SMRs in a post-Fukushima world

Dr. Paul Lorenzini
Chief Executive Officer
NuScale Power Inc.

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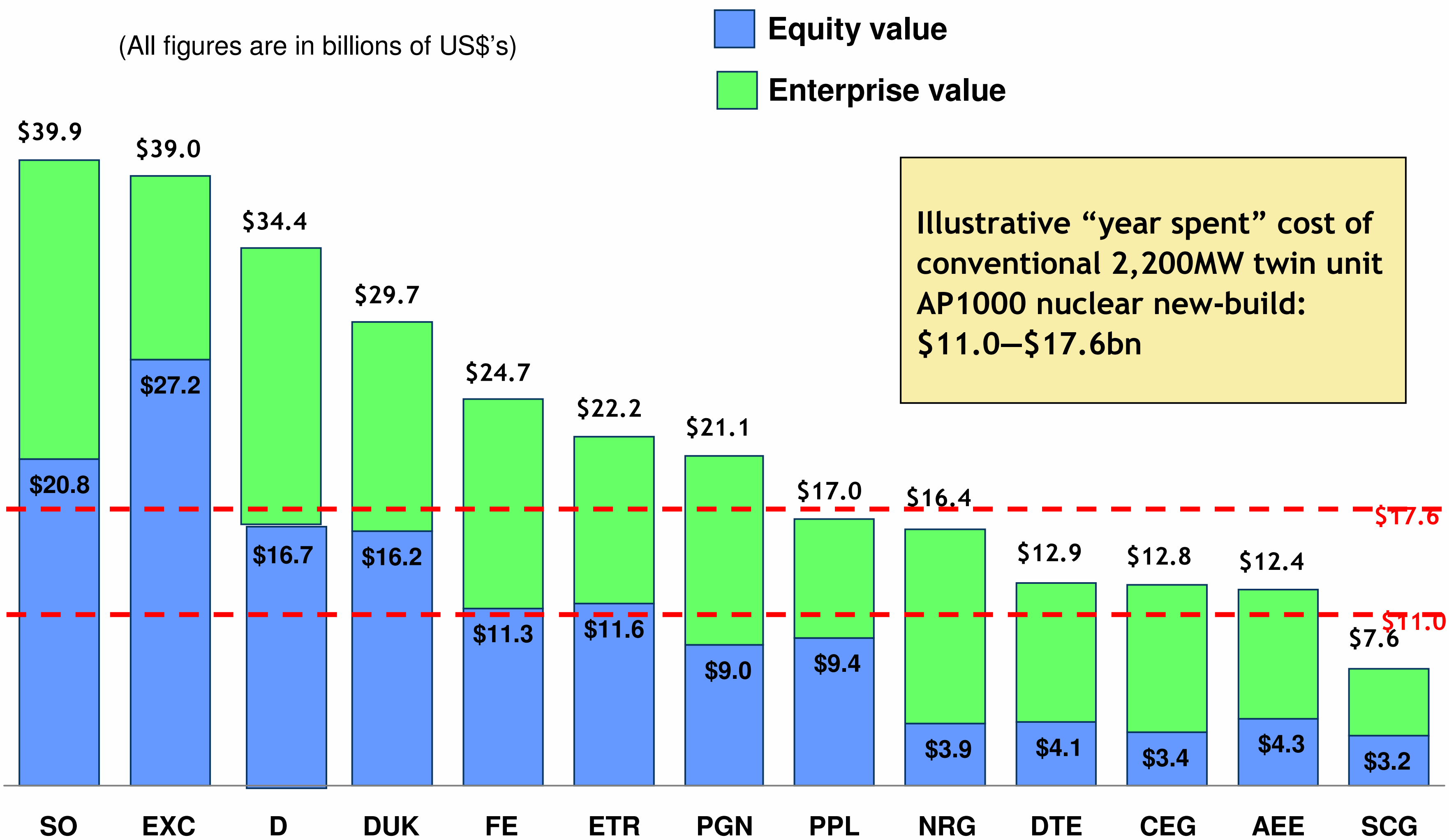
Why Small Modular Nuclear Reactors (SMRs)?

New Nuclear addressed many issues but plants remain large

Old Nuclear	New Nuclear
Every plant is different	NRC "Design Certification" standardizes plant designs for 20 years
Separate licenses for Construction and Operation	Combined Construction & Operating License issued before construction begins
Capacity factors less than 70%	Capacity factors routinely exceed 90%
Active safety systems require emergency power to operate	Passive safety systems rely on natural circulation
All plants > 1000 MWe requiring large financial commitment	All plants > 1000 MWe requiring large financial commitment

The financial risks of large nuclear plants



Source: JPMorgan; FactSet as of 3/13/09

SMRs have changed the game

- Modular scalable nuclear plants reduce financial risks
  - Factory manufacturing lowers costs and on-site construction risks
  - Smaller plants can be served by multiple domestic suppliers
  - New capacity can be added to match load growth – incremental build out lowers initial investment
  - Simplicity enhances safety
- Current DOE program supports commercialization of two LWR SMRs with cost sharing of $452 million over five years.

Green Tech Media named "Modular Nuclear Power" as Number 1 on its list of "Top Ten High Concepts" for 2009

SMR support continues Post-Fukushima

President Obama, *Washington Post,* March 18, 2011

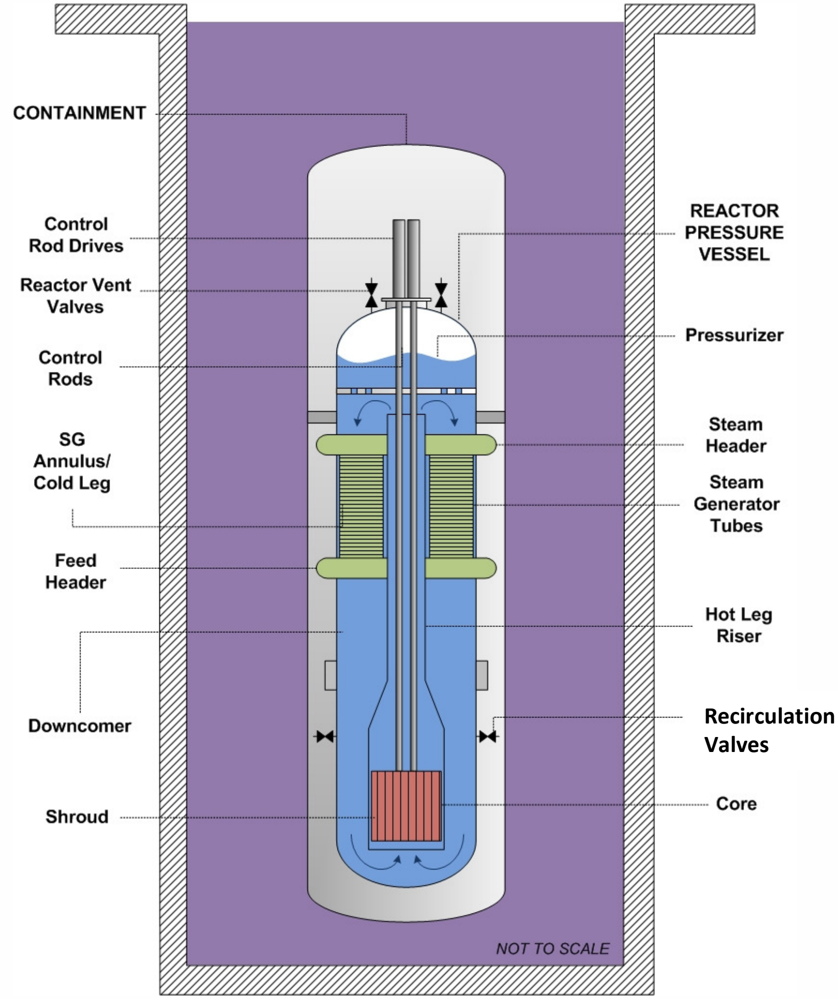
- As the deepening crisis in Japan presents the nuclear power industry with its gravest test in years, President Obama has emerged as a critical ally and defender.
- Repeatedly in recent days, Obama has peppered public remarks on Japan with assurances that U.S. reactors are safe and that nuclear energy remains a key component of his energy agenda.

  "I still think that nuclear power is an important part of our overall energy mix …we've got to do it in a safe and sensible way."

"DOE Acting Assistant Secretary Lyons Touts Advantages of SMRs in House Appropriations Hearing"

NuScale Safety Advantages: Simple, Small, and Relies on Natural Systems

- Underwater, Underground
  - *Both the reactor vessel and the containment are submerged in a pool of water underground*
- Natural Circulation Cooling
  - *Inherently safe natural circulation of water over the fuel during normal operation and shutdown using gravity and natural forces*
  - *No emergency electrical generators required if power is lost from the grid*
- Large Natural Heat Sink
  - *Heat from the nuclear fuel can be transferred to the reactor pool by opening valves that allow for natural circulation (no pumps or power required)*
- Simple and Small:
  - *Reactor output is 1/20th the size of large reactors*



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NUCLEAR FUEL AND CONTAINMENT COOLED BY NATURAL CONVECTION

Does not require external supply of water.

Does not require external power, pumps, or generators.

Nuclear fuel is contained in the reactor vessel.

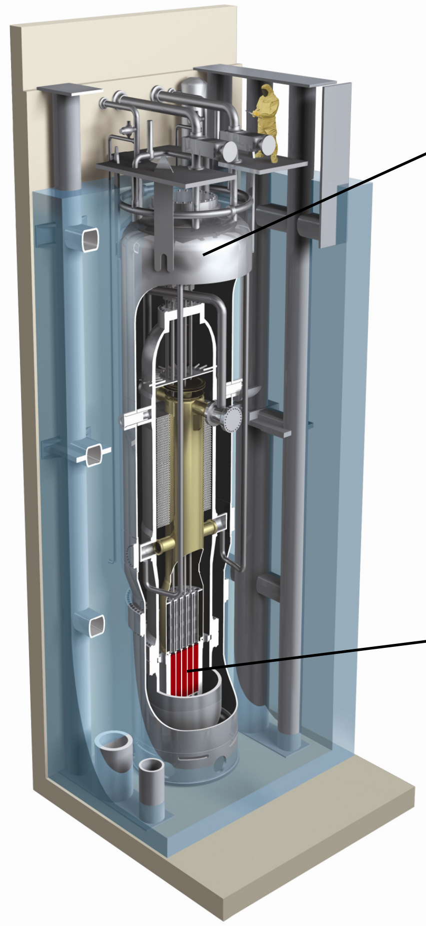
Reactor vessel is housed in the containment vessel.

Containment is immersed in water-filled stainless steel lined concrete pool during normal operating conditions.

Pool is located underground and housed inside a seismically robust reactor building.

Water in pool is always in place and serves as the ultimate heat sink for safety.

30 days of pool cooling without replenishment of water followed by an indefinite air cooling period.



High strength stainless steel containment has 10 times pressure capability of conventional containments.

Small nuclear core has only 5% the fuel of a large reactor.

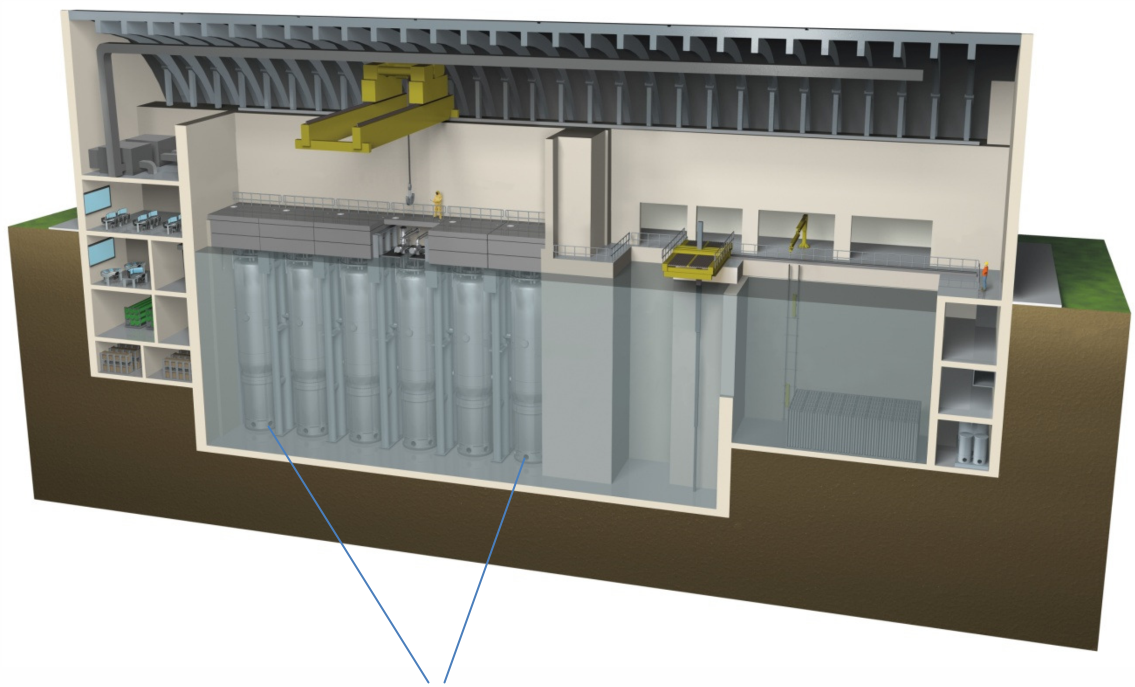
At one second after shutdown, a NuScale reactor is producing only 10 MW of thermal energy.

By one hour after shutdown, the thermal energy is down to 2.5 MW.

Large Pool of Water Holds Reactor Modules

NuScale nuclear power reactors are housed inside high strength steel containment vessels and submerged in a large pool of water below ground level inside the Reactor Building.

The Reactor Building is designed to withstand earthquakes, tsunamis, tornados, hurricane force winds and aircraft impact.



Containments submerged in underground steel-lined concrete pool with 30 day supply of cooling water.

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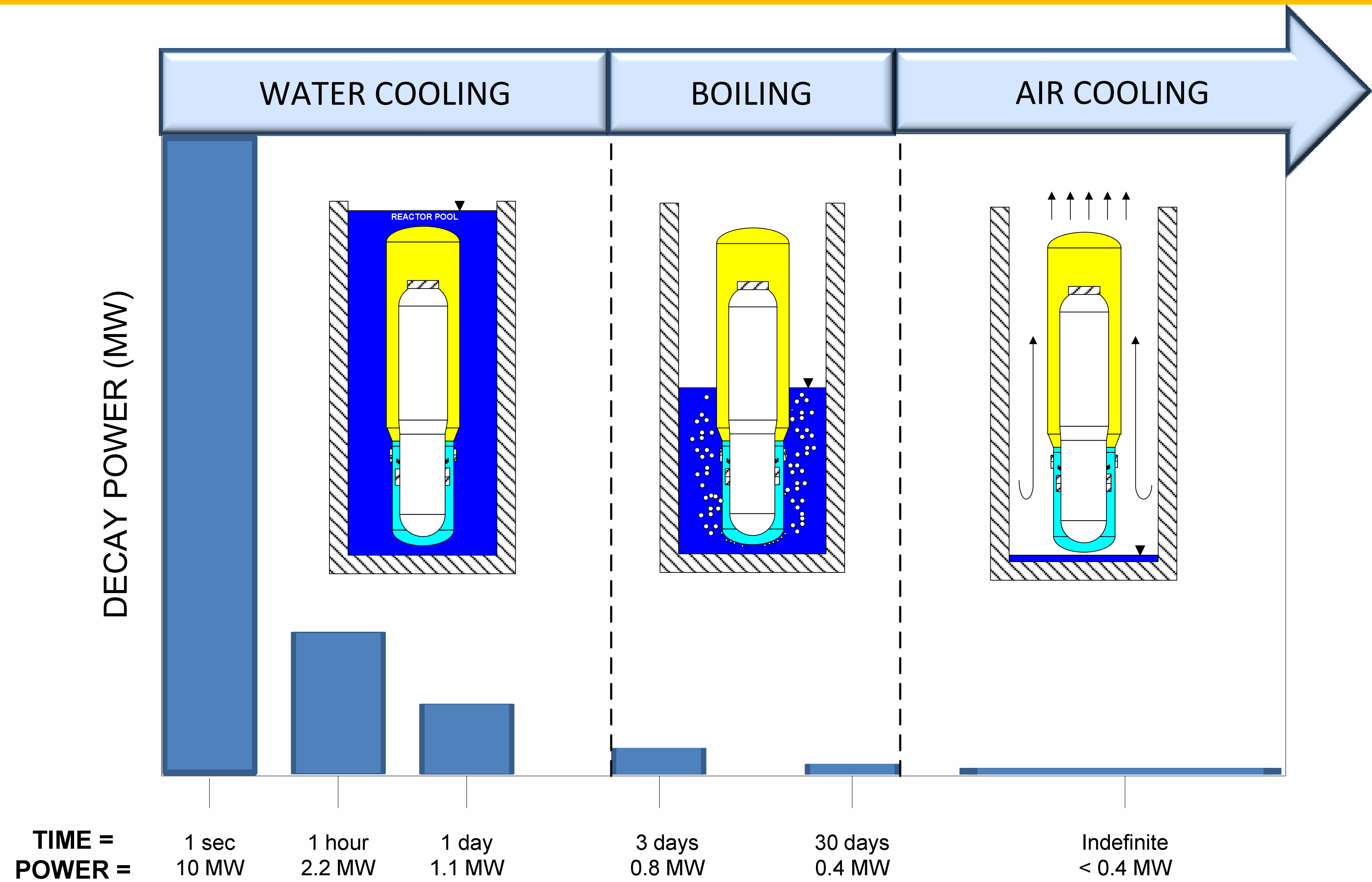
LONG TERM COOLING - *NuScale Containment and Nuclear Fuel can be cooled indefinitely without pumps or power*



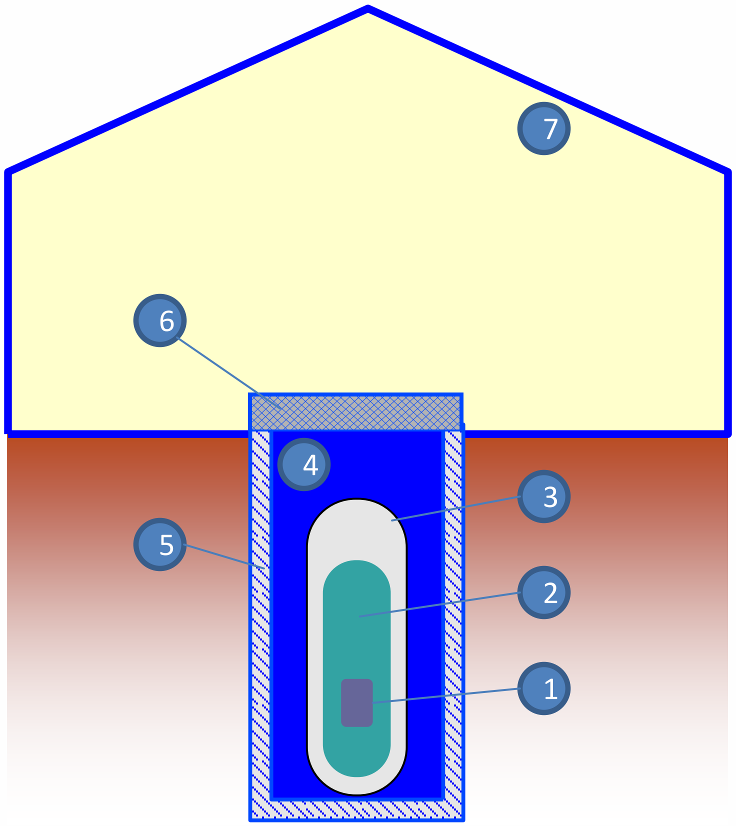
Added Barriers Between Fuel and Environmnet

Conventional Designs

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

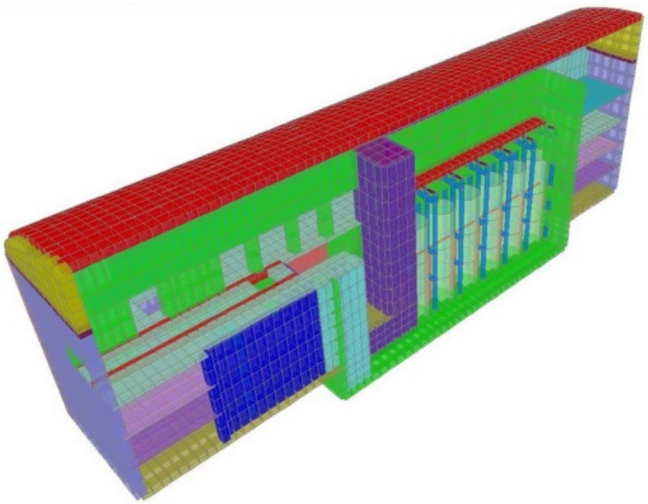
Additions to NuScale Design

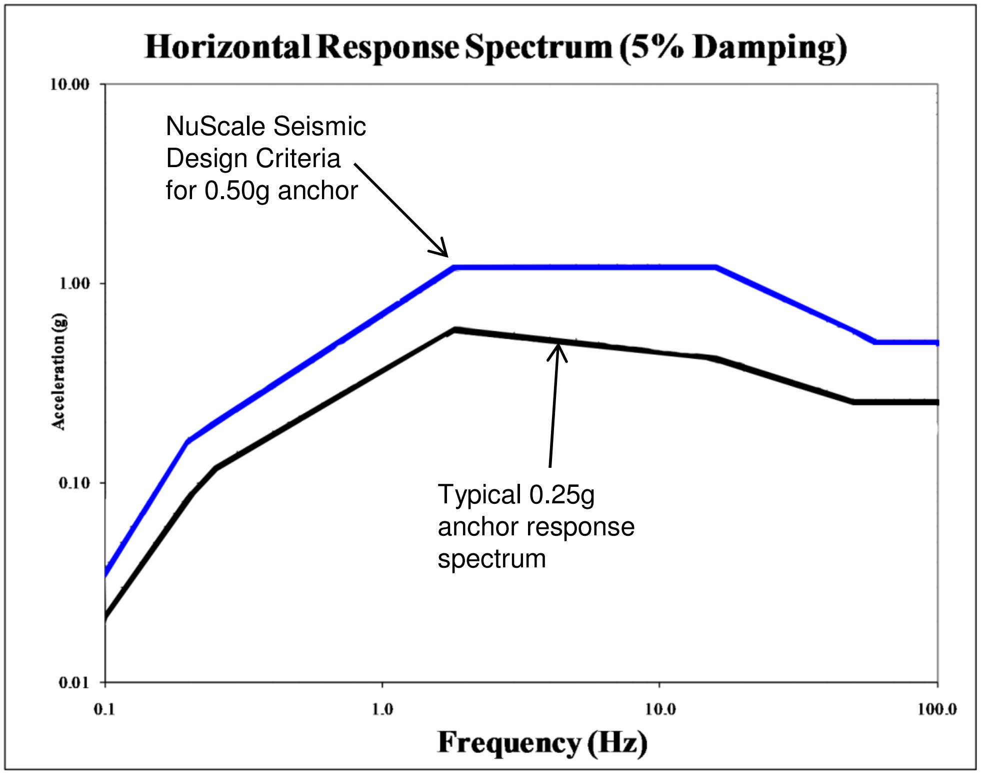
4. Containment Cooling Pool Water
5. Containment Pool Structure
6. Biological Shield
7. Reactor Building



Seismic Robust Design

- Seismic criteria for the NuScale plant envelopes criteria for almost any site in the US.
- Seismic design uses reinforced concrete structure with rigid diaphragms and special reinforced shear walls.





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Spent Fuel Pool Defense In Depth

Increased Cooling Capacity

- Several times more coolant inventory available to cool the spent fuel than Gen II designs
- Redundant, cross-connected reactor and refueling pool heat exchangers (redundant systems)
- Stainless steel refueling pool liner is not integrated (independent) from concrete building

Below Ground Robust Deep-Earth Structure.

- Below ground spent fuel pool is housed in Seismic Category I reactor building.
- Underground pool wall is shielded from tsunami wave impact and damage
- Accessibility to the pool is increased (fire trucks can drive up to the outside of the building)
- Increased ability to supply additional inventory (compared to above ground pools)
- Potential leak rates reduced

Effective External Coolant Supply Connections

- Auxiliary external water supply connections are easily accessible to plant personnel and away from potential high radiation zones (current problem in Japan)

Summary

Small and Simple, Reliance on Natural Circulation

- The NuScale reactor design relies entirely on natural forces such as convection to circulate water over the nuclear fuel.

Emergency Electrical Generators Not Required for Safe Shutdown

- Because the NuScale design uses natural circulation instead of forced mechanical systems such as pumps to circulate water over the fuel it eliminates the need for back-up or emergency electrical generators.
- In a shutdown scenario when no electrical power is available from the grid, the NuScale reactor can be cooled simply by opening battery powered valves that allow water to circulate through heat exchangers in the reactor building pool or by heat transfer through the containment wall.

Underwater, Underground Improves Seismic Capability

- The placement of the containment and reactor vessels in a pool of water underground dampens the effects of any earth movement and greatly enhances the ability of the system to withstand earthquakes.

Robust, Extra Large, Underground Spent Fuel Pool (SFP)

Summary (continued)

Less Heat to Remove, More Ways to Remove It

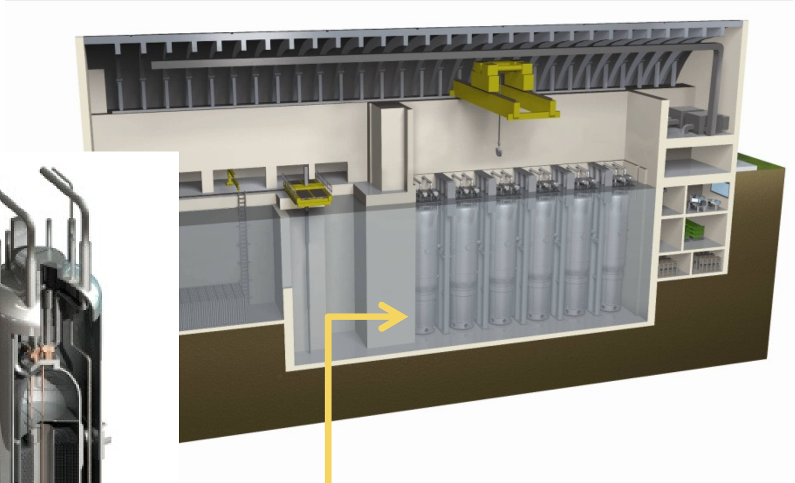
- At full operating power, a NuScale reactor produces about the same thermal energy as a large reactor does when it is shutdown. At one second after shutdown, a NuScale reactor is producing only 10 MW of thermal energy. By one hour after shutdown, the thermal energy is down to 2.5 MW.
- Heat removal is accomplished by opening valves that allow the hot water in the reactor to transfer its heat to the cool water in the reactor pool. Several systems allow heat transfer either through the containment vessel or directly to the reactor pool.
- 30 days of pool cooling is possible without replenishment of water followed by an indefinite period of air cooling.

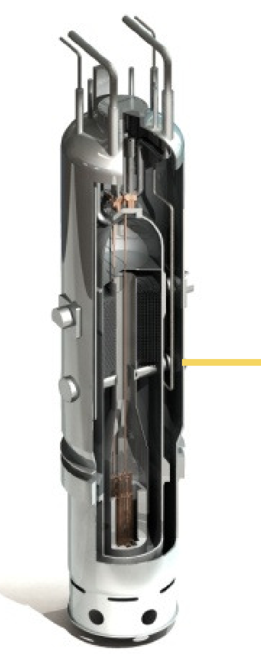
Additional Barriers Between Fuel and Environment

- The nuclear reactor enclosed in an extremely strong steel containment vessel; designed to hold 10 times the pressure of the large, reinforced-concrete containment buildings used at conventional nuclear power plants.
- Both the containment vessel and the reactor are submerged in a pool of water that also is underground.
- The NuScale design includes several additional physical barriers between the nuclear fuel and the environment.

Safety reinforced by the "economies of small"

Nuclear Steam Supply System Construction for typical large nuclear plant



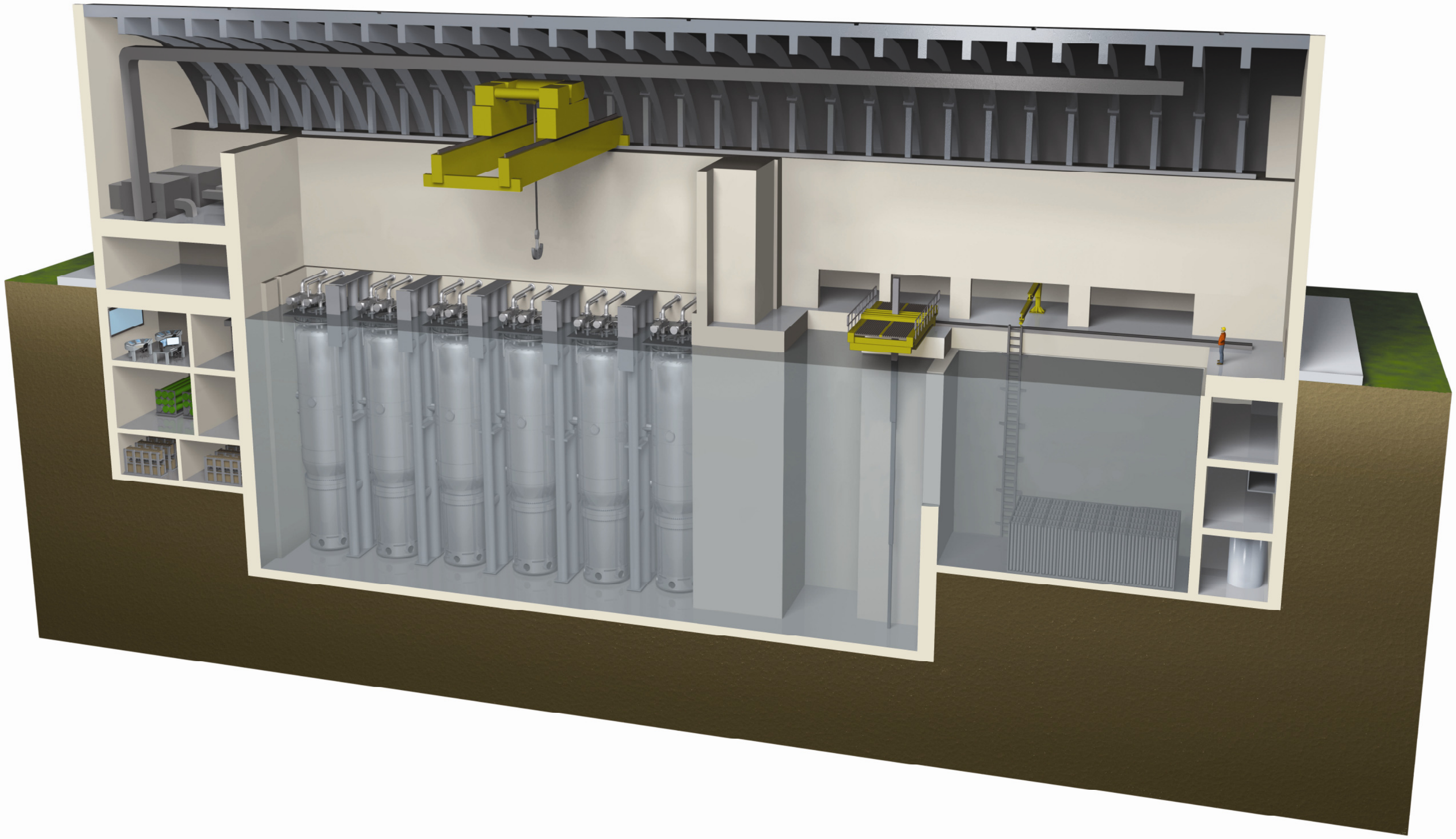


Prefabrication of NuScale reactor and containment enables:

- Elimination of field work
- Simplified construction which lowers construction costs, shortens schedules, reduces financing costs

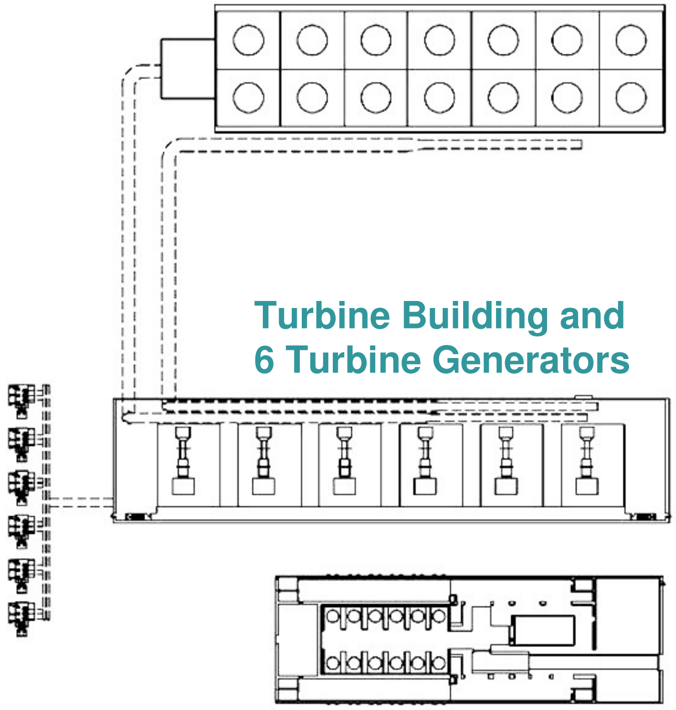
Modularity permits scaling to any size

12 modules, 45 MWe each produces 540 MWe



Incremental build out

Initial installation 270 MWe



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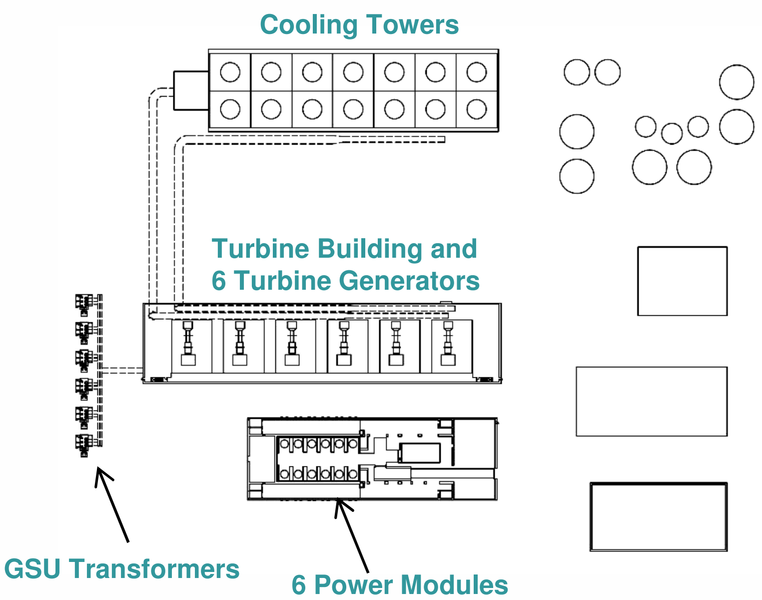
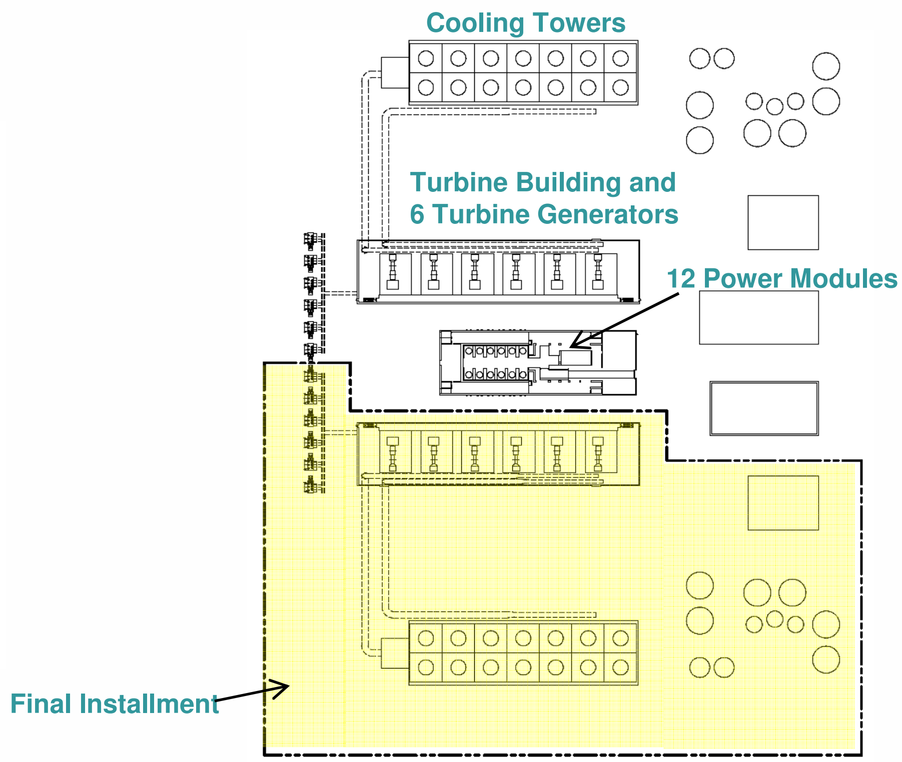
Incremental build out minimizes risks; matches demand to load growth

Initial installment (270 MWe)



Final Installment (540 MWe)



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Cost comparison from Highbridge study

NuScale Small Modular Nuclear Steam Supply System (NSSS) - High Bridge Associates External Independent Review (EIR) of Kiewit Power Constructors Reference Estimate (RE)

COST CATEGORY COMPARISON OF NEW NUCLEAR TECHNOLOGIES - $ IN MILLIONS

Cost Category	Average Large LWR	Average Liquid Metal	Average Gas Cooled	NuScale / Kiewit	NuScale / Kiewit / High Bridge
Licensing, Design and Planning	$ 196	$ 140	$ 131	$ 50	$ 75
Site Preparation	$ 209	$ 114	$ 25	$ 10	$ 10
Standard Plant Turbine Island	$ 1,181	$ 706	$ 241	$ 406	$ 373
Standard Plant Nuclear Island	$ 2,631	$ 815	$ 975	$ 741	$ 922
Non Standard Plant Yard	$ 960	$ 375	$ 472	$ 189	$ 134
Support Activities	$ 79	$ 74	$ 35	$ 2	$ 2
Distributables	$ 608	$ 79	$ 121	$ 128	$ 125
Total Base Cost	$ 5,864	$ 2,303	$ 2,000	$ 1,526	$ 1,641
Corporate Fees	$ 432	$ 348	$ 284	$ 291	$ 271
Contingency	$ 454	$ 345	$ 301	$ 118	$ 245
$'s	8%	15%	15%	8%	15%
G&A plus Escalation				115	78
Total Cost	$ 6,750	$ 2,996	$ 2,584	$ 2,049	$ 2,234
Installed Overnight Cost ~ $/Kwe	4968	4830	6460	3794	4091

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NuScale Features Summarized

- **Factory manufacturing** of entire NSSS fully captures the “economies of small”
- **Natural convection** cooling offers simplicity. enhanced safety
- **Proven light water** principles reduce technology risks and shorten regulatory path.
- **Integral test facility** operating and built – reduces regulatory risks and confirms design.
- **Seismically robust** to serve wide variety of sites
- **Strategic partnership** with Kiewit Power Constructors
- **Economics validated** by detailed design estimates
- **Established supply chain** relies on proven nuclear industry leaders

201 NW 3rd Street
Corvallis, OR 97330
541-207-3931
nuscalepower.com