Challenges and Lessons Learned in Applying NEI 18-04 During Active Design: The eVinci™ Microreactor

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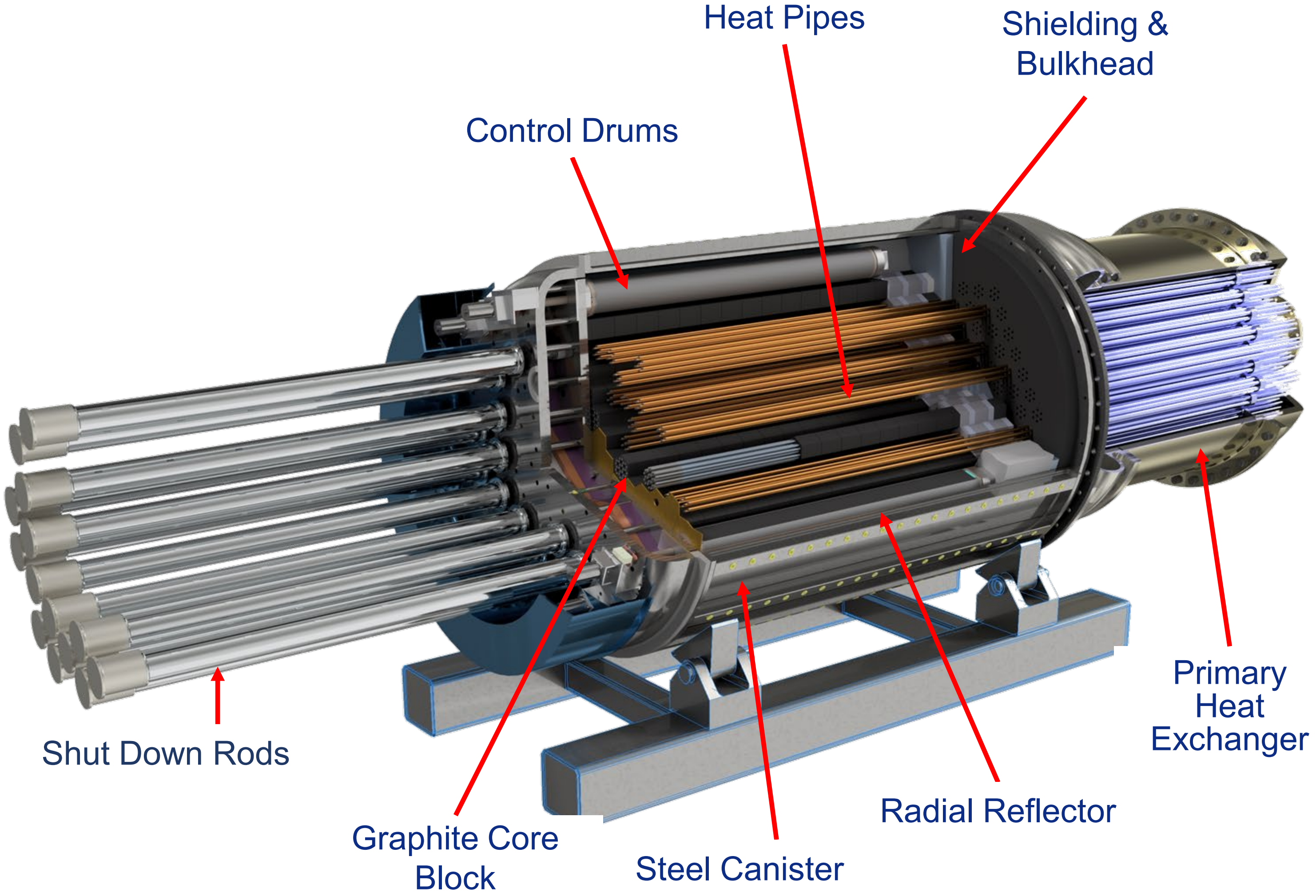
Agenda

- eVinci Microreactor Design Overview
- Nuclear Test Reactor (NTR) Plan Overview and Interface with INL/DOME
- NTR PRA model development to date
- Licensing Approach and Challenges with NEI 18-04
  - (-) Cumulative risk targets not well defined
  - (-) Reliability data not readily available for advanced reactor components
  - (-) Division of responsibility between PRA and thermal hydraulic analysis
  - (+) Importance of interviews with other functional areas (SY, POS, RI, ESQ, SC)
  - (+) Databases for model configuration control

The eVinci Microreactor Design Overview

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

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



eVinci Microreactor Design Overview

Key Design Features for PRA

- Reactivity control provided by banks of control drums with neutron absorbing material
  - Shutdown rod assemblies provide defense-in-depth shutdown capability
- Heat flows from core through heat pipes to primary heat exchanger (PHX) and then through power conversion system (PCS) to environment
  - Passive heat removal system (PHS) and normal residual heat removal system (RNS) provide decay heat removal in accident sequences
- Functional containment provided by TRISO fuel layers, graphite fuel compact, and canister pressure boundary
- No operator interaction required in accident scenarios
  - Operator intervention possible as defense-in-depth function
  - PRA not crediting any human actions
- NTR design changes secondary side cooling and adds DOME as an additional layer of functional containment

NTR Plan Overview and Interface with INL/DOE

1. Support authorization of facility-aligned requirements in DOE-STD-1628-2013
2. Develop integrated safety case using NEI 18-04 Rev 1
3. Meet applicable SRs of ASME/ANS RA-S-1.4-2021 for pre-operational phase

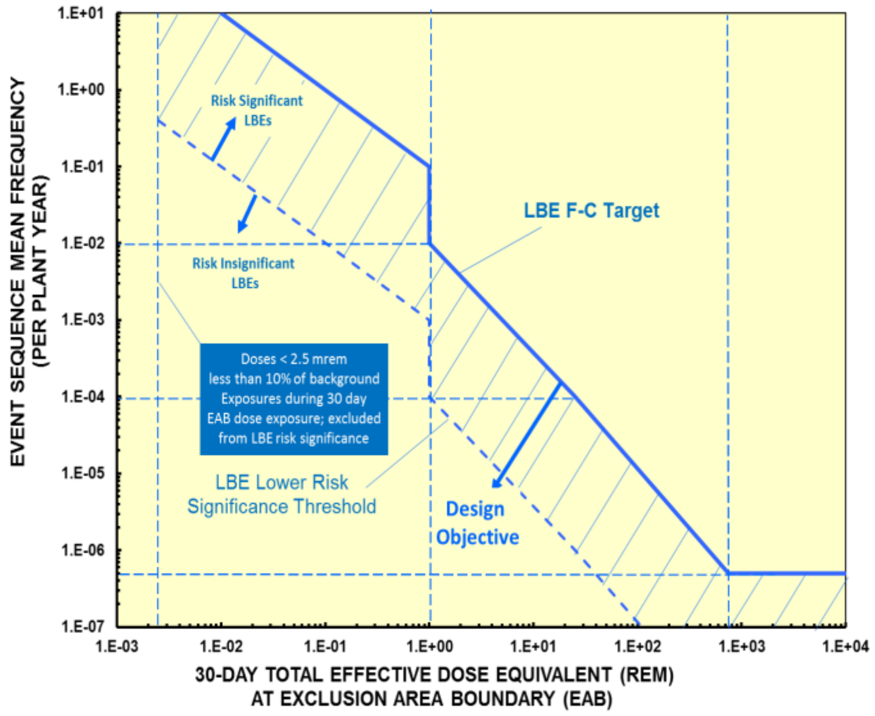
NTR PRA Model Development to Date

- As design continues to develop, many key PRA inputs are also in development:
  - Technical specifications
  - Operating procedures
  - System design documents or specifications
  - Operating experience for determining initiating event frequencies and component reliability data via frequentist approach
- Completed preliminary (tabletop) PRA
- Nearing completion of full-power, internal events quantification
- Starting simplified assessments of other hazards and operating modes

Licensing Approach and Challenges with NEI 18-04 Rev 1

Cumulative Risk Targets (-)

- Guidance on how to evaluate against cumulative risk targets for integrated risk of entire facility would be helpful:
  - Total frequency of exceeding 100 mrem dose from all LBEs ≤ 1/yr
  - Early fatality risk ≤ 5.0E-07/yr
  - Latent cancer risk ≤ 2.0E-06/yr
- Looking to share best practices relating to:
  - Deriving risk importance measures relative to cumulative criteria
  - How and when to best characterize uncertainties
  - Summation method?
  - Visualization of meeting cumulative criteria
  - Event sequence family definition and grouping



Licensing Approach and Challenges with NEI 18-04 Rev 1

Reliability Data for Advanced Reactor Components (-)

- No LWR experience base to draw on for data for some components specific to advanced reactor designs that are modeled in PRA
- Currently evaluating existing data sources and adjustment mechanisms
- When failure data is available, the applicability of the data needs to be assessed:
  - Is applicability data scale invariant? eVinci microreactor components much smaller than LWR
  - Is data applicable when using helium instead of water? A valve leakage rate, for example, may be significantly different when passing a gas through a valve vs a liquid.

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Success criteria definition in FATE (-)

- FATE (Facility Flow, Aerosol, Thermal, and Explosion) is a new code for this application
  - Models heat and mass transfer and radionuclide release
- Challenges understanding how success criteria should be stated
  - Light water reactor (LWR) analog of core damage as top event no longer applicable
    - Assessing consequences from non-core sources, e.g., sodium from heat pipes
  - FATE model considers TRISO failure due to peak temperature as well as time-at-temperature
- First experience with several NLWR technical elements (MS, RC, RI)
  - Mechanistic source term and consequences developed by thermal hydraulic team
  - Communicating and understanding PRA concepts with analysis team and vice versa

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Interviews with other functional areas (+)

- Required by ASME/ANS RA-S-1.4-2021 for systems analysis (SY-A6) and plant operating states definition (POS-A8)
  - Additional requirements in HR and hazard technical elements
- System engineer interviews crucial for understanding system function (as expected) but even more so due to in-progress nature of design
  - Example: understanding signal processing for primary I&C system
- Operations interviews for understanding operating modes
  - Names of operating modes match PWR experience (e.g., hot standby) but not always intuitive with this design – only nuclear heat-up
  - Mode transitions based on sodium phase change temperatures
  - Ops input critical for judging system (in)operability, needed for defining POS characterizations

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Interviews with other functional areas [cont.] (+)

- No explicit requirement for interviews in SC technical element
  - Interface with thermal fluid analyses is critical
  - Especially for meeting, e.g., SC-B3
- Example of unexpected result for NTR
  - Expected event tree path with failure of all top events to be most limiting dose consequence
  - Some cases where normal residual heat removal system (RNS) success results in worse consequences
  - Also helps inform our eVinci microreactor design
- Must understand and document what the thermal analysis code models for event tree success, failure, and bypass branches

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Model Configuration Control Database (+)

- Optimal time to set up database to link model elements
  - Links assumptions to affected system models, type codes, event sequences, etc.
  - Pulls data from other technical areas such as cable mapping database
- PRA model logic added directly from logic model database file when system model is finalized
- Automates fault tree linking process
- Anticipate many design changes
  - Documentation of PRA impact statements
  - Plan implementation of design changes that impact PRA model and link to affected elements
  - Space for documenting resolution or justification for deferral
  - Allows for the iterative process of NEI 18-04 to be implemented as intended

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PRA - Logic

Main

Node Id	Logic Type	Applicable Plants	Source	Children
CCS-ISO-01	EQU	NTR		CCS-TKP-EXL-MV-001
CCS-ISO	OR	NTR		CCS-ISO-01, CCS-ISO-02, CCS-ISO-03, CCS-ISO-06, IGS-ISO, IGS-H2-ISO, CCS-ISO-10
CCS-ISO-02	OR	NTR		CCS-ISO-04, CCS-ISO-05
CCS-ISO-04	OR	NTR		CCS-XVM-ELS-V112, CCS-XVM-ELL-V112
CCS-ISO-05	OR	NTR		CCS-XVM-ELS-V113, CCS-XVM-ELL-V113
CCS-ISO-03	OR	NTR		CCS-XVM-ELS-V111, CCS-XVM-ELL-V111
CCS-ISO-06	OR	NTR		CCS-ISO-09, CCS-ISO-07, CCS-ISO-08

Licensing Approach and Challenges with NEI 18-04 Rev 1

Model configuration control database [cont.] (+)

- Some challenges with FMEAs because of overlap with other functional groups
  - Want system designers to “own” the FMEA documentation but for PRA to be able to add our input (IE contribution, assoc. type code for each line item)
  - Document FMEA review to link to assumptions so that PRA treatment can be modified if design change triggers an FMEA change
    - Ex.: oxidation of DHS components assumed to not significantly affect heat transfer

Conclusions and Westinghouse perspective on future actions

- NEI 18-04 process generally clear but some areas still challenging for first application
- Need for practical guidance or OE sharing
  - Event sequence family grouping, treatment of component reliability data, and treatment of cumulative risk metrics
  - Underscores need for implementation experience prior to issuing RG 1.247
- NEI 18-04 drives interactions with other technical areas which is beneficial

Thank You

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