NuScale SMR – On Track for Deployment

Tony Irwin
Technical Director
SMR Nuclear Technology Pty Ltd

ANA

26 June 2019

NuScale

- Brief history
- Design and specifications
- Safety Features
- Fuel management
- NRC GDA progress
- First deployment
- Multipurpose applications (Diverse Energy Platform)
- Economics
- Industrial partners and supply chain

Small Modular Reactors (SMRs)

- Reactors with a power output < 300 MWe (IAEA), more usually < 200 MWe
- Factory built reactor module

Technologies:

- Light water reactors (coolant and moderator)
- Gen IV
  - High temperature gas reactors
  - Molten salt reactors
  - Fast neutron reactors

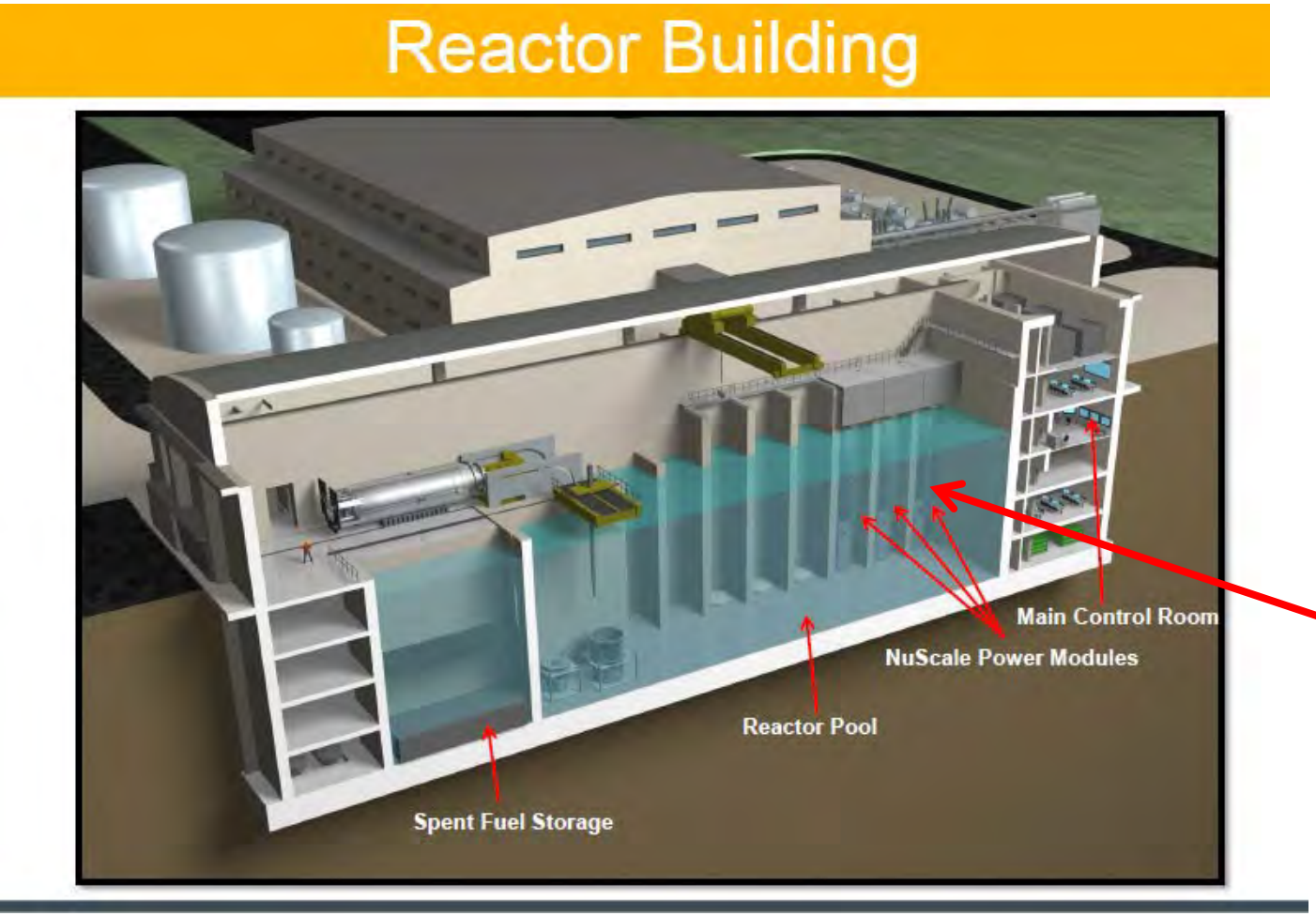
Small Modular Reactors (SMRs)

- Provide reliable, low emissions power in remote locations or for small grid systems
- High level of passive or inherent safety
- Reactor vessel can be installed below ground
- Compact, factory built, transportable module – reduced on-site construction time
- Lower initial capital cost and modules can be added as demand increases
- One module shutdown for refuelling, remaining modules producing power
- Simpler to operate and maintain
- Load following capabilities
- Compact site

Brief History of NuScale

- 2000 – Design based on MASLWR (Multi-Application Small Light Water Reactor) , a DOE funded project at Oregon State University
- 2007 – NuScale company formed, based in Corvallis, Oregon
- 2008 – NRC pre-application process commenced
- 2011 – Financial crisis, rescued by Fluor who became the major shareholder
- 2013 – won DOE grant award, first customer secured
- 2017 –Licensing application to NRC (first SMR to enter the full NRC licensing process)

NuScale Power (USA) 60 MWe power modules

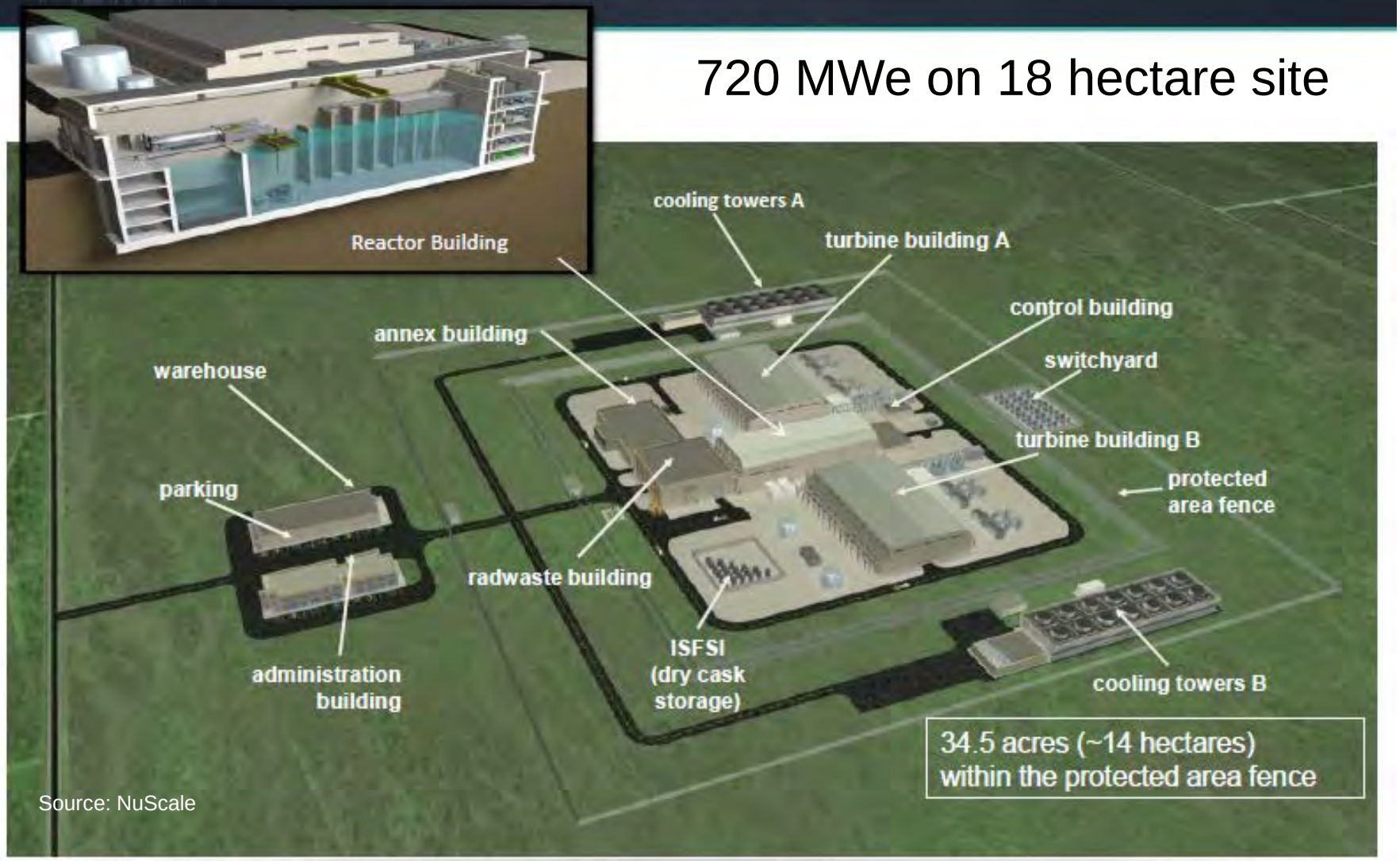


Up to twelve x 60MWe modules in 6m x 6m x 30m bays. Modules underground in a large common pool of water (assured heat sink). Pool water surface 1.8m below ground, pool water depth 21m

Reactor building 119m long x 60m wide, with 26m below ground. Source: NuScale Power

Site Layout

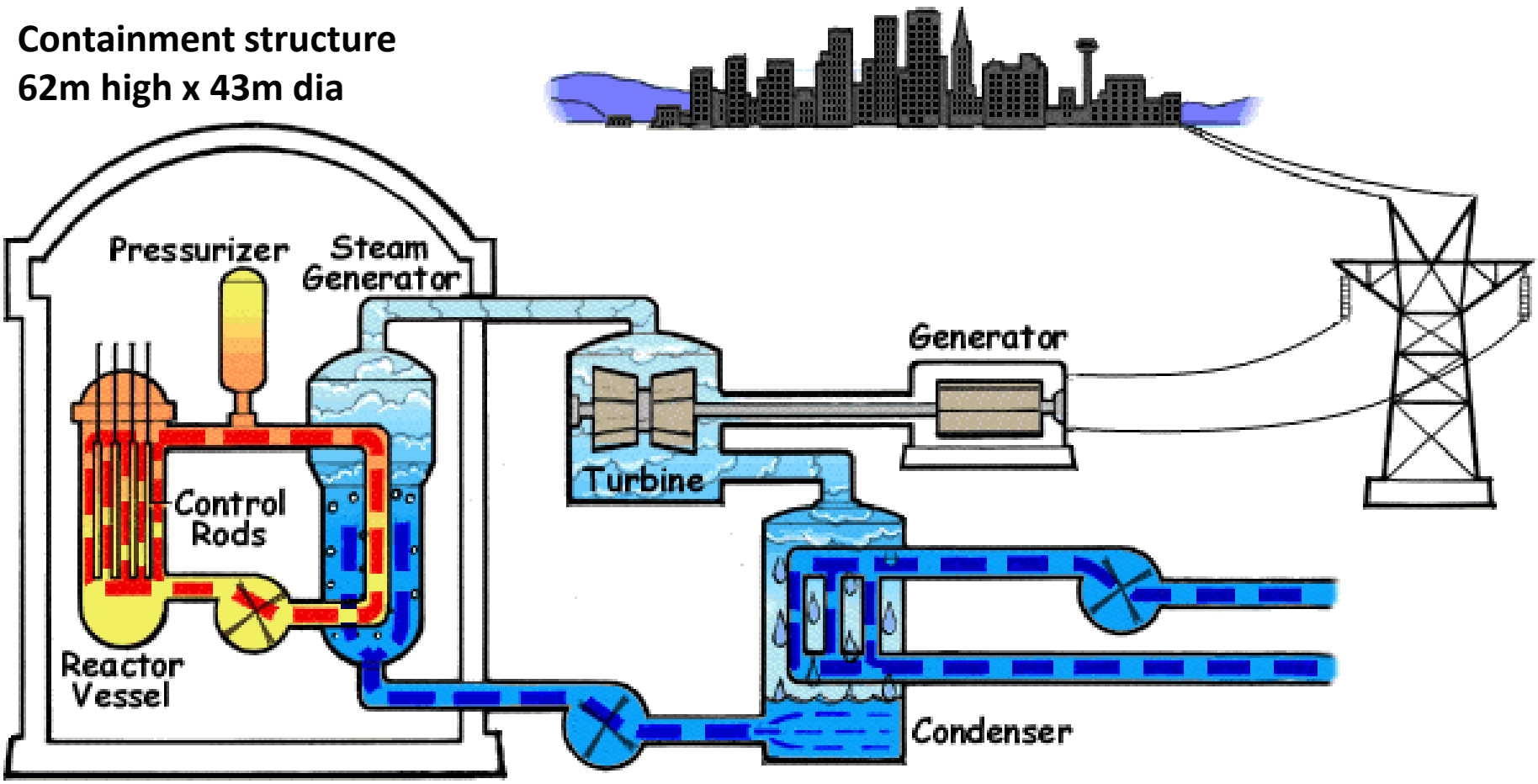
720 MWe on 18 hectare site



Source: NuScale

Pressurised Water Reactor (PWR)

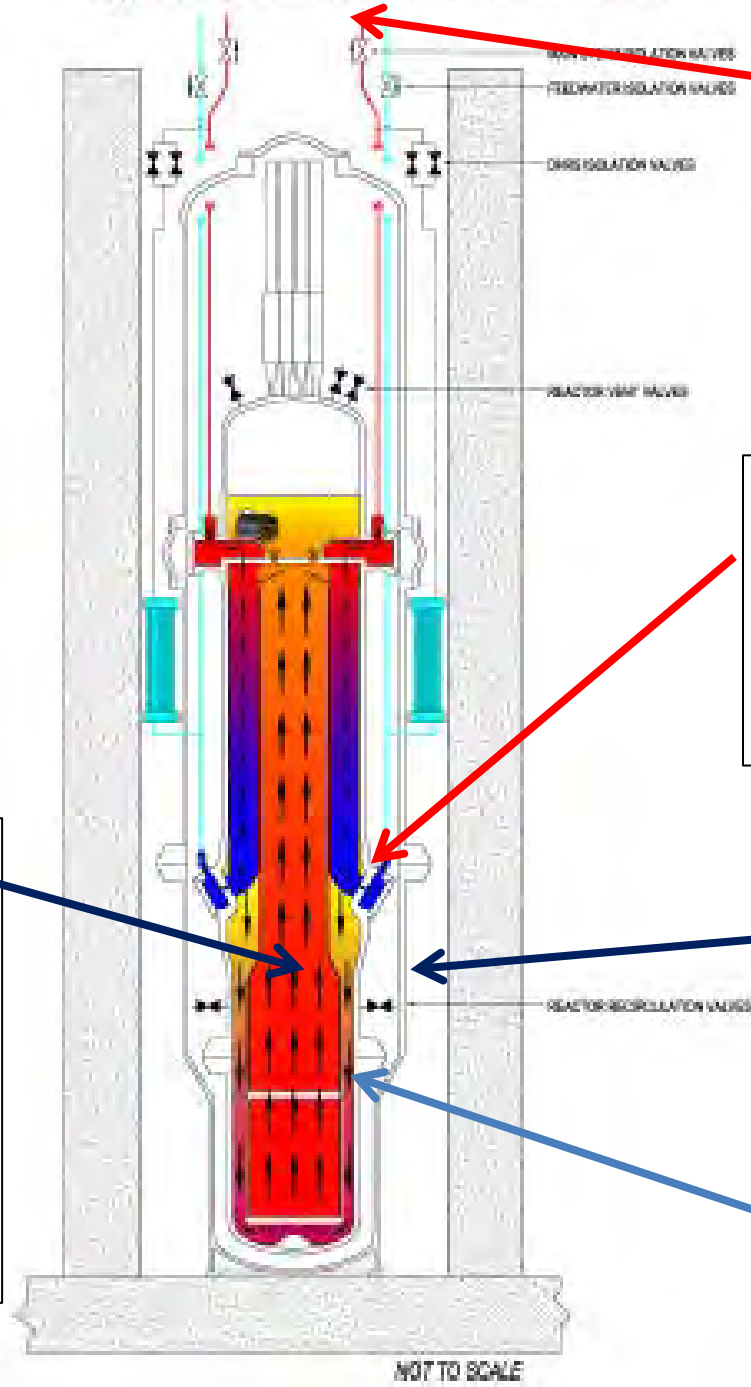
Containment structure
62m high x 43m dia



Typical PWR:
Primary circuit – 15 MPa, inlet 294^{o}C, outlet 325^{o}C (no boiling)
Secondary circuit – 6.2 MPa, inlet 224^{o}C**,** turbine inlet 275^{o}C

Source: US NRC

Figure 1.2-7: Steam Generator and Reactor Flow



Steam outlet to turbine
3.5 MPa, 302°C

Secondary Circuit
Main feed through 2 helical coil steam generators
Feed water 149°C

Primary Circuit
Natural circulation
12.7 MPa
Inlet 258°C
Average core temperature 284°C
Outlet 310°C

Containment vessel
23.08 m high x 4.32m ID
Under vacuum

Reactor vessel
17.7m high x 2.74m ID

Figure 1.2-3: Schematic of a Single NuScale Power Module and Associated Secondary Equipment

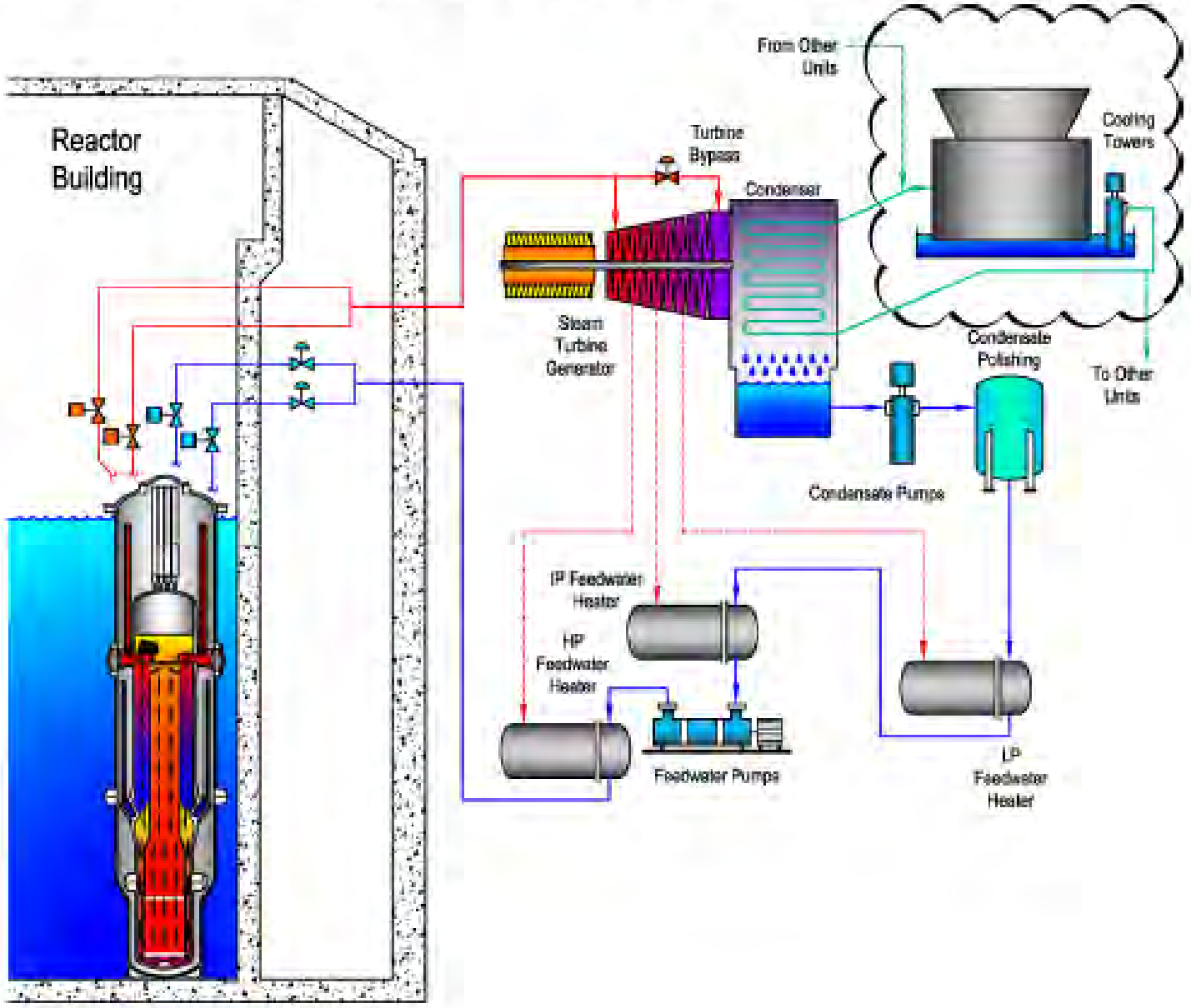
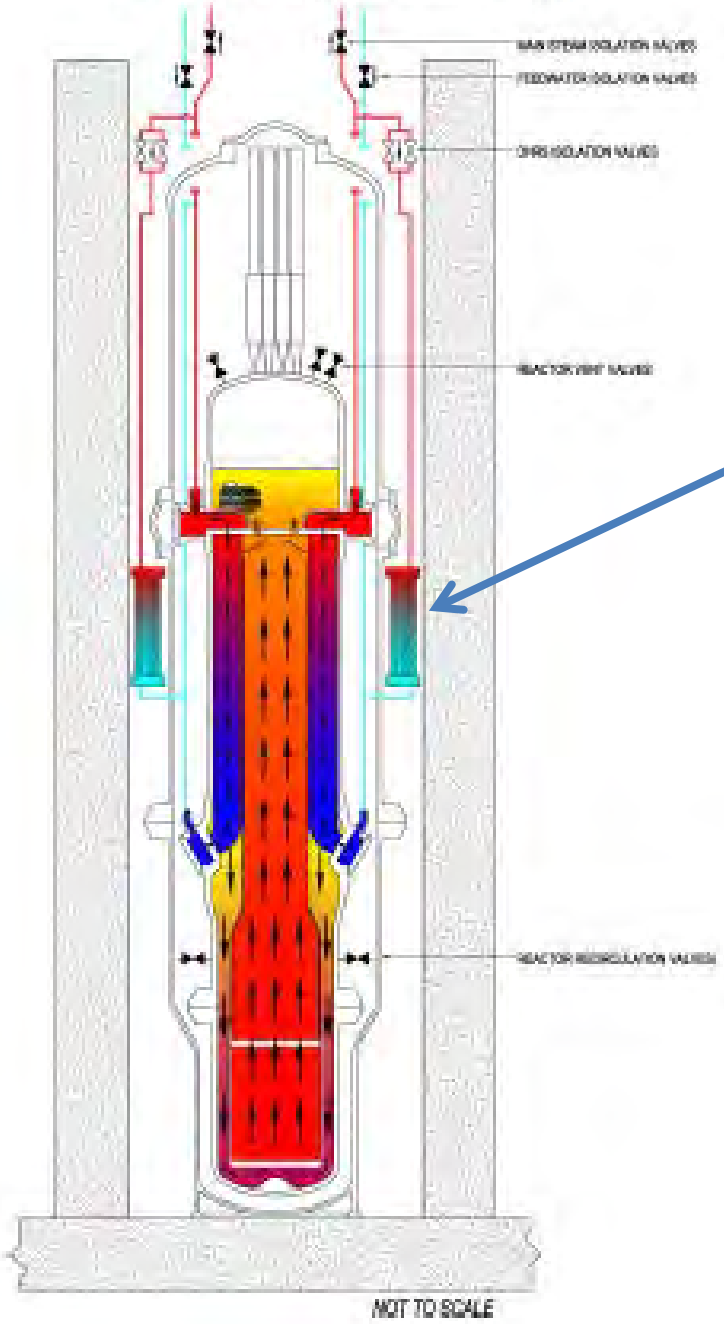


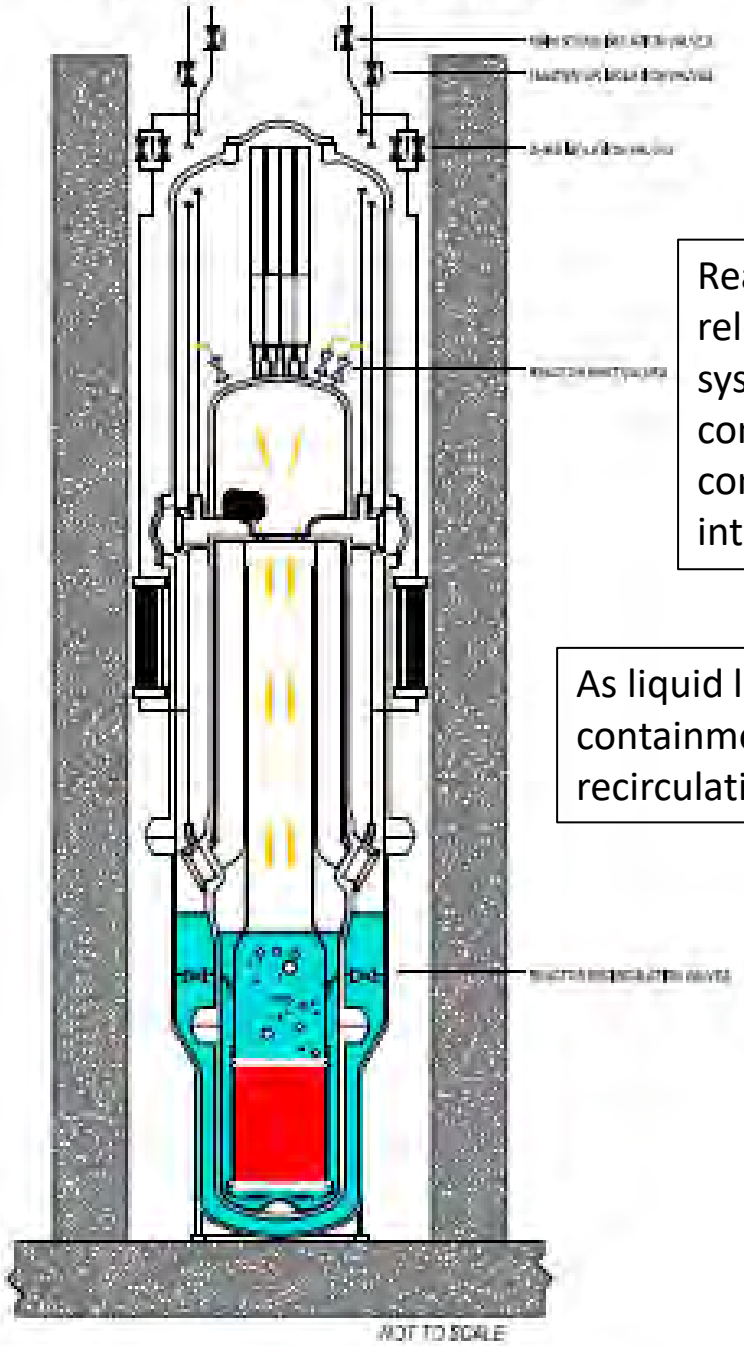
Figure 1.2-8: Decay Heat Removal System



Decay Heat Removal System (DHRS)

- Transfers core heat from either of the SGs to isolation condensers (heat exchangers) immersed in the common reactor pool
- 2 x 100% trains,
- Capable of decay heat removal for a minimum of 3 days without pumps or power

Figure 1.2-9: Emergency Core Cooling System

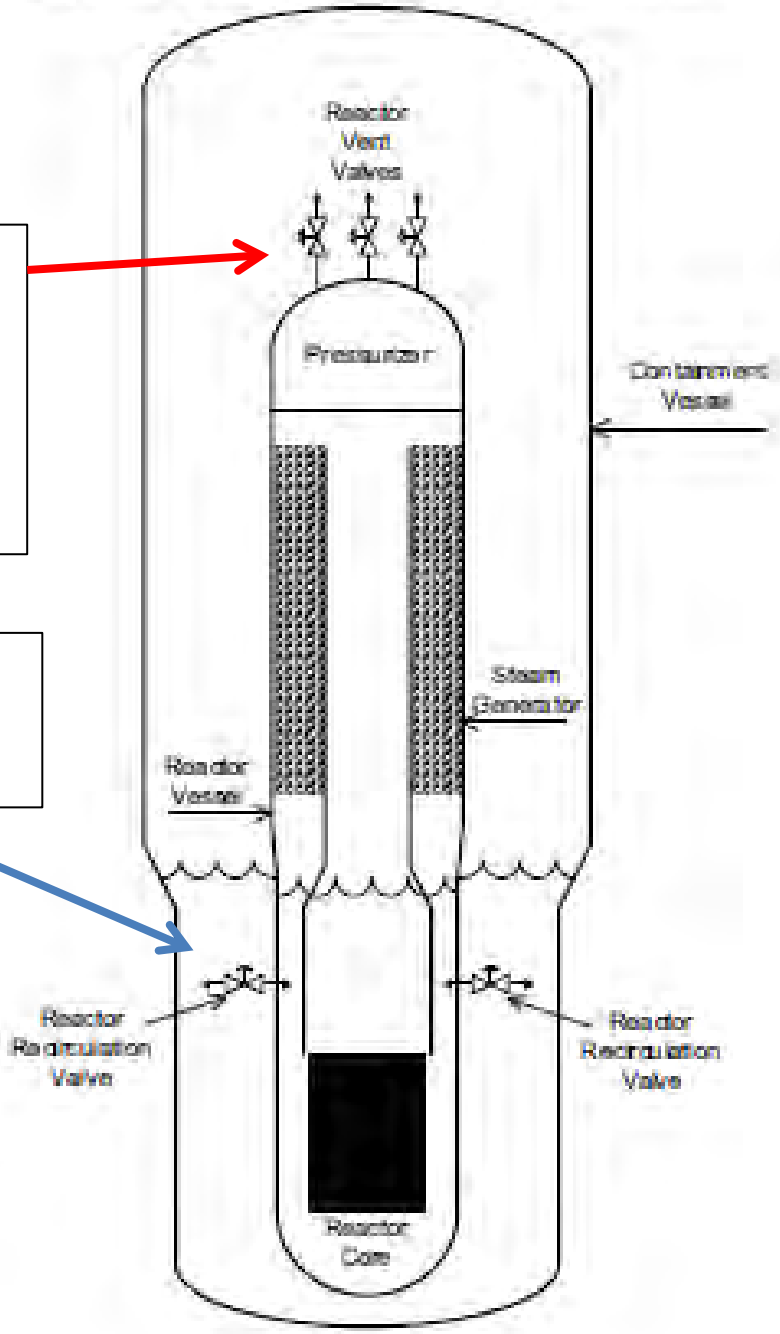


NOT TO SCALE

Reactor vent valves release primary system steam into containment – condenses on internal surface

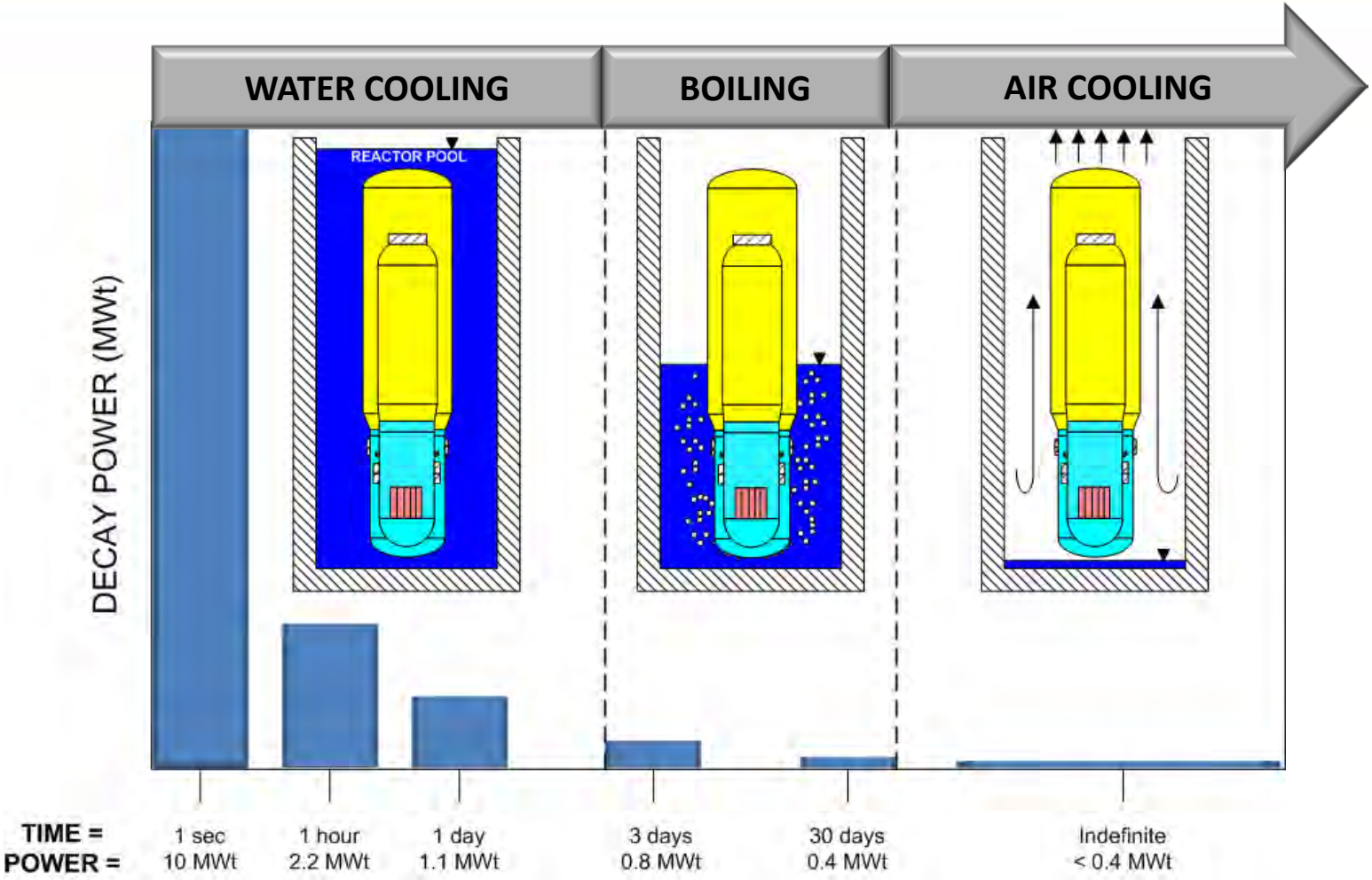
As liquid level rises in containment, reactor recirculation valves open

Figure 6.3-2: Emergency Core Cooling System Operation



Stable Long Term Cooling

Reactor and nuclear fuel cooled indefinitely without pumps or power



NuScale Power

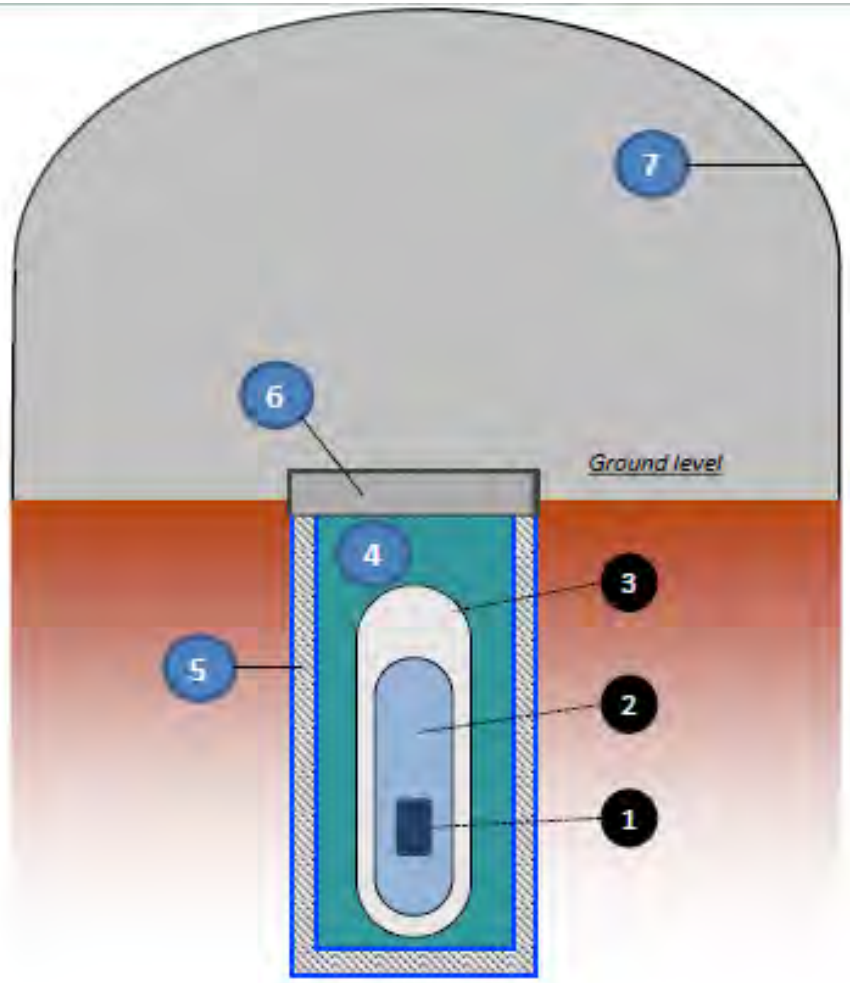
NuScale SMR Additional Physical Barriers

Conventional Designs

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

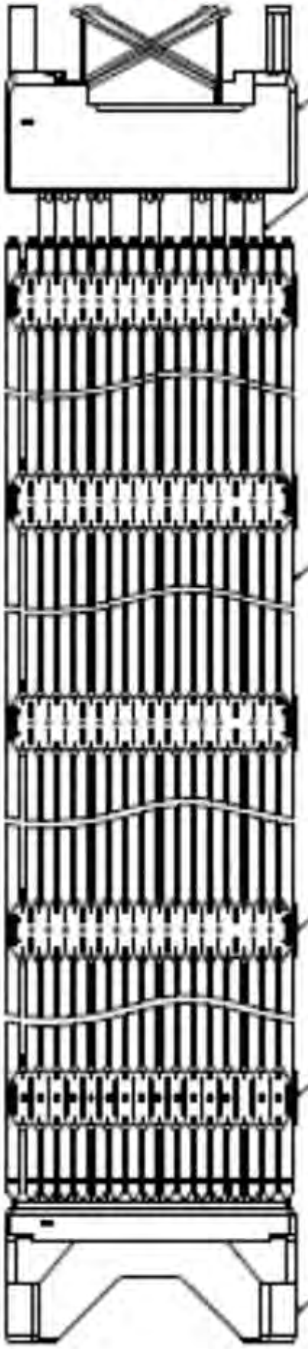
NuScale's Additional Barriers

4. Water in Reactor Pool
5. Stainless Steel Lined Concrete Reactor Pool
6. Biological Shield Covers Each Reactor
7. Reactor Building



NuScale 60MWe SMR Module

Figure 4.2-1: Fuel Assembly General Arrangement



Stainless steel top nozzle

24 Zr-4 CRA guide tubes
1 centre instrumentation tube

Control Rod Assembly (CRA)
24 individual rods in the guide tubes fixed to a top spider. B_4C pellets upper portion, silver-indium-cadmium (AIC) lower, all in 304 stainless steel tube.

264 fuel rods
Length 2159 mm
Active fuel length 2000 mm
M5 (zirconium alloy) clad
OD 9.5mm

Four Zr-4 HTP spacer grids

Alloy 718 HMP spacer grid

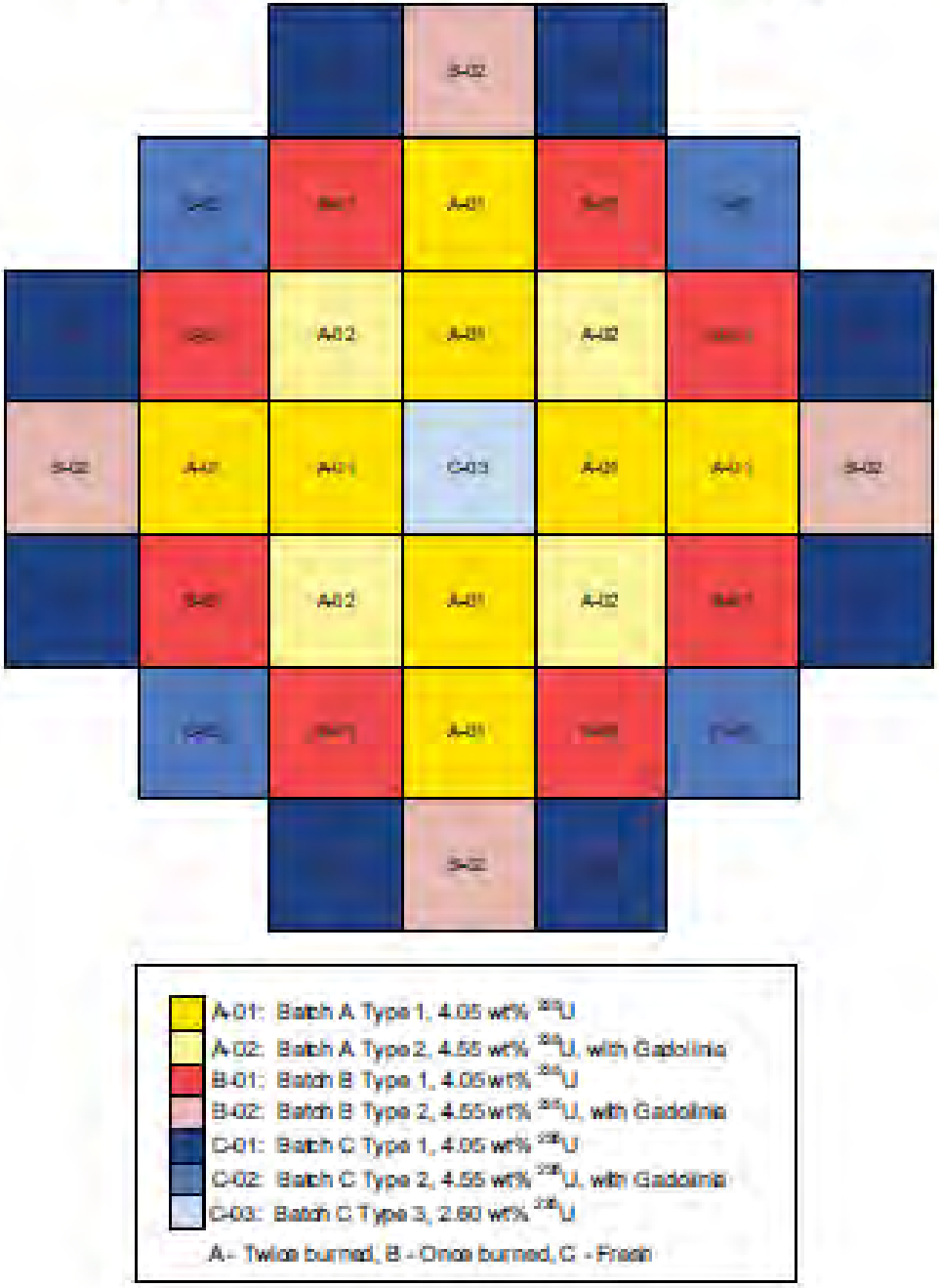
Stainless steel bottom nozzle with mesh filter to trap debris

Fuel Assemblies
AREVA NuFuel HTP-2

Standard 17 x 17 FA's,
Length = 2.43m

Reduced enrichment axial blanket at top and bottom with a central fully enriched zone.
Gadolinia burnable poison

Figure 4.3-1: Loading Pattern for Reference Equilibrium Cycle



Refuelling Schedule

24 months operating cycle
10 days to refuel module

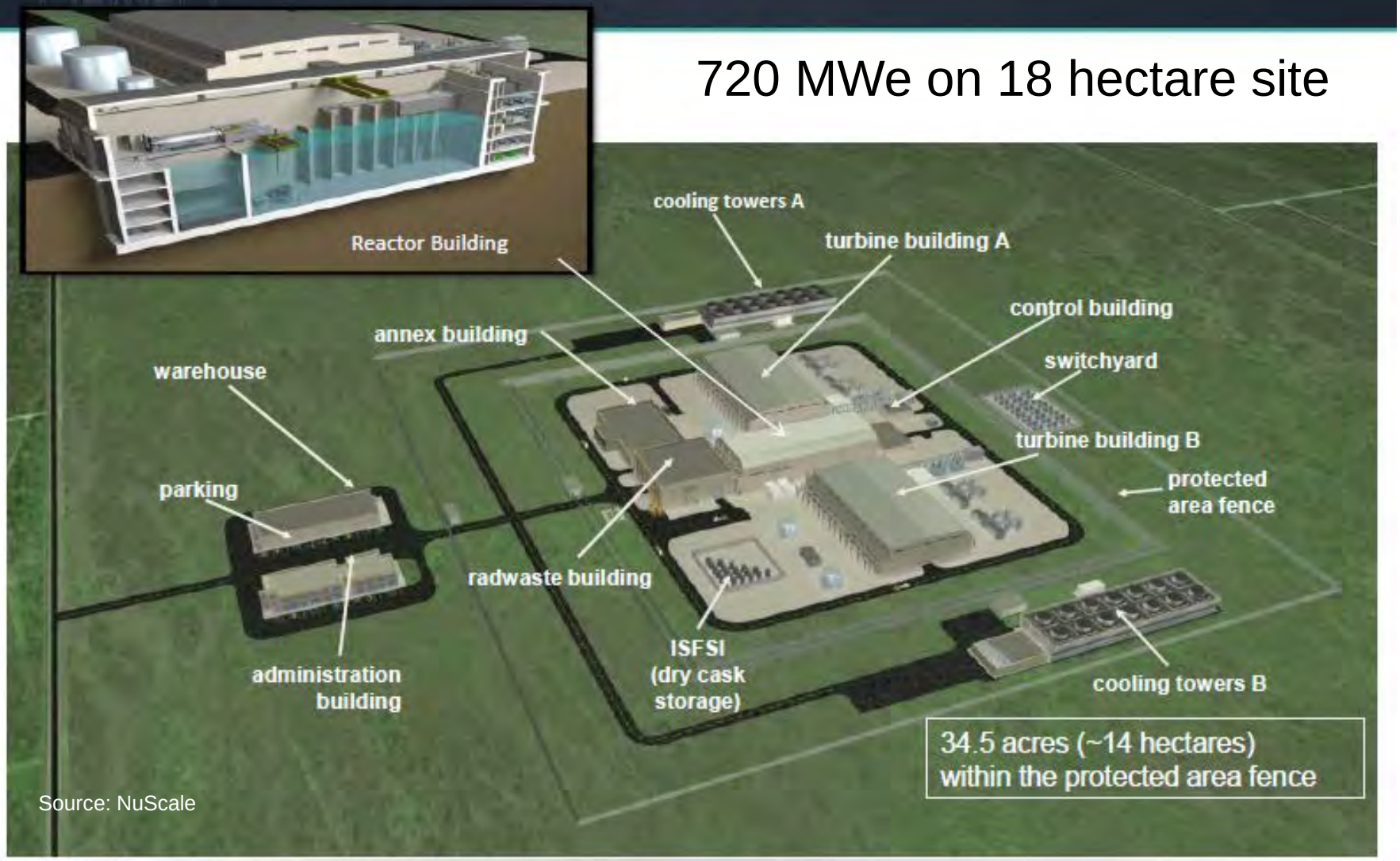
Core contains 37 fuel assemblies
Refuel one third of the core (12/13 fuel assemblies)
Fresh fuel on periphery of core and shuffles burned fuel into the middle
"out-in" refuelling

37 Fuel assemblies
9.23 tonnes UO_2
Nominal 249.5 kg UO_2 /FA

Ref: NuScale FSAR

Site Layout

720 MWe on 18 hectare site



Turbine cooling water requirements for 12 modules: 696 l/s, dry cooling would reduce requirements by 75% and decrease output by ~ 30 MW

Ref: NuScale response to SANFCRC question

Radioactive Waste

Total solid waste = 126 m^3/year (2 shipping containers) for 12 module (720 MWe) plant

Sources of solid dry and wet waste:

- HVAC and HEPA filters, used PPE, rags and wipes, tools = 104m^3/year
- failed equipment = 0.2m^3/year
- LRWS (Liquid radioactive Waste System) resins, filter cartridges, oily waste, charcoal = 7.3 m^3/year
- CVCS (Chemical and volume Control System) and PCUS resins and filters = 14.2 m^3/year

Gaseous Radioactive Waste- filter and decay:

- moisture separator – guard bed – charcoal decay beds (2 trains, 4 beds/train) – discharge

Spent fuel

- Average 6 FAs/module/year
- Stored in spent fuel pond for >5 years
- Transferred to dry casks on site

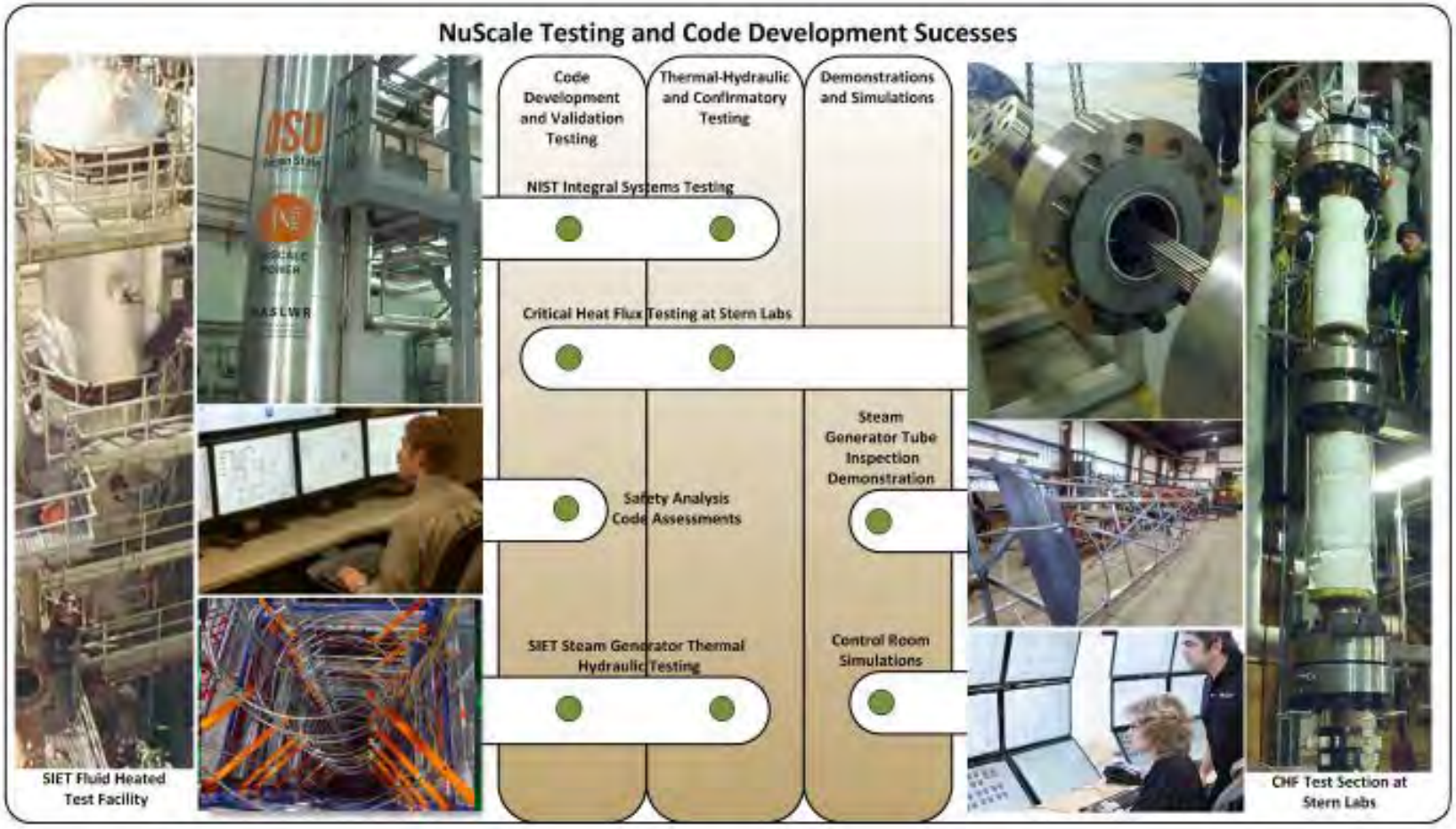
FSAR Table 11.4-2

NRC Licensing Process

- July 2008 – began pre-application interactions
- January 2017 – Generic Design Certification application to NRC (first ever SMR)
- Jan 2018 – NRC accepted that the NuScale SMR can operate without the need for safety related electrical equipment
- April 2018 – Phase 1 completed – preliminary SER with open items
- September 2020 –NRC issue Final Safety Evaluation Report (FSER)
- January 2021 – Design certified

Comprehensive Testing Program

Our testing supports reactor safety code development and validation, reactor design, and technology maturation to reduce FOAK risk.



Source: NuScale Power

NuScale Control Room Simulator

NuScale Power

Image: NuScale

NuScale Upper Module

Full scale mock up including upper section of containment vessel, reactor vessel head, major piping and valves, control rod drive mechanisms, module access platform

Assists in assessment of inspection and maintenance activities

Project WIN

- Western Initiative for Nuclear (WIN) is a multi-western state collaboration to deploy a series of NuScale Power Projects

- Involved Program WIN participants: NuScale, UAMPS, Energy Northwest, ID, UT, OR, WA, WY, AZ,

Utah Associated Municipal Power Systems (UAMPS) Carbon Free Power Project (CFPP) will be the first deployment

NuScale first customer

- Utah Associated Municipal Power Systems (UAMPS) – a consortium of 45 Western community-owned utilities
- Low emissions replacement for coal plants
- Site – 35 acre (14 hectare) on US Department of Energy Idaho National Laboratory (INL) site west of Idaho Falls
- Combined construction and operating licence application (COLA) by UAMPS in 2019
- Plant will be operated by Energy Northwest

12 Module (720 MWeG) Plant on INL Site

Joint Use Modular Power Program (JUMP)

- Agreement with DOE for first module to be used for R&D, including integration with other energy sources

- Provision for integrating equipment with the steam producing side of the reactor, for example steam to drive an industrial process
- Could also connect with the microgrid test bed at INL

- Module will have additional instrumentation

- Agreement with DOE for second module to supply INL's energy needs under a Power Purchase Agreement

UAMPS timescale

- 2019/20 Combined construction and operating licence application (COLA) by UAMPS
- 2021 – site preparation starts
- 2023 – start of nuclear construction
- 2026 – First 50 MW module operating
- 2027 – all 12 modules operating

DOE awarded $16.5m in matching funds to perform site selection, secure site and water, and prepare COLA to NRC

Tennessee Valley Authority (TVA)

- May 2016 – TVA submitted an Early Site Permit (ESP) Application for use of a site at Clinch River for two or more SMRs. NuScale SMR used as a technical basis for evaluation of Emergency Planning Zones (EPZ)

- August 2018 – NRC agreed that the EPZ around SMRs can be scaled down to reflect their reduced risk. For NuScale this would be reduced to the site boundary.

- June 2019 – NRC published final safety evaluation report (FSER), concluded that there are no safety concerns preventing issue of an ESP

-

Small Modular Reactors

- Multipurpose
  - electricity
  - heating for buildings
  - process heat for industry
  - desalination

NuScale Diverse Energy Platform

Oil Refineries Study - Reduction of Carbon Emissions
(Fluor and NuScale)

10-Module Plant coupled to a 250,000 barrels/d refinery

Integration with Wind Study - Horse Butte Site
(UAMPS, ENW and NuScale)

1-Module dedicated to UAMPS 57.6 MW wind farm

Reliable Power for Mission Critical Facilities *(NuScale)*

12-Module Plant coupled to a 100 MWe Mission Critical Facility

Hydrogen Production Study – High-Temperature Steam Electrolysis
(INL and NuScale)

6-Module Plant for Emission Free Hydrogen Production

Desalination Study – Sized for the Carlsbad CA Site
(Aquatech and NuScale)

8-Module Plant can produce 50 Mgal/d (190K m^3/d) of clean water plus 350 MWe

NUSCALE POWER

NuScale Load Following Capability

- Module output can be varied by 40%/hour. 12 module plant has 12 degrees of freedom
- Shutdown of one module of 12 module plant reduces output by 8%. A module can be returned to service in a few hours from a hot shutdown
- Each module has a 100% turbine bypass enabling fast load changes
- Can continue operating if disconnected from the grid

600 MWe
12 module plant
Overnight cost
FOAK $3 billion
NOAK $2.6 billion

Overall EPC Overnight Plant Costs

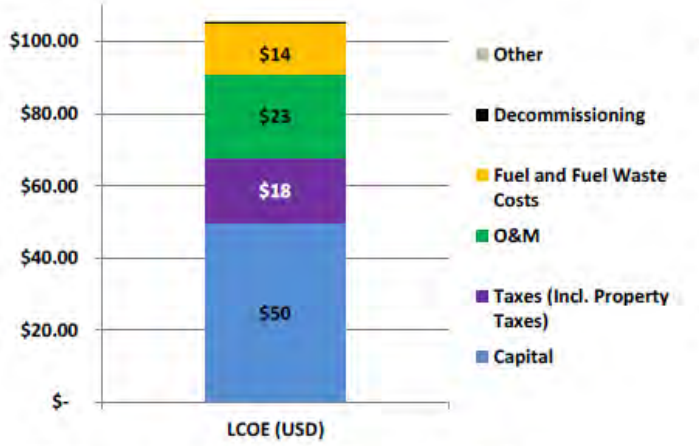
($1,000,000)

ITEM	2014 Dollars
Power Modules (FOAK Cost plus Fee, Transportation, & Site Assembly)	$ 848
Home Office Engineering and Support	$ 144
Site Infrastructure	$ 60
Nuclear Island (RXB, RWB, MCR)	$ 538
Turbine Island (2 buildings with 6 turbines each)	$ 350
Balance of Plant (annex, cooling towers, etc)	$ 225
Distributables (Temp. Bldgs., Field Staff, Const. Equip., etc.)	$ 545
Other Costs	$ 185
Total Overnight Price	**$ 2,895**

$ 5,078 per kWe net

60 MWeG module $4,200 per kWe net

Levelized Cost in 2015 US Dollars



FOAK with Regulated Utility Financing (IOU)

- 55% debt at 5.5%, 45% equity at 10%

$ 106 USD

FOAK with Municipal Financing

- 100% debt at 3.5%, no equity

$ 72 USD

Note: Capital costs reflect the Fluor SE estimate completed in 2014.

Target LCOE $65/MWh

Industrial Partnerships and Supply Chain

- **Sargent & Lundy** – development of the standard plant, additional architect engineering support
- **Doosan Heavy Industries & Construction** – co-operation and investment
- **BWXT** – optimize the engineering design for manufacturing, assembly and transportation
- **Rock Creek Innovations –** highly integrated protection system for module protection
- **Ultra Electronics Energy –** safety display and indication
- **Areva –** fuel assemblies
- **Rolls-Royce –** advanced nuclear technology
- **Curtiss-Wright –** control rod drive mechanism design
- **Sheffield Forgemasters –** RPV head
- **Concurrent Technologies Corporation –** advanced manufacturing processes for helicoil steam generators

International

- **Canada** – Service agreement with CNSC for vendor design review in 2019. MOU's with Ontario Power Generation and Bruce Power
- **Romania** – agreement with Societata Nationala Nuclearelectrica SA
- **UK** – office established in UK, looking to deployment in the UK in the next decade
- **Jordan** – possible deployment for desalination
- **Estonia** – included in short list for feasibility study

- **Australia** – SMR Nuclear Technology Pty Ltd since 2011

- **NuScale is on track for deployment in the 2020’s**