TerraPower

NATRIUM

Natrium™ PRA and Application of the Licensing Modernization Project

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
- The Licensing Modernization Project (LMP) (NEI 18-04), as endorsed by RG 1.233, will support this application

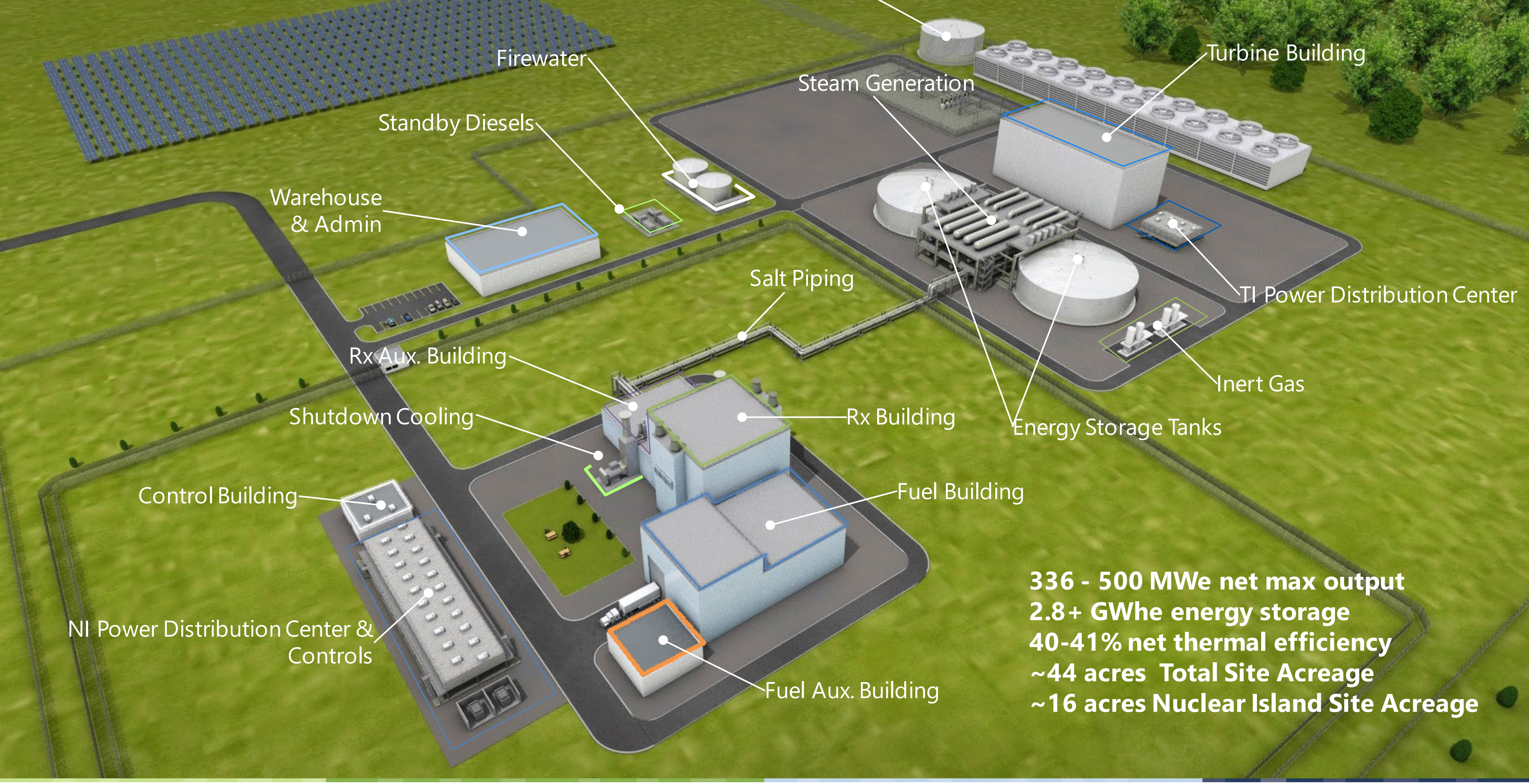
Natrium™ Reactor Licensing Overview

- Each pre-application interaction will build upon risk insights from prior interactions to demonstrate the Natrium reactor's safety case.
- Future Meetings and Presentations for PRA specifically include, but are not limited to:
  – Internal Events At-Power (IEAP) PRA (Internal Events PRA), with peer review. Anticipated in August 2023.
  – Final Design PRA (with peer reviews). Anticipated October 2027.

Advanced Reactor Demonstration Program (ARDP)

- 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

TerraPower NATRIUM

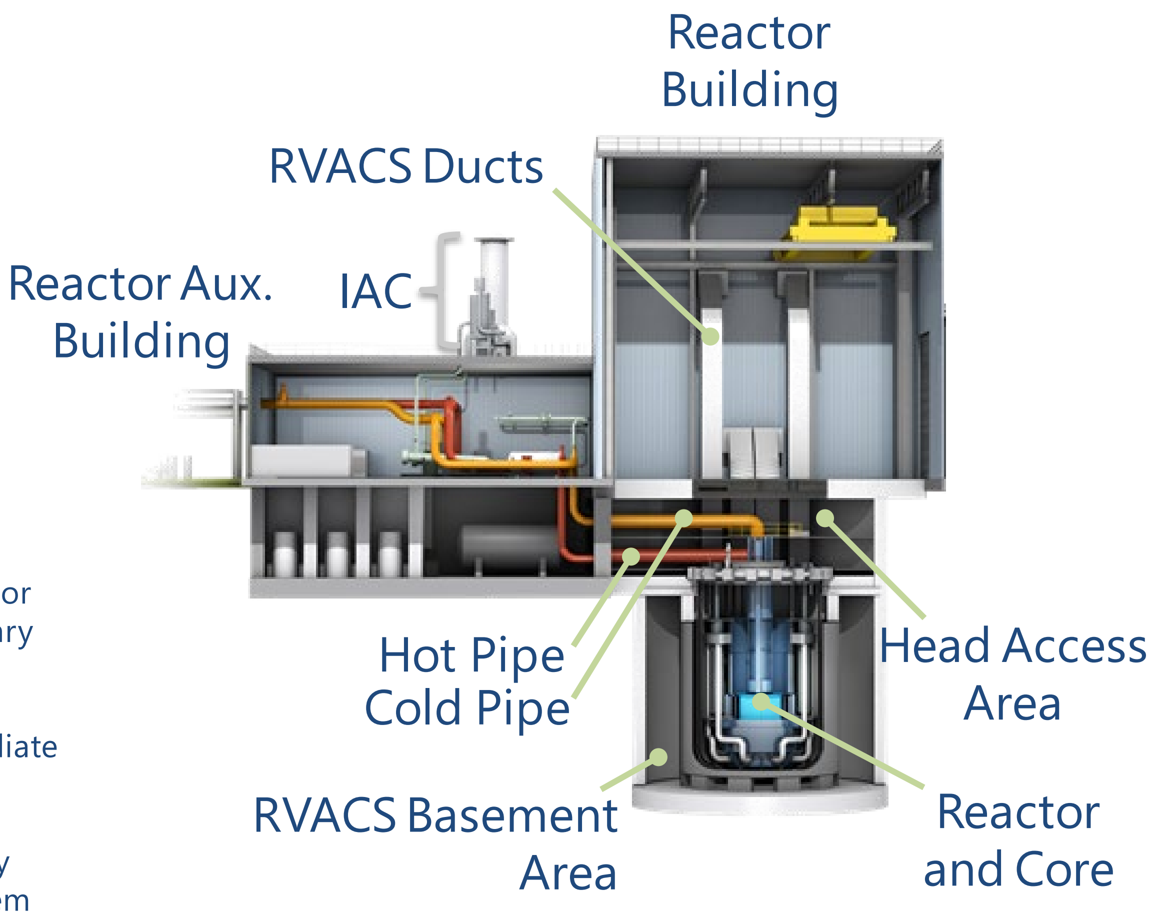


336 - 500 MWe net max output
2.8+ GWhe energy storage
40-41% net thermal efficiency
~44 acres Total Site Acreage
~16 acres Nuclear Island Site Acreage

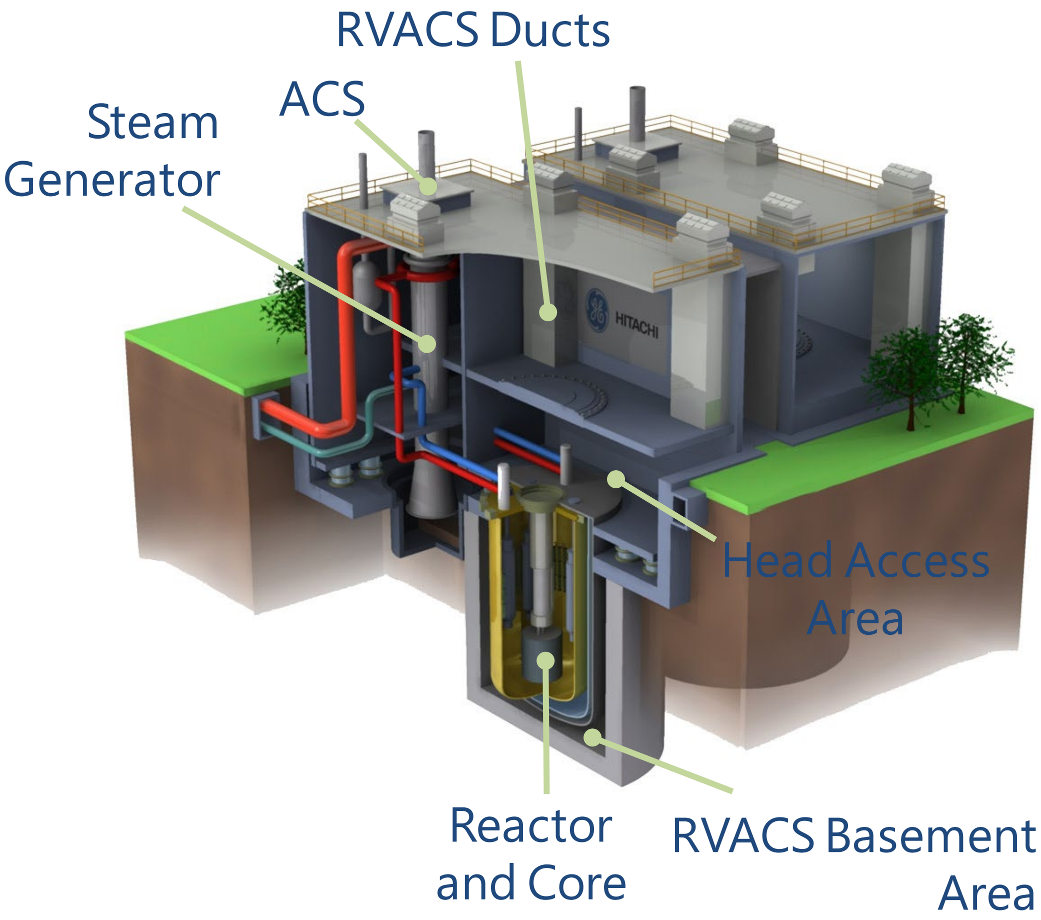
SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

Natrium and PRISM Nuclear Island (NI) Similarities

Natrium NI



PRISM NI



RVACS: Reactor Vessel Auxiliary Cooling

IAC: Intermediate Air Cooling

ACS: Auxiliary Cooling System

TerraPower NATRIUM

Natrium PRA Previous Relevant Experience

- The Natrium PRA will build upon previous GEH experience, such as the PRISM PRA*
- Inherent and Passive safety features from PRISM that resulted in a large reduction of risk over previous light-water reactor (LWR) plant designs are also utilized in the Natrium design:
  - Passive decay heat removal via the Reactor Vessel Auxiliary Cooling System which has no moving mechanical parts and whose operation requires no actuation signals or external power sources
  - Strong inherent negative reactivity feedback for core reactivity control
  - Primary sodium coolant relatively large thermal capacity and low pressure
  - Release following core damage is reduced due to use of metal fuel and absorption of radionuclides into the primary sodium coolant

* See PSAM-13 paper on “PRISM Internal Events PRA Model Development and Results Summary, October 2016, Seoul, South Korea

Natrium PRA Previous Relevant Experience – Cont.

- The Natrium PRA will also build upon previous TerraPower experience, such as the Traveling Wave Reactor (TWR®) PRA*
  - TWR PRA was used a pilot for the Non-LWR Standard including a focused-scope peer review
  - Functional reliability assessment of inherent feedback using SAS4a/SASSYS-1
- Worked with ANL on Simplified Radionuclide Transport code Trial Calculations (ANL-ART-49)

* See PSAM-11 paper on ""Preliminary Results of the TerraPower – 1 Probabilistic Risk Assessment" (TWR) 2012, Helsinki, Finland.

Natrium PRA Background

- The Natrium PRA is being developed starting with the PRISM PRA model
- The PRISM PRA Development was performed under DOE Grant DE-NE0008325000, Development/Modernization of an Advanced Non-LWR Probabilistic Risk Assessment (PRA):
  - https://www.osti.gov/biblio/1352518-development-modernization-advanced-non-light-water-reactor-probabilistic-risk-assessment
- This effort built upon a PRA developed in the early 1990s for GE Hitachi's (GEH's) PRISM Sodium Fast Reactor (SFR) but using modern PRA techniques such as those used for ABWR and ESBWR PRAs

PRISM PRA Background

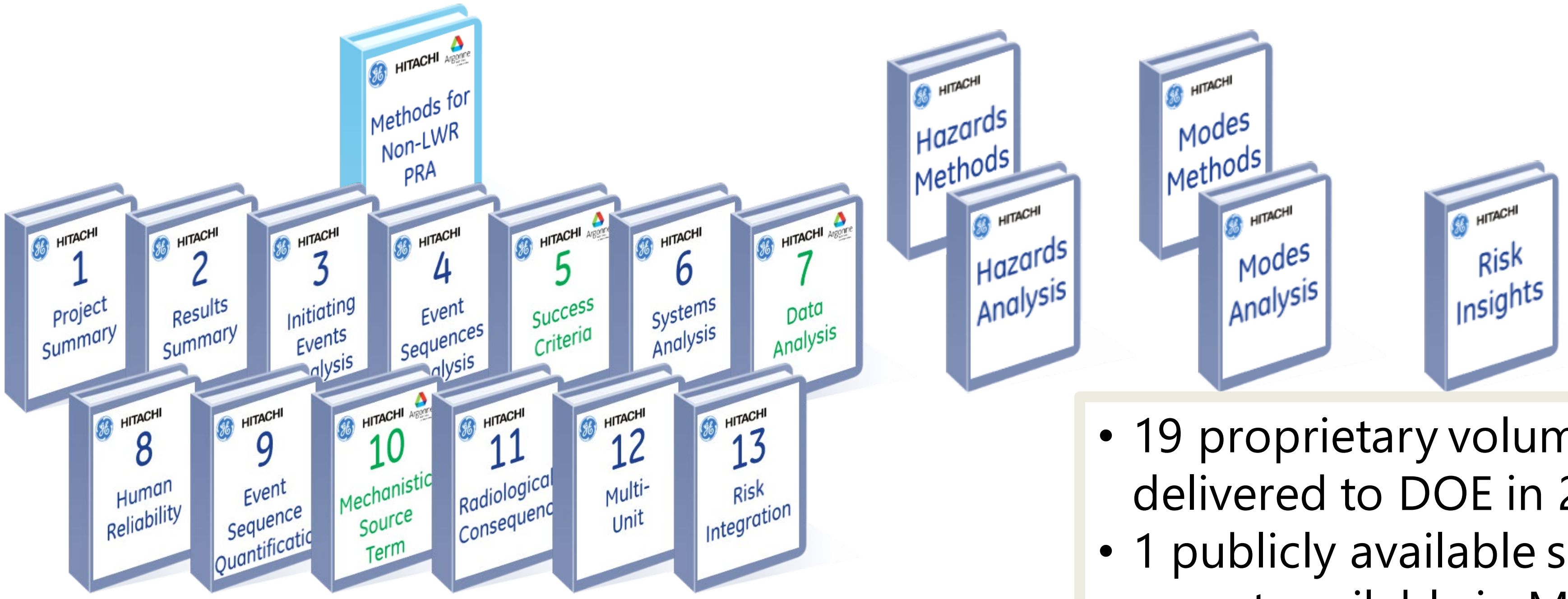
The PRISM PRA was comprised of four main tasks:

1. Internal events development modeling the risk from the reactor for hazards occurring at-power internal to the plant;
2. An all hazards scoping review to analyze the risk at a high level from external hazards such as earthquakes and high winds;
3. An all modes scoping review to understand the risk at a high level from operating modes other than at-power; and
4. Risk insights to integrate the results from each of the three phases above.

PRISM PRA Project Execution

The Internal Events At-Power model was the result of collaboration with Argonne National Laboratory

Internal Events At-Power → All Hazards → All Modes → Risk Insights



- 19 proprietary volumes were delivered to DOE in 2016
- 1 publicly available summary report available in March 2017

PRISM PRA Risk Metrics

- The risk metrics used included the three risk metrics used for the Level 3 PRA, including:
  - The risk of prompt fatalities that might result from reactor accidents to an average individual in the "vicinity" of a nuclear power plant. Similar to LWRs, "vicinity" is defined as the area within 1.61 km (1 mile) of the plant site boundary.
  - The risk of cancer fatalities that might result from nuclear power plant operation to the population in the area "near" a nuclear power plant. Similar to LWRs, "near" is defined as within 16.1 km (10 miles) of the plant.
  - The probability of exceeding a whole-body dose of 0.2 Sv at a distance of 805 m (one-half mile) from the reactor.

TerraPower NATRIUM

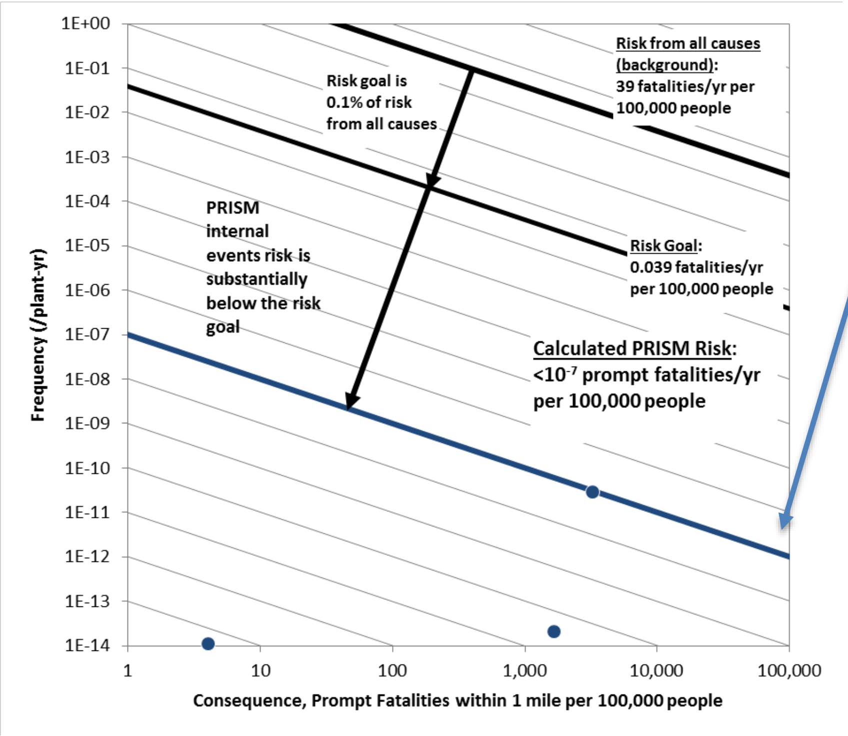
PRISM PRA Results

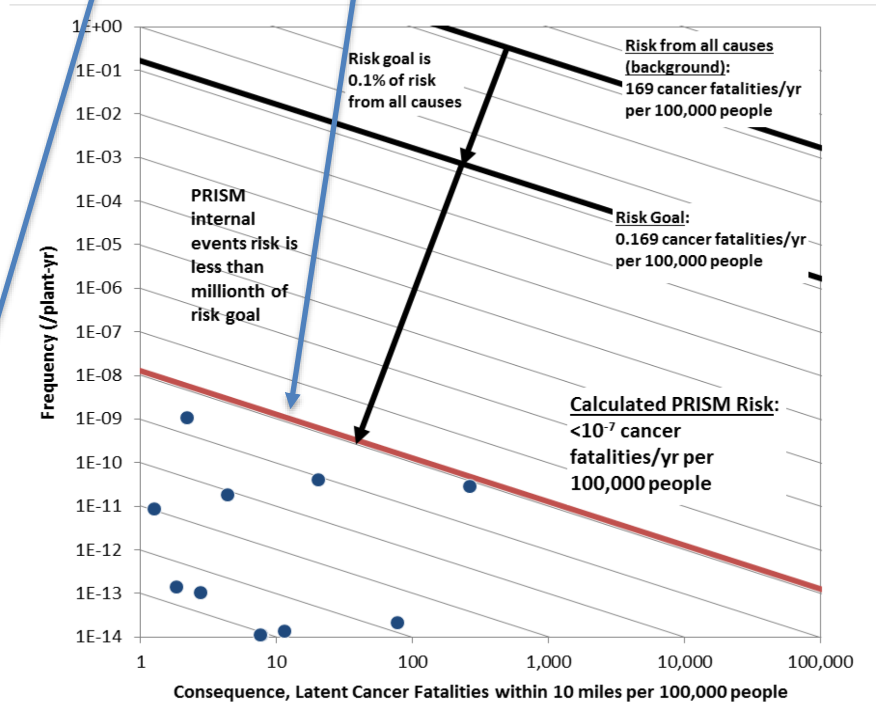
- Quantitative Health Objective (QHO) results, using conservative modeling, resulted in an estimated risk substantially below risk goals

PRISM PRA Results:

Individual Risk QHO

Societal Risk QHO





Development of Modern Standards and Use of PRA

- The PRISM PRA was used for the following:
  - Pilot for the application of the draft ANS/ASME Non-LWR PRA Standard (available through ANS/ASME JCNRM member site)
    - Provided feedback to the Non-LWR working group in support of the development of the final version of the Non-LWR standard
  - Licensing Modernization Project pilot application using the PRISM PRA
    - See Report SC-29980-201 (ML19036A584)
  - Use of the PRISM PRA to support the IAEA Guidance on Multi-Unit PSA (MUPSA)
    - IAEA currently publishing a Safety Report on MUPSA (draft available through ANS/ASME JCNRM member site – MUPRA Working Group)
  - Use of the PRISM PRA in support of the VTR PRA, including application of LMP
- TWR PRA used for internal LMP tabletop and provided feedback to LMP team

Natrium PRA Plan

- Let's discuss:
  - Scope of the Current PRA for the Construction Permit
  - Proposed Application of LMP
  - Proposed Application of Defense-in-Depth (DID)
  - Proposed plan for meeting the ANS/ASME Non-LWR PRA Standard

Scope of the Natrium PRA for Construction Permit

- Key activities*:
  - Use of PRA during the design phase – to inform design decisions, evaluate options, and provide risk insights
  - Develop a PRA Methods Report; updated to meet the current version of the Non-LWR PRA Standard (ASME/ANS RA-S-1.4-2021)
  - Develop and document the PRA, based on the methods report:
    - Internal Events At-Power PRA
    - Scoping Seismic, High Winds, Flood, and Fire PRAs
      - Proposed Seismic PRA is a scoping level PRA (e.g., fragilities at a functional level)
      - Similar scoping level for Fire and Flood, with Fire PRA including both sodium and non-sodium fire sources
    - Low-Power/Shutdown Internal Events PRA

* Note; the detailed PRA reports are not part of the Construction Permit submittal but will be summarized

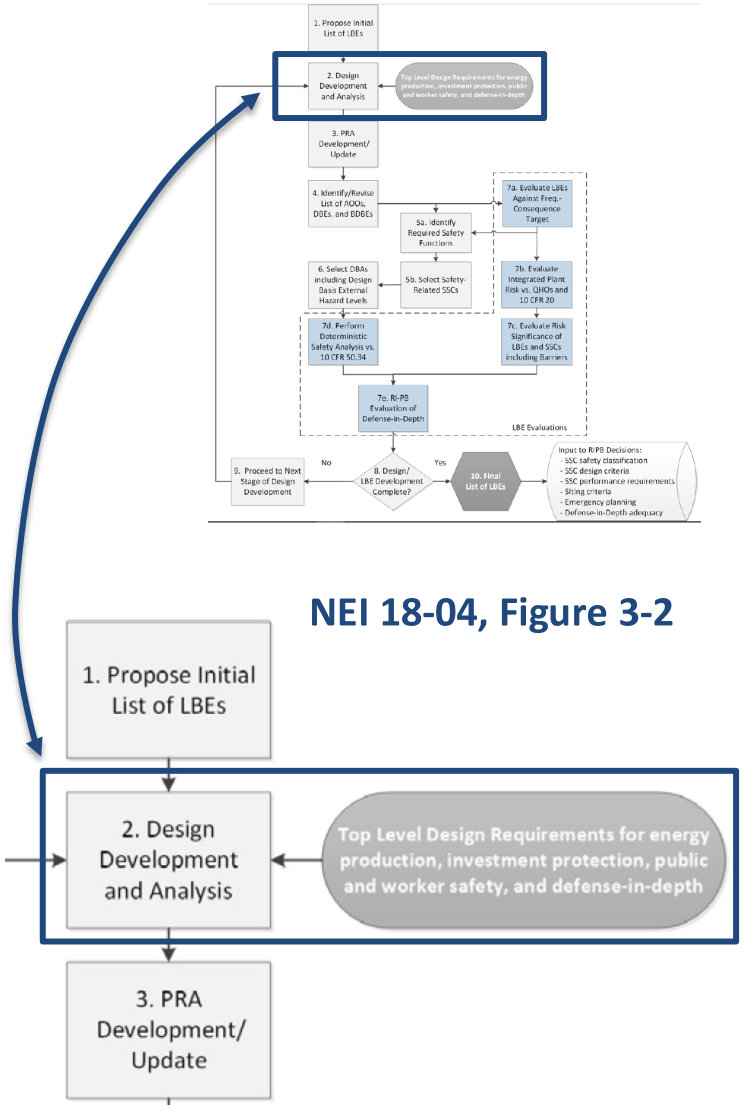
Proposed Application of LMP

- Use of LMP for the Natrium design:
  - LMP Analysis including Licensing-Basis Event (LBE) selection, Plant-Level Structures, Systems, and Components (SSC) classification (input to system level SSC classification) and DID evaluation
    - Interface between design fault list, PRA, and deterministic safety analysis (see next slide)
    - Establishing the Independent Decision-making Panel (IDP) and SSC classification process at the project level
  - LMP process considers any missing scope/limitations and uncertainties both in the DID review and during the IDP process

Early Design Application of DID

- Design team is applying an explicit Defense Line (DL) approach consistent with IAEA SSR-2/1 DL definitions:
  - Identification of mitigating functions for each LBE
  - Assignment of functions to DLs
  - Confirmation of two functional DLs capable of mitigating initiating events
  - Derivation of independence and diversity requirements between functional DLs
- Supports early indications of safety classifications:
  - DL3 functions 'match' SR assignment in LMP
  - DL4 functions align with NSRST assignment in LMP but with some expected differences
  - In exceptional cases, a DL2 function may align with NSRST

- This approach is intended to minimize the number of needed design iterations and decreases opportunity for 'surprises' when the RI-PB Evaluation of DID Adequacy step is performed



NEI 18-04, Figure 3-2

Proposed Application of LMP – Reliability Goals

- Reliability goals include both LMP/Risk and plant availability inputs. Tasks include:
  - Develop a Natrium Reliability, Availability, Maintainability and Inspectability (RAMI) Program Plan/Guidance
  - Develop a Natrium Design for Reliability Guidance/Procedure.
  - Develop a Plant Availability Analysis (e.g., generation risk assessment)
  - Consider the above in support of the LMP special treatment and reliability/capability requirements
  - Incorporate RAMI analysis results including reliability goals into system design documents and plant requirements

Proposed Plan for Meeting the ANS/ASME Non-LWR PRA Standard

- The Natrium PRA will be developed based on the PRA Methods report, which is being developed based on the current version of the Non-LWR PRA Standard (ASME/ANS RA-S-1.4-2021)
- Where design details are not available, this will be noted in the PRA documentation and assumptions will be added
  - However, at the CP stage, it is not possible to completely meet CC-II of the standard. Examples include:
    - Lack of Molten Salt SSC data (PRA standard supporting requirements (SRs) DA-D1, D2)
    - Lack of procedures or operational responses – such as for a loss of the turbine/generator (SRs IE-A15, ES-A5, SC-A9, DA-C9, etc.)
    - FMEAs not fully complete to determine all LBEs or assign causes/frequencies for each LBE (e.g., transient over-power, flow blockage) (SRs IE-A9, A10, etc.)
  - Review of Table 1.4-2 of the Non-LWR standard against the CP stage PRA likely means the PRA would be CC-I for some SRs due to “level of detail” and “realism”

TerraPower NATRIUM

Proposed Plan for Meeting the ANS/ASME Non-LWR PRA Standard

- Plan to perform a peer review for the IEAP PRA only in the Construction Permit (CP) stage, understanding there will be numerous SRs that can not be met at this time
  - Peer Review will be performed after the completion of the PRA, likely after the initial CP submittal
  - Any F&Os that can be corrected at the CP stage will result in the PRA update, and revision of the base LMP evaluation
  - F&Os that are not able to be corrected at the CP stage will be carried forward to the next phase
- The other PRA scopes (e.g., LPSD, Seismic, hazards, etc.) will not be peer reviewed at the CP stage, since the scoping level for the PRAs would not meet the standard at that time

Questions and Discussion?