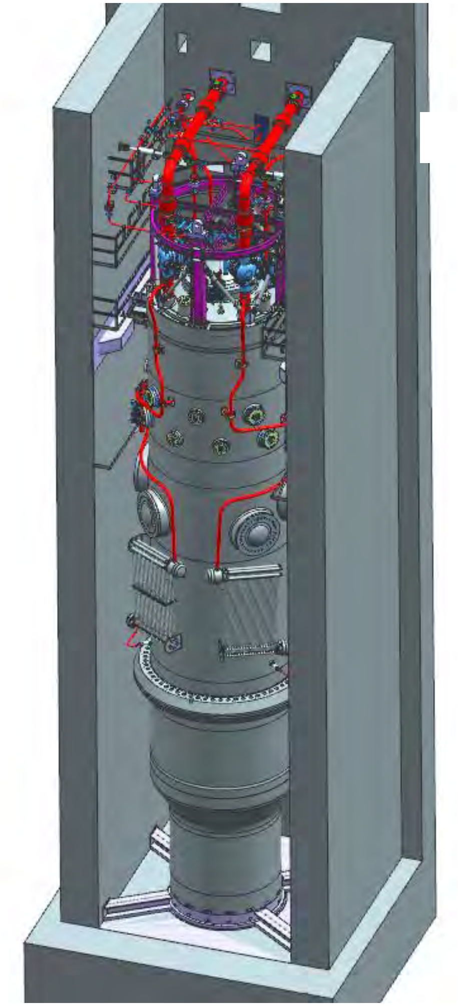
NUSCALE™ Power for all humankind



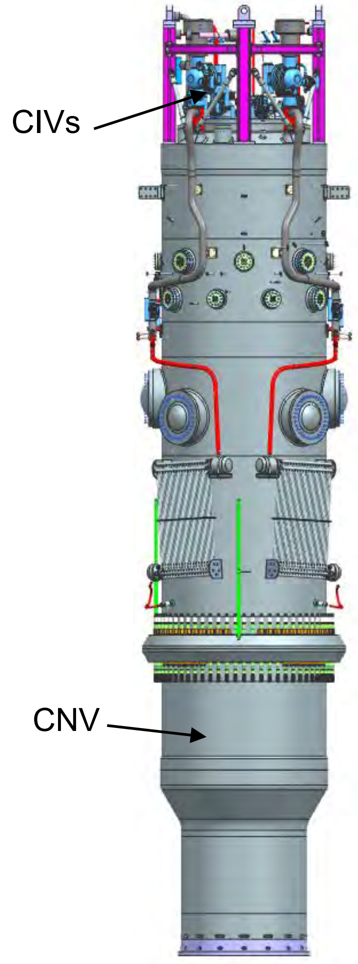
Core Technology: NuScale Power Module

- 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

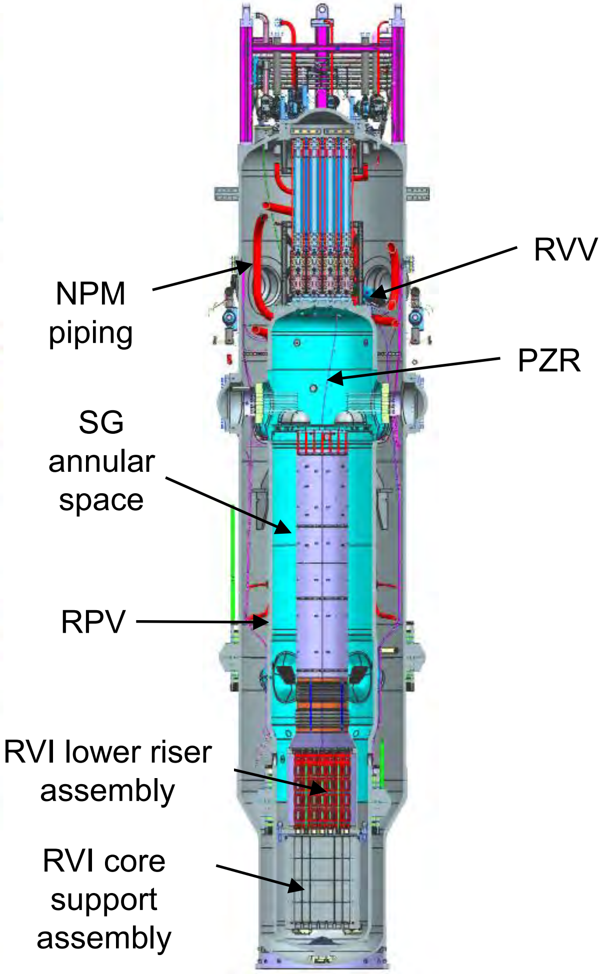
NuScale Power Module Arrangement



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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Power for all humankind

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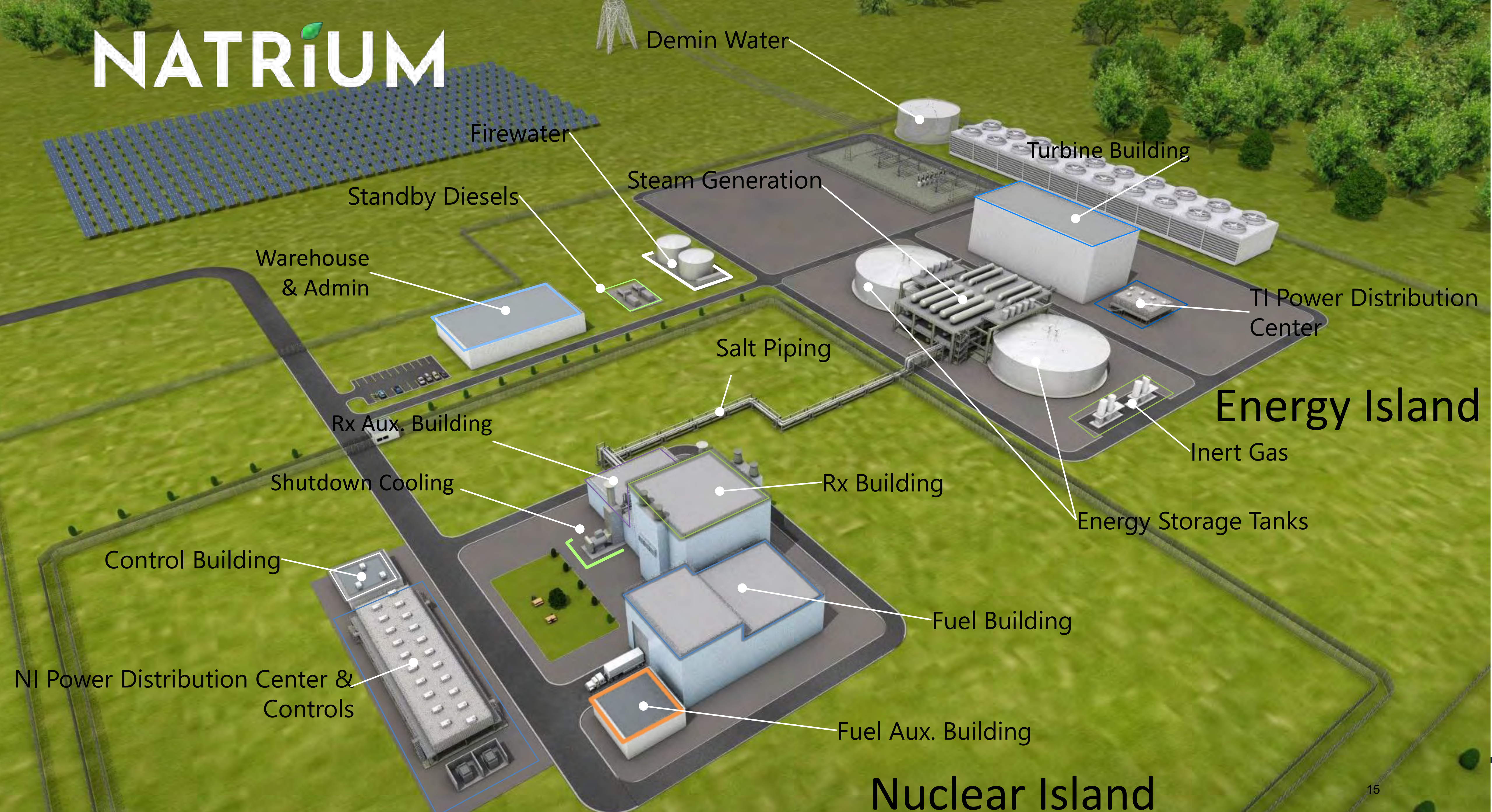
Plant Overview – NRC Adv Rx Forum

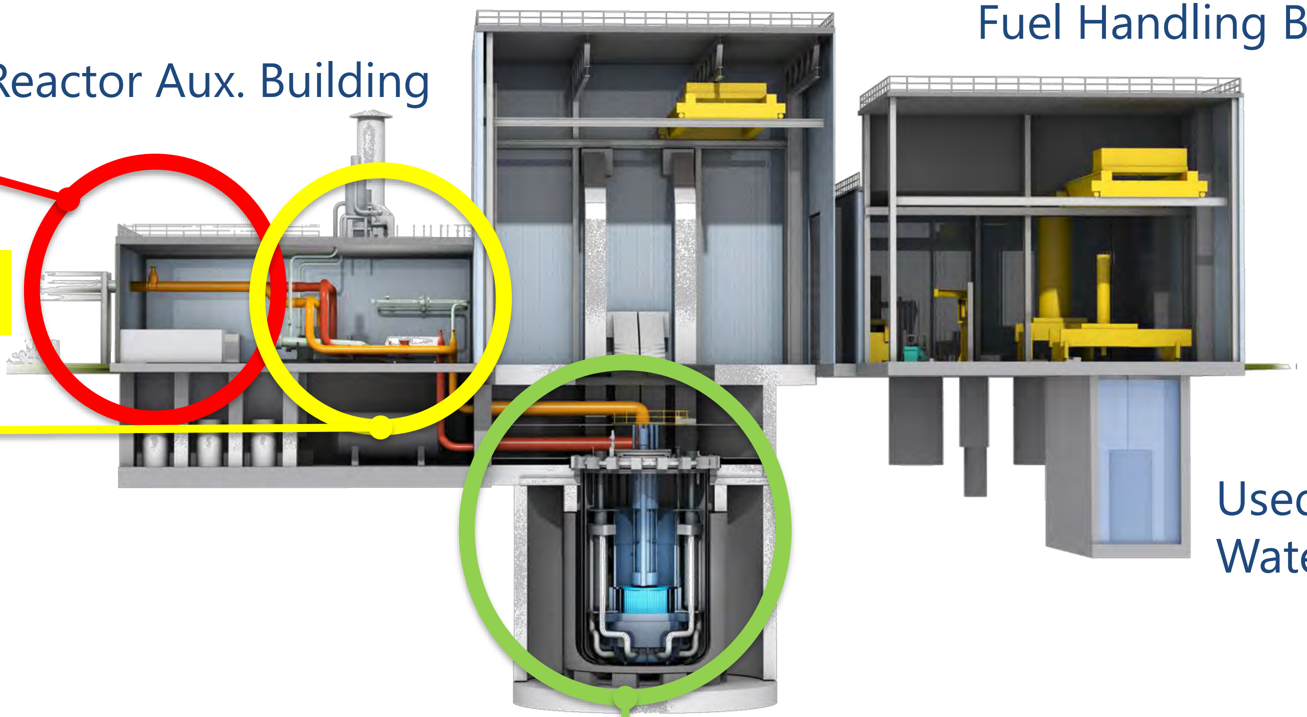
Steven Unikewicz

Terra Power Advanced Reactor Types

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


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

Integrated Energy Storage Sodium-Salt Heat Exchanger Loop Tests



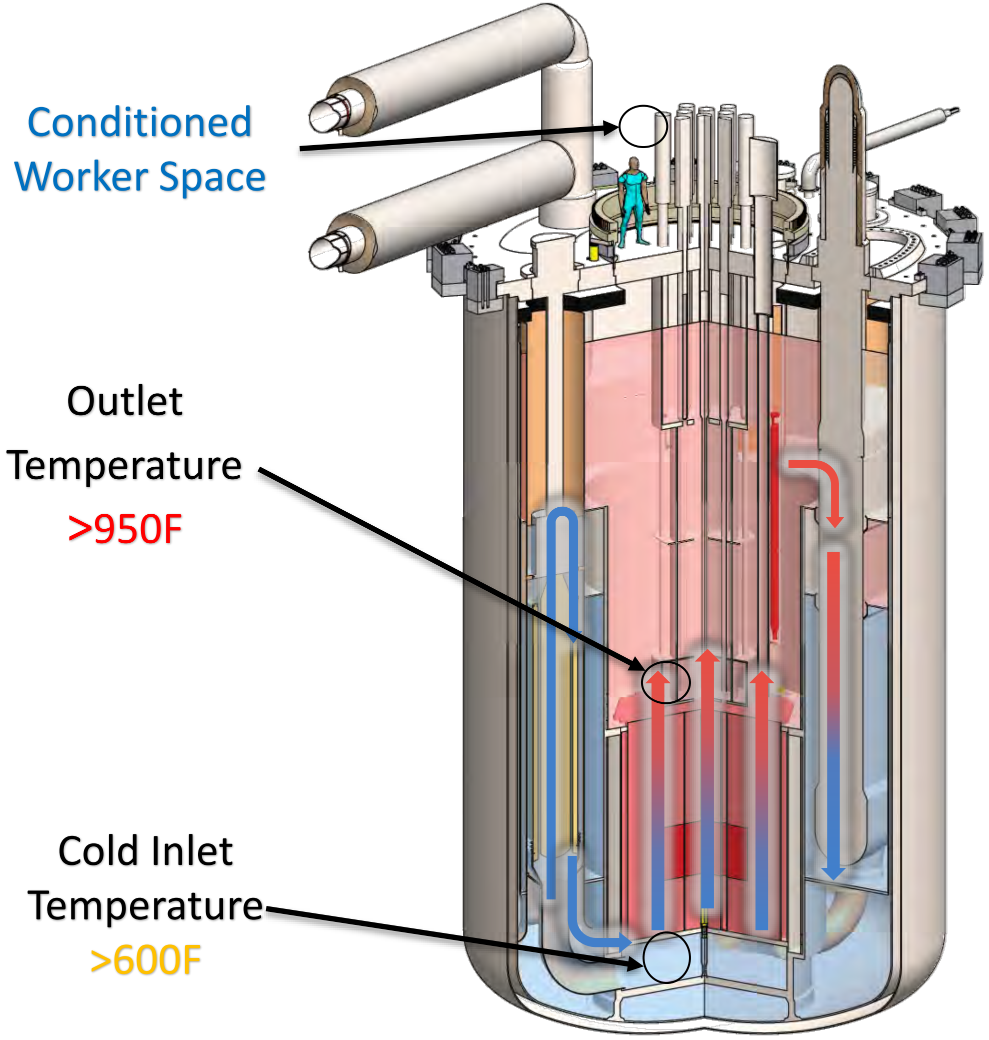
TerraPower

Natrium Profile

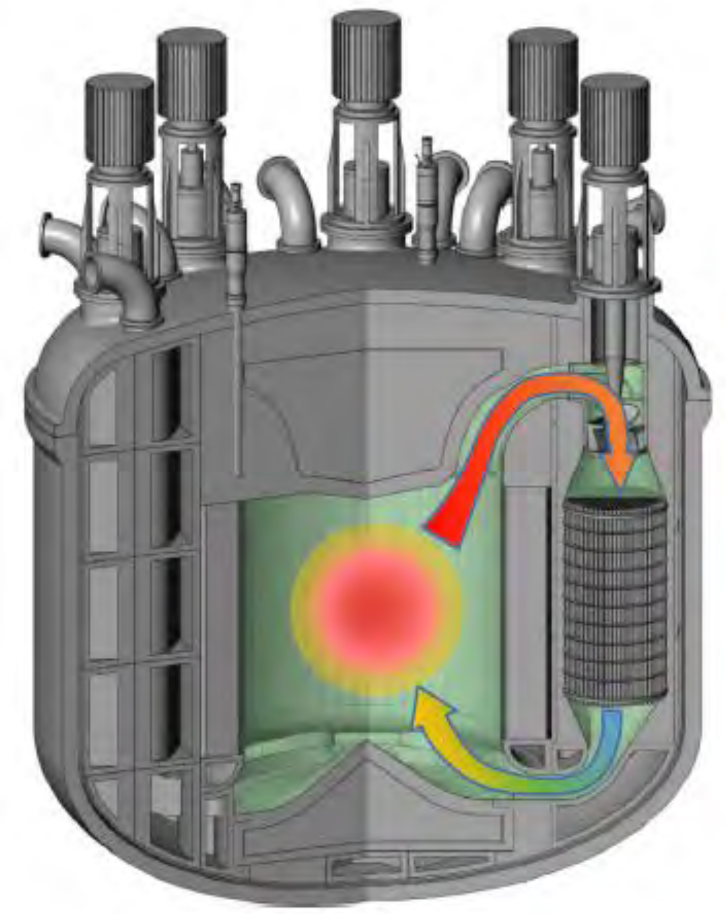
Reactor and Power Parameters

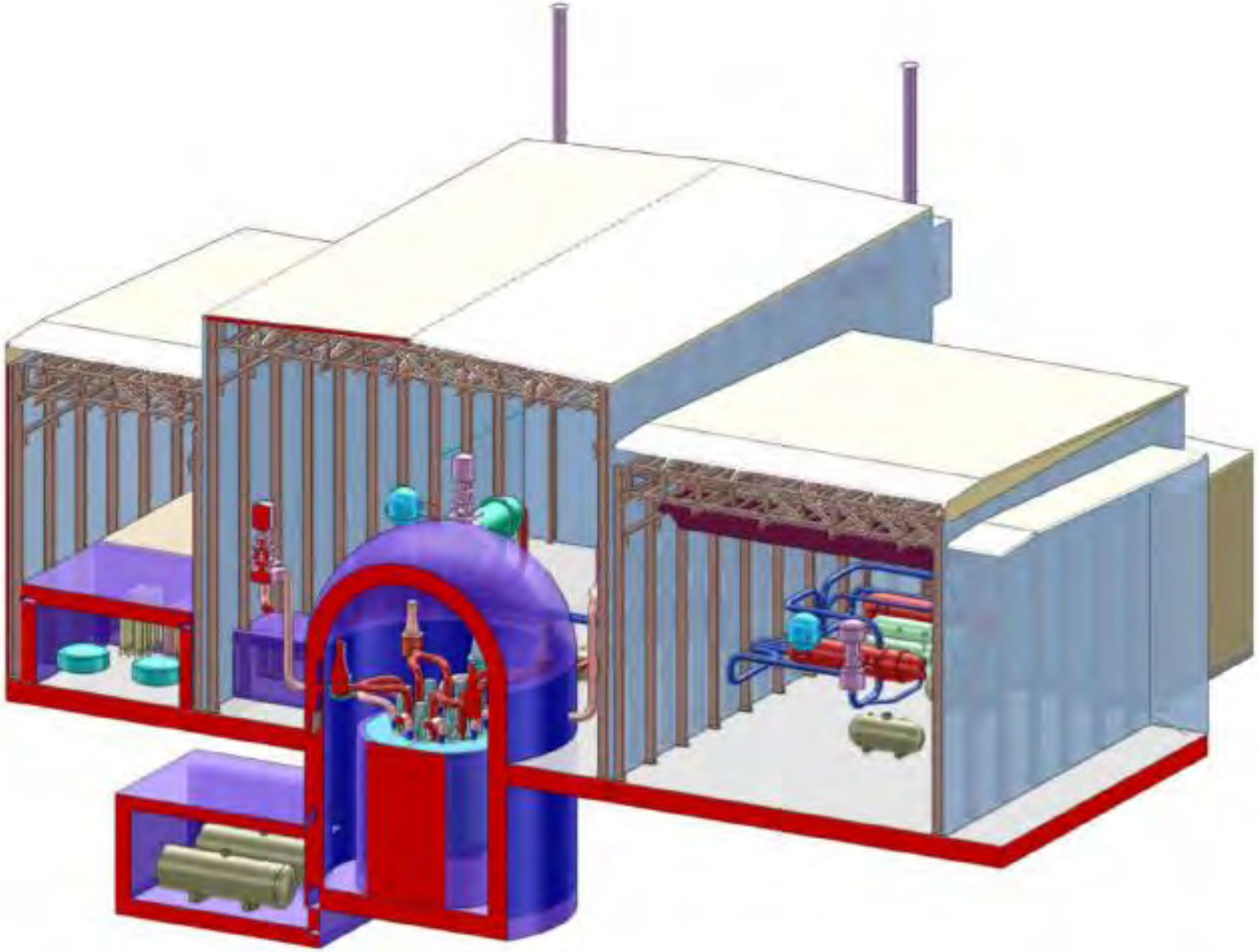
- Reactor Power Class: 840 MWt
- Reactor Type: Pool-Type Sodium Fast Reactor
- Reactor Coolant: Liquid Metal (Sodium)
- Reactor Fuel Type: Metal Uranium Fuel, Ferritic-Martensitic Cladding

- 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

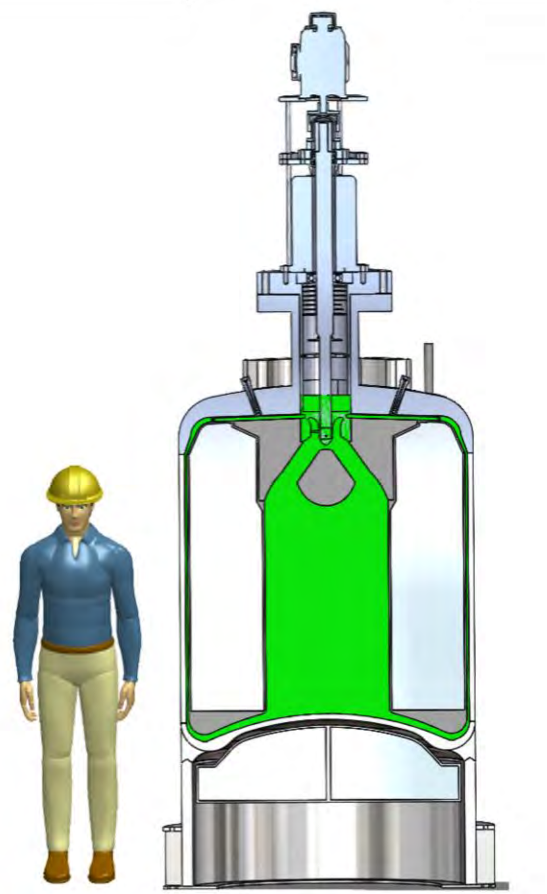




Credit: Jeff Latkowski

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

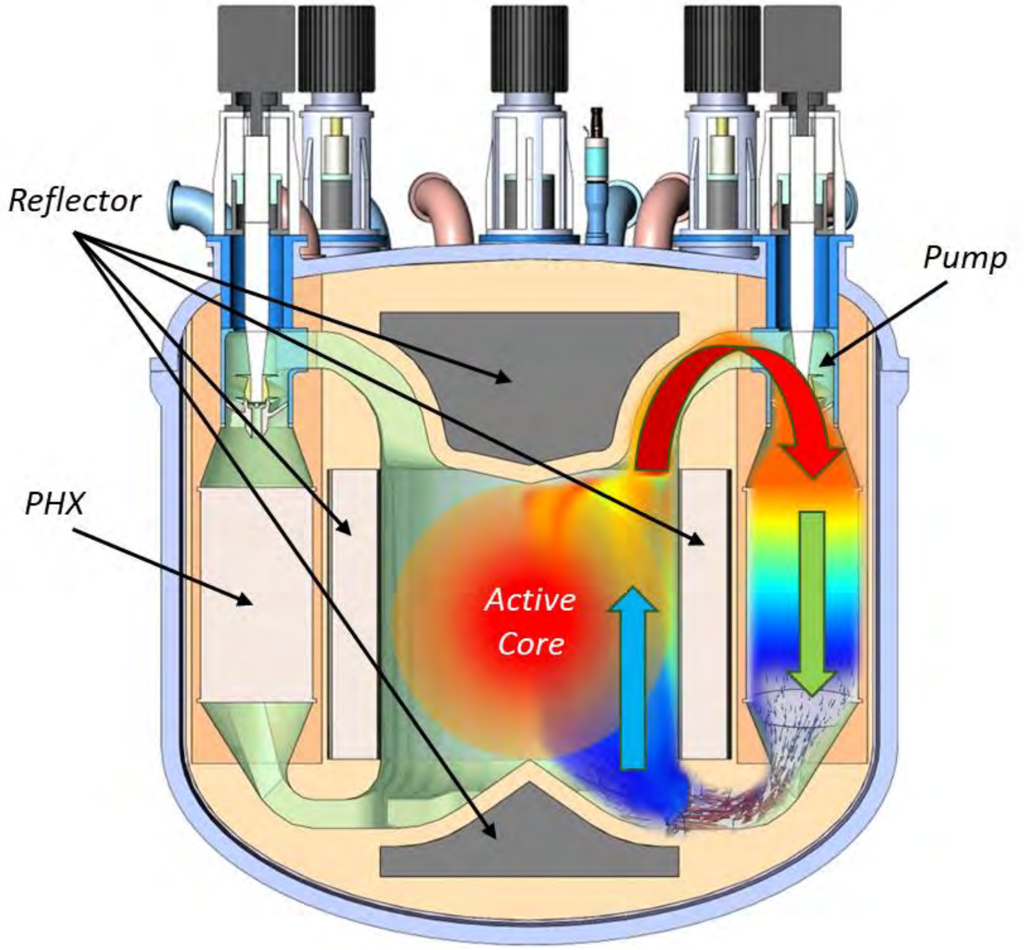
Parameter	MCRE
100% Thermal Power	200 kW
Nominal Temperature	1200°F
Nominal Pressure	37 PSI
Design Temperature	1300°F
Design Pressure	70 PSI
Time at Temperature	6000 hr
Time at Power	1000 hr (out of 6000 hr)



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-UCl_3 eutectic
- Initial U enrichment of 11-13 wt%
- Feed depleted UCl_3
- $PuCl_3$ is bred up
- Fuel salt flows out of active core around 8 discrete flow paths
- 8 axial flow pumps
- 8 shell & tube PHXs



TerraPower

Codes and Standards Needs

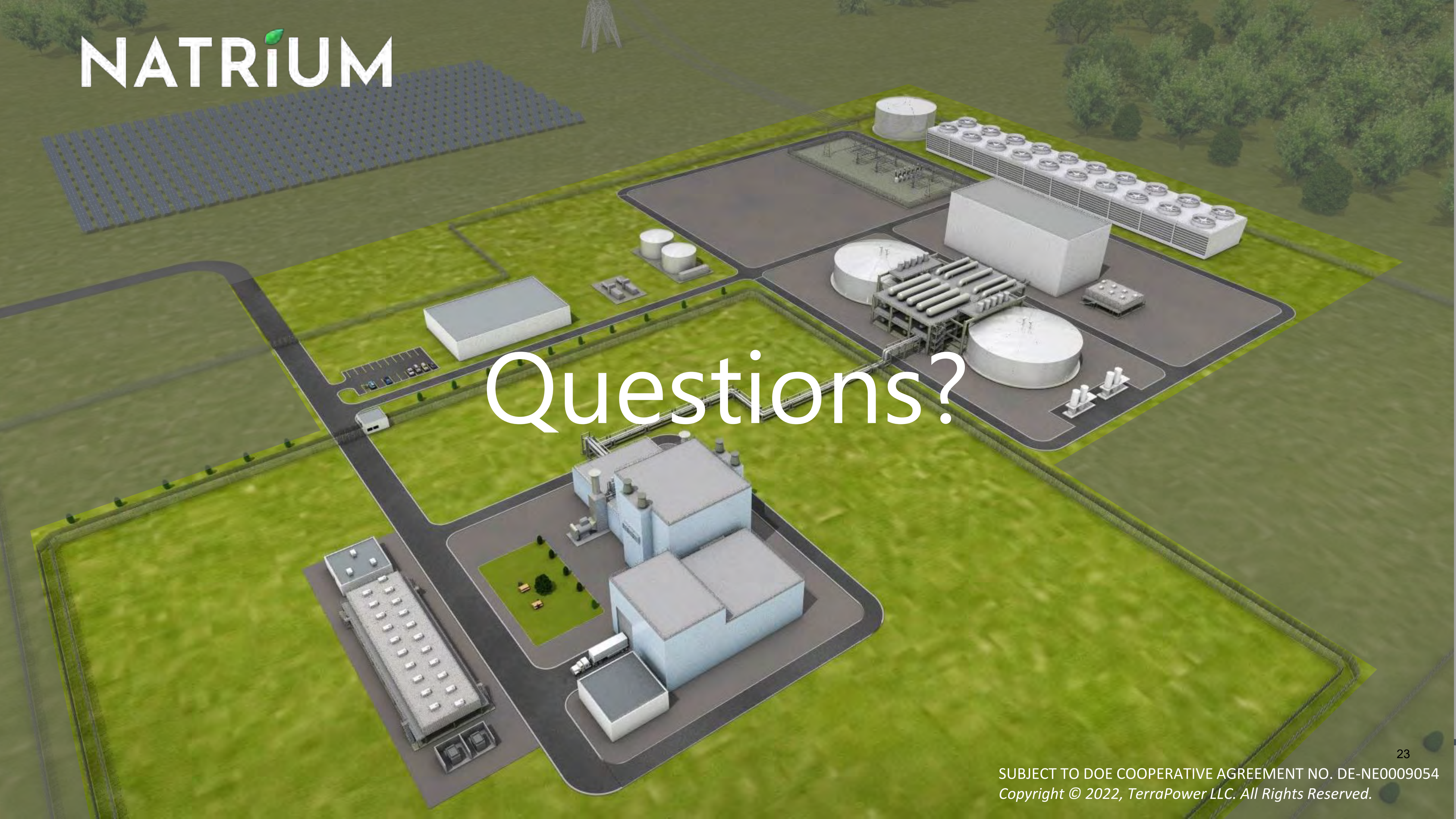
- Sodium Fast Reactor applicability is not fully addressed by Codes and Standards currently endorsed and referenced by the NRC. Coordination with Standards Organizations and NRC is ongoing.

- 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

NATRIUM



Questions?

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Code Overview – NRC

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

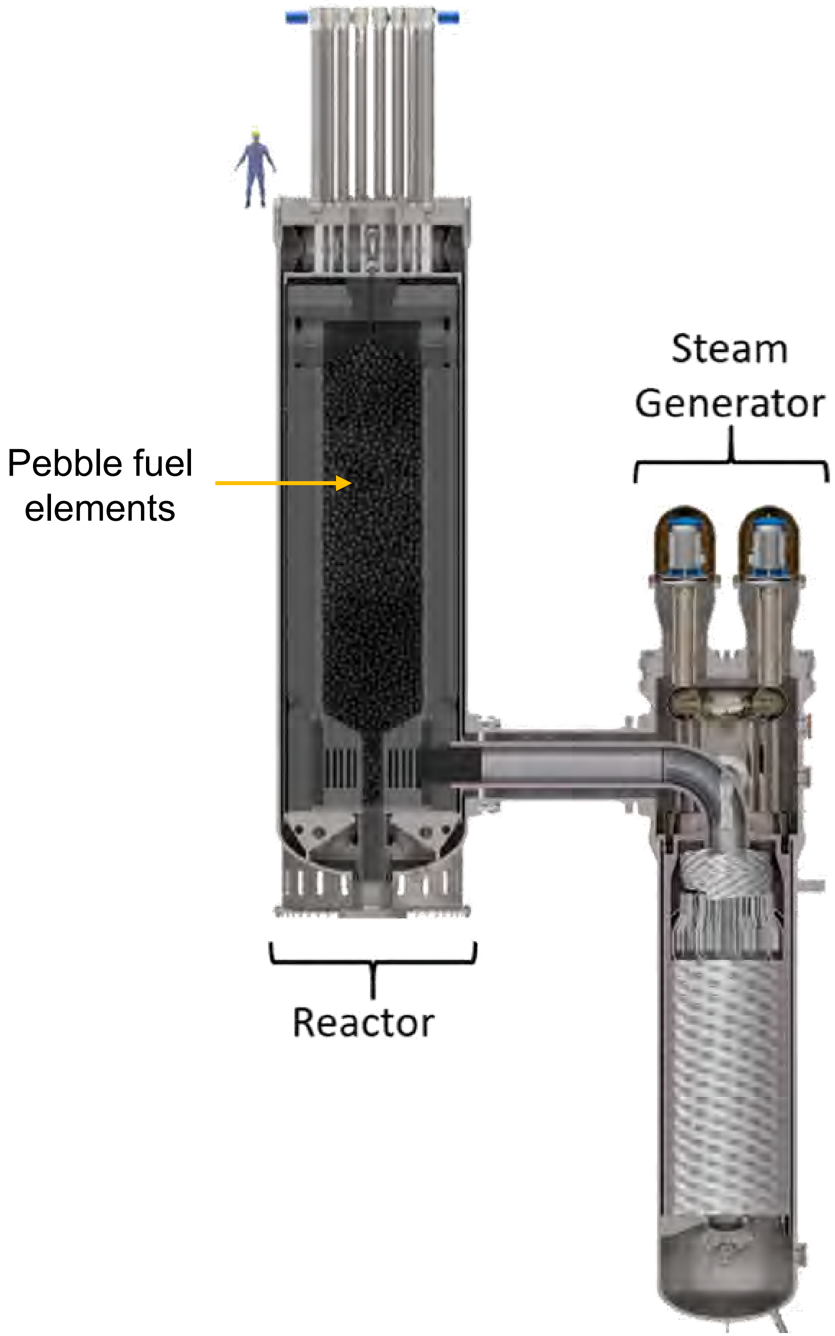
9/28/2022

Agenda

- 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

Xe-100 Introduction

- 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



ASME Code Section III, Division 5

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.*

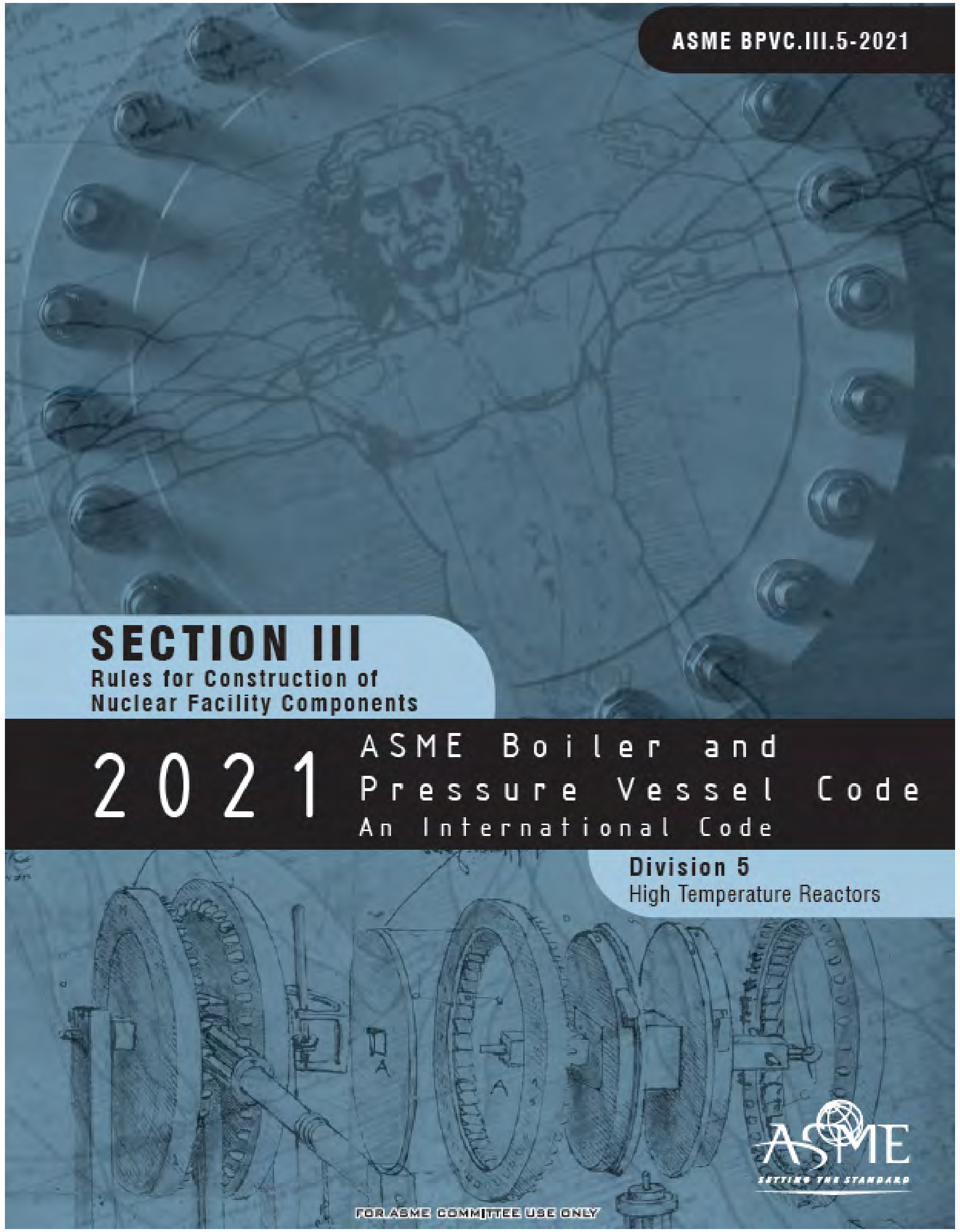
ASME Code does not address the classification of components, only the construction of components
- Historically covered by ANS Standards
- Addressed in Regulatory Guides

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



RPV, PB and Metallic Internal Components

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

RPV, PB and Metallic Internal Components

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.

Graphite Reflector

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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energy

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