NuScale Power Advanced SMR’s: Blazing the Trail to the Future of Nuclear Energy

Nuclear Infrastructure Council
Advanced Reactors Summit III
Mike McGough, CCO, NuScale Power

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Blazing the Trail to Commercialization
What Does it Take to Bring a New Design to Market?

- **Vision**—improvements vis-à-vis existing designs (safety, fuels, efficiency, costs, speed of deployment)
- **Time**—concept, modeling, prototype, testing, materials (NuScale will be ~24 years)
- **Money**—For NuScale ~$1B+, currently ~$12MM+/month, >600 people
- **Market**—Unless someone is willing to buy it there is no point
- **Government Support**—this is a heavy lift for private sector
- **Licensing**—certainty of dedicated resources, requirements, schedule
- **Supply chain**—lots of new stuff needs to be made and constructed
- **People**—600+ currently on project at NuScale
- **WARNING**: New fuels, non-LWR’s, new materials will take longer—design, testing, demonstration, licensing
Why advanced reactors?

- Technologies must be responsive to key nuclear questions:
  - Develop more inherently safe designs.
  - Address fuel cycle issues to demonstrate long term sustainability.

- Insure strength of the US economy through technologies that:
  - Achieve significant capital cost reductions
  - Are highly efficient and provide operational flexibility
  - Account for future uncertainties (opportunities) through product diversity
Innovation in Energy requires public/private partnership

- **The role of industry:**
  - *End users* – communicate what we want and need from technology
  - *Technology companies* – identify what is possible and innovate to deliver it to market

- **The role of government:**
  - *National Labs* – provide foundation of core R&D and infrastructure necessary to support an uncertain future.
  - *DOE* – partnership with industry to buy down risk of development and demonstrations ("valley of death").
  - *Regulator* - Facilitate deployment through efficient and timely regulatory environment
Time is of the essence

2020s
- Small scale demonstrations (target 2025)
- Technology validation
- Utilize existing licensing paradigms

2030s
- Large scale demonstrations, likely power reactors
- Demonstration of enhanced licensing pathway

2035-2040
- Commercial technology in market
- Enhanced licensing pathway fully realized
Brief NuScale History

- NuScale first of current US SMRs to begin design of commercial NPP.
- NuScale technology in development and design since 2000 (DOE) MASLWR program, with INL, lessons from AP600/1000 1/4-scale testing facility built and operational
- Electrically-heated 1/3-scale Integral test facility first operational in 2003
- Began NRC design certification (DC) pre-application project in April 2008, >20K Mhrs
- Acquired by Fluor in October 2011
- >600 people currently on project, ~$380MM spent project life-to-date ($12MM/mo)
- 240 patents pending/granted, 19 countries
- Portland, Corvallis, Rockville, Charlotte, Richland, London
- US DOE SMR Grant Awardee, 12/12/13
A NuScale Power Module (NPM) includes the reactor vessel, steam generators, pressurizer and containment in an integral package that eliminates reactor coolant pumps and large bore piping (no LB-LOCA).

Each NPM is 50 MWe and factory built for easy transport and installation.

Each NPM has its own skid-mounted steam turbine-generator and condenser.

- Each NPM is installed below-grade in a seismically robust, steel-lined, concrete pool.
- NPMs can be incrementally added to match load growth - up to 12 NPMs for 600 MWe gross (~570 net) total output.

What is a NuScale Power Module?
Size Comparison

Comparison size envelope of new nuclear plants currently under construction in the United States

126 NuScale Power Modules

Typical Pressurized Water Reactor

NuScale’s combined containment vessel and reactor system

*Source: NRC
Coolant Flow Driven By Physics

**Convection** – energy from the nuclear reaction heats the primary reactor coolant causing it to rise by convection and natural buoyancy through the riser, much like a chimney effect.

**Conduction** – heat is transferred through the walls of the tubes in the steam generator, heating the water (secondary coolant) inside them to turn it to steam. Primary water cools.

**Gravity** – colder (denser) primary coolant “falls” to bottom of reactor pressure vessel, cycle continues.
NuScale Fuel—(NuFuel HTP2 ™)

- Standard 17 X 17 PWR Fuel Assembly
- Half height
- 37 FA’s/core
- Enriched ~3.7%
- ~ 4% MTU of ESBWR core
- RFO 24-month cycle
- ~1/3 core replaced
- MOX capable
- Areva design and Fab—NuAB guidance
Site Overview

34.5 acres (~14 hectares) within the protected area fence
SAFETY
NuScale Safety Systems

Systems and Components Needed to Protect the Core:

- Reactor Pressure Vessel
- Containment Vessel
- Reactor Coolant System
- Decay Heat Removal System
- Emergency Core Cooling System
- Control Rod Drive System
- Containment Isolation System
- Ultimate Heat Sink
- Residual Heat Removal System
- Safety Injection System
- Refueling Water Storage Tank
- Condensate Storage Tank

- Auxiliary Feedwater System
- Emergency Service Water System
- Hydrogen Recombiner or Ignition System
- Containment Spray System
- Reactor Coolant Pumps
- Safety Related Electrical Distribution Systems
- Alternative Off-site Power
- Emergency Diesel Generators
- Safety Related 1E Battery System
- Anticipated Transient without Scram (ATWS) System
Reduced Core Damage Frequency

Source: NRC White Paper, D. Dube; basis for discussion at 2/18/09 public meeting on implementation of risk matrices for new nuclear reactors
More Barriers Between Fuel & Environment

Conventional Designs
1. Fuel Pellet and Cladding
2. Reactor Vessel
3. Containment

NuScale’s Additional Barriers
4. Water in Reactor Pool
5. Stainless Steel Lined Concrete Reactor Pool
6. Biological Shield Covers Each Reactor
7. Reactor Building
Smaller Emergency Planning Zone (EPZ) Due to Safer Design

Traditional PWR

10 mi EPZ

NuScale Plant

Site Boundary EPZ

- Passive Safety
- Additional Fission Product Barriers
- Significant Delay in Release of Radiation

(depending on site characteristics)
Innovative Advancements to Reactor Safety

*Alternate 1E power system design eliminates the need for 1E qualified batteries to perform ESFAS protective functions – Patent Pending
How do we know it works?

NuScale Testing Programs
NuScale Reactor Qualification Test Plan outlines Design Certification and First Of A Kind Engineering (FOAKE) projects for reactor safety code development, validation, reactor design and technology maturation to reduce First Of A Kind (FOAK) design risk.
## Testing Progress

<table>
<thead>
<tr>
<th>Test/Demonstration Program</th>
<th>Test Facility</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Heat Flux Test – Initial Fuel Design</td>
<td>Stern Lab, Canada</td>
<td>Completed</td>
</tr>
<tr>
<td>Steam Generator Tube Inspection Feasibility Study</td>
<td>Corvallis, Oregon</td>
<td>Completed</td>
</tr>
<tr>
<td>SIET TF1; 3-Coil, Full-Length, Electrically Heated Steam Generator</td>
<td>SIET, Piacenza, Italy</td>
<td>Completed</td>
</tr>
<tr>
<td>SIET TF2; 252-Coils, full length, Prototypic Fluid-to-Fluid heat transfer</td>
<td>SIET, Piacenza, Italy</td>
<td>Completed</td>
</tr>
<tr>
<td>Upper Module Mock-up</td>
<td>OIW, Vancouver, WA</td>
<td>Completed</td>
</tr>
<tr>
<td>Fuel Mechanical and Hydraulic</td>
<td>Richland, WA</td>
<td>Completed</td>
</tr>
<tr>
<td>NIST-1 Facility; Integral System</td>
<td>OSU, Corvallis, OR</td>
<td>Critical Path Testing Complete</td>
</tr>
<tr>
<td>CRA and Drive Shaft Alignment and Drop</td>
<td>Erlangen, Germany</td>
<td>Under Construction</td>
</tr>
<tr>
<td>Steam Generator Flow Induced Vibration</td>
<td>Erlangen, Germany</td>
<td>Under Construction</td>
</tr>
<tr>
<td>CRA/Cragt Flow Induced Vibration</td>
<td>Erlangen, Germany</td>
<td>Under Construction</td>
</tr>
<tr>
<td>Critical Heat Flux – NuScale Fuel Design w/AREVA HMP/HTP grids</td>
<td>Karlstein, Germany</td>
<td>Under Construction</td>
</tr>
<tr>
<td>Steam Generator Orifice Hydraulic Testing</td>
<td>TBD (US Domestic)</td>
<td>Bid Down Selection</td>
</tr>
</tbody>
</table>

**Percentage of Required DCA Testing Completed:** > 60%

**Total Testing Expenditures to Date:** $24 Million
Full Length SG Test (TF-2) Construction/Hardware
All tests required to validate NRELAP5 for LOCA applications are complete

- HP-01 (volume and elevation)
- HP-02 (high pressure condensation)
- HP-03 (DHRX characterization)
- HP-04 (cooling pool characterization)
- HP-05 (powered natural circulation flow)
- HP-06 (CVCS discharge line break)
- HP-07 (pressurizer spray line break)
- HP-09 (ECCS RVV spurious opening)

NRELAP5 test assessment is complete
NRC inspection of NIST-1 is complete

Status:
- Facility completed shutdown, reconfiguration and maintenance
- Resumed testing week of Jan 4
CVCS piping rupture (LOCA):
- Excellent predictions of:
  - reactor and containment vessel water levels
  - reactor and containment vessel pressures through ECCS valve opening
- Significant margin to core uncover
- NRELAP5 correctly captures LOCA physics

ECCS trips
Licensing Plan and Status
This will be our 3\textsuperscript{rd} Certified Design

- 1993--Dr. Jose Reyes led the team that designed and built the ¼-scale Advanced Plant Experiment test facility under contract to Westinghouse.
- AP600—76 tests, qualified, confirmatory, NRC witnessed
- AP600 DCD Issued by NRC 1/6/2000
- 2002 WH submits AP1000 DCA to NRC
- 2002 WH hires Jose et. al. to scale up APEX to 1000MW
- 2004 22 additional tests on AP1000 for WH and NRC
- Total 98 tests, NQA-1, NRC witnessed, basis for AP1000 Design Certification, and of course AP 1000 COL’s
- 1/27/2006 NRC issues AP1000 Design Certification
- The NuScale Integrated System Test Facility is based on these proven methods of testing and licensing a nuclear power plant through the NRC
RIS 2015-07  Response

- NRC Regulatory Information Summary (RIS) is for budgeting, staffing and planning purposes
- Joint response by NuScale and UAMPS submitted on June 17, 2015
- DCA submittal no later than 12/31/2016
- UAMPS COLA submittal by 4Q-2017 or 1Q-2018
- COLA to reference DCA for up to 12 modules
- COL site in Idaho including INL
- UAMPS teaming agreement with ENW identified
## Topical Report Submittals

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<th>Title</th>
<th>Submittal Date</th>
<th>NRC Review/Development Status</th>
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<tr>
<td>Quality Assurance Program Description</td>
<td>May 2015</td>
<td>Accepted for Review: 3 RAIs issued</td>
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<tr>
<td>Risk Significant Determination</td>
<td>July 2015</td>
<td>Accepted for Review: 3 RAIs issued</td>
</tr>
<tr>
<td>Electrical System</td>
<td>October 2015</td>
<td>Accepted for Review</td>
</tr>
<tr>
<td>Accident Source Term</td>
<td>December 2015</td>
<td>Under NRC Acceptance Review</td>
</tr>
<tr>
<td>Emergency Planning Zone</td>
<td>December 2015</td>
<td>Under NRC Acceptance Review</td>
</tr>
<tr>
<td>Highly Integrated Protection System</td>
<td>December 2015</td>
<td>Accepted for Review</td>
</tr>
<tr>
<td>Containment Integrated Leak Rate Test</td>
<td>March 2016</td>
<td>Under Development</td>
</tr>
<tr>
<td>AREVA Fuel and CR Topical Report Applicability to NuScale Design</td>
<td>March 2016</td>
<td>Under Development</td>
</tr>
<tr>
<td>Nuclear Analysis Codes and Methods</td>
<td>June 2016</td>
<td>Under Development</td>
</tr>
<tr>
<td>Steady State Core Thermal-Hydraulics - Primary System Stability</td>
<td>July 2016</td>
<td>Under Development</td>
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<tr>
<td>LOCA Evaluation Model (NRELAPS Code Description)</td>
<td>July 2016</td>
<td>Under Development</td>
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<tr>
<td>VIPRE Subchannel Methodology</td>
<td>September 2016</td>
<td>Under Development</td>
</tr>
<tr>
<td>Non LOCA Methodology</td>
<td>September 2016</td>
<td>Under Development</td>
</tr>
<tr>
<td>Critical Heat Flux Correlation</td>
<td>September 2016</td>
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</table>
Commercialization Plan and Status
First Deployment: UAMPS CFPP

- Utah Associated Municipal Power Systems (UAMPS) Carbon Free Power Project (CFPP) will be first deployment, sited somewhere in Idaho.
- Site selection underway
- DOE INL site use agreement
- NRC COLA commitment
- UAMPS consists of 45 members serving load in 8 western states.
- 33 UAMPS members are subscribers in CFPP
NuScale Diverse Energy Platform (NuDEP) Initiative

- SAFE
- SMALL
- SCALABLE
- FLEXIBLE
- RELIABLE
NuEx Tours – NIST, Control Room Simulator and UMM
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