Innovative Water-Cooled Reactor Concepts - SMR

Dr. José N. Reyes, Jr.

Chief Technical Officer
NuScale Power Inc.

Schuette Endowed Chair Professor
Department of Nuclear Engineering
& Radiation Health Physics
Oregon State University

Conference on Opportunities and Challenges for
Water-Cooled Reactors in the 21st Century
October 27-30, 2009
Vienna, Austria

Outline

- International Interest in SMRs
- Description of NuScale
  - **Technology**
  - **Safety**
- Opportunities for International Collaboration and Training

International Interest in SMRs

- Numerous programs worldwide to develop Small (< 300 MWe) and Medium (300-700 MWe) water-cooled reactors:
  - **Ingersoll, Progress in Nuclear Energy 51 (2009) 589-603**
  - **Small and Medium Power Reactors, Project Initiation Study, Phase 1, 1985, IAEA-TECDOC-347**
  - **Status of Innovative Small and Medium Sized Reactor Designs: Reactors with Conventional Refueling Schemes, 2006, IAEA-TECDOC-1485**
  - **Status of Small Reactor Designs without Onsite Refueling, 2007, IAEA-TECDOC-1536**
- Recent Changes at NRC with regards to SMRs

Examples of Water-Cooled SMR Designs

Integral PWRs		
Design	**Company**	**Power MW(e)**
CAREM	CNEA, Argentina	300
SCOR	CEA, France	630
SMART	KAERI, Republic of Korea	90 MWe and 40,000 tons fresh water/day
IRIS	Westinghouse/Toshiba, USA	335
IMR	Mitsubishi Heavy Industries, Japan	350
NuScale	NuScale Power Inc., USA	45 – 540
mPower	Babcock & Wilcox, USA	125
Loop Type Reactors		
KLT-40S	OKBM, Russian Federation	40
MARS	Univ. of Rome, Italy	150
AHWR	BARC, India	300
VBER-300	OKBM, Russian Federation	295

Water-Cooled SMRs Designed to Respond to the Challenges in the 21st Century

- Potential for Design Innovations that:
  - **Simplify Construction**
  - **Provide Greater Safety Margin**
  - **Improve Reliability**
  - **Increase Cost Certainty**
  - **Offer Competitive Costs at Smaller Power Increments**
  - **Multi-Applications (Desalination, District Heating, Industrial Steam)**
- Relying on existing water technology to obtain:
  - **Greater Regulatory Certainty**
  - **Increased Speed to Market**

NuScale – *Modular Scalable Nuclear Power*

- NuScale is commercializing a 45 MWe natural circulation PWR module that can be scaled to meet customer requirements of virtually any size.
- Base Design is a 12-Module, 540 MWe plant.
- NuScale technology developed and tested by Oregon State University. Based on OSU, INL and Nexant (Bechtel) DOE NERI program for MASLWR
- Company formed in 2007 with tech-transfer agreement from OSU and **privately funded**.
- **Designed to meet NuScale Customer Advisory Board Utility Requirements for near-term deployment in the USA.**
- Seeking USNRC Design Certification

NuScale Project Organization

Nuclear Vendor

– Design & Engineering (NSSS)
– Licensing (Certification)
– Support services

Owner (typical utility)

– Site selection
– Licensing (ESP/COL)
– Operations

Suppliers

– Fabricate Modules
– Steam Generator
– Forgings
– CRDM's

A/E Constructor

– Design & Engineering (BOP)
– Project Management
– Site Preparation & Construction

Kiewit

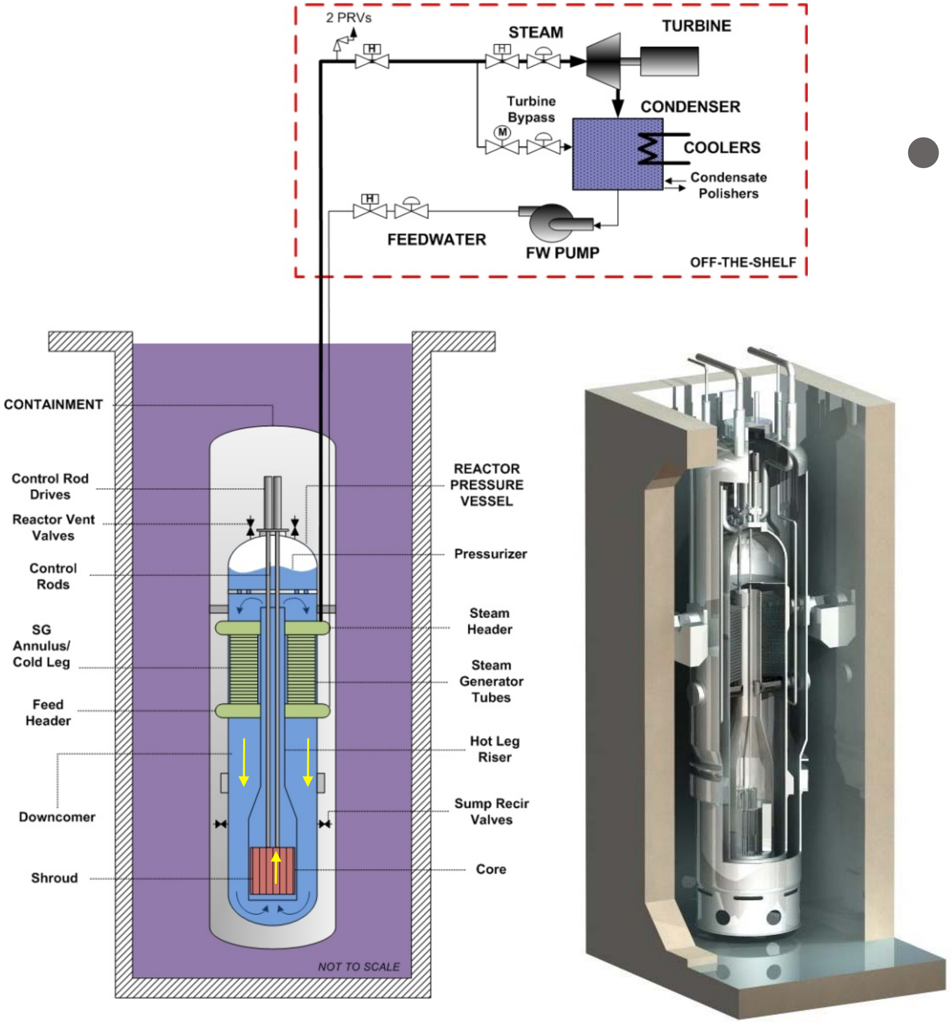
NuScale Power

Strategic Partner - Kiewit Construction: NuScale / Kiewit MOU signed April 2008

- Employee-owned company; $6 billion annual revenue with 120 year history and 16,600 Employees
- FORTUNE's most admired company in the engineering and construction industry in 2007
- Major power plant constructor
- Major commitment to new nuclear projects based on past nuclear construction experience

Kiewit Corporate Headquarters
Omaha, NE

Prefabricated, simple, safe …



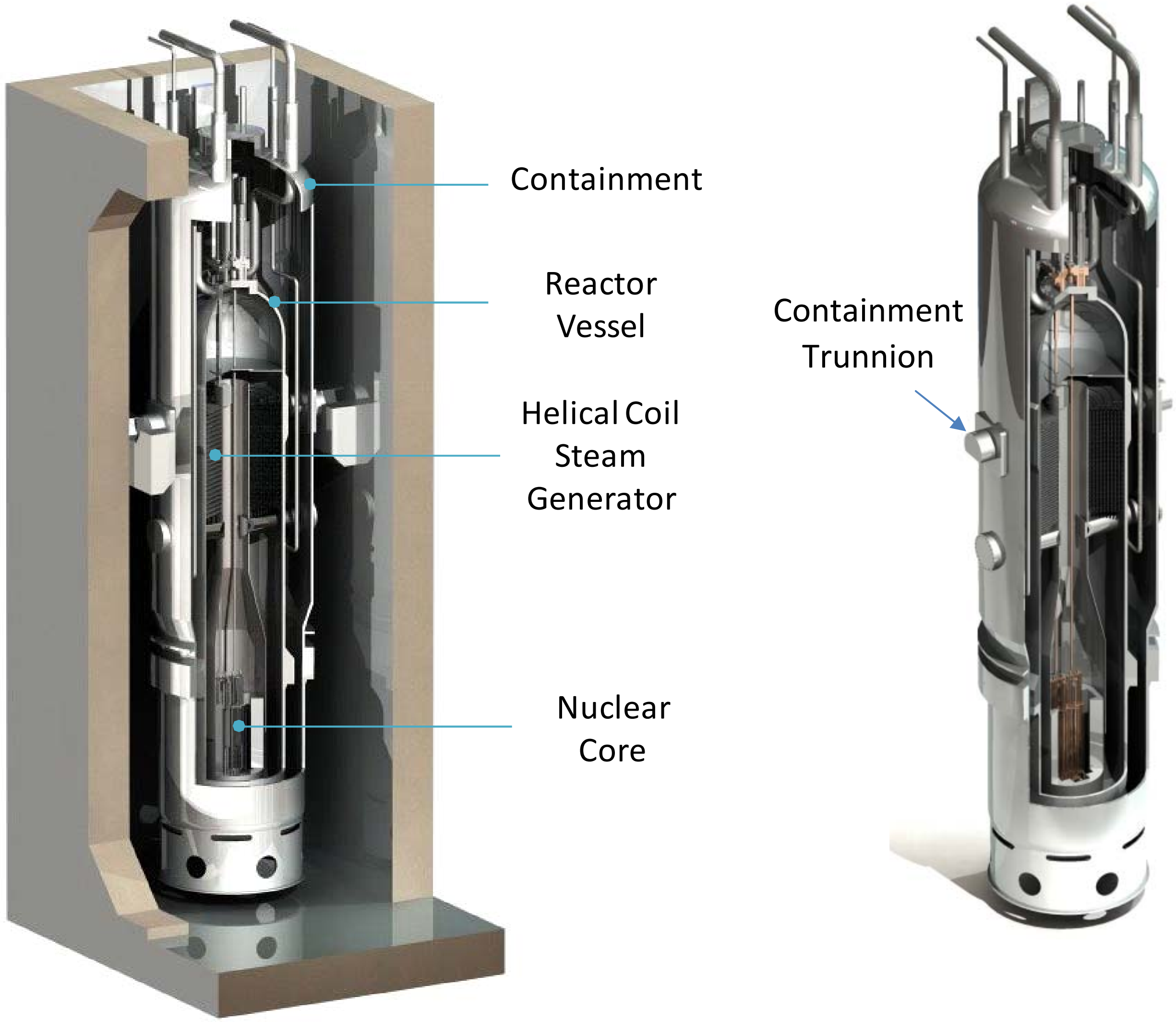
- Construction Simplicity:
  - Entire NSSS is 60’ x 15’. *Prefabricated and shipped by rail, truck or barge*

Natural Circulation cooling:

- *Enhances safety* – eliminates large break LOCA; strengthens passive safety
- *Improves economics* -- eliminates pumps, pipes, auxiliary equipment

Below grade configuration enhances security

NSSS and Containment

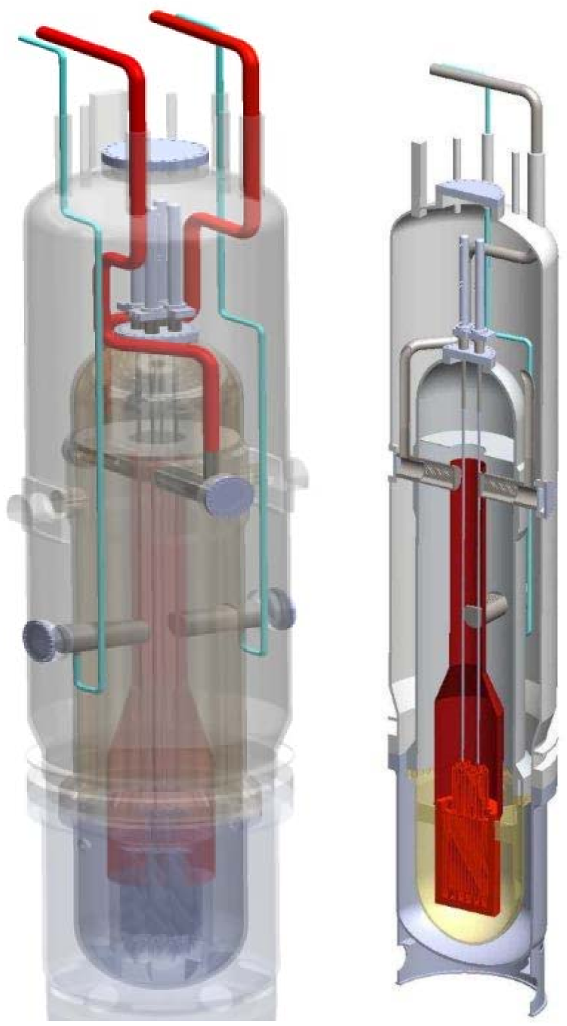


Engineered Safety Features

- High Pressure Containment Vessel
- Passive Safety Systems
  - Decay Heat Removal System (DHRS)
  - Containment Heat Removal System (CHRS)
- Severe Accident Mitigation and Prevention Design Features

High Pressure Containment

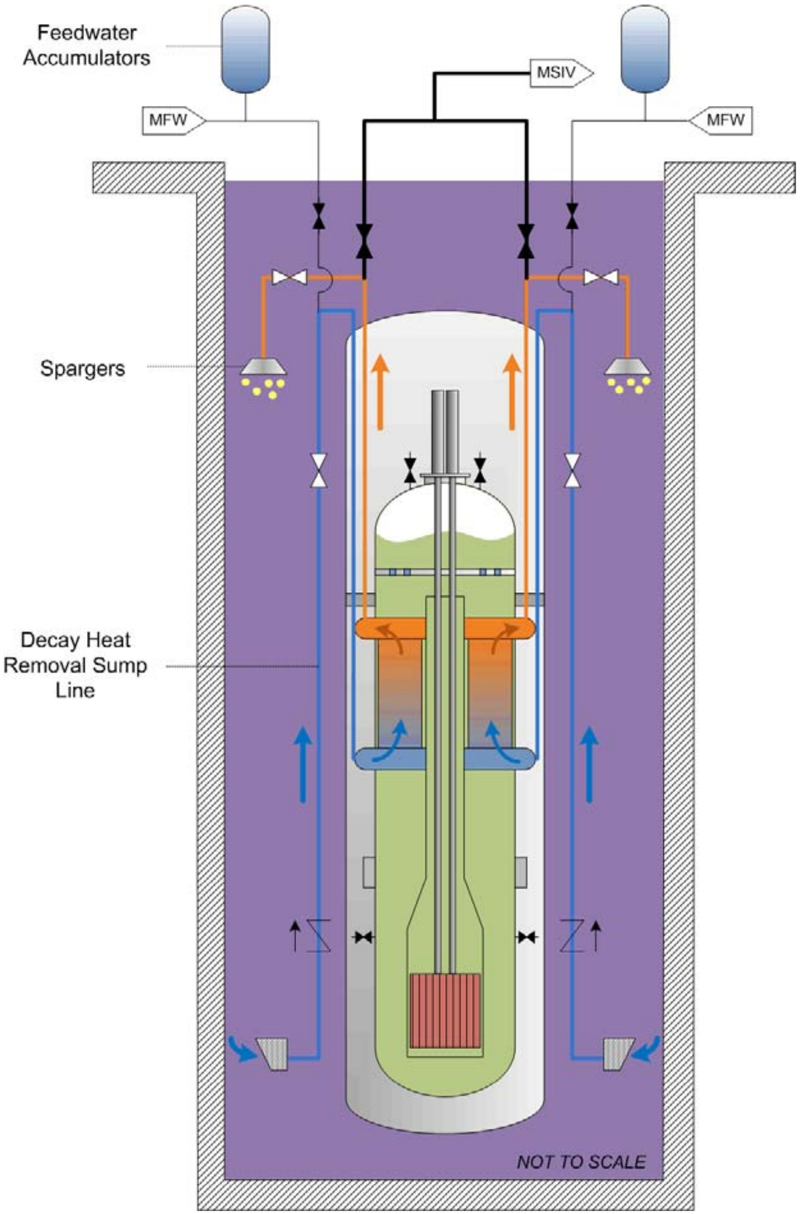
Enhanced Safety



- **Pressure Capability -** Equilibrium pressure between reactor and containment following any LOCA is always below containment design pressure.
- **Insulating Vacuum**
  - Significantly reduces convection heat transfer during normal operation.
  - No insulation on reactor vessel. ELIMINATES SUMP SCREEN BLOCKAGE ISSUE (GSI-191).
  - Improves steam condensation rates during a LOCA by eliminating air.
  - Prevents combustible hydrogen mixture in the unlikely event of a severe accident (i.e., little or no oxygen).
  - Eliminates corrosion and humidity problems inside containment.

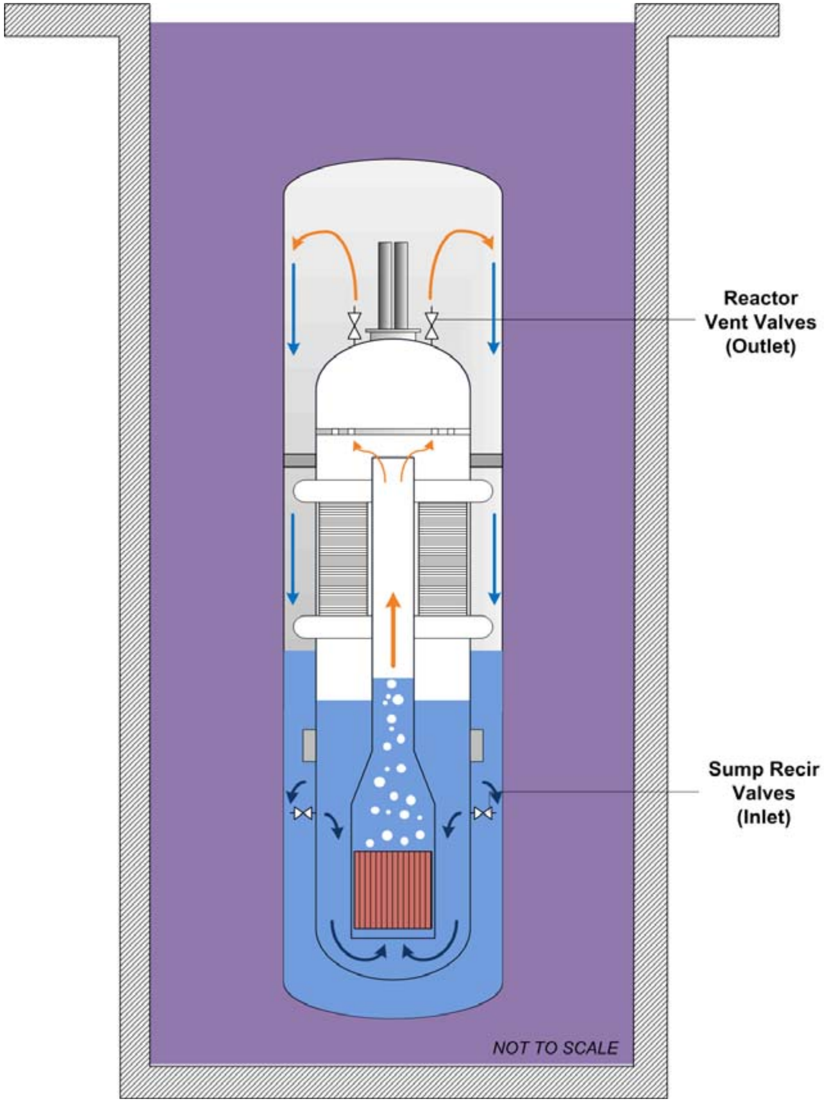
Decay Heat Removal Using Steam Generators (DHRS)

- 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.



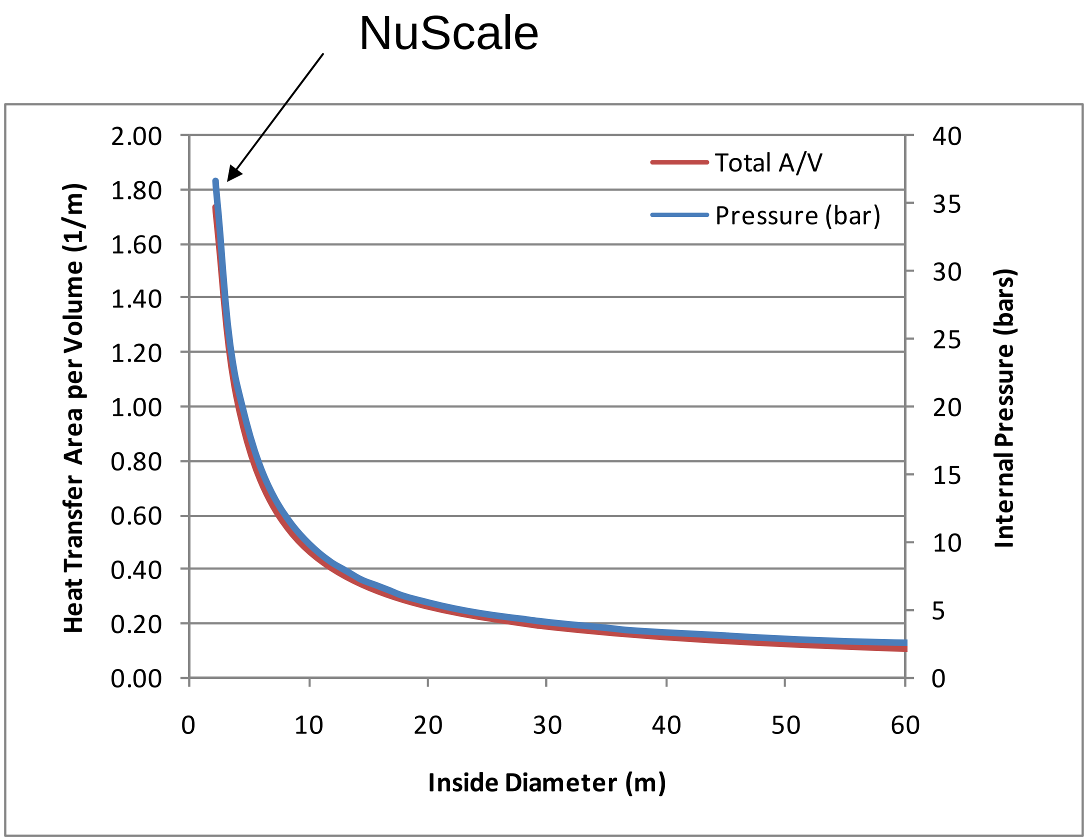
Decay Heat Removal Using Containment (CHRS)

- 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.



Compact Passively Cooled Containment

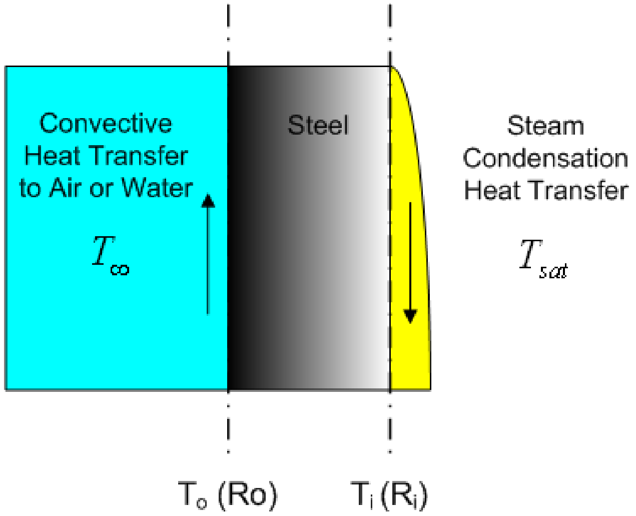
- Heat transfer surface area to volume increases with decreasing containment diameter.
- Maximum Internal Pressure capability increases with decreasing containment diameter.

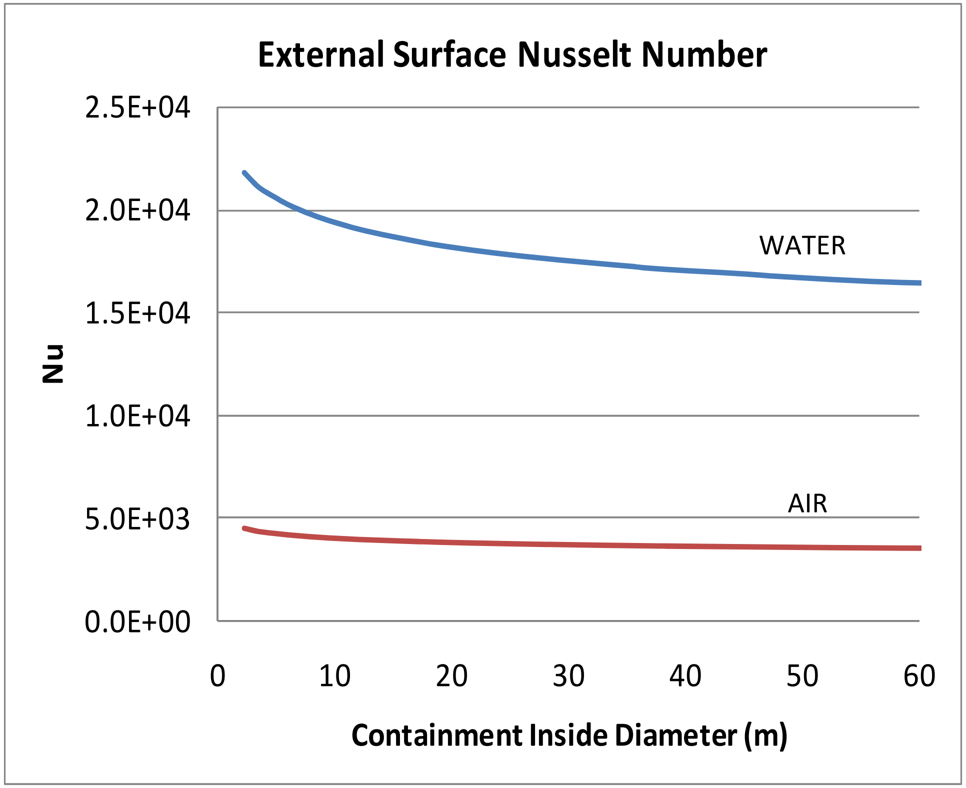


- **Steel cylindrical containment with 2:1 elliptical heads and a fixed wall thickness (7.6 cm) and cylinder length (15m).**

Compact Passively Cooled Containment

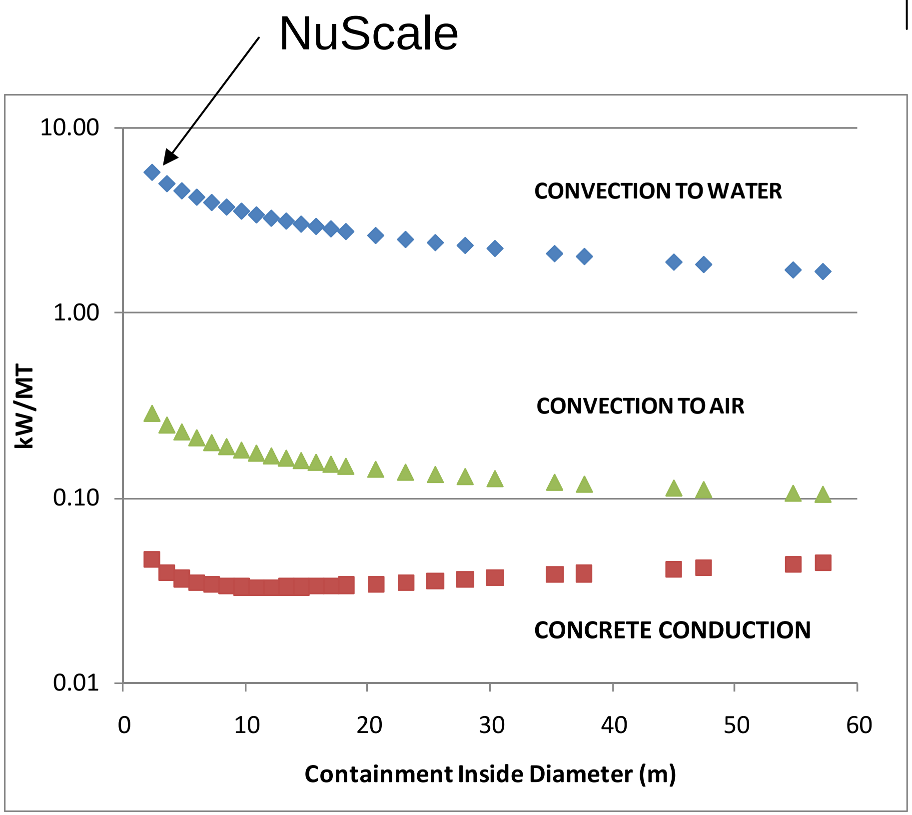
- **For a fixed wall thickness and containment length:**
  - **Heat transfer coefficient increases with decreasing containment diameter.**





Compact Passively Cooled Containment

- Heat removal capability per containment metal mass increases with decreasing containment diameter.
- The NuScale containment offers the highest heat removal rate per metric ton of containment vessel.
- Conservative estimate of condensation heat transfer using Uchida correlation.

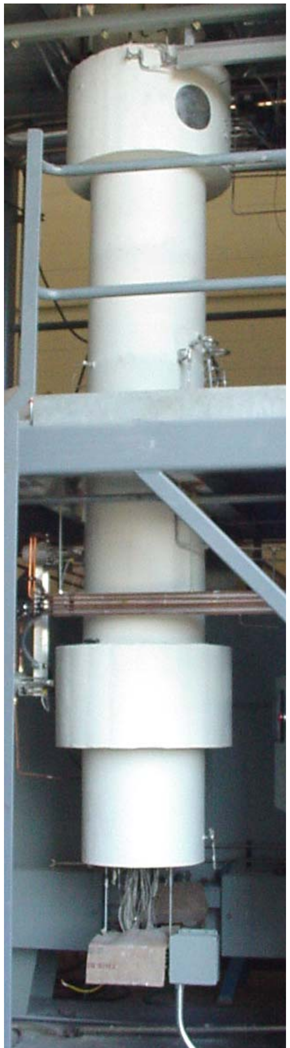


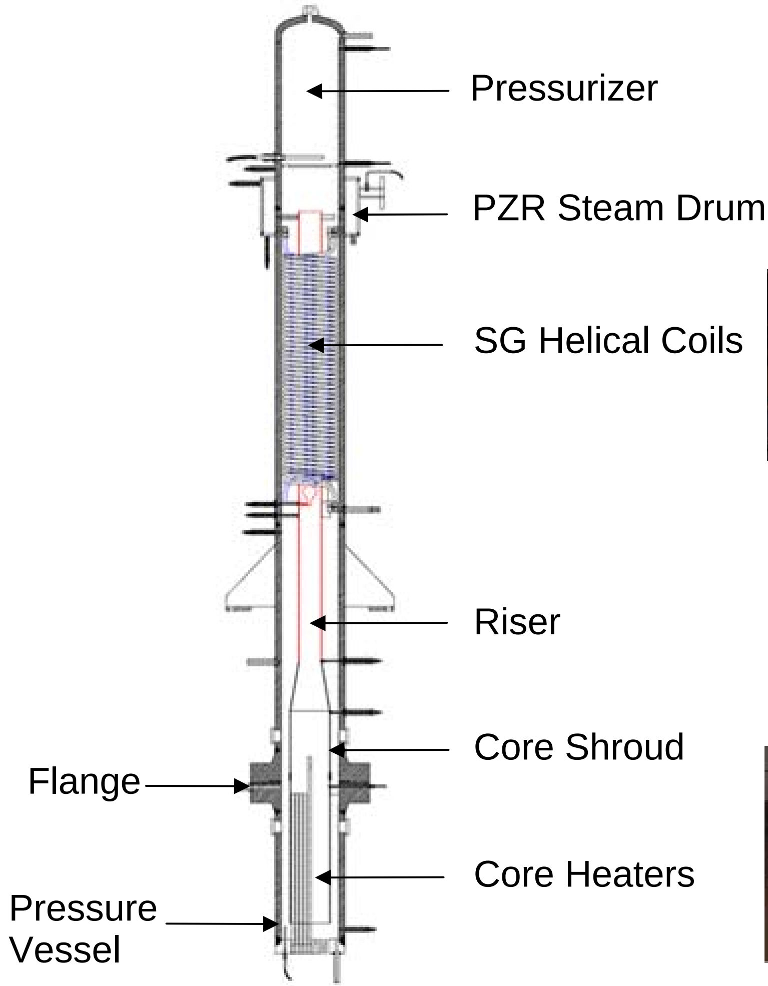
Fixed-wall thickness and containment length

Validated Using NuScale Integral System Test Facility at Oregon State University

- A Scaling Analysis was used to guide the design, construction and operation a 1/3-Scale Integral System Test facility for the MASLWR design.
- Full-Pressure Full-Temperature
- Facility can be used to:
  - Evaluate design improvements
  - Conduct integral system tests for NRC certification
- OSU has significant testing capability.
  - Performed DOE and NRC certification tests for the AP600 and AP1000 designs.
  - 10 CFR 50 Appendix B, NQA-1, 10 CFR 21

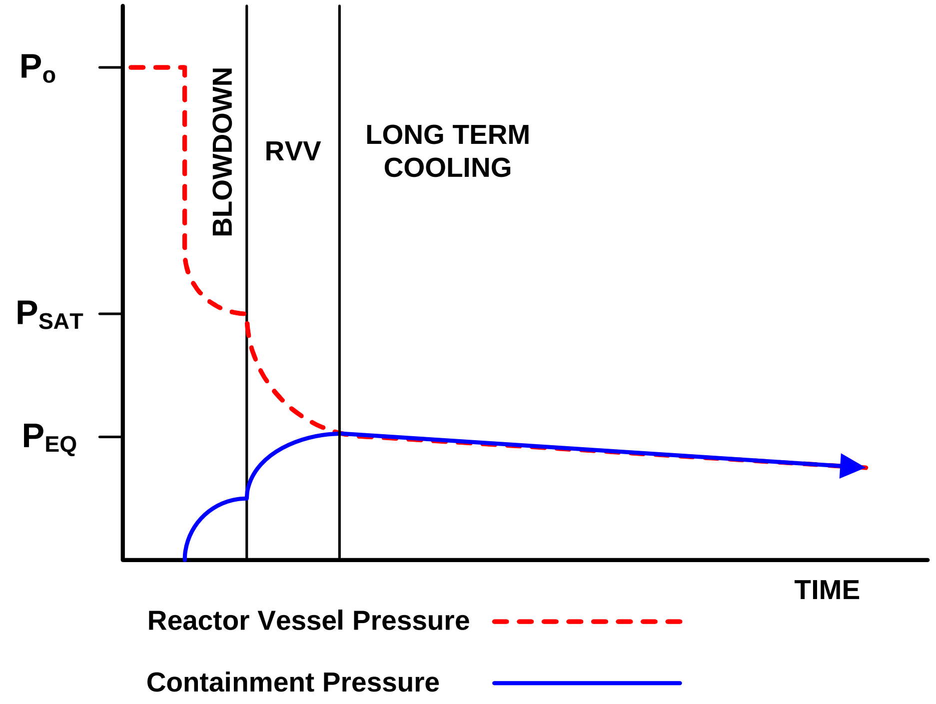
Integrated Reactor Test Vessel

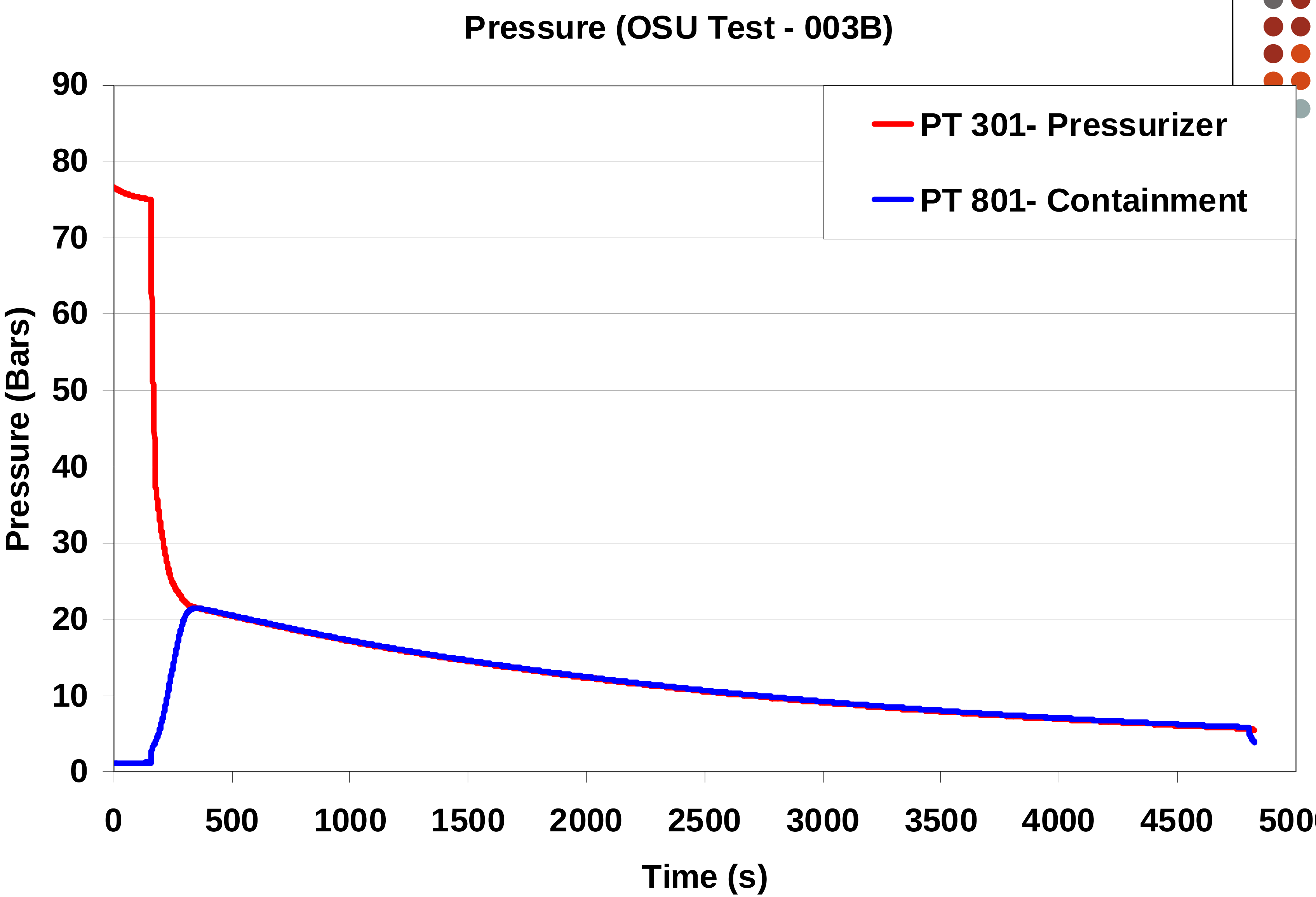




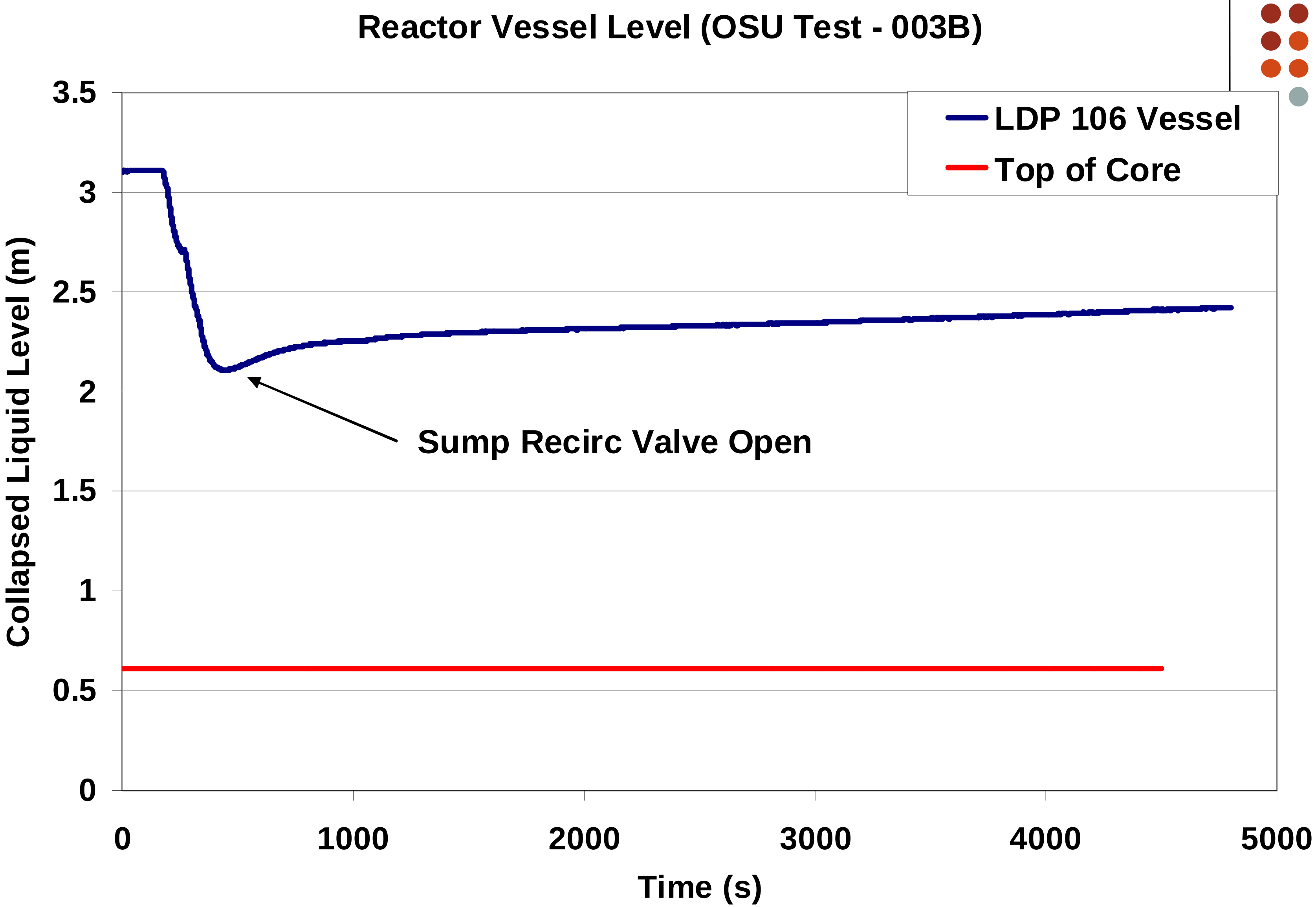
SBLOCA Transient Phases

- Phase 1: Blowdown Phase
  - Begins with the opening of the break and ends with the reactor vent valve (RVV) initiation
- Phase 2: RVV Operation
  - Begins with the opening of the reactor vent valve and ends when the containment and reactor system pressures are equalized
- Phase 3 - Long Term Cooling
  - Begins with the equalization of the containment and reactor system pressures and ends when stable cooling is established via opening of the sump recirculation valves





Pressure (OSU Test - 003B)
Pressure (Bars)
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time (s)
PT 301- Pressurizer
PT 801- Containment



Reactor Vessel Level (OSU Test - 003B)
3.5
3
2.5
2
1.5
1
0.5
0
Collapsed Liquid Level (m)
0
1000
2000
3000
4000
5000
Time (s)
LDP 106 Vessel
Top of Core
Sump Recirc Valve Open

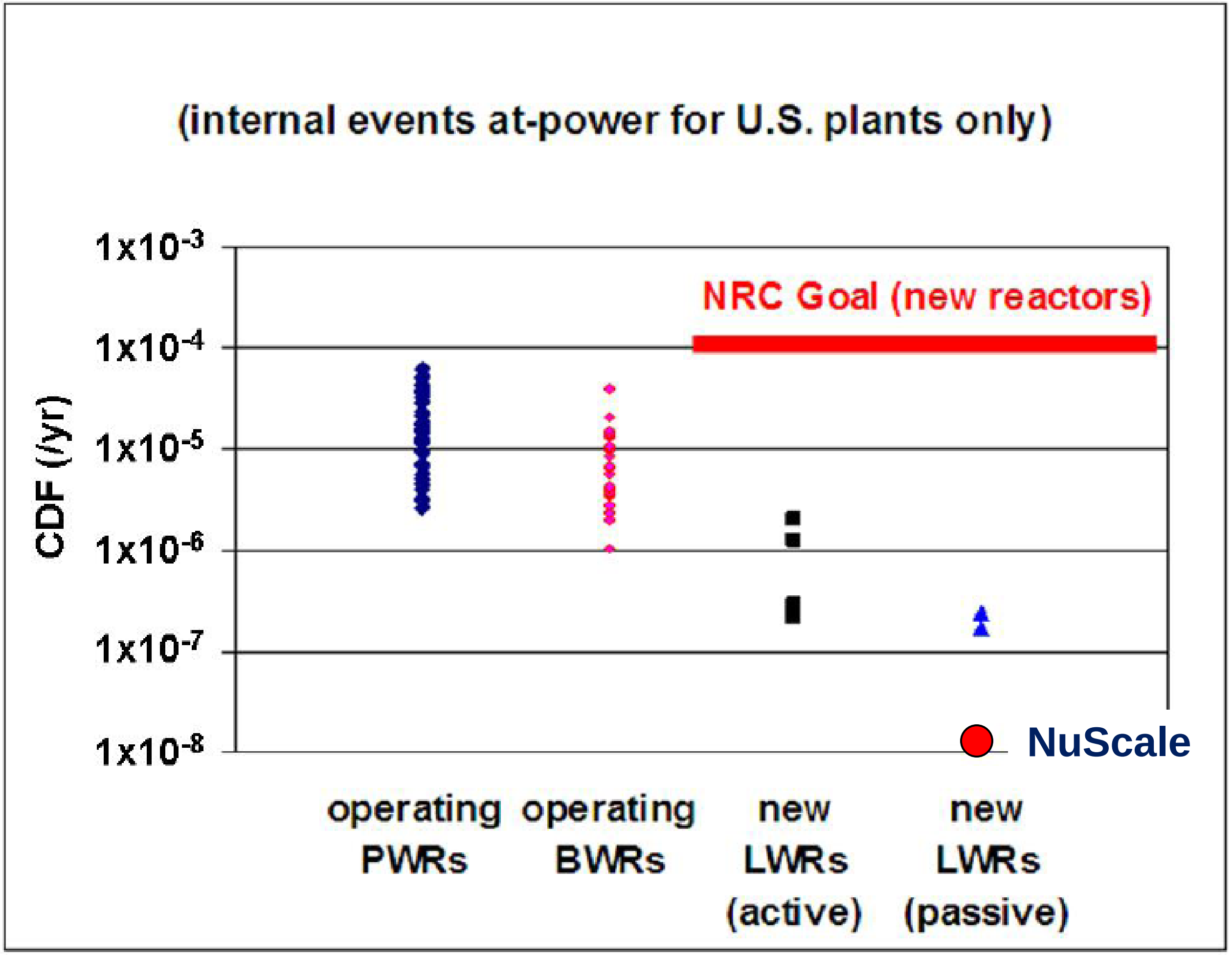
Expert Panel Reviews

- June 2-3, 2008, a panel of experts convened to develop a Thermal-Hydraulics/Neutronics Phenomena Identification and Ranking Table (PIRT) for the NuScale module:
  - Graham Wallis, Creare (Panel Chairman)
  - Mujid Kazimi, MIT
  - Larry Hochreiter, Penn State
  - Kord Smith, Studsvik Scanpower
  - Brent Boyack, LANL retired
  - Jose Reyes, NuScale Power, OSU
- February 24-26, 2009 Severe Accidents Analysis PIRT Panel convened in Corvallis
  - Mike Corradini (Panel Chairman)
  - Vijay Dhir
  - Joy Rempe

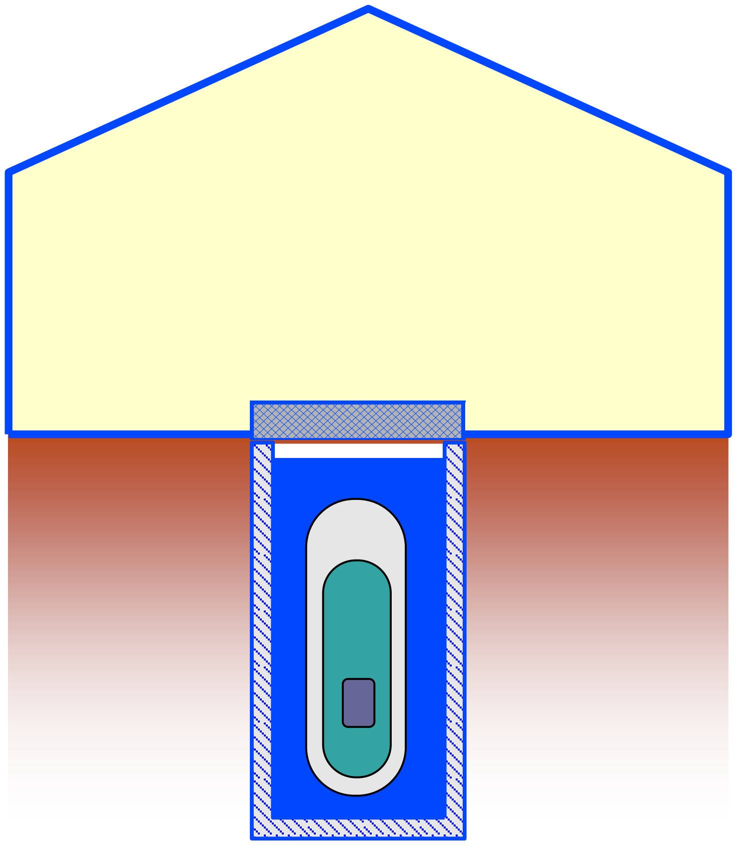
Independent Review Panel Results

- LOCA Thermal Hydraulic Review
  - Large-break Loss of Cooling Accident (LOCA) eliminated by design
  - DBA LOCA's will not uncover the core, thus do not challenge plant safety
- Severe Accident Review
  - Indicated that the PRA is overly conservative with regard to events that lead to core damage.
- NuScale LOCA PRA indicates that the overall Core Damage Frequency is extremely low

NRC White Paper for discussion at February 18, 2009 Public Meeting on Implementation of Risk Metrics for New Reactors – D. Dube 2/12/09



Additional Fission Product Barriers



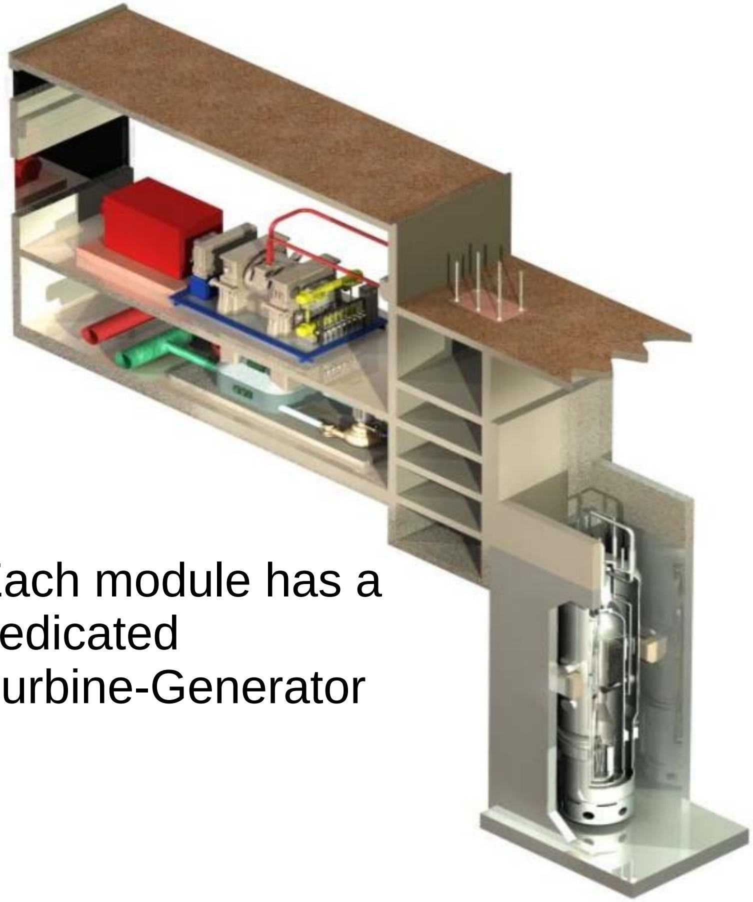
NOT TO SCALE

- Fuel Pellet and Cladding
- Reactor Vessel
- Containment
- **Containment Cooling Pool Water**
- **Containment Pool Structure**
- **Biological Shield**
- **Reactor Building**

Low CDF , Increased Fission Product Barriers, Small Source term means potential for smaller EPZ

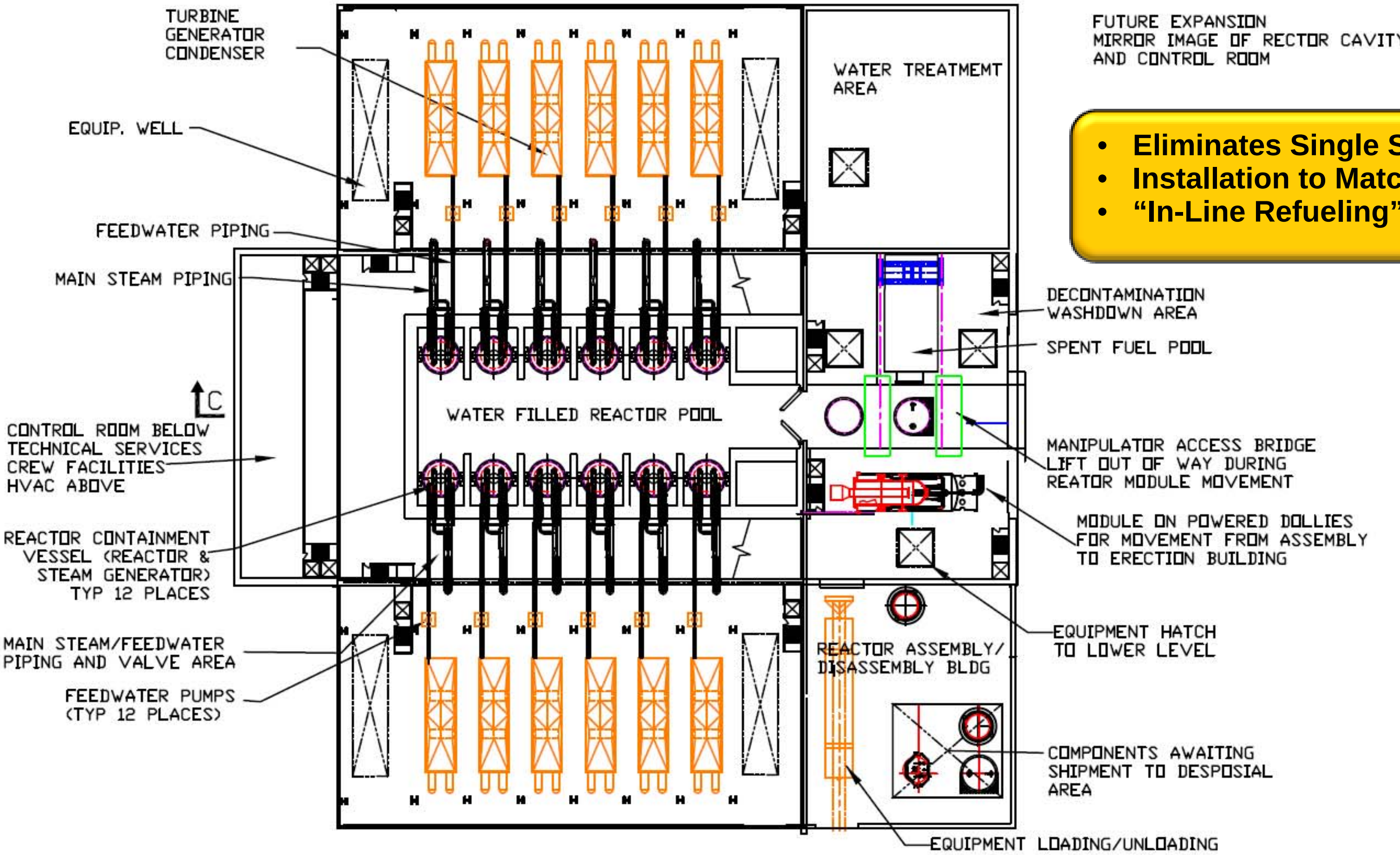
Modules can be "Numbered-Up"

Modules can be "numbered up" to achieve large generation capacities



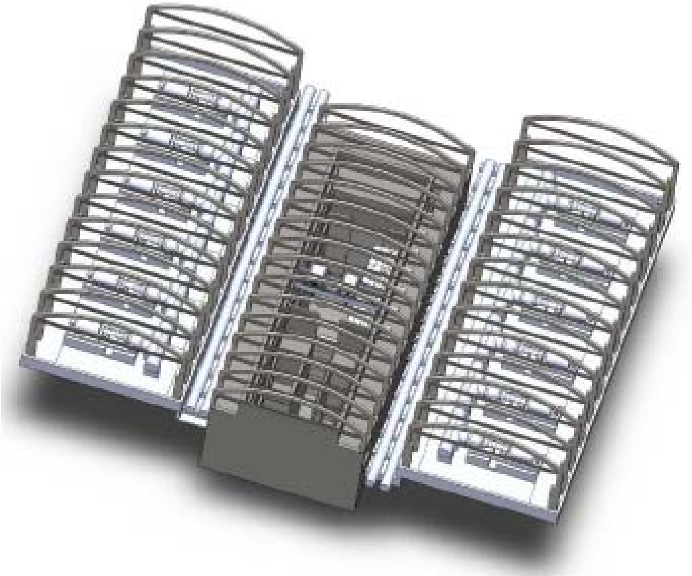
Each module has a dedicated Turbine-Generator

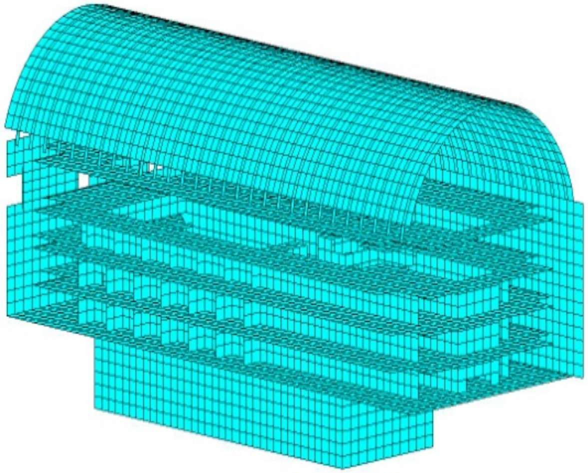
Multiple-Module Plant (12 modules – 540 MWe)



- **Eliminates Single Shaft Risk**
- **Installation to Match Demand**
- **“In-Line Refueling”**

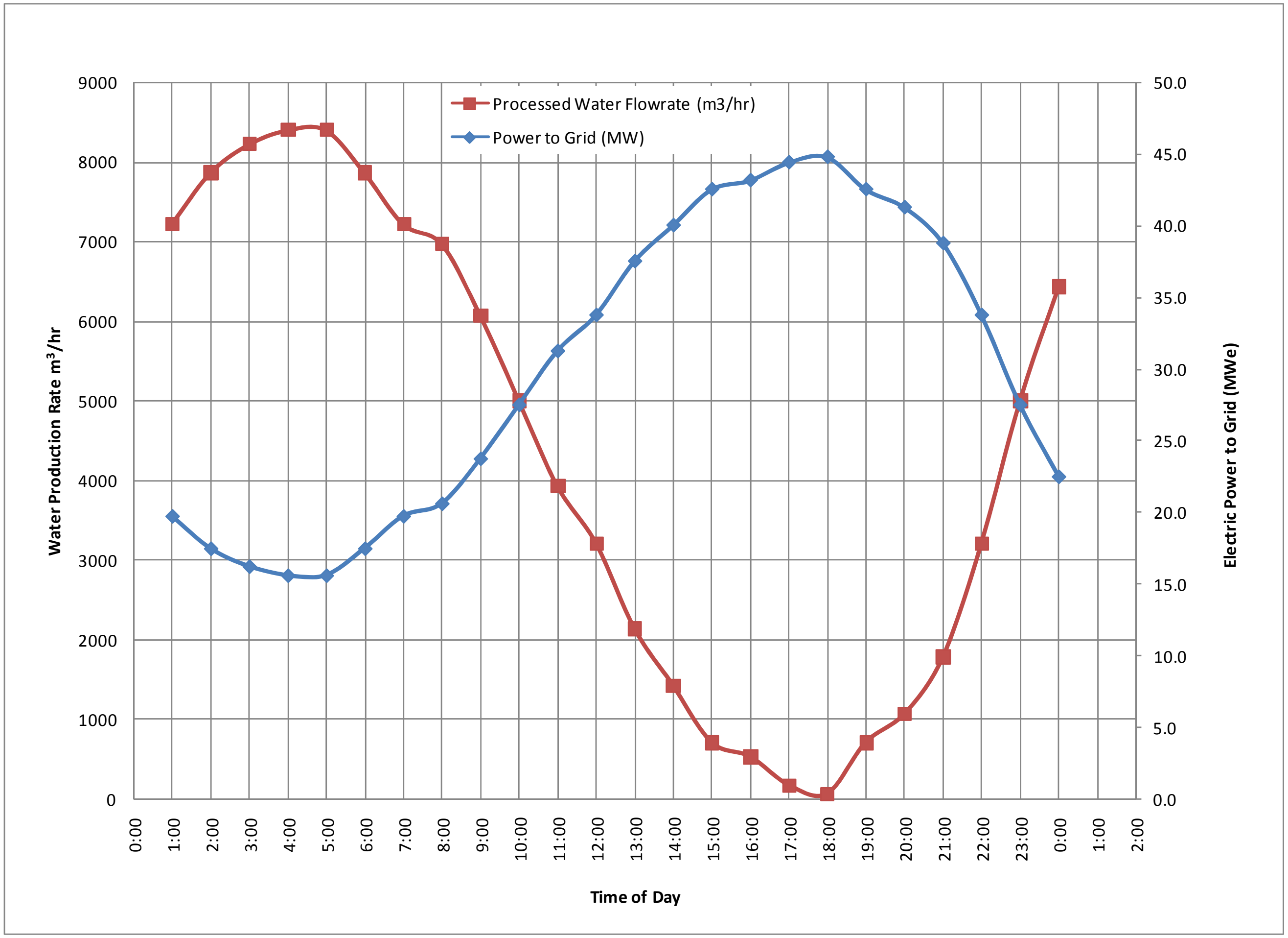
Robust Seismic Design





- Designed for West Coast US Seismic Activity
- Structure composed almost entirely out of concrete, with well arranged shear walls and diaphragms which provides for high rigidity.
- Significant portion of the structure located below grade partially supported by bedrock.
- Large pools filled with water will dampen seismic forces.

Desalination – Fresh Water and Power Production from a 45 MW(e) Base Loaded NuScale Module



**Using hourly average residential load profile from the Southern California Edison Territory.*

- Peak water production between 03:00 and 05:00 hours
- **104 000 liters of desalinated water per day per module**
- Peak electric power to the grid between 16:00 to 19:00 hours.
- **717 MWh of electrical energy to the grid per day per module**

IAEA International Collaborations

- IAEA Coordinated Research Program (CRP) on Natural Circulation Phenomena, Modeling and Reliability of Passive Systems that Utilize Natural Circulation
  - **IAEA International Collaborative Standard Problem (ICSP) on MASLWR – Experiments and Thermal Hydraulic Code Benchmarks**
- IAEA Training Course on Natural Circulation Phenomena and Modeling in Water Cooled Nuclear Power Plants

Contact: Mr. J.H. Choi, IAEA, J.H.Choi@iaea.org ,+43(1) 2600 22825

IAEA Coordinated Research Program

Natural Circulation Phenomena, Modeling and Reliability of Passive Systems that Utilize Natural Circulation

- Established a major program through the United Nations International Atomic Energy Agency to study passive safety systems.
  - **Delegates from 17 countries visited Corvallis in September 2005**
  - **Meetings in Cadarache, France September 2006**
  - **Meetings in Vienna, Austria, September 2007 and 2008**
- MASLWR test facility selected for International Collaborative Standard Problem to validate member state computer codes.
  - **Meeting of code assessment group scheduled for Corvallis, OR**
- **Contact: Mr. J.H. Choi, IAEA, J.H.Choi@iaea.org , +43(1) 2600 22825**

IAEA Coordinated Research Program

Natural Circulation Phenomena, Modeling and Reliability of Passive Systems that Utilize Natural Circulation

- Barilochi Research Centre of the National Atomic Energy Commission (Argentina)
- Commissariat à l’Energie Atomique, Cadarache (France)
- Research Center Rossendorf (Germany)
- Bhabha Atomic Research Centre (India)
- Ente per le Nuove tecnologie, l'Energia e l'Ambiente, and the University of Pisa (Italy)
- Japan Atomic Energy Agency (Japan)
- Korea Atomic Energy Research Institute (Republic of Korea)
- Gidropress (Russian Federation)
- Institute for Technical Analysis, IVS (Slovakia)
University of Valencia (Spain)
- Paul Scherrer Institute (Switzerland)
- Oregon State University, Purdue University and Idaho State University (United States of America)
- European Commission Joint Research Centre Institute for Energy (the Netherlands).

NuScale Captures the *"Economy, Safety and Security of Small"*

- Based on well-established LWR technology, NuScale is cost competitive and highly standardized. – **Less licensing risk.**
- Offsite manufacturing of entire NSSS and Containment
  - **Reduces costs**
  - **Short learning curve**
  - **Improves predictability and control – reliable cost estimates**
  - **Opportunity to create manufacturing plants within customer countries or regions**
- Simplicity – Less parts, smaller parts, robust supply chain, competitive pricing on components. Multiple suppliers eliminates choke points.

NuScale Captures the "*Economy, Safety and Security of Small*"

- Modularity of NSSS
  - **Sequential addition of generation matches load growth – less financial risk**
  - **Eliminates "single-shaft" risk – less operational risk**
- Smaller size permits construction in "bite-size" chunks
  - **Reduced Capital Costs**
  - **Reduced Plant Construction Schedule**
  - **Parallel fabrication and construction**
  - **Reduced Finance Interest Costs**
- Enhanced safety
  - **Elimination of Loss of Coolant Accident**
  - **Passive cooling/natural circulation**
  - **Additional barriers to environment**

NuScale Captures the “*Economy, Safety and Security of Small*”

- NuScale Enhanced Operating Characteristics
  - **“In-Line Refueling” offers high capacity factors and reduced refueling staff**
- Security advantages
  - **Nuclear plant, control room, and spent fuel storage all below ground**
  - **Potential for Remote Monitoring**
  - **Potential for advanced detection systems for material assays**
- Training Opportunities
  - **IAEA Benchmark tests and Code Assessments**

201 NW 3RD STREET
CORVALLIS, OR 97330
541-207-3931

FOR MORE INFORMATION CONTACT:

JOSE N. REYES JR
CHIEF TECHNICAL OFFICER
JNR@NUSCALEPOWER.COM