Perspectives from Using PRA in Designing Advanced Reactors: An Iterative Approach to Uses of Risk Information in NuScale Design

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Presented at the Workshop on

PRA in Design:

Increasing Confidence in Pre-Operational Assessments of Risk

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Presentation Summary

- Background
- Description of NuScale
- Back of Envelop PRA
- More Detailed PRA
- PRA Evolution
- Experiences
- Conclusions

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Background

- USDOE Funded the Original Concept in 2000-2003
- OSU & INL Developed the Conceptual Design
- OSU Continued to Pursue the Design
- OSU Built a 1/3-scale Version
- OSU Granted NuScale Power Exclusive Rights in 2007
- NuScale Signs MOU With Kiewit Constructors
- Initial Pre-Application Reviews Of Design With NRC Started in Jan 2008
- Largely Investor Funded
- Design Certification Application Expected In 2010

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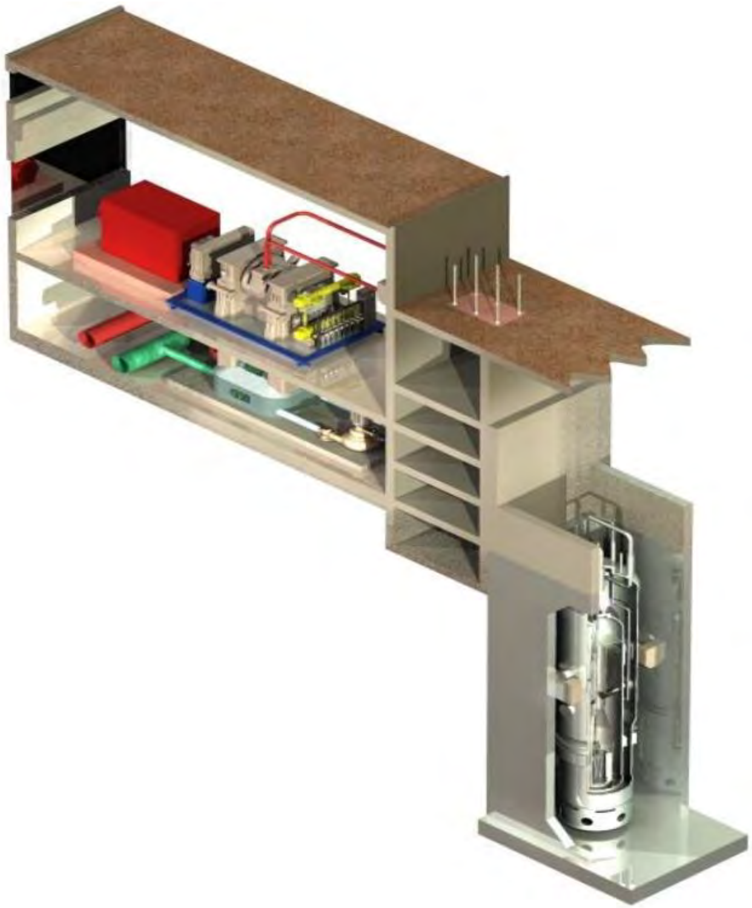
Design Overview



Modules can be numbered up to achieve large generation capacities

Each module has a dedicated Steam Turbine-Generator

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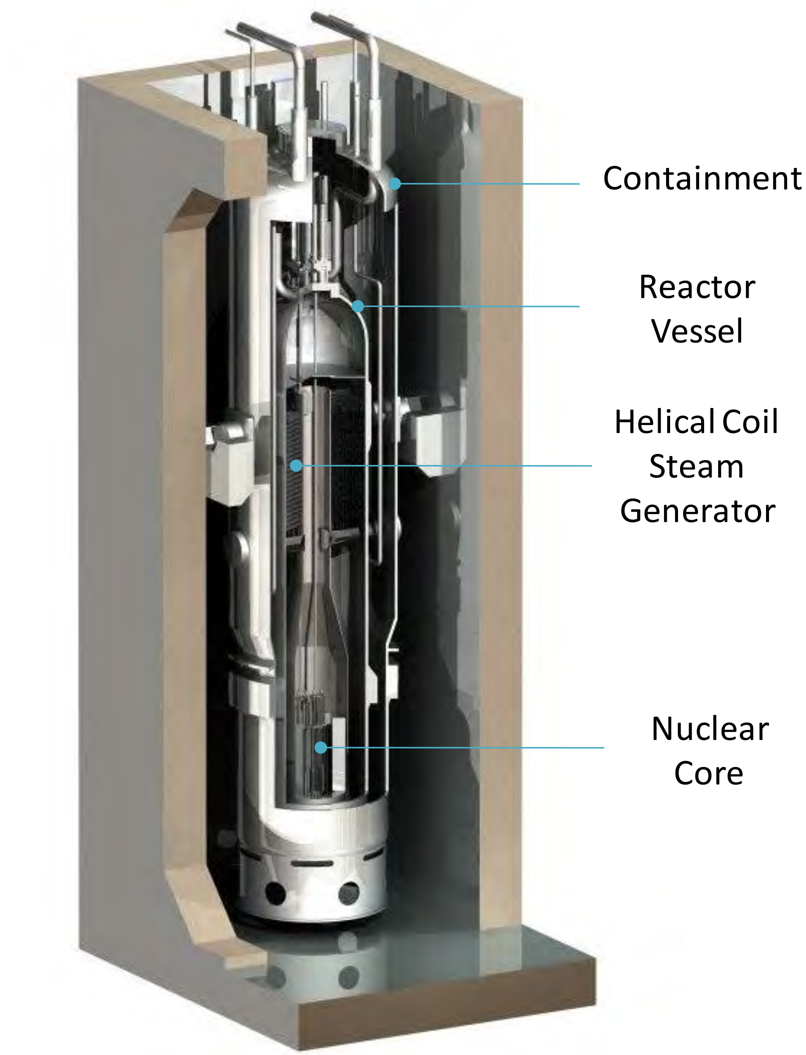
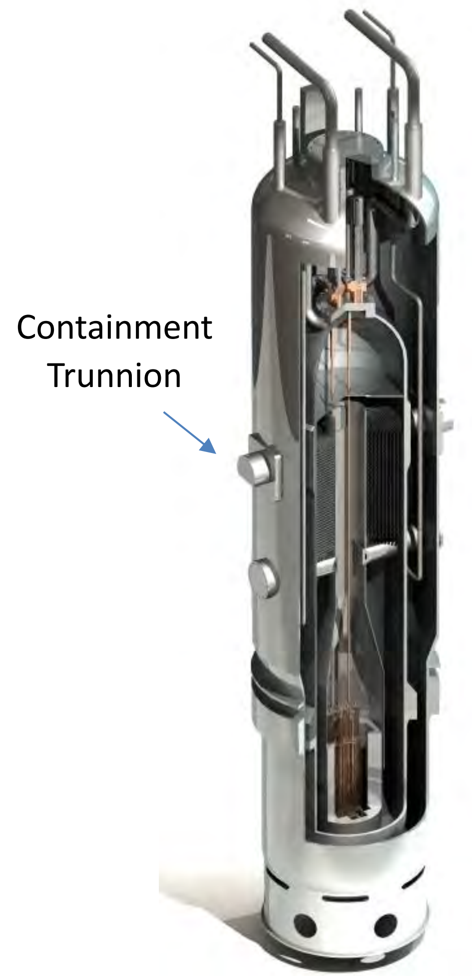
NSSS and Containment





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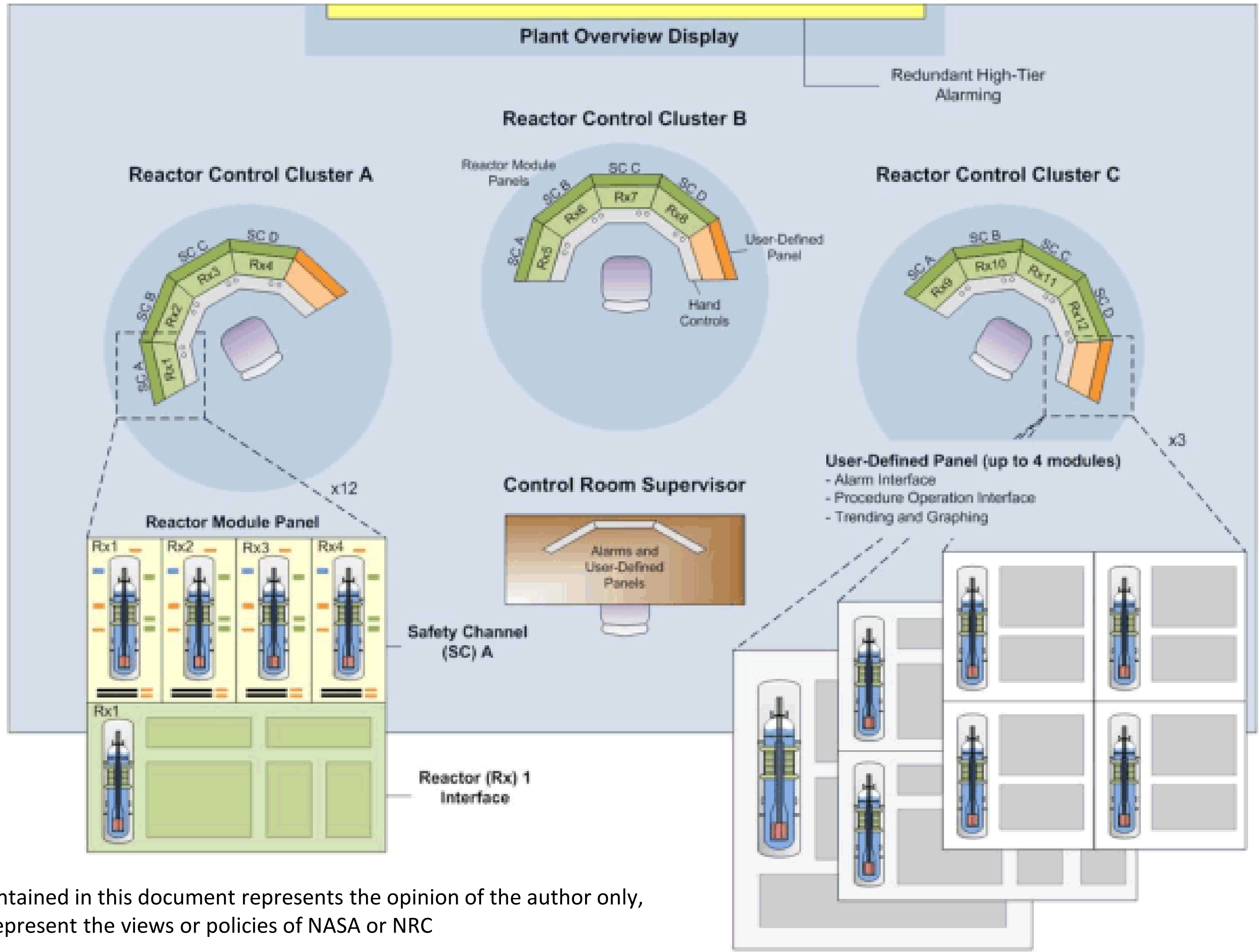
Control Room Layout



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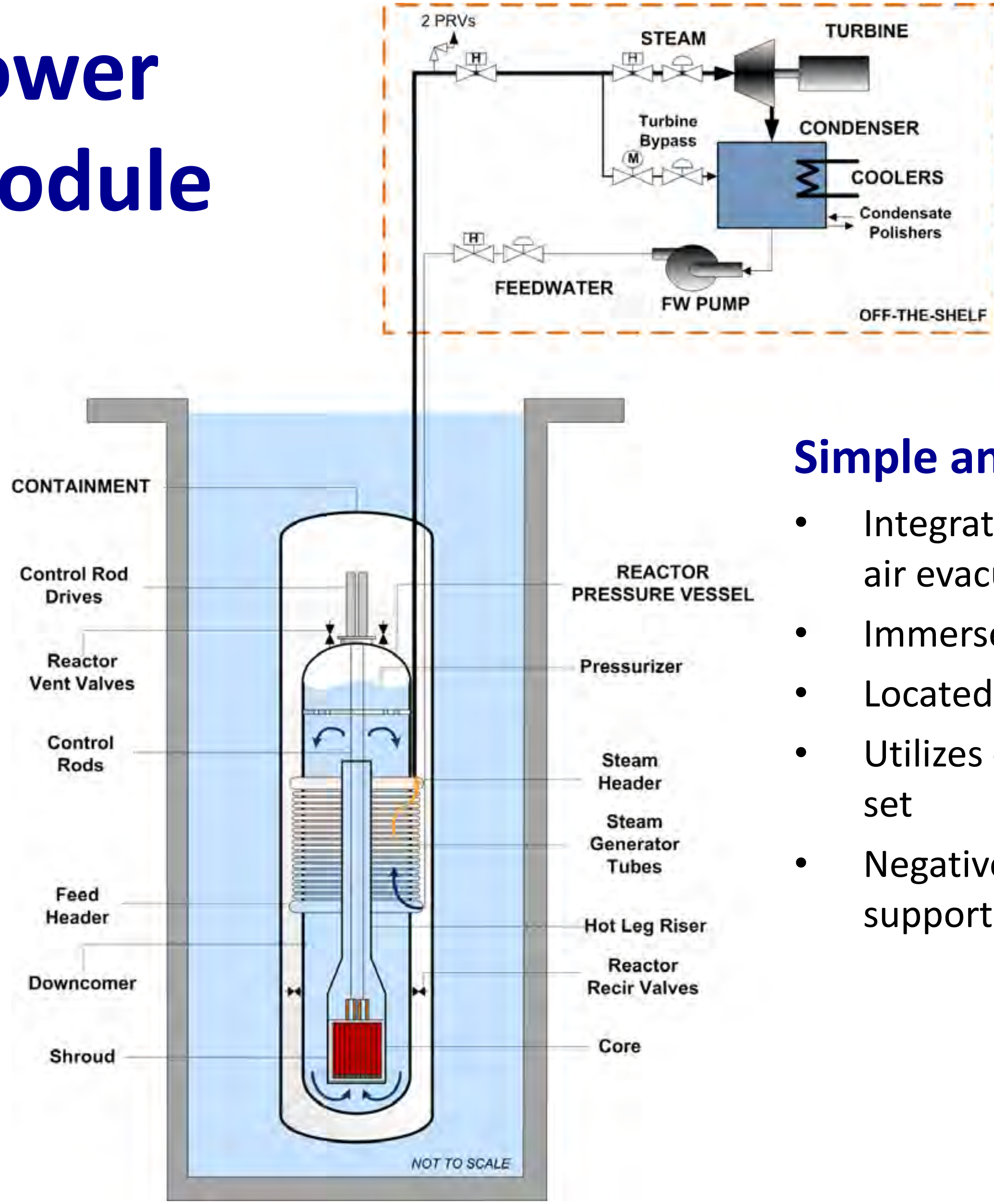
Power Module



Simple and Robust Design

- Integrated Reactor Vessel enclosed in an air evacuated Containment Vessel
- Immersed in a large pool of water
- Located below grade
- Utilizes off-the-shelf turbine-generator set
- Negatively buoyant module with seismic supports on the side (not shown)

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Preliminary Plant Parameters

Overall Plant	
• Nominal Power Rating	540 MW(e)
• Net Station Efficiency	28%
• Number of Power Generation Modules	12
• Nominal Plant Capacity Factor	> 90%
Power Generation Module	
• Number of Reactors	One
• Nominal Power Rating	45 MW(e)
• Steam Generator Number	Two, independent tube bundles
• Steam Generator Type	Vertical helical tube
• Steam Generator Average Tube Length	30.1 m (98.8 ft)
• Steam Generator Heat Transfer Area	1624.2 m^2 (17,482.8 ft^2)
• Steam Cycle	Slightly superheated
• Turbine Type	3600 rpm, single pressure
• Turbine Throttle Conditions	3.1 MPa/537 K (450 psia/507°F)
• Steam Flow	56.1 kg/s (445,000 lb/hr)
• Feedwater Temperature	306K (92°F)
• Feedwater Flow	56.1 kg/s (1,082 gpm)
Reactor Module	
• Thermal Power Rating	160 MWt
• Core Inlet/Exit Temperature	521 K/562 K (478 °F /552 °F)
• Coolant Mass Flow Rate	700 kg/s (15,400 gpm)
• Operating Pressure	10.7 MPa (1550 psig)
Reactor Core	
▪ Fuel	UO_2 (< 4.95% enrichment)
▪ Refueling Intervals	24 months

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Engineered Safety Features

ESF	Primary Function(s)
High Pressure Containment Vessel	Prevents release of fission products to environment and provides core decay heat removal.
Decay Heat Removal System (DHRS)	Provides core decay heat removal and emergency feedwater cooling via natural circulation through two independent helical coil steam generator tube bundles.
Containment Heat Removal System (CHRS)	Provides a means to rapidly reduce containment pressure and temperature during any LOCA. Maintains acceptably low pressure and temperature for extended periods of time.
Emergency Core Cooling System (ECCS) •Reactor Vent Valves (RVVs) •Reactor Recirculation Valves (RRVs) •CHRS	Provides core decay and containment heat removal by steam condensation, natural circulation and sump recirculation. Includes two RVVs on the reactor vessel head to vent steam, two RRVs at the reactor vessel midsection to provide coolant recirculation, and the containment cooling pool to serve as the emergency heat sink.

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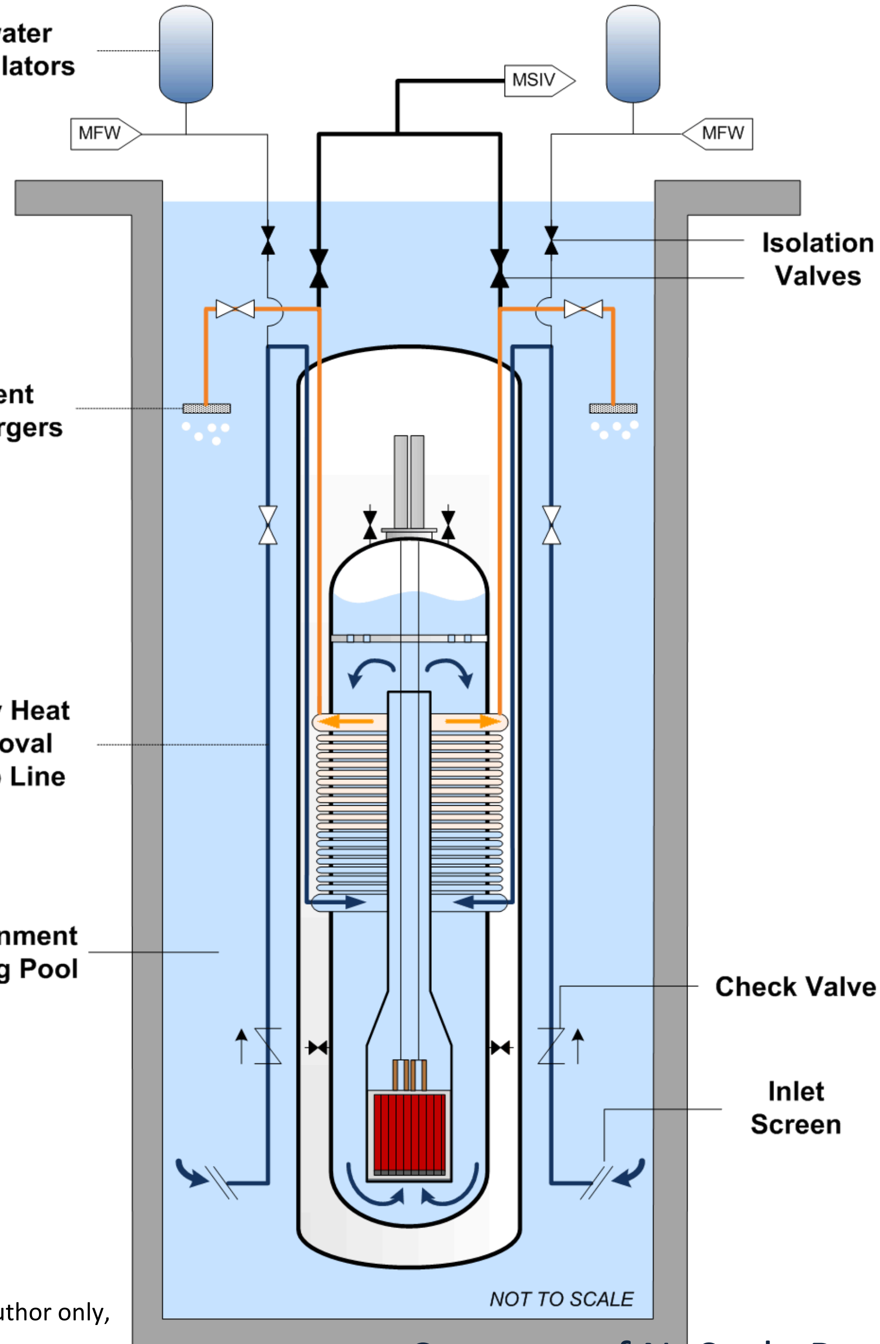
Decay Heat Removal System (DHRS)

- Two independent trains of emergency feedwater to the steam generator tube bundles
- Water is drawn from the containment cooling pool through a sump screen
- Steam is vented through spargers and condensed in the pool
- Feedwater Accumulators provide initial feed flow while DHRS transitions to natural circulation flow
- Pool provides a 3-day cooling supply for decay heat removal



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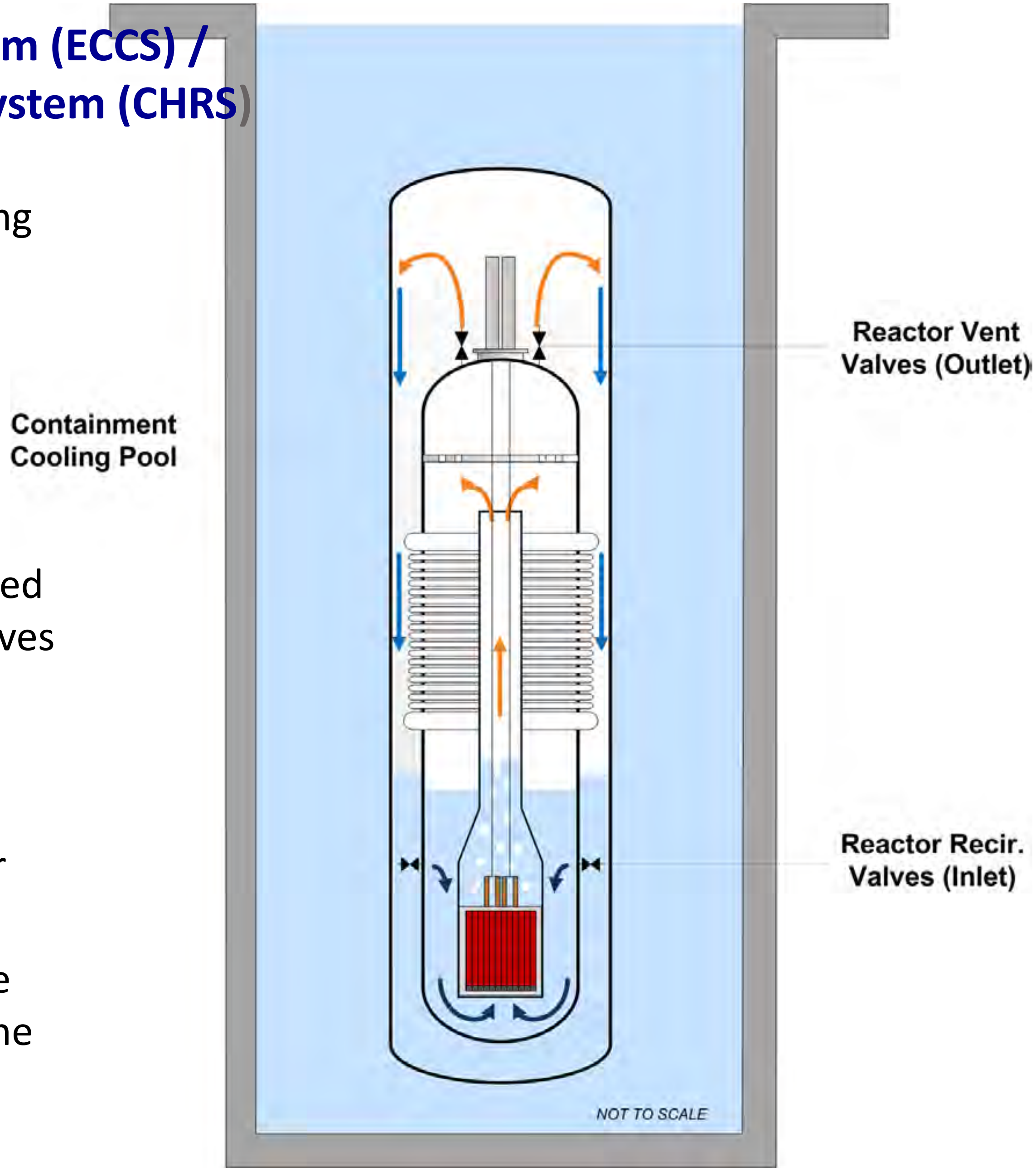
Emergency Core Cooling System (ECCS) / Containment Heat Removal System (CHRS)

- Provides a means of removing core decay heat and limits containment pressure by:
  - Steam Condensation
  - Convective Heat Transfer
  - Heat Conduction
  - Sump Recirculation
- Reactor Vessel steam is vented through the reactor vent valves (flow limiter)
- Steam condenses on containment
- Condensate collects in lower containment region (sump)
- Sump valves open to provide recirculation path through the core



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Background of the PRA

- Started From The Inception: Jan. 08
  - "Back-of-Envelop" Version Finished: March 08
  - Level-1 Version Finished: Aug. 08
  - PRA-Informed Design Evolution Started: Aug. 08
- Commercial Design: January 08
- Design Certification Process: Jan. 08
- Severe Accident Analysis: Aug. 08
- No Time To Rely on Any Fancy Formal Risk-Allocation or Risk-Based Design Technique

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Back of Envelop (BoE) PRA

- High-Level Analysis
- Few Simple Event Trees Important to Conventional Plants
- Simple RBD Models Of Key Systems
- Conventional Plant Data
- Gave The “Birds Eye View” Of Risk Contributors
- Defined The Scope Of Work For Level I & II PRA
- Gave Early Feedback to Designers

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Back of Envelop (BoE) PRA (Cont.)

- Gave a Ball Park Figure Of Risk Values
- Focused Attention To Differences With Conventional Plants
- Identified Design Features That Needed Attention
- Identified Areas Not Significant to Risk
- Provided Valuable Information on Strengths and Vulnerabilities
- Fixes Proposed To Obvious Vulnerabilities

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Design Goals

- Designed to Meet or Exceed NRC and Customer Requirements for Preventing and Mitigating Beyond Design Bases Accidents
- Core Damage Frequency (CDF) < $1\text{x}10^{-5}$/Ry
- Large Release Frequency (LRF) < $1\text{x}10^{-6}$/Ry
- Major Contributors to Risk Identified and Addressed Early in Design Process
- Results of PRA to Inform Plant Design, Construction, Inspection, Operation, And Maintenance

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PRA Scope

- Phase I SA Evaluation, "Storyboard" Approach
- Single Module Level-I PRA
- Multi-Module Level-I PRA
- Low Power & Shutdown
- Internal Fire Risk
- Internal Flood
- External Flood
- External Wind
- Limited-Scope Seismic
- Single Module Level-2 PRA
- Phase II SA Evaluation
- Multi-Module Level-2 PRA
- Multi-Module Level-3 PRA

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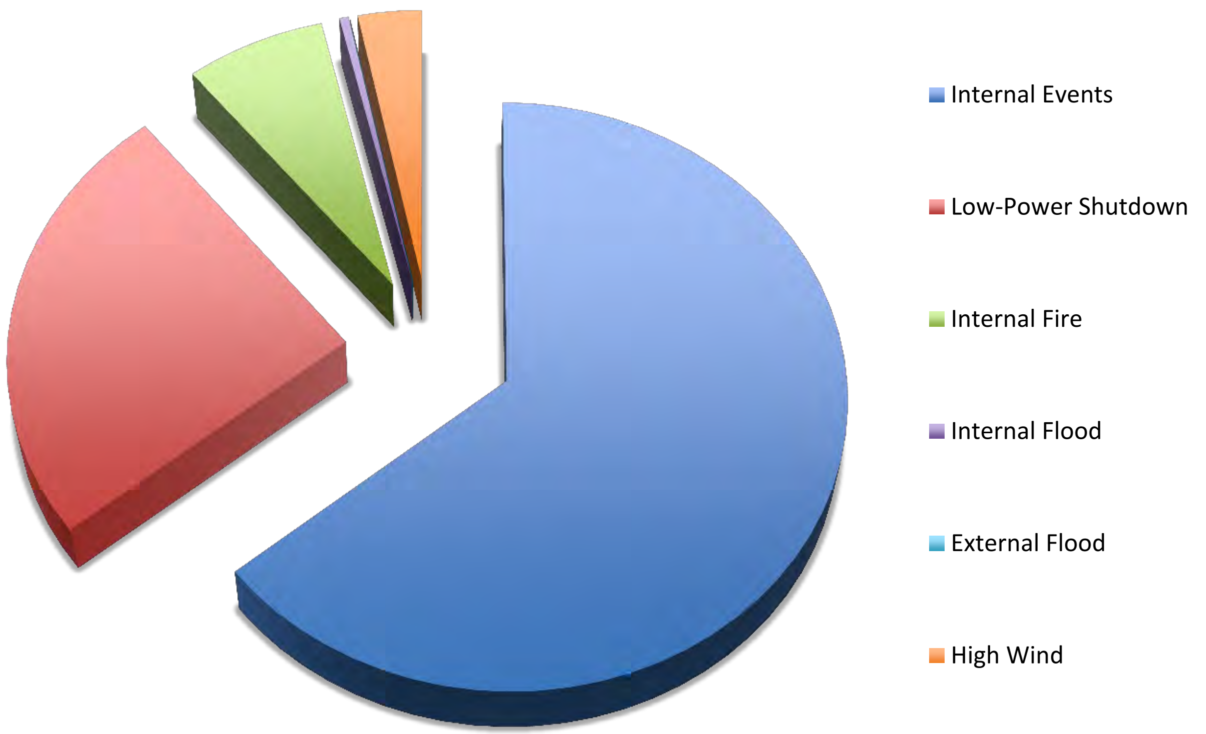
Preliminary Single Module Results



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Areas of Current Focus

- Improve Assessment of SGTR
- Improve MSIV Operation
- Better Characterization of AFW Valves
- Further Decoupling of Modules
- Addition of More Diverse Features for Reactor Venting (SRVs)

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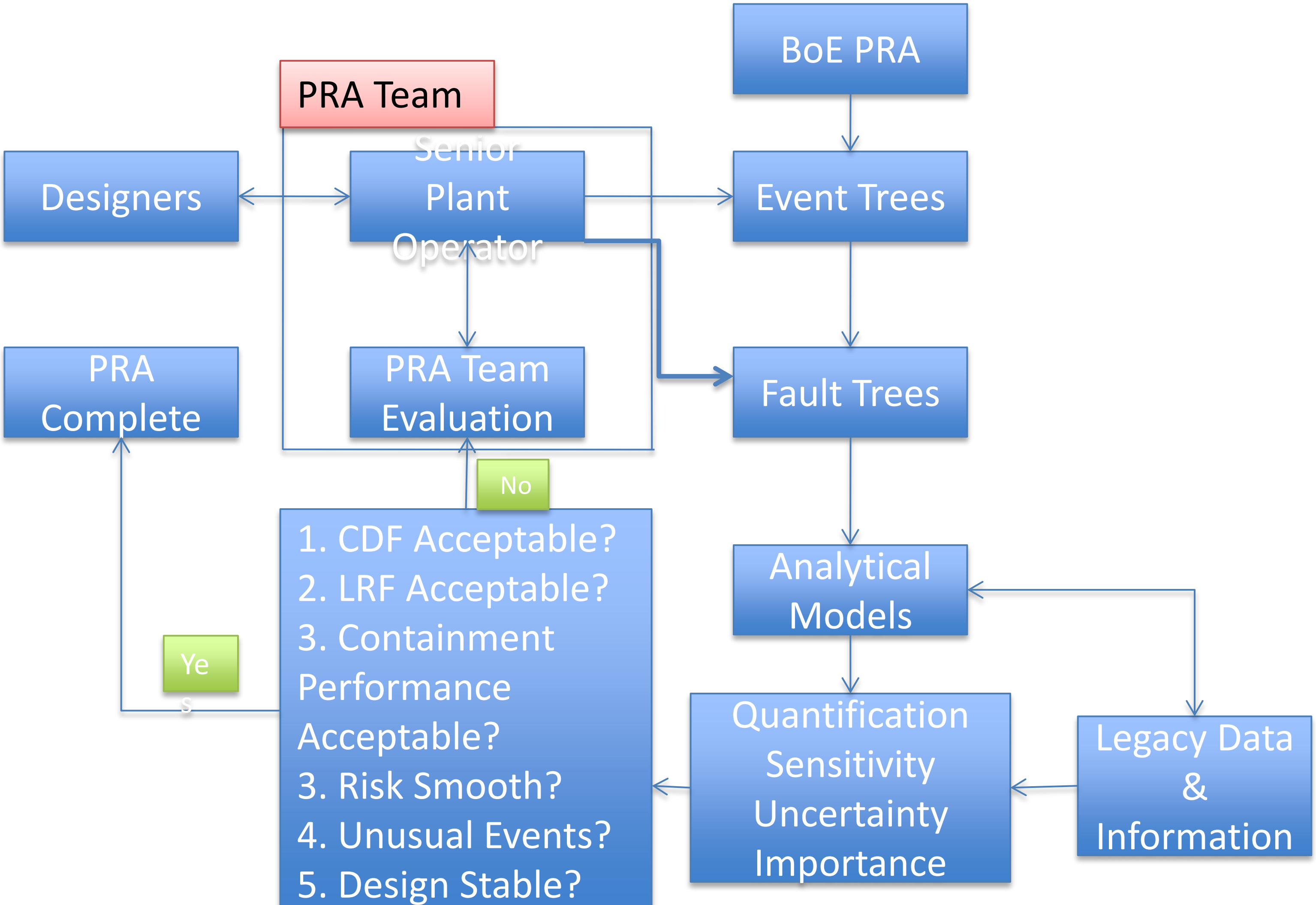
PRA Evolution and Informing NuScale Design



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Lesson Learned

- Informal Exchanges Provide Valuable Insights and Information
- Documentation and Documentation Control Essential
- PRA Should be Developed Hierarchically (Top-Down) with Flexibility for Change in Mind
- PRA Should be Designed so that Changes Should be Accommodated Without Disturbing the PRA
- Systematically Keep Track of all Assumptions and Changes
- Are Conservative Assumptions Masking Real Results?
- No Further Analysis for Systems/Events/Scenarios with Low Risk Contribution
- Place the Resources for re-Design on Leading Contributors so as to "smoothen" Scenarios
- Focus Design Changes on High Risk Impact Low Cost Fixes
- Involvement of an Experienced Designer and/or Operator is Critical

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Conclusions

When Applying PRA to Inform/Support Design:

- Commitment of the Management and Designers including belief in PRA is the most important factor
- Strong and Knowledgeable PRA team is Critical
- Communication is Vital

"You have your way. I have my way. As for the right way, the correct way, and the only way, it does not exist" --ANONYMOUS

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