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NATRIUM

Functional Containment

a TerraPower & GE-Hitachi technology

NATD-LIC-PRSNT-0014

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Objectives

- Natrium™ reactor overview
- Functional Containment Background and Natrium Strategy
- Application of SECY 18-0096 Enclosure 2 for the Natrium Design
- Functional Containment Analysis & Source Term Methodology

Natrium Reactor Licensing Overview

- Regulatory Engagement Plan submitted 6/8/2021.
- 10 CFR 50 licensing process will be followed.
  - Construction Permit Application 8/2023
  - Operating License Application 3/2026
- Numerous pre-application interactions are planned to reduce regulatory uncertainty and facilitate the NRC's understanding of Natrium technology and its safety case.
- LMP (NEI 18-04), as endorsed by RG 1.233, will support this application.

Natrium Reactor Licensing Overview

- Each pre-application interaction will build upon risk insights from prior interactions to demonstrate the Natrium reactor's safety case.

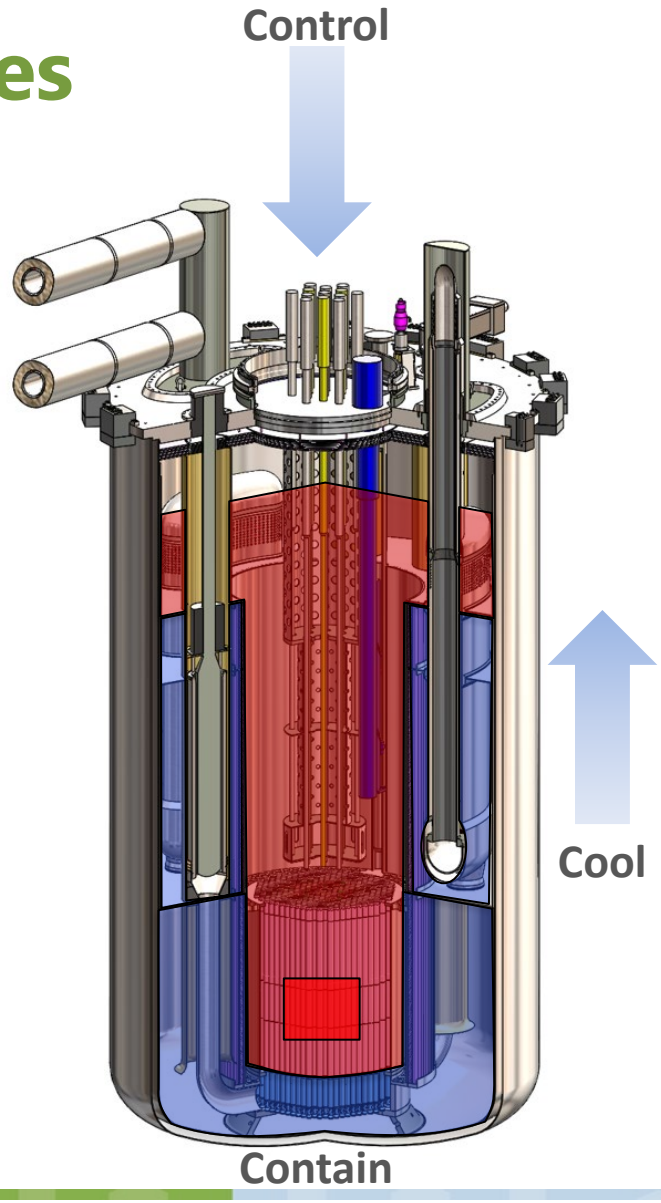
- Future Meetings and Presentations include:
  - Testing Plan and Methodology
  - Environmental Fuel Cycle Impacts

Advanced Reactor Demonstration Program

- Demonstrate the ability to design, license, construct, startup and operate the Natrium reactor within the Congressionally mandated seven-year timeframe.
- Include improvements in safety, security, economics, and environmental impacts.
- Utilize a simple, robust, reliable, and proven safety profile.
- Lower emissions by initiating the deployment of a fleet of Natrium reactors – demonstrate that the plants can be built economically and that they will be attractive for future owner/operators.

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
- 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

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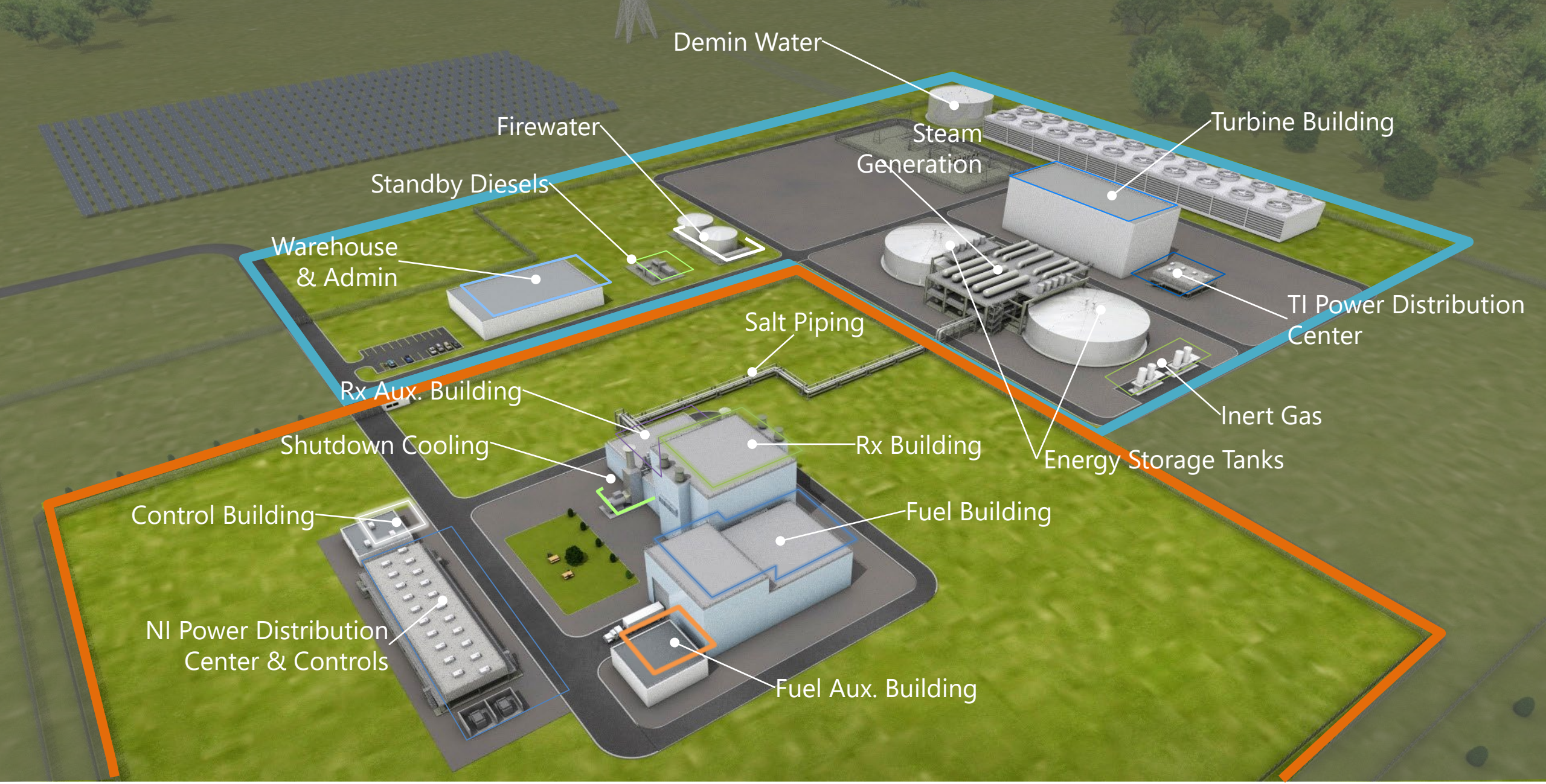

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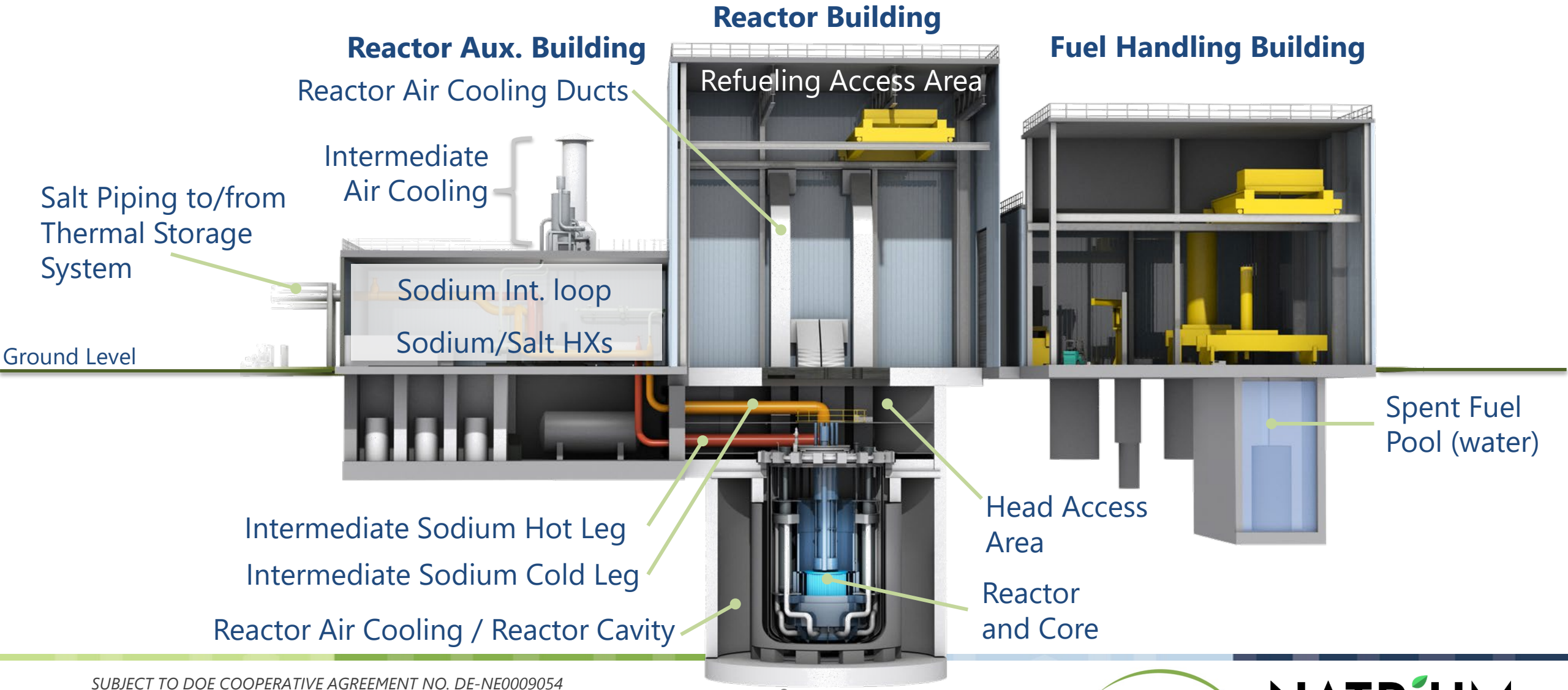
Plant Overview



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FUNCTIONAL CONTAINMENT

Historical Background and Natrium Strategy

LWR Containments and Source Term

- Traditional LWR containment is the final barrier after breach of reactor coolant pressure boundary and cladding failure
  - RCS parameters: **~575 °F, ~2250 psia** (typical PWR large dry ambient containment)
  - Containment sustained accident pressure: **~58 psig**
  - Typical leak rate: **0.1 wt % per day at 60 psig** (input to NUREG-0800 Chapter 15 analyses)

- LWR containment integrity demonstrated by:
  - Leak rate testing (Appendix J)
    - *Confirms actual leakage is less than design leakage.*
  - Deterministic accident analysis (NUREG-0800 Chapter 6)
    - *Confirms that containment design pressure will not be exceeded.*

- LWR source term guidance has evolved with testing and industry experience:
  - Conservative: TID-14844 (1962) → RG 1.195
  - Alternative: NUREG-1465 (1995) → RG 1.183

Evolution of Functional Containment Guidance

- Fort St. Vrain SER (Jan 1972; ML100820279) – deterministic application of Functional Containment / confinement.

- Functional performance criteria for non-LWR containment considered by Commission and Staff since the 1990s.
  - NUREG-1368 (PRISM SER), SECY-93-092, SECY-03-0047

- Regulatory Guide 1.232 (April 2018) – Principal Design Criteria for non-LWRs.
  - Functional Containment presented as an option for MHTGR (Appendix C)

- SRM to SECY-18-0096 – Commission approved most current guidance for developing functional containment performance criteria.

Functional Containment Definition

From SECY 18-0096:

A "functional containment" [is] a barrier, or a **set of barriers** taken together, that effectively **limits the physical transport** of radioactive material to the environment. (pg 2)

In terms of functional containment, a given SSC may have performance criteria associated with its role to limit effluent releases during **normal operation** and **anticipated events** as well as performance criteria associated with its role to retain radionuclides during **design basis accidents** or **beyond-design-basis events**. (pg 4)

Natrium PDC 16 – Functional Containment:

(as proposed in the TerraPower PDC & LMP Public Meeting, 12/09/2021 ML21340A107)

A functional containment, **consisting of multiple barriers** internal and/or external to the reactor and its primary coolant boundary shall be provided to **control the release of radioactivity** to the environment. Leakage through the **aggregate SSCs** making up the functional containment shall be restricted to be less than that needed to meet the functional containment performance **criteria established for each event category**, including 10 CFR 50.34 postulated accidents.

Functional Containment Strategy

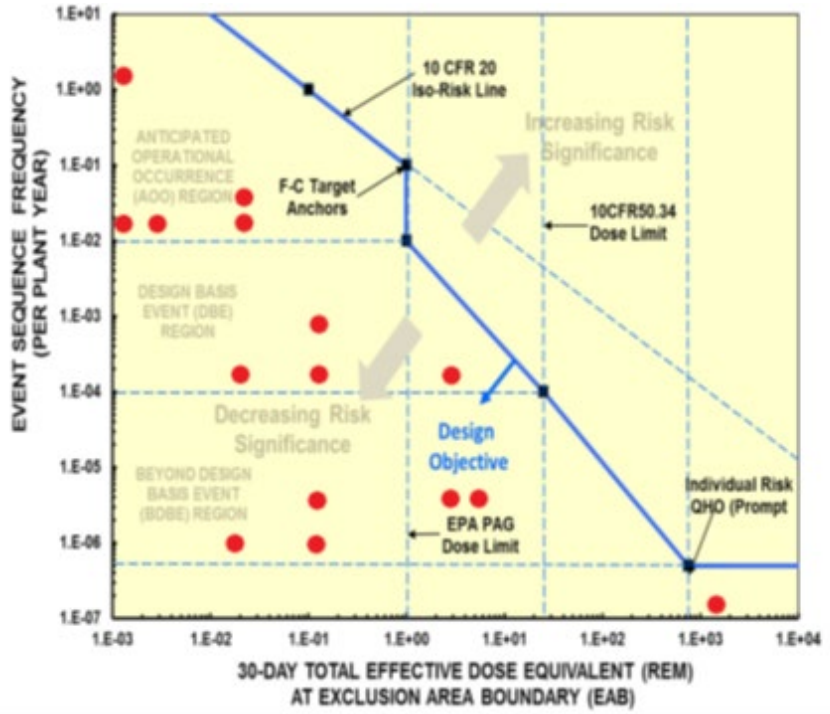
- Applications of Functional Containment:
  - *Fort St. Vrain (HTGR) - licensed by AEC (1972)*
  - *Recent non-LWR applicants - proposed*
  - *Natrium reactor (SFR) - proposed*

- Goal is margin to acceptable dose limits per event category.

- Dose consequence is directly related to the number of barriers and the effective leakage across those barriers.

- Functional Containment complements the Natrium Mechanistic Source Term and SARRDL approach.

- Functional Containment provides diverse barriers against release of radioactivity, providing additional defense-in-depth.



Adapted from NEI 18-04
*(**for illustrative purposes only**)*

Functional Containment Strategy – Diverse Barriers

Functional Containment Barriers*

Clad Integrity
Subcooled Sodium Pool
Primary System Boundary
Guard Vessel
Building Compartments
Penetration Seals
Process Tanks & Piping

Related Diverse Features*

Reactivity Control
Multiple Heat Removal Paths
Passive SR Emergency Cooling
Emergency Planning Zone
…and others

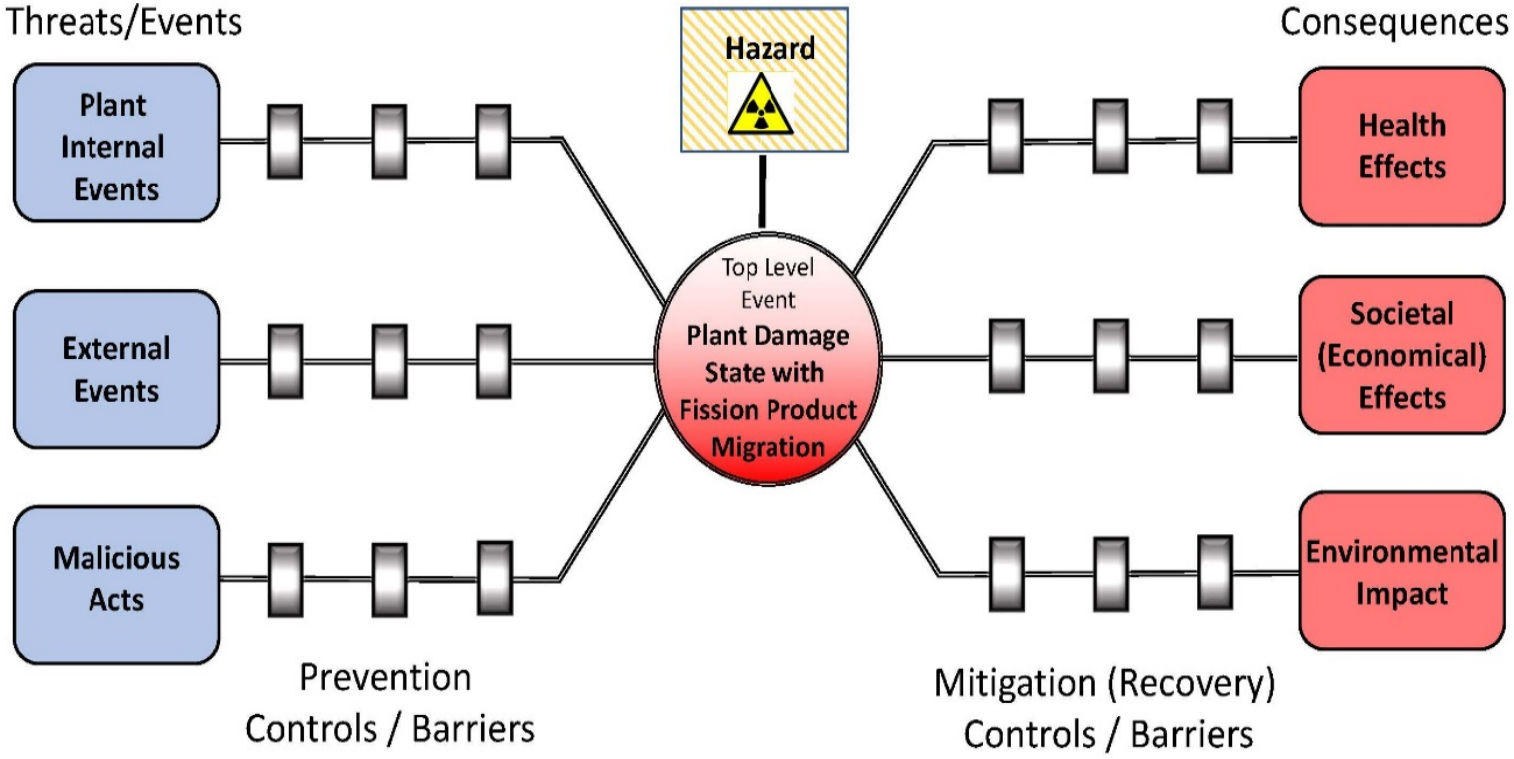


Figure 1 from SECY 18-0096 Enclosure 2

** Note- Listed barriers and features are not intended to signify any certain level of SCC classification but are features of the plant that could be used in several events to limit radioactive releases.*

Functional Containment Strategy – Key Elements

- Plant Design (physical barriers, and features)
- Event Classification (based on event frequencies)
- Establish Functional Containment Performance Criteria
- Analysis and Testing
  (demonstrate performance criteria are satisfied)
- SSC Classification, informing:
  - Administrative/Procedural Controls (control the status of barriers)
  - Maintenance and Inspection (ensure barriers are in good working order)

SECY 18-0096 ENCLOSURE 2

Natrium Methodology and Application

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SECY 18-0096 Methodology

- Identify and categorize LBEs.
- Define performance criteria (per event category) for SSCs serving to limit release of radioactive material.
- Apply SSC classification and evaluate LBEs against performance criteria.
- Perform defense-in-depth adequacy assessments.
- Assess SSC classification and re-evaluate LBEs as necessary.
- Consider other purposes and roles for physical structures.

POLICY ISSUE
(Notation Vote)

DATE: September 28, 2018

FOR: The Commissioners

FROM: Margaret M. Doane
Executive Director for Operations

SECY-18-0096

SUBJECT: FUNCTIONAL CONTAINMENT PERFORMANCE CRITERIA FOR NON-LIGHT-WATER-REACTORS

PURPOSE:

The purpose of this paper is to seek Commission approval of the U.S. Nuclear Regulatory Commission (NRC) staff's proposed methodology for establishing functional containment performance criteria for non-light-water-reactors (non-LWRs). This paper does not address any new commitments or resource implications.

Define Functional Containment Performance Criteria

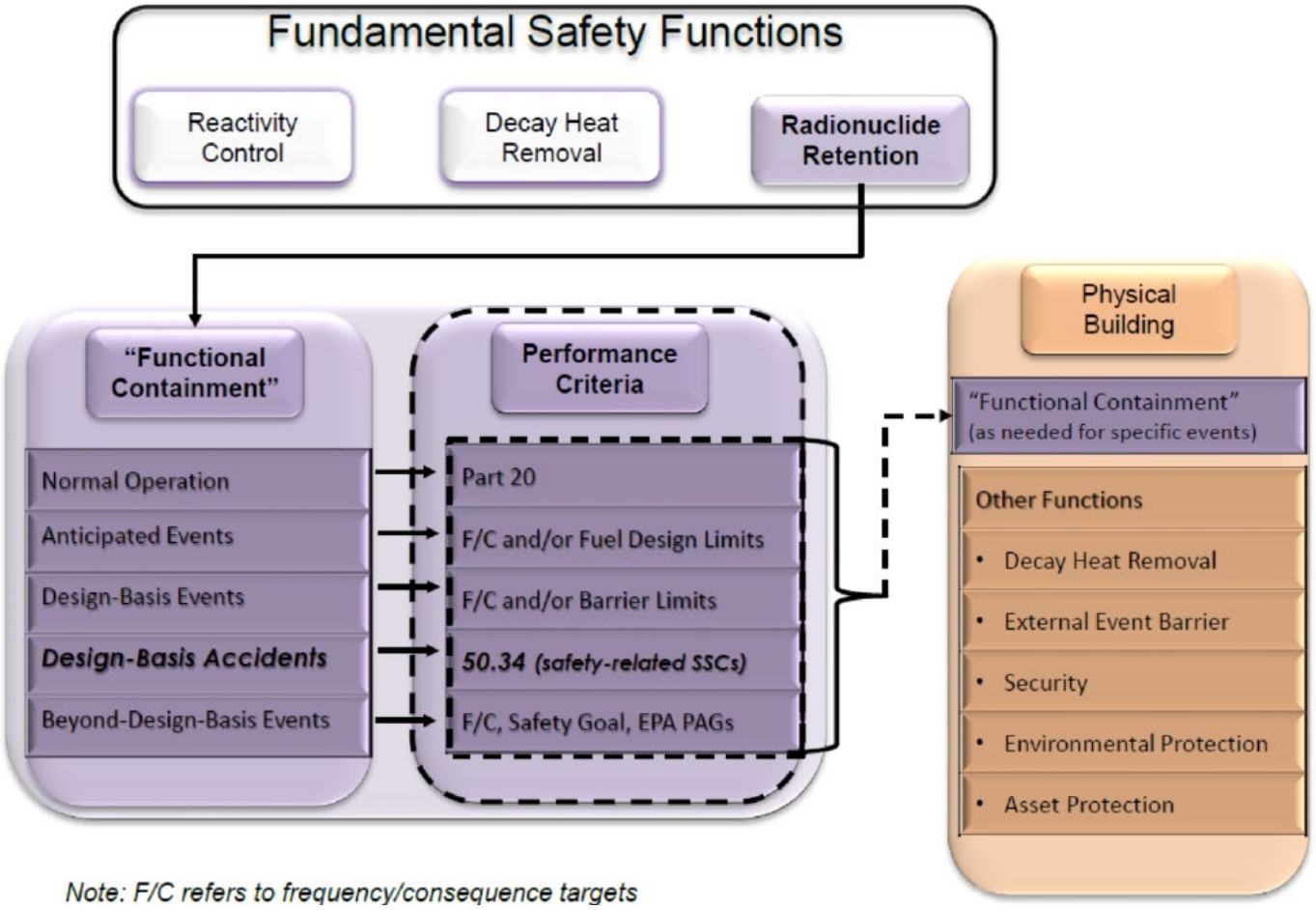

Figure 3 from SECY 18-0096 Enclosure 2

- Fundamental Safety Function is CONTAIN.
- Graded criteria according to event category from the LMP process.
- DBAs are chosen from DBE category
  - Credit only safety-related SSCs.
  - Held to 10 CFR 50.34 requirements.
  - DBAs historically used to define safety margins and LCOs.
- "Other Functions" fall outside of Functional Containment but considered as part of the building design requirements.

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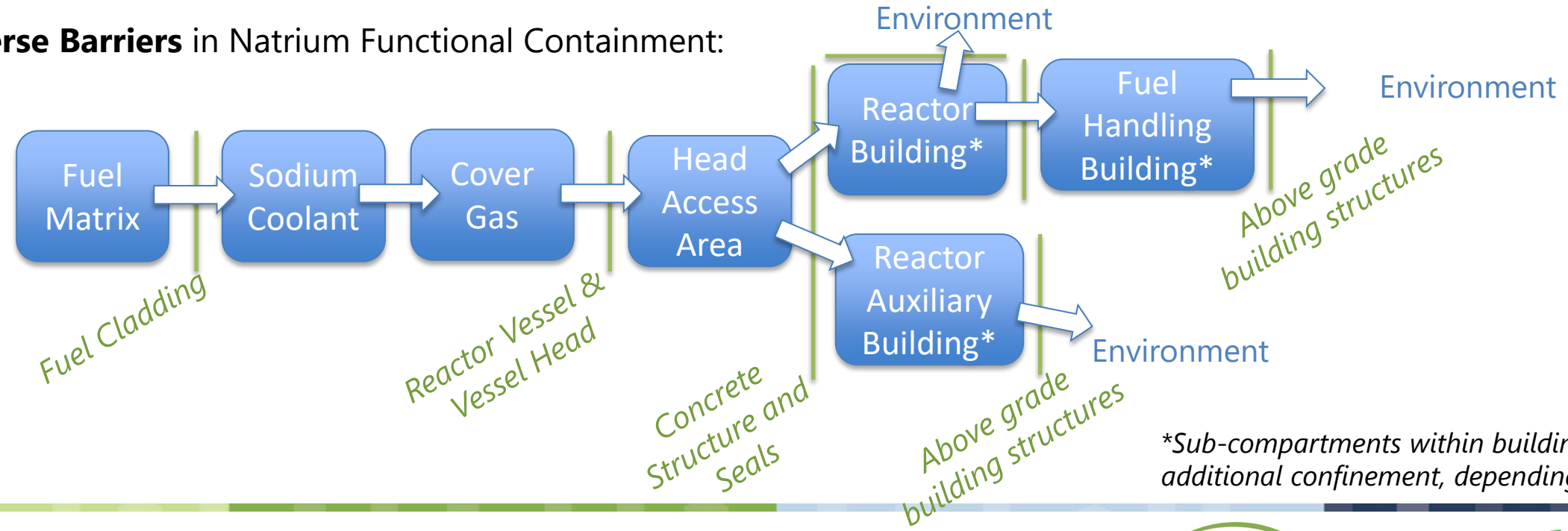
Natrium Application of Functional Containment

The Natrium design is well suited for Functional Containment:

- **Low** operating pressures & **large margin** to sodium boiling
- **Low** differential pressure between vessel and compartments
- **High** conductivity coolant & **passive** emergency core cooling
- Design precludes any consequential LOCA

Diverse Barriers in Natrium Functional Containment:



**Sub-compartments within building provides additional confinement, depending on event.*

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FUNCTIONAL CONTAINMENT ANALYSIS

Natrium Source Term Methodology

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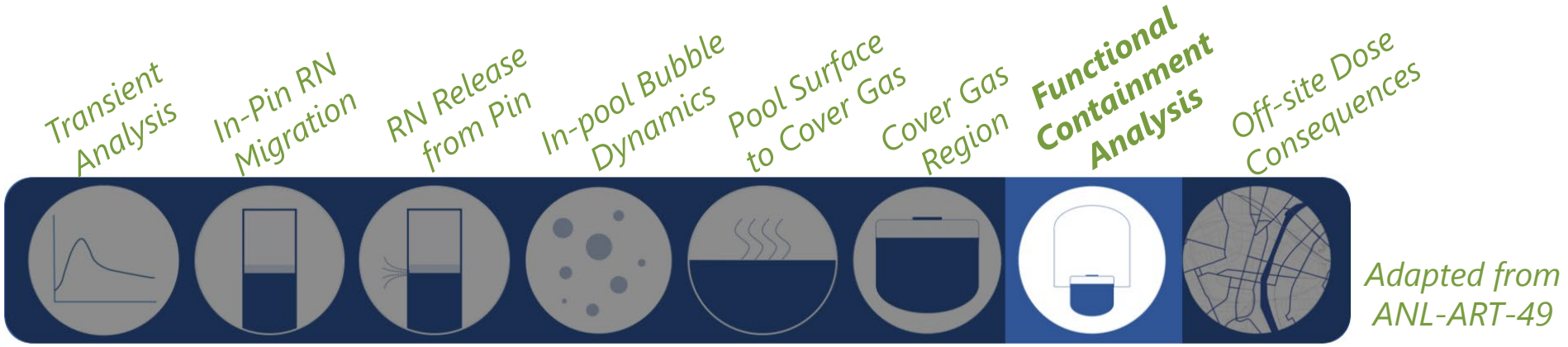
Functional Containment Analysis and Source Term

- Quantify compartment to compartment leakage (P/T dependent).
- Assess aerosol behavior in compartments.
  (deposition/condensation, RN decay, and agglomeration)*
- Assess sodium-chemical reactions in air-filled spaces (event specific).
- Assess barrier performance for LBEs with Radiological Consequences, and Design Basis Accidents.
  (includes cliff edge effects, considerations for severe accidents, EPZ methodology, and others)

**phenomena also considered in the cover gas region*



Adapted from ANL-ART-49

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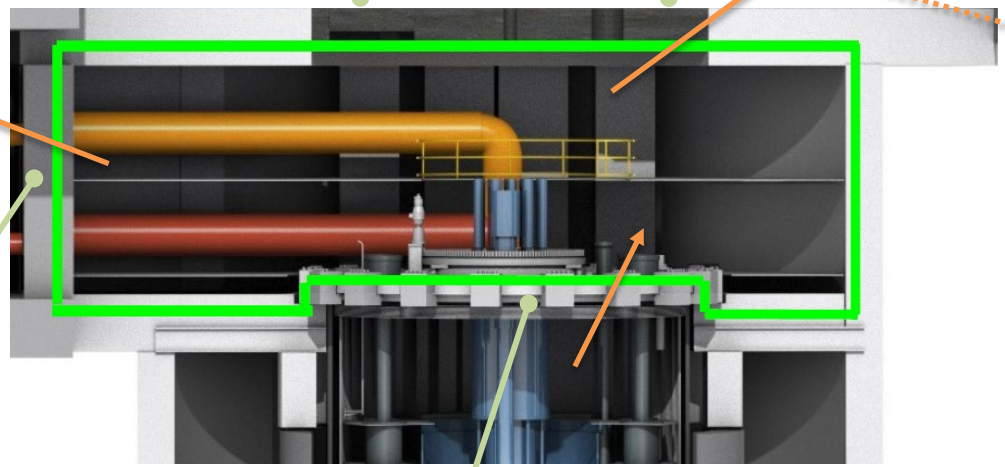
Functional Containment (example barriers)

Head Access Area

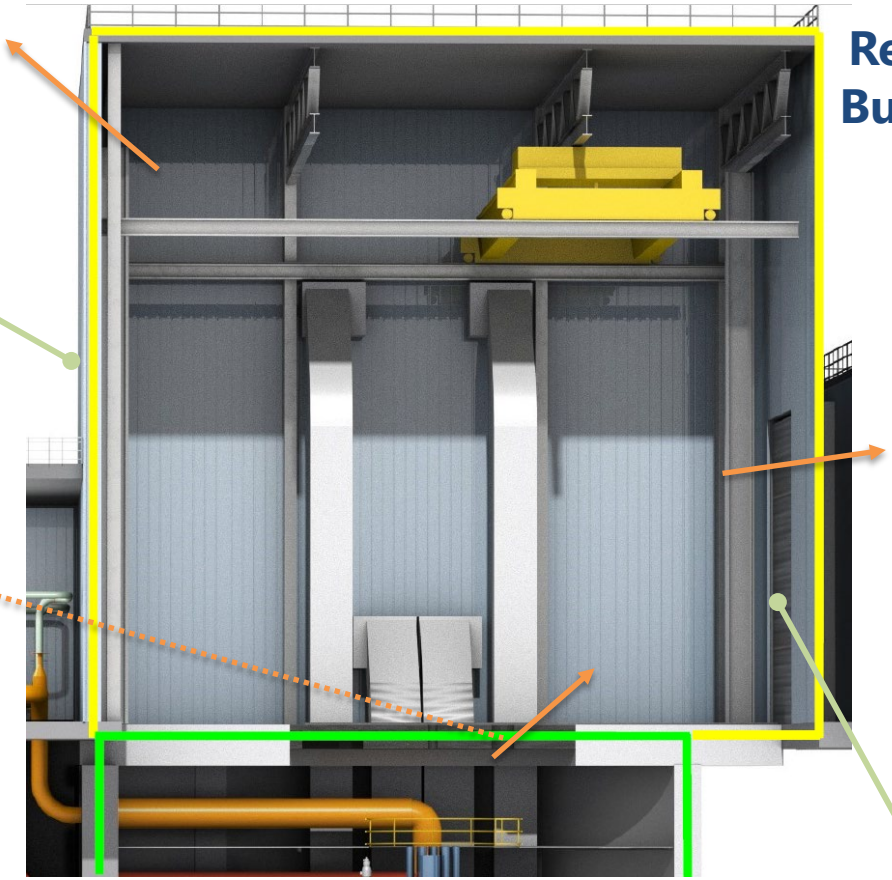
Reactor Building Floor Plugs
(in-place during operation)



IHT Piping Penetrations
(to Reactor Aux Building)

Zero-Leakage Rx Vessel Head

Above-Ground
Structure



Reactor Building

Rollup Door to
Fuel Handling Building

Additional Considerations

- Maintenance, Testing, and Inspection of Barriers
- Treatment of NSRST and NST barriers in analyses
- Developing technical specifications around Functional Containment
- Functional Containment Analysis
  - Code Selection
  - Sodium-chemical reactions
  - Considerations for cliff edge effects, and severe accidents
  - Design Basis Accidents

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Acronym List

AEC – Atomic Energy Commission
CFR – Code of Federal Regulations
DBA – Design Basis Accident
EBR – Experimental Breeder Reactor
EPZ – Emergency Planning Zone
FFTF – Fast Flux Test Facility
HTGR – High Temperature Gas Reactor
IHT – Intermediate Heat Transport system
LBE – Licensing Basis Event
LCO – Limiting Condition of Operation
LOCA – Loss of Coolant Accident
LMP – Licensing Modernization Project
LWR – Light Water Reactor
MHTGR/HTGR – Modular High Temperature Gas Reactor
NSRST – Non-Safety-Related with Special Treatment
NST – Non-Safety-Related with No Special Treatment
PDC – Principal Design Criteria
PRISM – Power Reactor Innovative Small Module
P/T – Pressure / Temperature
PWR – Pressurized Water Reactor
RCS – Reactor Coolant System
RN - Radionuclide
SARRDL – Specified Acceptable system Radionuclide Release Design Limit
SFR – Sodium Fast Reactor
SR – Safety Related
SSC – Structures, systems, and components
TREAT – Transient Reactor Test