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Power for all humankind

NuScale Plant Overview And FPGA Licensing History

October 2019

Presenter
Cyrus Afshar
Licensing Supervisor, NuScale

Acknowledgement and Disclaimer

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Artistic concept of the NuScale Power Plant

NuScale's Mission

NuScale Power provides scalable advanced nuclear technology for the production of electricity, heat, and clean water to **improve the quality of life for people around the world.**

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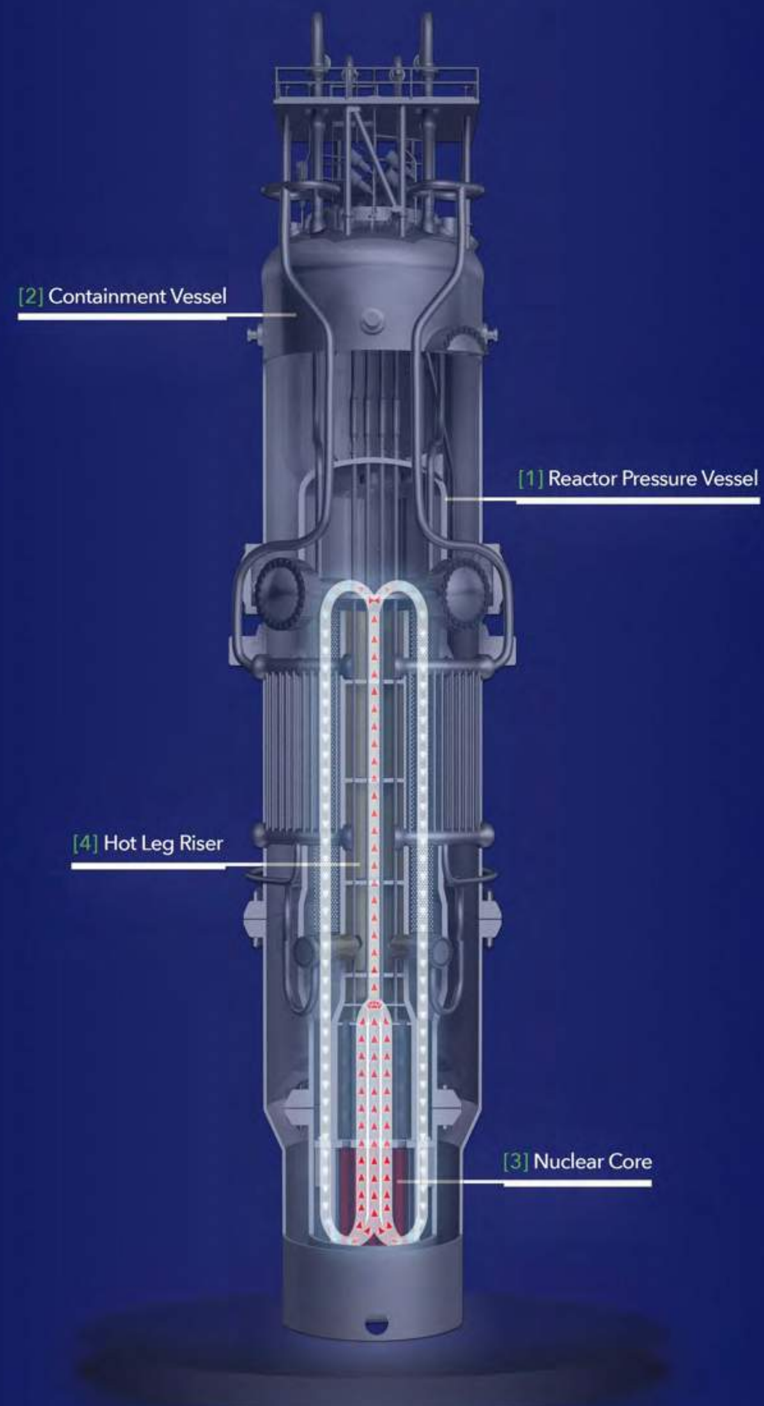
Who is NuScale Power?

- NuScale Power was formed in 2007 for the sole purpose of completing the design and commercializing a small modular reactor (SMR) – the NuScale Power Module™.
- Initial concept had been in development and testing since the 2000 U.S. Department of Energy (DOE) MASLWR program.
- Fluor, global engineering and construction company, became lead investor in 2011.
- In 2013, NuScale won a $226M competitive U.S. DOE Funding Opportunity for matching funds.
- >400 patents granted or pending in nearly 20 countries.
- >350 employees in 6 offices in the U.S. and 1 office in the U.K.
- Making substantial progress with a rigorous design review by the U.S. Nuclear Regulatory Commission (NRC).
  - Phase 4 of NRC Review is on schedule for completion December 2019.
- Total investment in NuScale to date ~US$800M.
- On track for first plant operation in 2026 in the U.S.

NuScale Engineering Offices Corvallis

One-third scale NIST-1 Test Facility

NuScale Control Room Simulator



Core Technology: NuScale Power Module

- A **NuScale Power Module**™ (NPM) includes the reactor vessel, steam generators, pressurizer, and containment in an **integral package** – simple design that eliminates reactor coolant pumps, large bore piping and other systems and components found in large conventional reactors.

- Each module produces **up to 60 MWe**
  - small enough to be factory built for easy transport and installation
  - dedicated power conversion system for flexible, independent operation
  - incrementally added to match load growth – up to **12 modules for 720 MWe** gross (684 MWe net) total output

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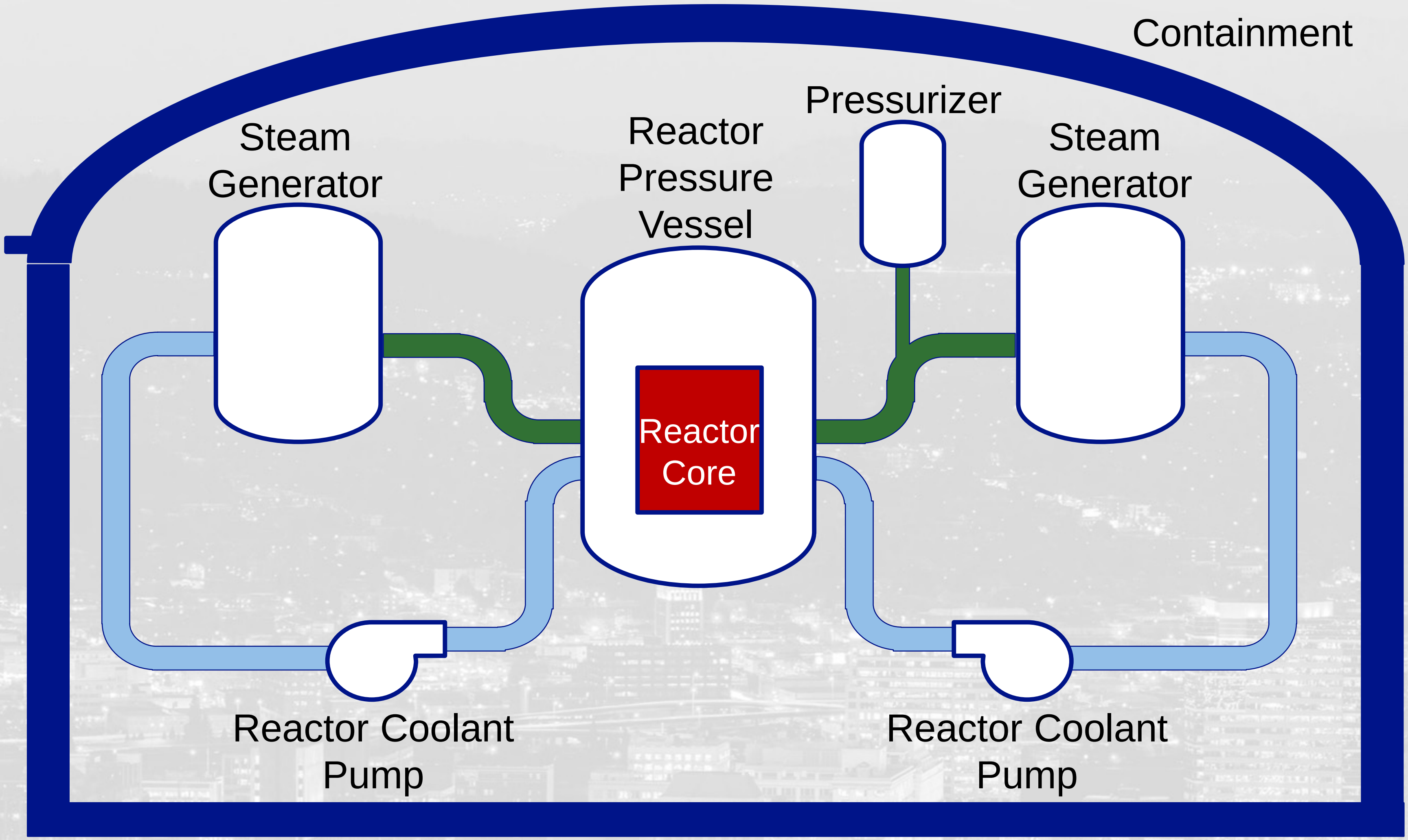
Typical Pressurized Water Reactor



NuScale Small Modular Reactor

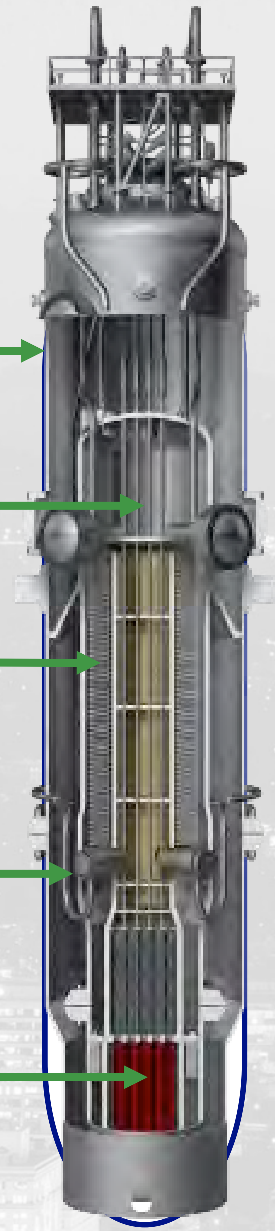
Containment

Pressurizer

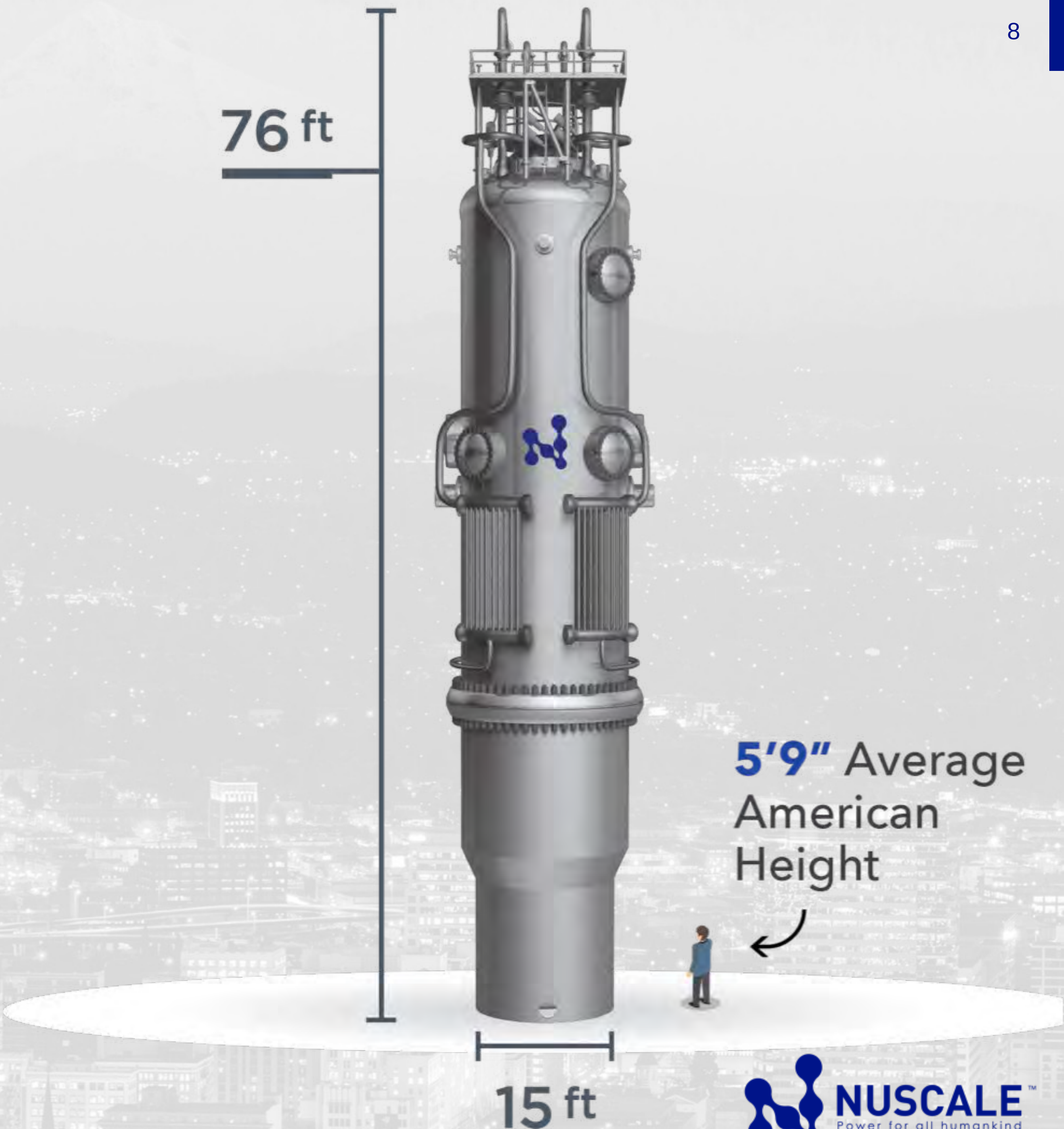
Steam Generators

Reactor Pressure Vessel

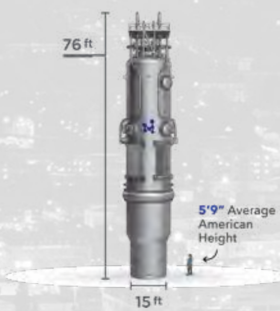
Reactor Core



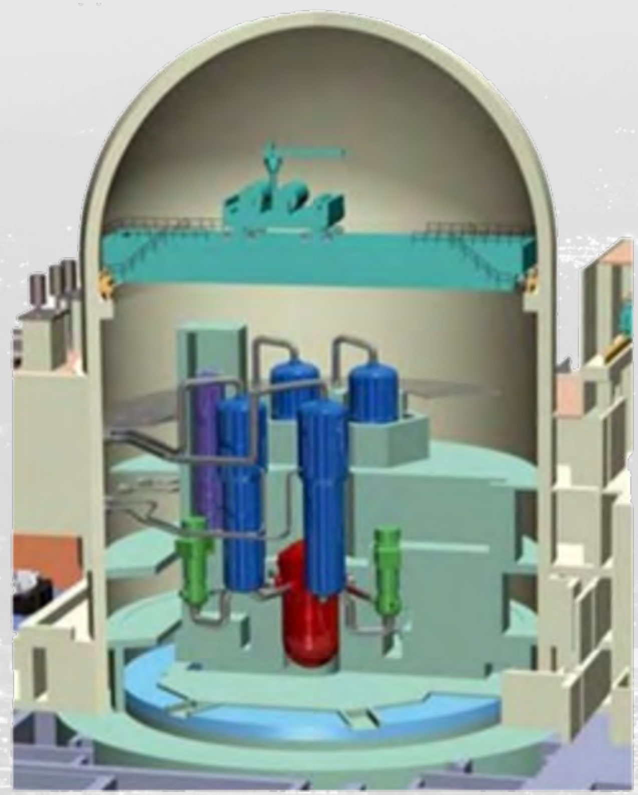
Dimensions



Comparison to a Large Pressurized Water Reactor (PWR)



NuScale Power Module



Typical Large PWR

Image: U.S. Nuclear Regulatory Commission

Simplicity Enhances Safety

Natural Convection for Cooling

- Passively safe - cooling water circulates through the nuclear core by natural convection eliminating the need for pumps

Seismically Robust

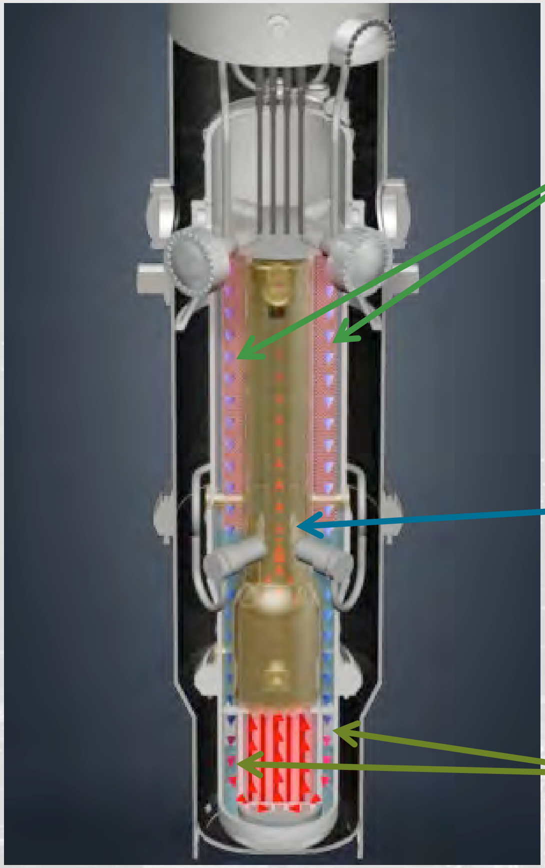
- System submerged in a below-grade pool of water in an earthquake and aircraft impact resistant building

Simple and Small

- Reactor core is 1/20th the size of large reactor cores
- Integrated reactor design - no large-break loss-of-coolant accidents

Defense-in-Depth

- Multiple additional barriers to protect against the release of radiation to the environment



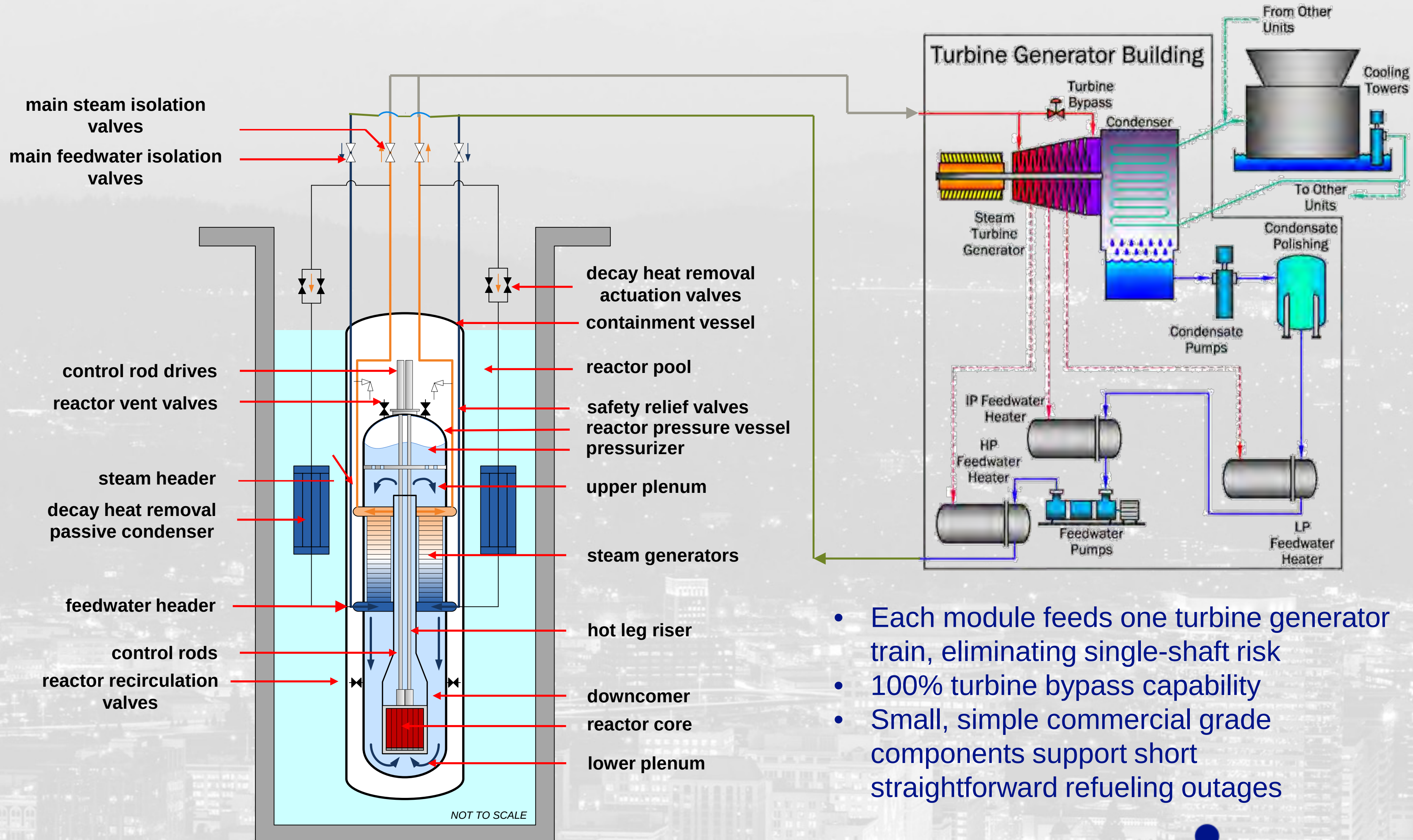
Conduction **– the water heated by the nuclear reaction (primary water) transfers its heat through the walls of the tubes in the steam generator, heating the water inside the tubes (secondary water) and turning it to steam. This heat transfer cools the primary water.**

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

Gravity / Buoyancy **– colder (denser) primary water “falls” to bottom of reactor pressure vessel, and the natural circulation cycle continues**

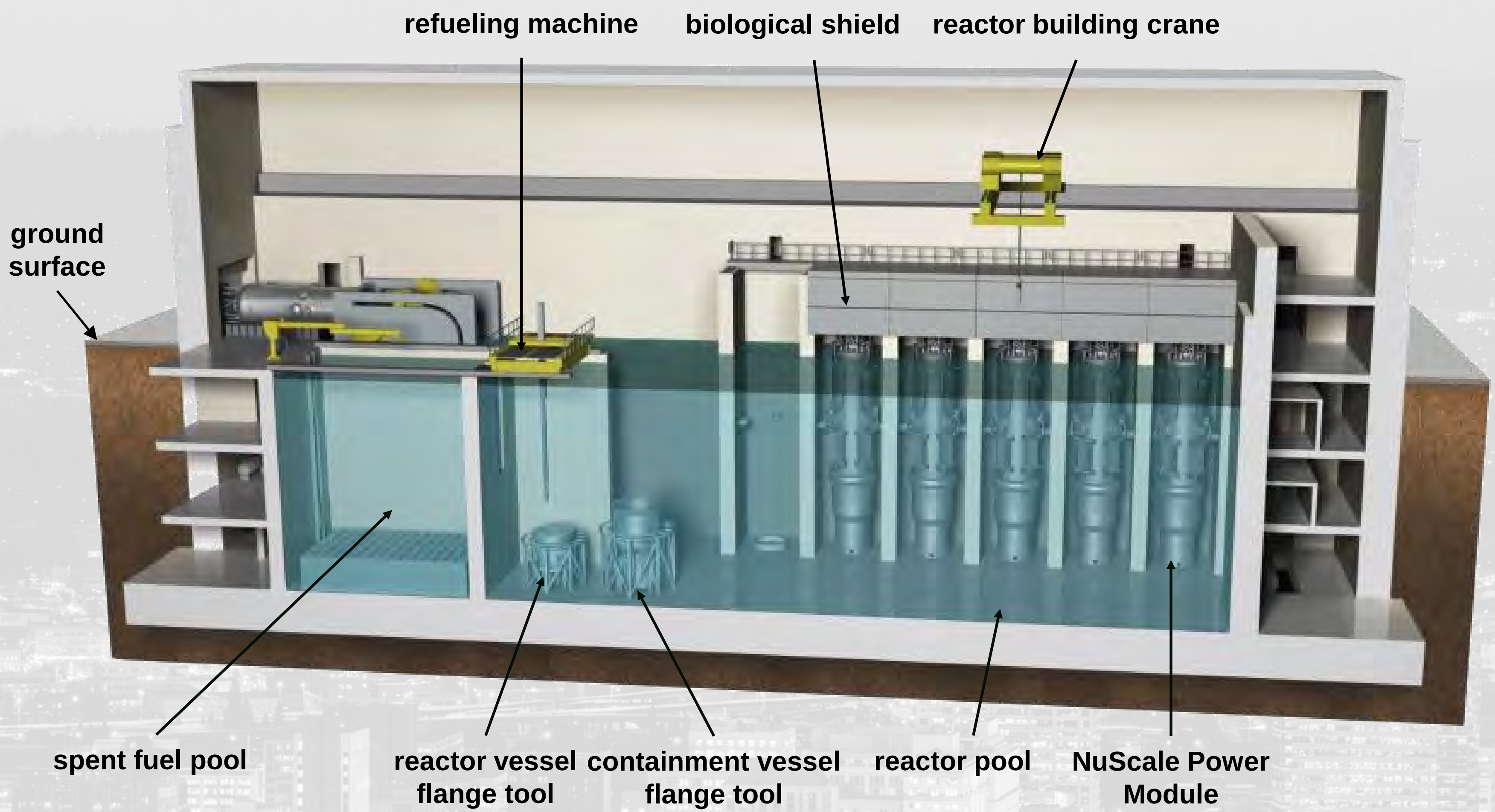
Second-to-none safety case – site boundary Emergency Planning Zone capable

NuScale Power Train

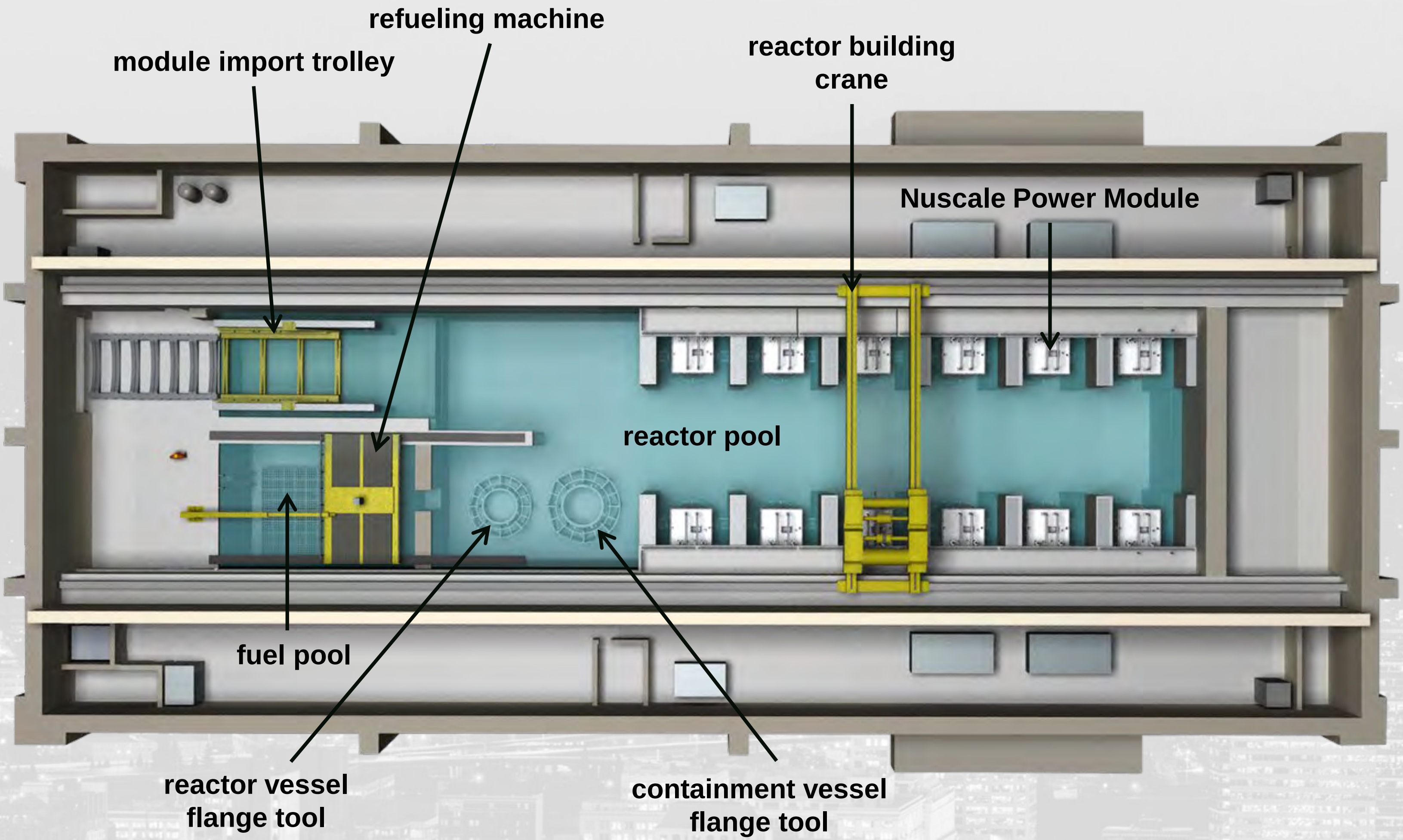


- Each module feeds one turbine generator train, eliminating single-shaft risk
- 100% turbine bypass capability
- Small, simple commercial grade components support short straightforward refueling outages

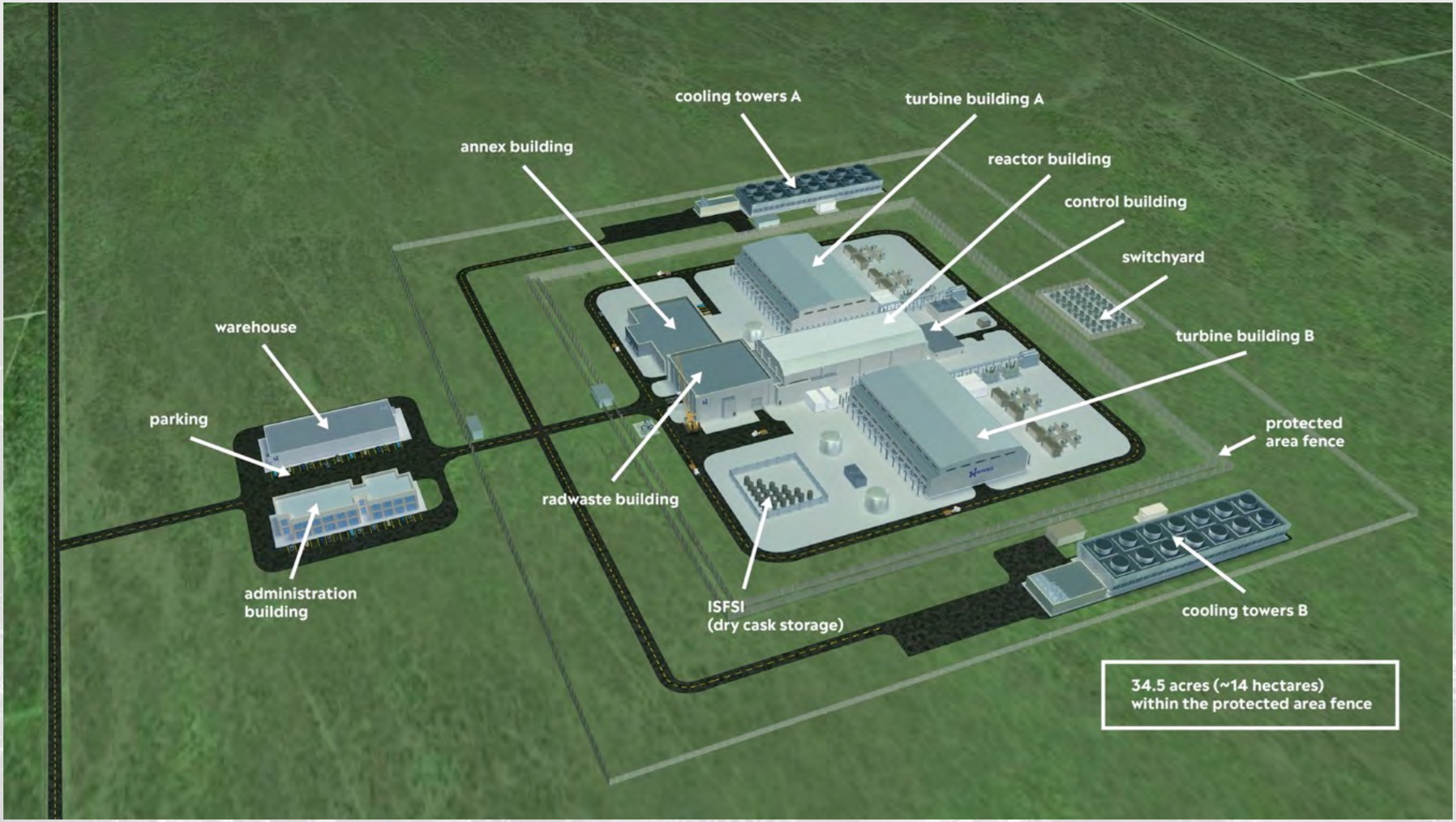
Reactor building houses NuScale Power Modules™, spent fuel pool, and reactor pool



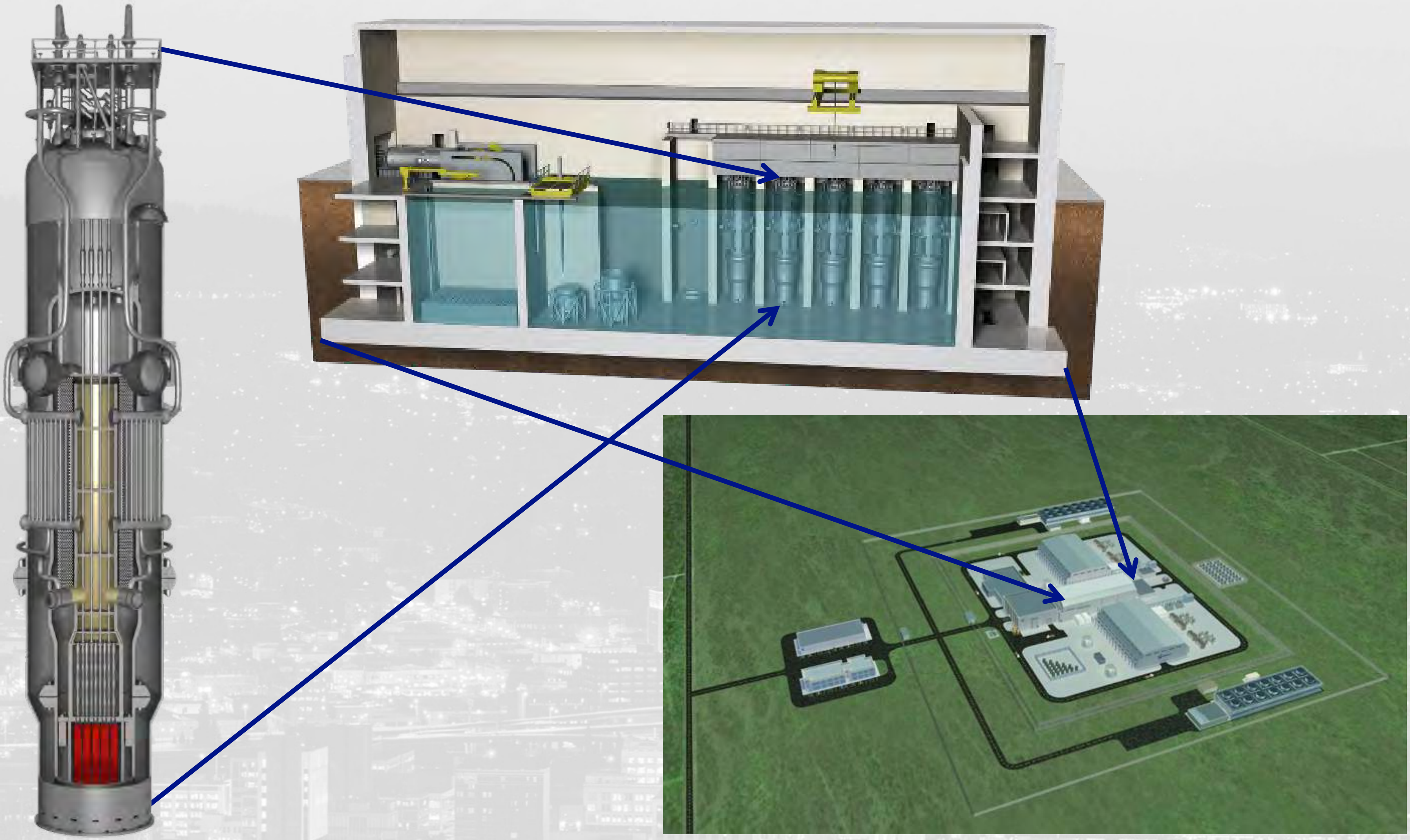
Reactor Building Overhead View



Detailed Plant Site Layout

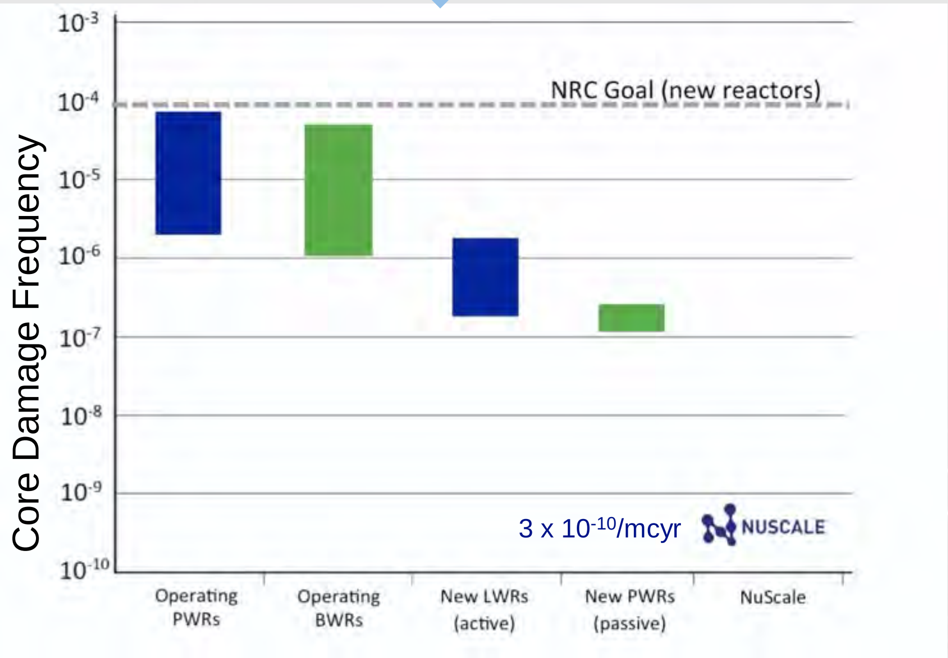


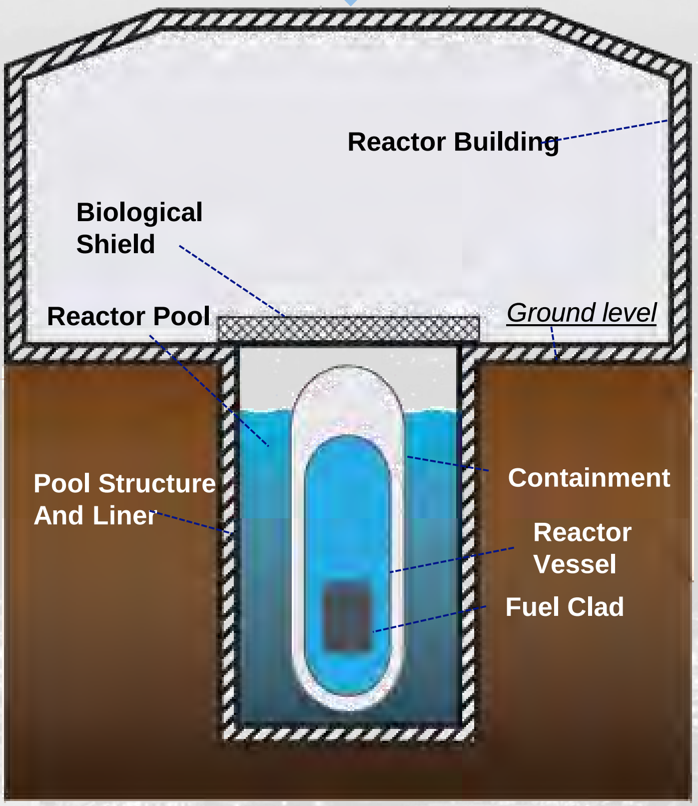
NuScale Plant Site Overview



Reducing Plant Risk

Risk = (frequency of failure) X (consequences)





Probability of core damage (Full Power) due to NuScale reactor equipment failures is
1 event per module every ~3 Billion Years

Four additional barriers to release of radioactivity from a NuScale plant.

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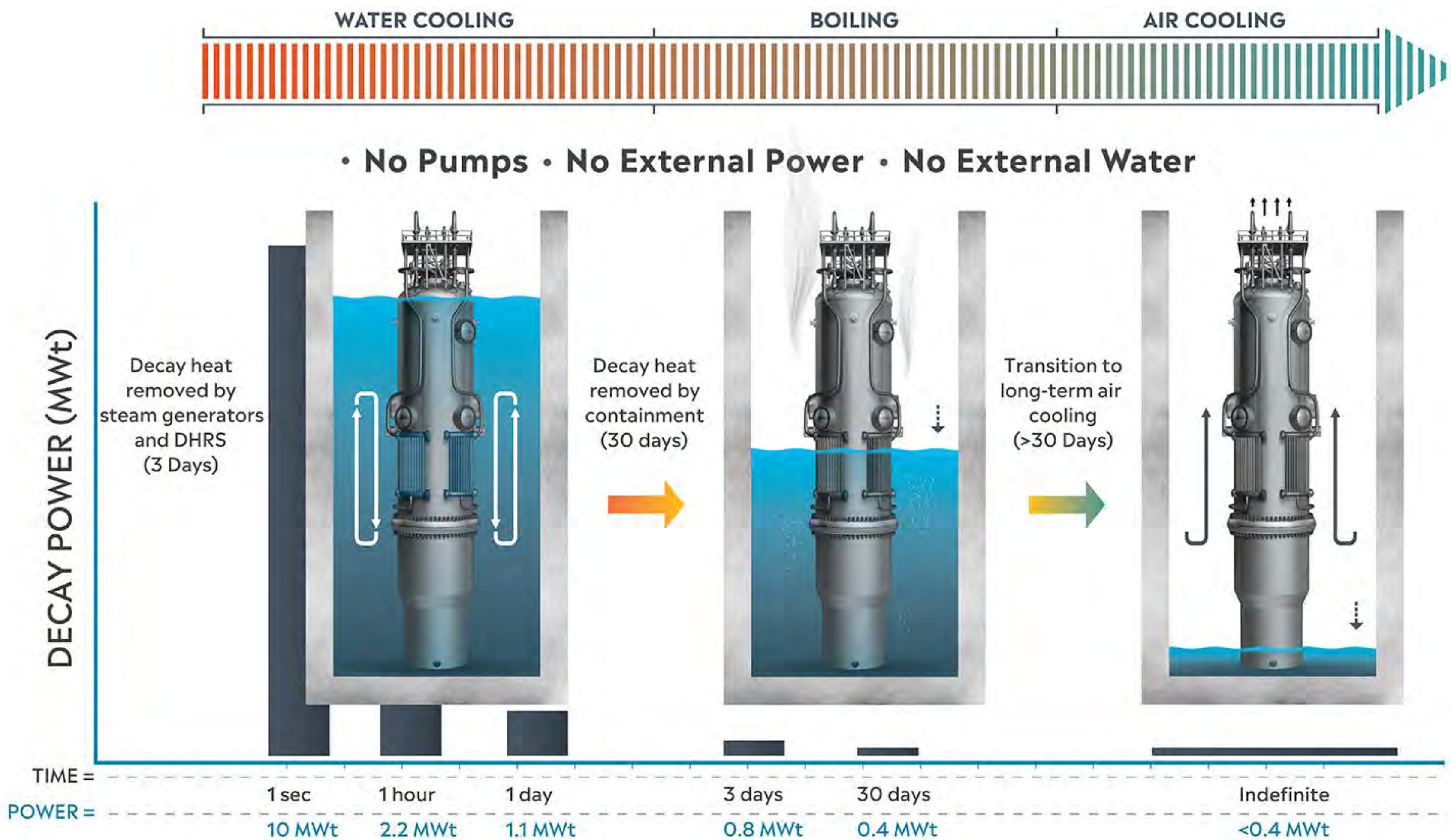
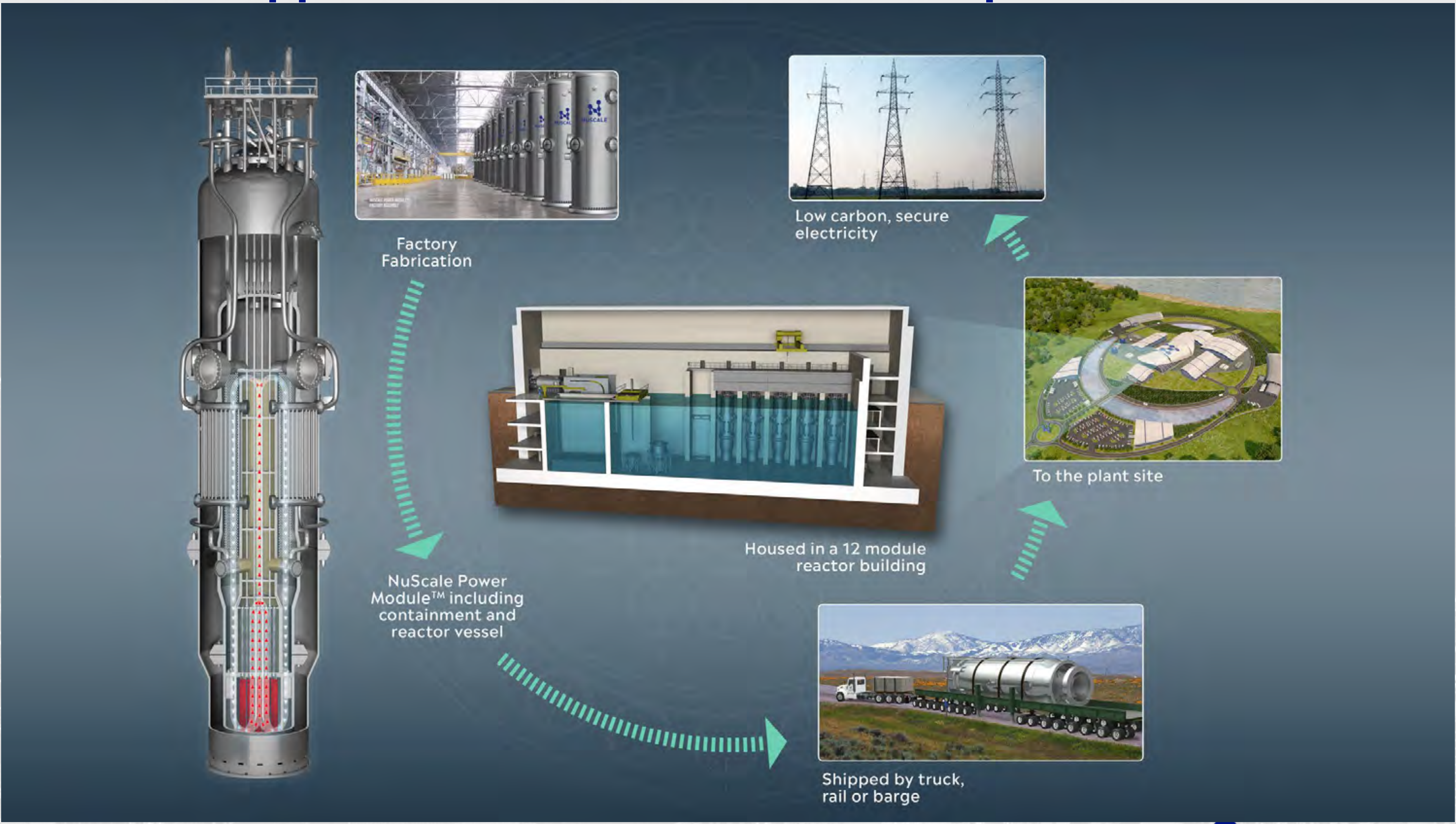
Innovative Advancements to Reactor Safety

Nuclear fuel cooled indefinitely without AC or DC power*



**Alternate 1E power system design eliminates the need for 1E qualified batteries to perform ESFAS protective functions – Patent Pending*

A New Approach to Construction and Operation



Technology Validation

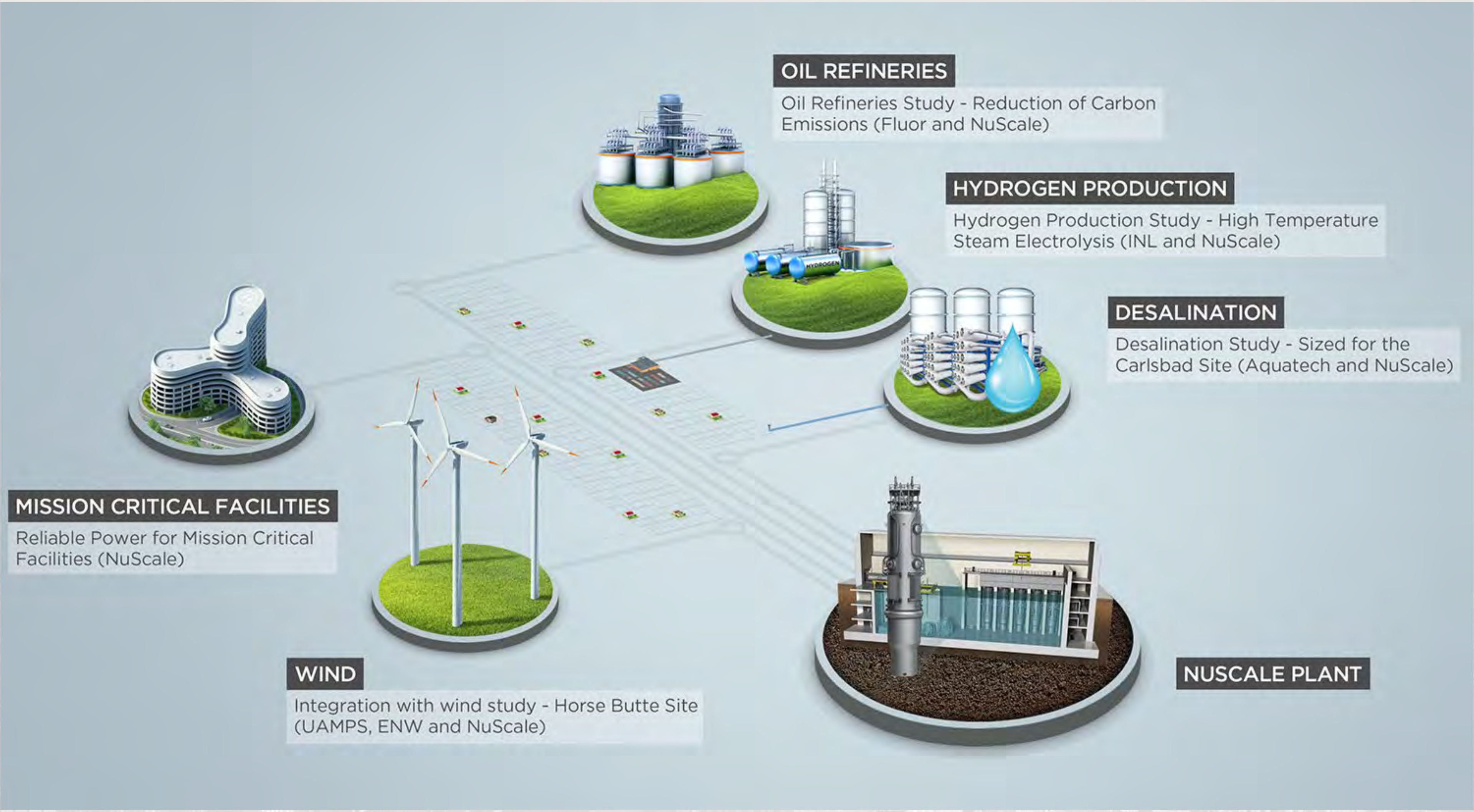
- **NuScale Integral System Test (NIST-1)** facility located at Oregon State University in Corvallis, Oregon
- **Critical Heat Flux** testing at Stern Laboratories in Hamilton, Ontario Canada
- **Helical Coil Steam Generator** testing at SIET SpA in Piacenza, Italy
- **Fuels testing** at AREVA's Richland Test Facility (RTF) in Richland, Washington
- **Critical Heat Flux** testing at AREVA's KATHY loop in Karlstein, Germany
- **Control Rod Assembly (CRA)** drop / shaft alignment testing at AREVA's KOPRA facility in Erlangen, Germany
- **Steam Generator** Flow Induced Vibration (FIV) testing at AREVA's PETER Loop in Erlangen, Germany
- **Control Rod Assembly Guide Tube (CRAGT)** FIV at AREVA's MAGALY facility in Le Creusot, France

Integrated System Validation Completed

Integrated System Validation (ISV) – verifies the integrated system that supports safe operation (NUREG-0711)

- Performance based evaluation of hardware, software, and personnel
- Three crews of six licensed operators
- Operators trained similar to a license class
  - 56 classroom lectures over 9 weeks
  - 36 simulator sessions for each crew over 10 weeks
- 12 full-scope, evaluated scenarios over 11 weeks

Beyond Baseload: NuScale Diverse Energy Platform



Reports for associated technical studies are available at: *www.nuscalepower.com/technology/technical-publications*

NuScale Co-Generation Studies

Oil Refinery Study Reducing Carbon Emissions
(Fluor and NuScale)

10-Module Plant coupled to a 250,000 barrels/d refinery, thus avoiding 190 MT/hr CO_2 emissions

Desalination Study for Clean Water and Electricity
(Aquatech and NuScale)

8-Module Plant producing 50 Mgal per day of clean water plus 340 MWe to the grid

High-Temp Steam Electrolysis for Carbon-free Hydrogen Production
(INL and NuScale)

6-Module Plant producing 200 tons per day carbon-free hydrogen for ammonia plant

Image courtesy of Third Way Nuclear Reimagined

Desalination for Clean Water

- A single power module coupled to a reverse osmosis desalination plant can produce **50 million gallons per day** of clean water.
- An 8-module plant can produce 190,000 cubic meters of desalinated water per day plus 348 MWe to the grid, enough to **power a city of about 300,000 people**.
- A 12-module plant could provide **all of the water for a city the size of Cape Town**, South Africa, about 3.8 million people.

A New Level of Plant Resiliency

Island Mode/Loss of Offsite Power

A single module can power the entire plant in case of loss of the grid; no operator or computer actions, AC/DC power or additional water required to keep the reactors safe

First Responder Power

On loss of the offsite grid, through variable (0% to 100%) steam bypass, all 12 modules can remain at power and be available to provide electricity to the grid as soon as the grid is restored

Resilience to Natural Events

Reactor modules and fuel pool located below grade in a Seismic Category 1 Building

- Capable of withstanding a Fukushima type seismic event
- Capable of withstanding hurricanes, tornados, and floods

Resilience to Aircraft Impact

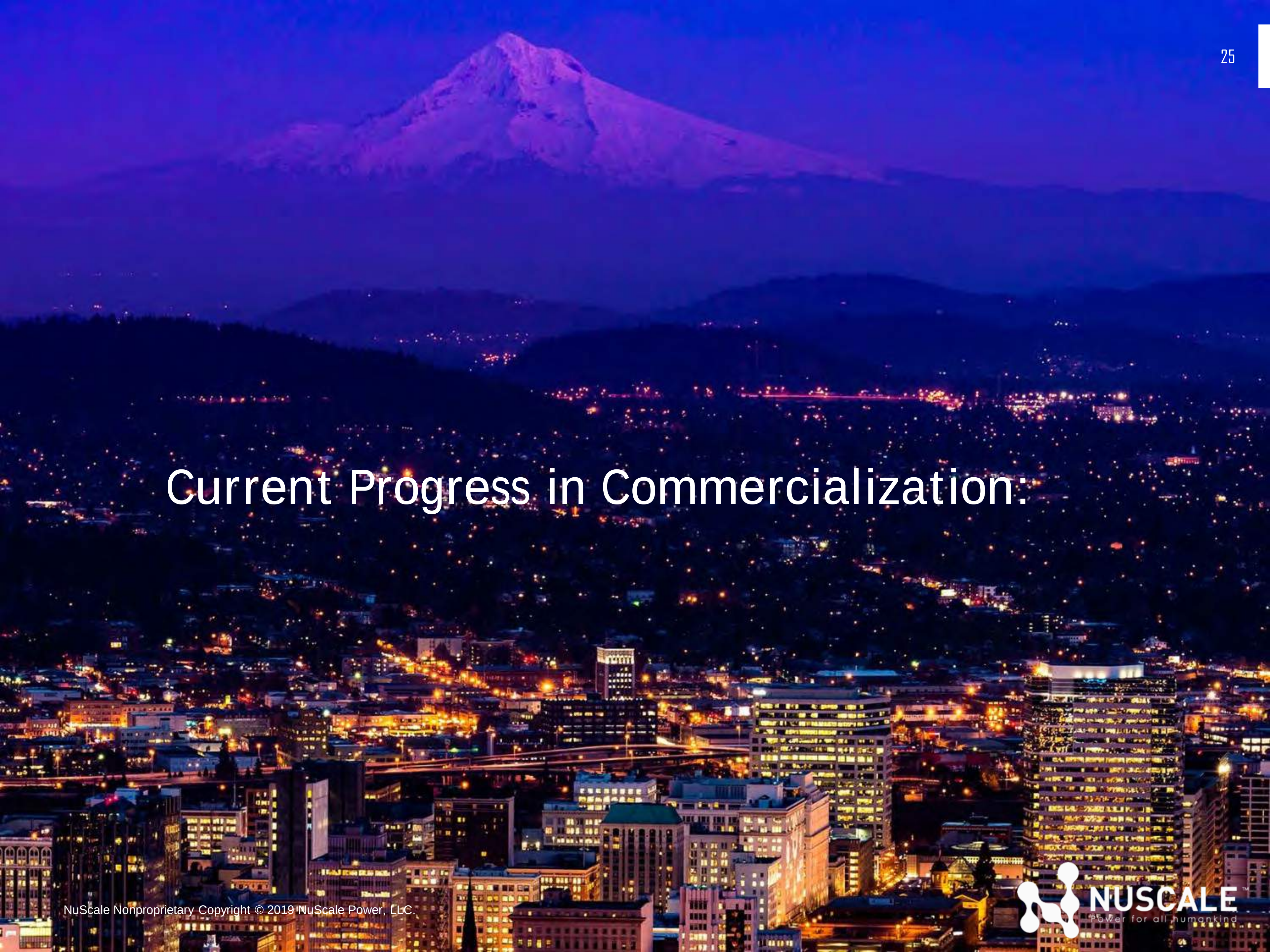
Reactor building is able to withstand aircraft impact as specified by the NRC aircraft impact rule

Cybersecurity

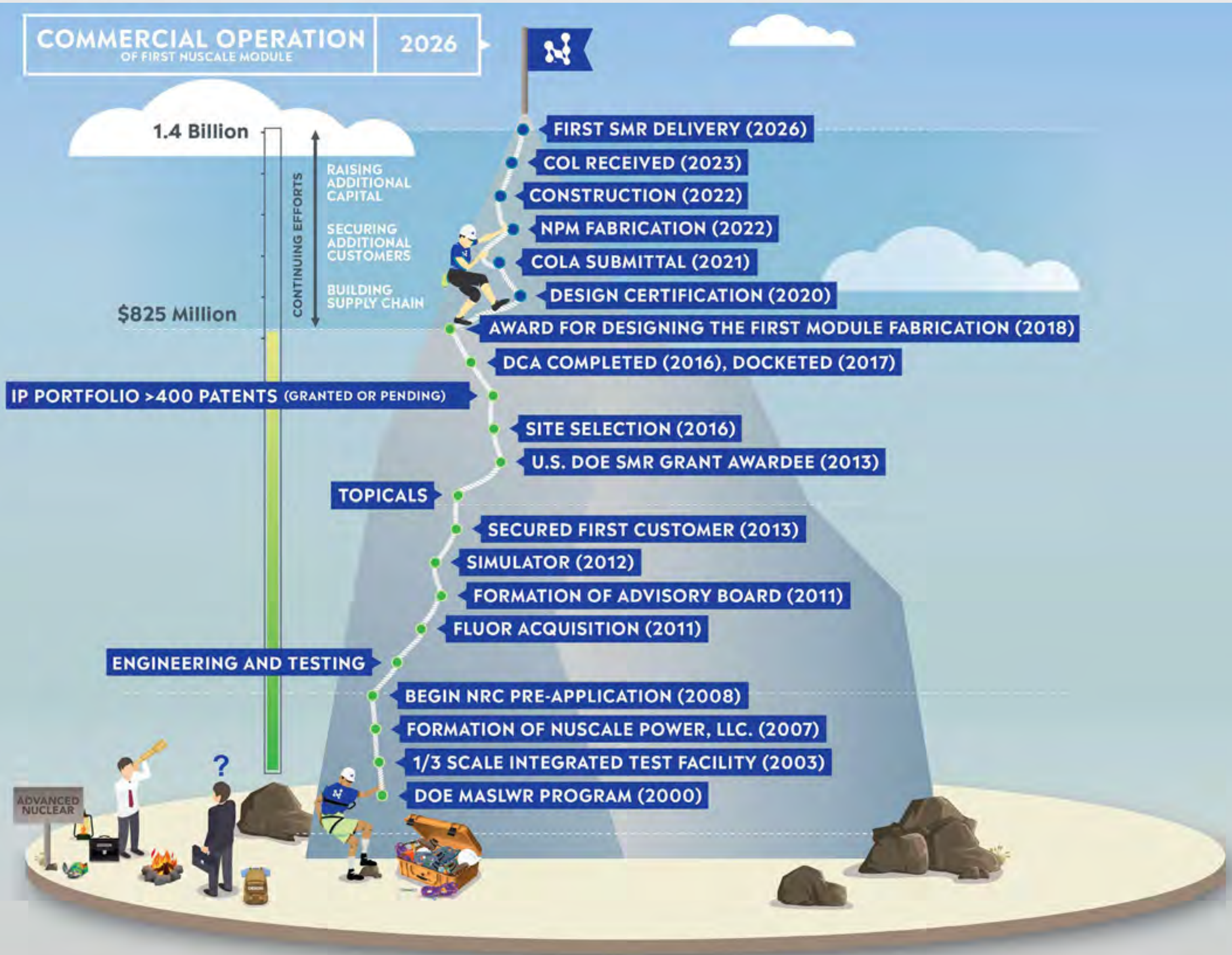
Module and plant protection systems are non-microprocessor based using field programmable gate arrays that do not use software and are therefore not vulnerable to internet cyber-attacks

Electromagnetic Pulse (EMP/GMD)

Resilience to solar-induced geomagnetic disturbances (GMDs) and electromagnetic pulse (EMP) events beyond current nuclear fleet.


Current Progress in Commercialization:

Blazing the Trail to Commercialization



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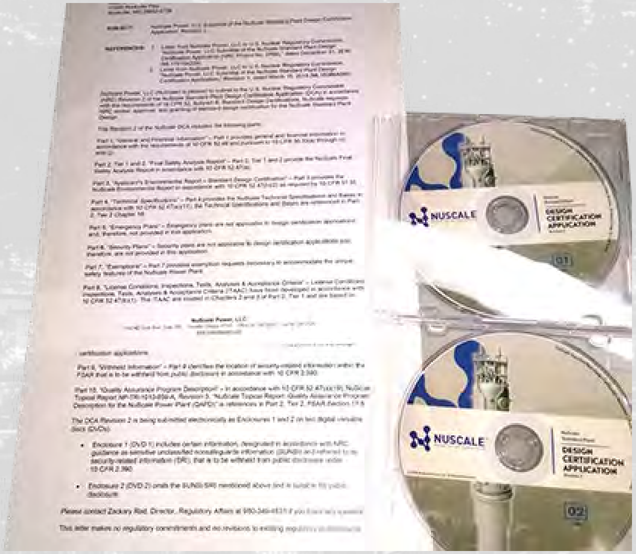
First SMR to Undergo Licensing in the U.S.

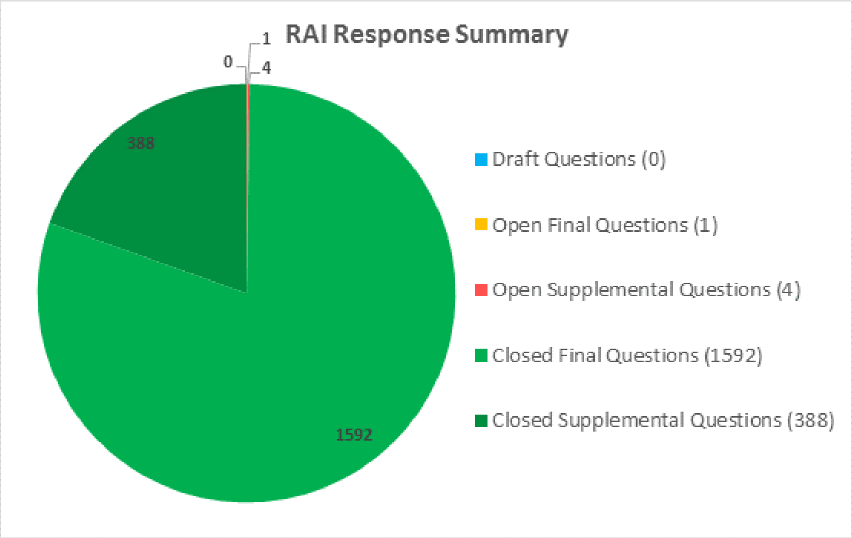
- Design Certification Application (DCA) completed in December 2016
- Docketed and review commenced by U.S. Nuclear Regulatory Commission (NRC) in March 2017
- Phase 4 of the NRC review on schedule for completion December 2019. Technical review would be completed.
- NRC has published its review and approval schedule; **to be approved in September 2020**



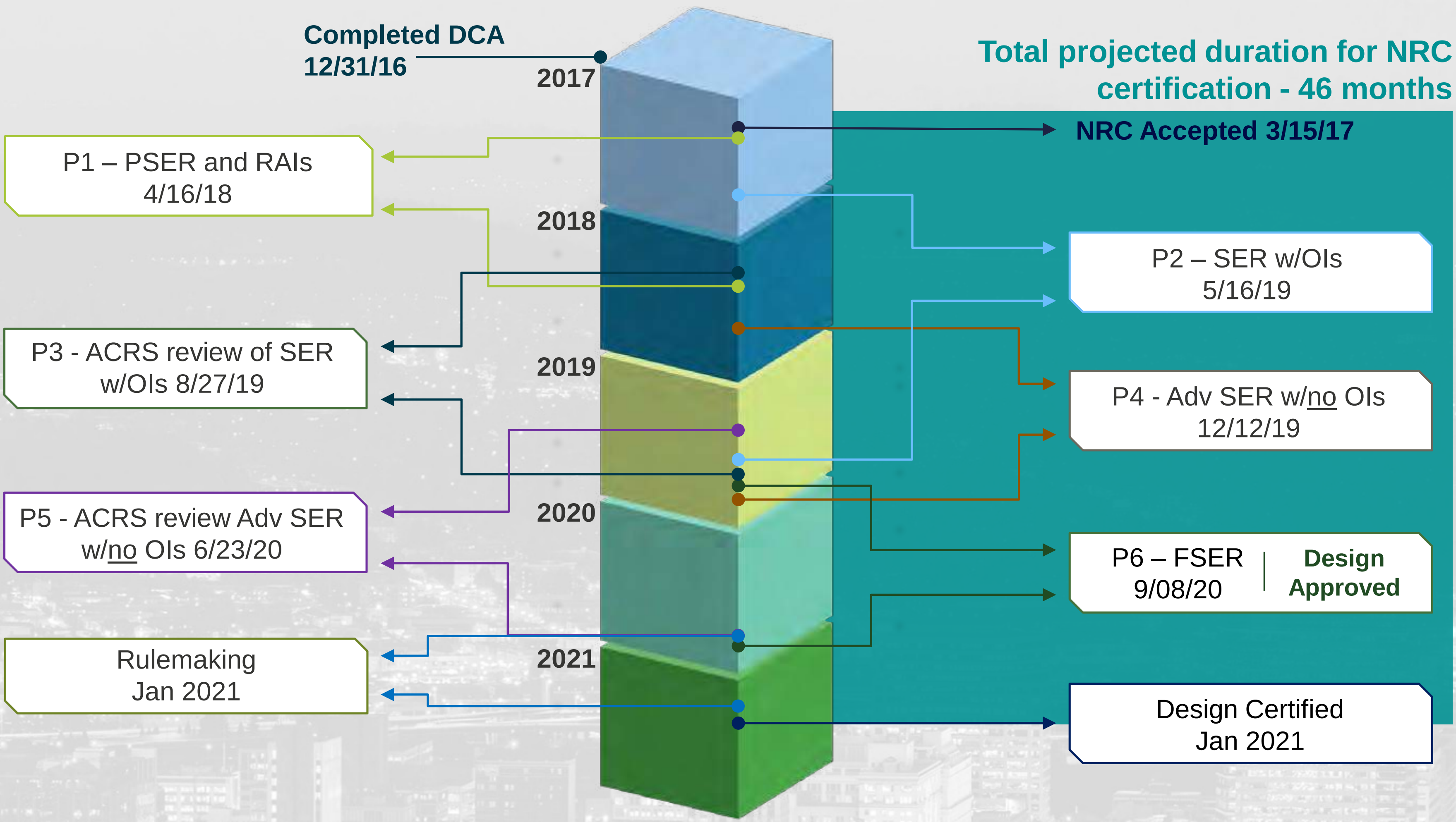
DCA Statistics
- 12,000+ pages
- 14 Topical Reports
- >2 million labor hours
- >800 people
- >50 supplier/partners
- Over $500M

Design Certification Review Progress

- **Design certification is proceeding on schedule**
  - All chapters completed in Phase 1-4
  - Phase 5: Chapters 7, 10, 11 and 17
  - Total remaining open items – 43
- **Request for Additional Information (RAI)**
  - RAI Status: All 1592 questions answered. 0 left!
  - 388 Supplemental Questions submitted/closed, only 4 in progress
- **Expect on-time design approval of September 2020**



NuScale Baseline DC Review



Progress in Licensing:

HIPS/FPGA

Introduction to HIPS

- The HIPS platform is based on the fundamental I&C design principles of independence, redundancy, diversity and defense-in-depth, and predictability and repeatability.
- The HIPS platform was developed to provide a simple and reliable solution for nuclear power plant I&C applications which support meeting the guidelines and the requirements of the NRC's regulatory guides and IEEE standards applicable to safety-related and important-to-safety applications
- The HIPS platform is based upon **FPGA technology** which has been previously approved by the NRC for safety-related applications
- The licensing topical report (LTR) demonstrates how the HIPS platform key design concepts meet the fundamental I&C design principles
- The LTR also describes testing and diagnostic concepts and how the key design concepts are implemented to achieve overall simplicity

History of NRC Interactions on HIPS/FPGA

- (Pre-submittal) Dec. 1 and 2, 2015 – Meeting and NRO ICE site visit to discuss various topics related to the I&C design, including the topical report (Corvallis, OR)
- Dec. 23, 2015 – NuScale submits Rev. 0 of TR-1015-18653, Highly Integrated Protection System (HIPS) Platform Topical Report to the NRC
- Feb. 19, 2016 – NRC acceptance letter issued for review of topical report
- March 24, 2016 – Meeting with NRC staff on HIPS platform details (Rockville, MD)
- April 20, 2016 – Meeting with NRC staff on compliance of HIPS platform design with NRC regulations and IEEE standards (Rockville, MD)
- May 24, 2016 – Meeting with NRC staff to discuss staff's draft RAIs on the HIPS platform topical report (Rockville, MD)
- June 22, 2016 – NRC issues RAIs on the HIPS Platform topical report
- July 6 – 7, 2016 – NRC audit of the HIPS platform prototype design documents (Rockville, MD)
- Aug. 19, 2016 – NuScale submits RAI responses to June 22 NRC RAIs
- Sept. – Oct. 2016 – NuScale and NRC hold teleconference calls on clarifications to RAI responses and follow-up clarification questions from NRC
- Nov. 4, 2016 – NuScale submits Rev. 1 to the HIPS platform topical report to the NRC
- Dec. 15, 2016 – NRO ICE visit to the NuScale Rockville office to review the prototype MPS factory acceptance testing (FAT) test specification and provide feedback ahead of the prototype MPS FAT Test audit
- Jan. 30 – Feb. 3, 2017 – NRC audit of the prototype MPS FAT (Wimborne Minster, UK)
- February 2, 2017 - Prototype FAT completed, no issues identified
- June 6, 2017 - HIPS Topical Report Approved.

HIPS Topical Letter Approval (June 2017)

June 6, 2017

Mr. Thomas Bergman
Vice President, Regulatory Affairs
NuScale Power, LLC
1100 NE Circle Boulevard, Suite 200
Corvallis, OR 97330

SUBJECT: FINAL SAFETY EVALUATION FOR NUSCALE POWER, LLC LICENSING TOPICAL REPORT: 1015-18653, "DESIGN OF THE HIGHLY INTEGRATED PROTECTION SYSTEM PLATFORM," REVISION 2, CAC NO. RQ6005

Dear Mr. Bergman:

On December 23, 2015, NuScale Power, LLC (NuScale) submitted Licensing Topical Report (TR) 1015-18653, "Highly Integrated Protection System," Revision 0 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15363A107), to the U.S. Nuclear Regulatory Staff (NRC) for staff review and approval. By letter dated November 4, 2016, NuScale submitted Revision 1, and by letter dated May 23, 2017, NuScale submitted Revision 2 to the TR 1015-18653, "Design of the Highly Integrated Protection System Platform" (ML17143A437). The NRC staff has found that the TR 1015-18653, "Design of the Highly Integrated Protection System Platform," Revision 2, is acceptable for referencing in licensing applications for the NuScale small modular reactor design to the extent specified and under the conditions and limitations delineated in the enclosed safety evaluation report (SER). The SER defines the basis for acceptance of the TR.

The NRC's acceptance applies only to matters approved in the subject TR. We do not intend to repeat our review of the acceptable matters described in the TR. When the report appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. Regulatory licensing action requests that deviate from this TR will be subject to additional staff reviews in accordance with applicable review standards.

In accordance with the guidance provided on the NRC's TR website (http://www.nrc.gov/about-nrc/regulatory/licensing/topical-reports.html), we request that NuScale publish an accepted version of this TR within three months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed safety evaluation between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in its appendices historical review information, such as questions and accepted responses, and original report pages that were replaced. The accepted version shall include an "-A" (designated accepted) following the report identification symbol.

T. Bergman - 2 -

If the NRC's criteria or regulations change so that its conclusion in this letter, that the TR is acceptable, is invalidated, NuScale and/or the applicant referencing the TR will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the TR without revision of the respective documentation.

Sincerely,

/RA/

Francis M. Akstulewicz, Director
Division of New Reactor Licensing
Office of New Reactors

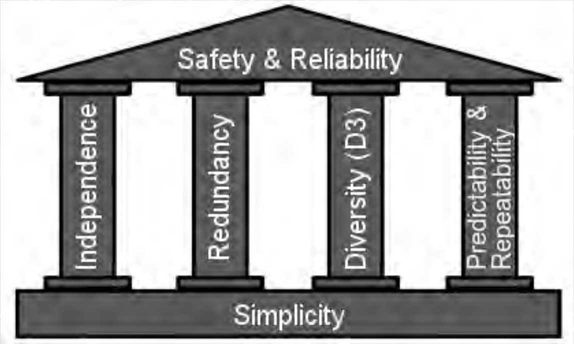
Project No. 0769

Enclosure: Safety Evaluation

cc w/encl: DC NuScale Power LLC Listserv

HIPS Platform Design Approach

- HIPS is designed to provide a robust platform for safety-related and important-to-safety applications
- Key design concepts incorporate the following fundamental design principles:
  - independence
  - redundancy
  - diversity and defense-in-depth (D3)
  - predictability and repeatability



- Hybrid analog and digital system with field programmable gate array (FPGA) logic on all modules implementing multiple deterministic finite state-machines.
- Design concepts support meeting requirements and guidelines for safety-related applications (RG 1.153, IEEE Std. 603, RG 1.152, IEEE Std. 7-4.3.2, DI&C-ISG-04, SECY-93-087)

Prototype

- Development of a NuScale prototype module protection system (MPS) began in October 2015 based on the HIPS platform
- Hardware scope includes:
  - two safety function module (SFMs)
  - four communication module (CMs) for one separation group of input:
    - three scheduling and bypass modules (SBM)
    - one monitoring and indication bus communication module (MIB-CM)
  - two equipment interface modules (EIMs)
  - four CMs
    - three scheduling and voting modules [SVMs]
    - One MIB-CM for one division of engineered safety features actuation system (ESFAS)
- Remaining scope of the MPS simulated with LabVIEW

Topical Report Scope

- The HIPS platform consists of the HIPS chassis and a system of modules that are interchangeable between chassis

Module Name	Description/Use
Safety Function Module (SFM)	Signal conditioning and actuation determination of safety function(s). Provides scaled value of input process to nonsafety controls and safety display for monitoring purposes (FPGA and analog)
Communications Module (CM)	Controls, collects, and transmits information between HIPS modules or to external components (FPGA and analog).
Equipment Interface Module (EIM)	Provides final equipment actuation output and includes priority logic circuitry for automatic and manual actuation inputs (FPGA and analog).
Hardwired Module (HWM)	Converts hardwired contact inputs into logic levels for direct connection on dedicated backplane traces to a particular module as per the detail application design (analog only).

The HIPS platform is an FPGA-based platform – there is no executable software within the runtime environment

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that changes the world