Nuclear Power for the Modern Grid

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NUCLEAR POWER
FOR THE MODERN GRID
HDIAC
Presented by:
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WEDNESDAY, JUNE 24 AT 1200 – 1300 EDT
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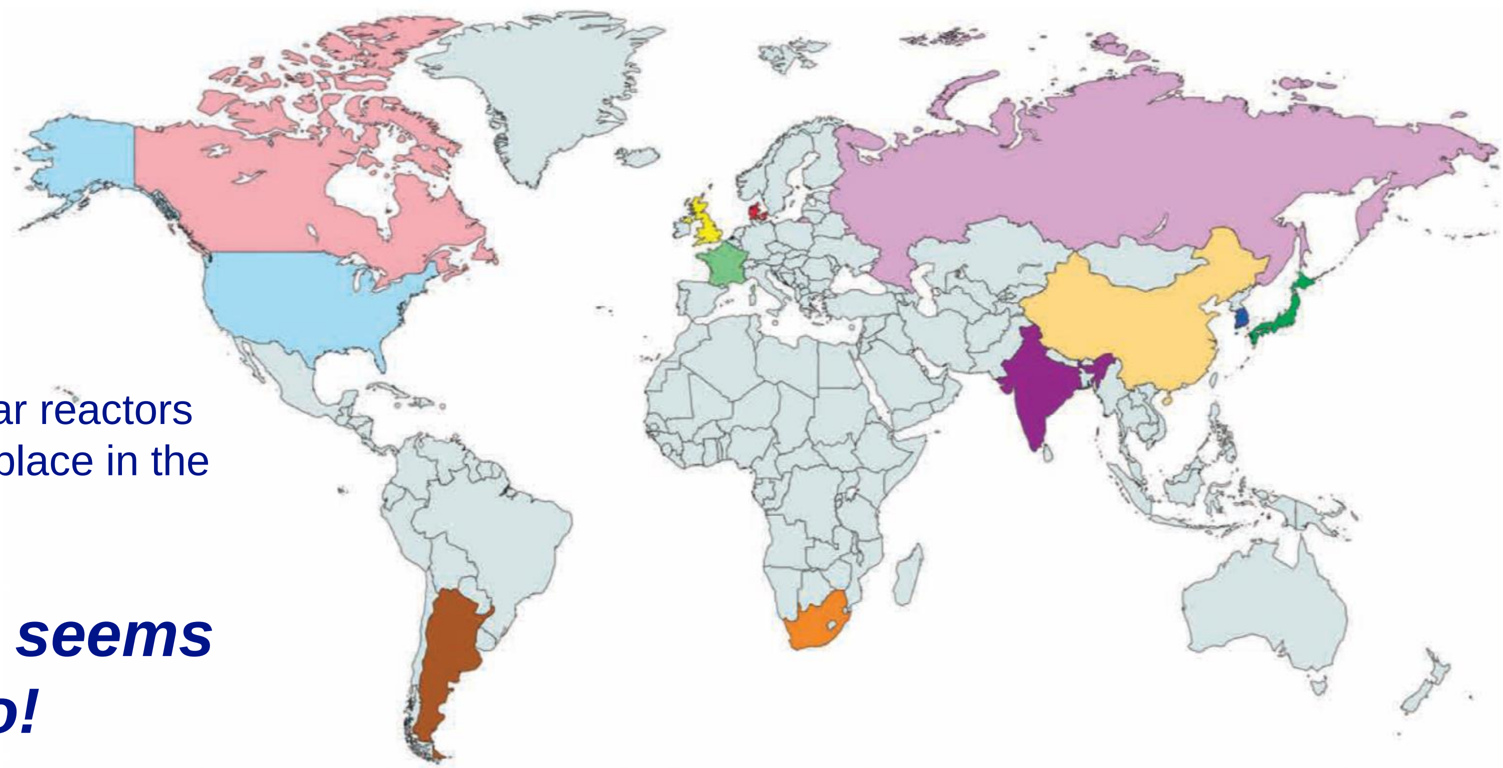
What should Nuclear Power look like for the Modern Grid?

- It should offer a level of safety that assures “no off-site consequences”
- Its safety should warrant a smaller site boundary to repurpose retiring fossil fuel plants
- It should be sufficiently flexible for load following variable power generation and to maintain grid stability
- It should be resilient to an increased frequency of severe weather events and other natural hazards
- It should be resilient to cybersecurity threats, GMD/EMP and long-term loss of fuel delivery
- It should help state governments achieve their carbon-free energy mandates
- It should be economically competitive with other sources of power generation

Do small modular reactors (SMRs) have a place in the modern grid?

The world seems to think so!



DOE Definition: SMR

- Less than 300 MWe output
- Factory fabrication and rail/road/barge transportable to site
- Operated as multi-module plant

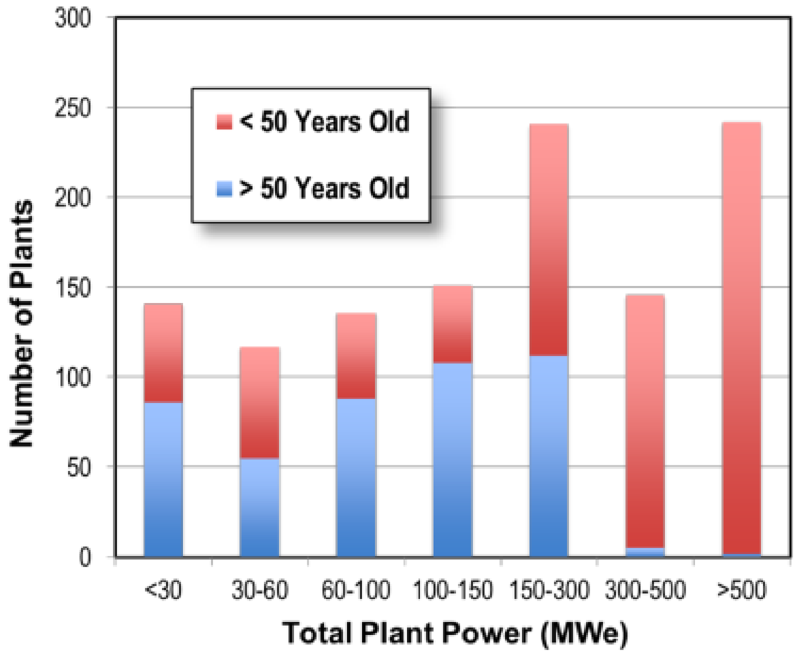
Source: Bowen, M. (October 2017). Enabling Nuclear Innovation: Leading on SMRs. A report by the Nuclear Innovation Alliance (map on p.27 of report).

Operational Flexibilities of Small Modular Reactors

- **Site selection**
  - Simplified emergency planning zone
  - Broader seismic conditions
  - Lower land and water usage
- **Load demand**
  - Better match to power needs
  - Repowering of coal plants
- **Demand growth**
  - Add (and pay for) smaller increments of new capacity
- **Grid stability**
  - Closer match to traditional power generators
  - Smaller fraction of total grid capacity

U.S. Coal Plants

99% of plants > 50 years old have less than 300 MWe capacity



U.S. Coal Plants Chart Source: Ingersoll, D. (2019)

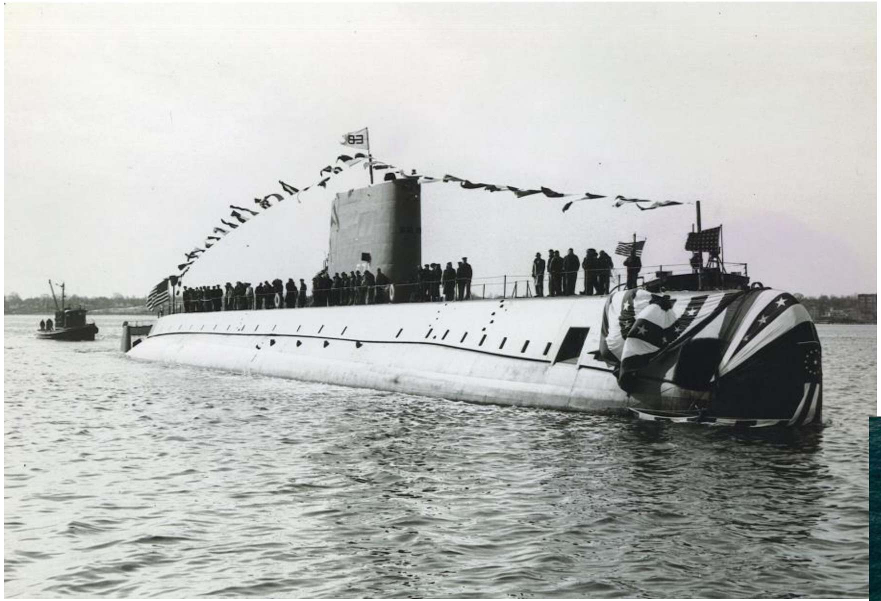
Economic Benefits of Small Modular Reactors

- **Total project cost**
  - Smaller plants should be cheaper
  - Improves financing options and lowers financing cost
  - May be the driving consideration for some customers

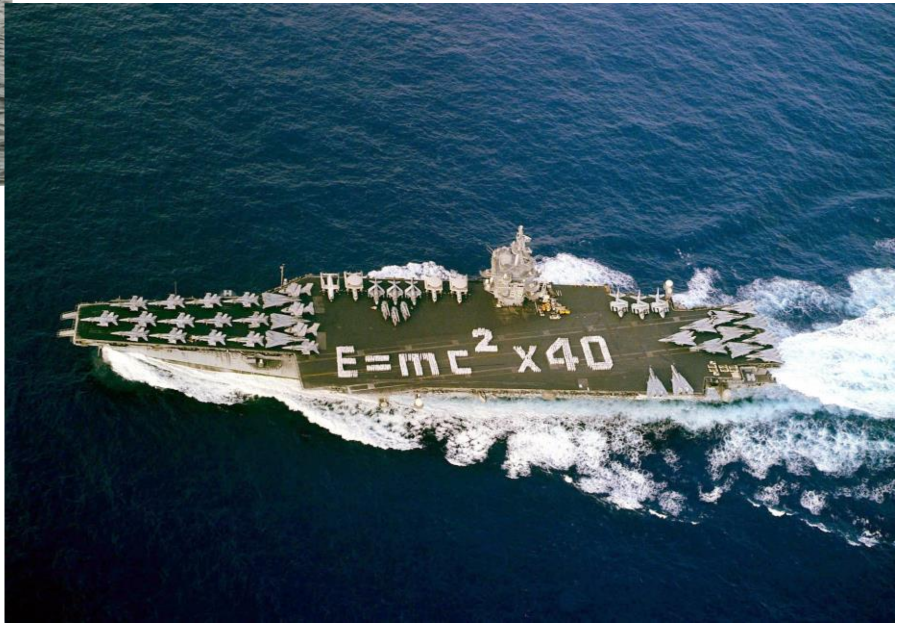
- **Cost of electricity**
  - Economy-of-scale works against smaller plants but can be mitigated by other economic factors
    - Accelerated learning, shared infrastructure, design simplification, factory replication, economy of numbering up

- **Investment risk**
  - Maximum cash outlay is lower and more predictable
  - Maximum cash outlay can be lower even for the same generating capacity

U.S. History with Small Reactors



USS Nautilus[1]
Launched 1954

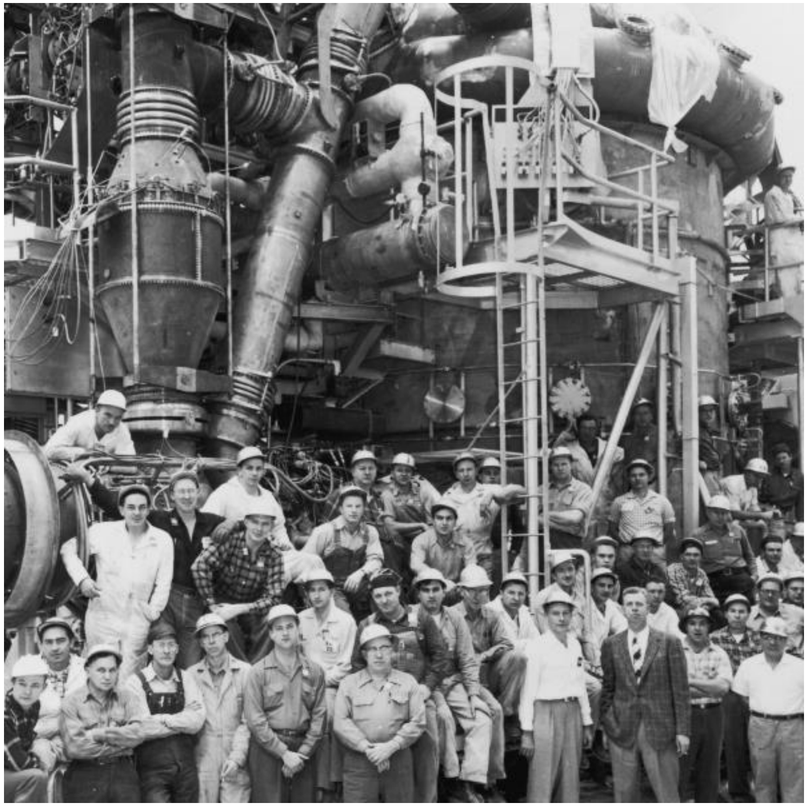


USS Enterprise[2]
Launched 1960

Image Sources:
1. *U.S. Navy mil photo* https://www.navy.mil/management/photodb/photos/120120-N-ZZ999-002.jpg
2. *U.S. Navy mil photo* https://www.navy.mil/management/photodb/photos/011105-N-6259P-001.jpg

U.S. Air Force - Nuclear Powered Aircraft

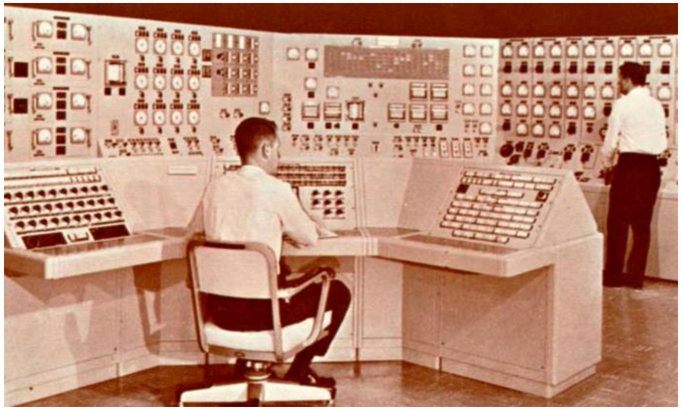
Nuclear Test Aircraft[1]
1955-57



Heat Transfer Reactor Experiment[2]
1955-57

Image Sources:
1. U.S. Defenseimagery.mil photo no. DF-SC-83-09332 https://commons.wikimedia.org/wiki/File:NB-36H_with_B-50,_1955_-_DF-SC-83-09332.jpeg
2. Idaho National Library Flicker : https://www.flickr.com/photos/inl/3463319143/

U.S. Army - Small Stationary Plants and Mobile Plants



Ft. Belvoir control room simulator[1]

USS Sturgis[2]

Reactor	Power (MWe)	Type	Location	Startup	Shutdown
SM-1	2	PWR	Fort Belvoir, Virginia	1957	1973
SM-1A	2	PWR	Fort Greely, Alaska	1962	1972
PM-1	1	PWR	Sundance, Wyoming	1962	1968
PM-2A	1	PWR	Camp Century, Greenland	1960	1962
PM-3A	1.5	PWR	McMurdo Station, Antarctica	1962	1972
SL-1	1	BWR	Arco, Idaho	1958	1960
MH-1	10	PWR	Panama Canal (Sturgis)	1967	1976
ML-1	.5	GCR	Arco, Idaho	1961	1966

Image Sources:
1. US Army https://commons.wikimedia.org/wiki/file:mh1asimulator.jpg
2. US Army https://commons.wikimedia.org/wiki/File:mh1anuclearpowerplant.jpg

Military to Commercial Propulsion

N.S. Savannah[1]
1961-71

N.S. Otto Hahn[2]
1968-79

Image Sources:
1. https://commons.wikimedia.org/wiki/File:NS_Savannah_at_Pier_13_Baltimore_MD1.jpg
2. Images from the German Federal Archive https://commons.wikimedia.org/wiki/File:Bundesarchiv_B_145_Bild-F031997-0013,_Frachter_NS_Otto_Hahn.jpg

First Commercial Power Plants Were Small Prototypes

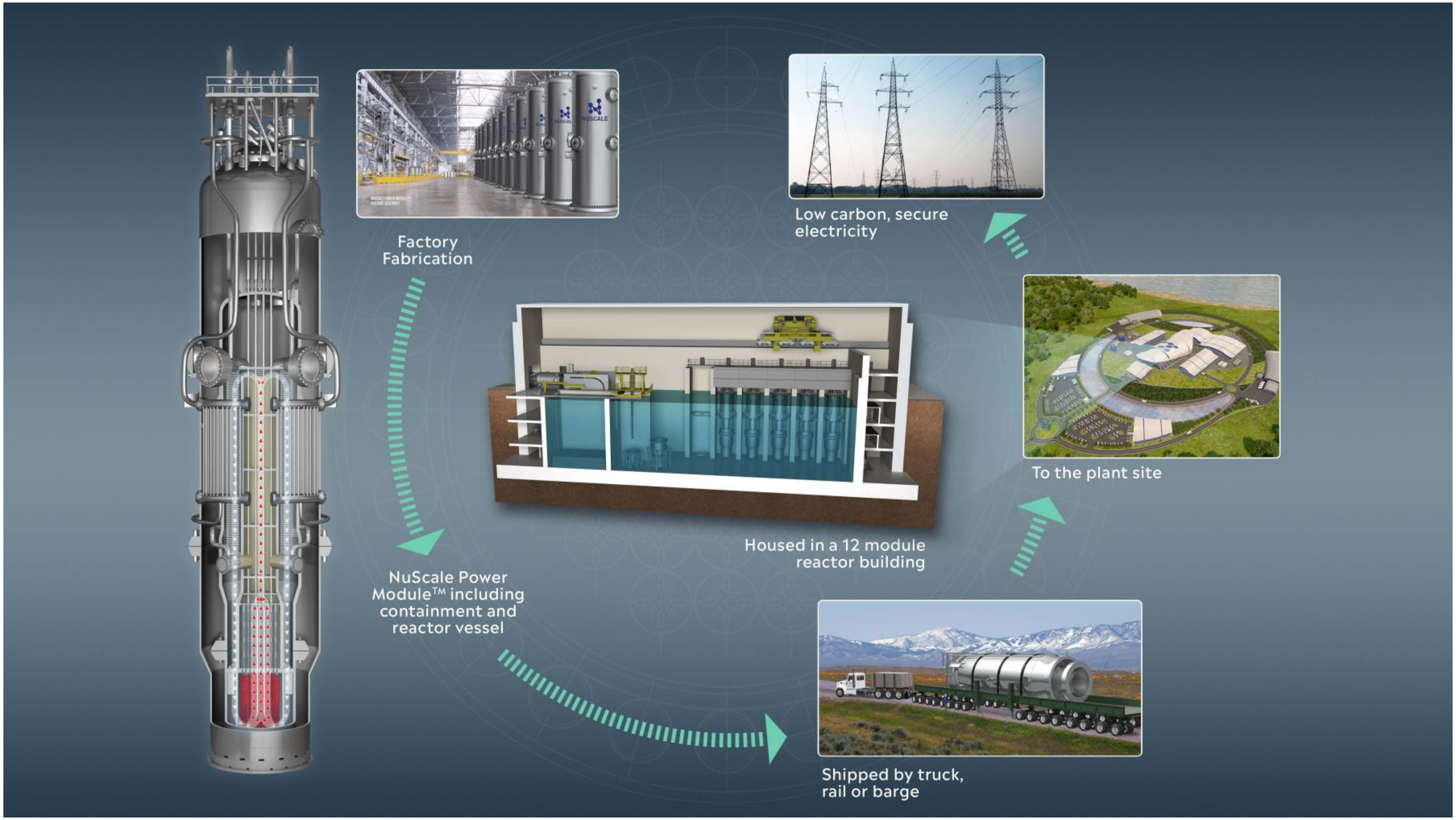
Vallicetos[1]
5 MWe
1957

Shippingport[2]
60 MWe
1957

Dresden 1[3]
200 MWe
1960

Image Sources:
1. https://commons.wikimedia.org/wiki/File:Vallecitos_Nuclear_Center.jpg
2. Library of Congress Prints and Photographs Division Washington, D.C. 20540 USA http://hdl.loc.gov/loc.pnp/pp.print
3. NRC Flicker Library: https://www.flickr.com/photos/nrcgov/17859259621/

A New Approach to Construction and Operation



A New Level of Safety to Assure "No Offsite Consequences"

Natural Convection for Cooling

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

Seismically Robust

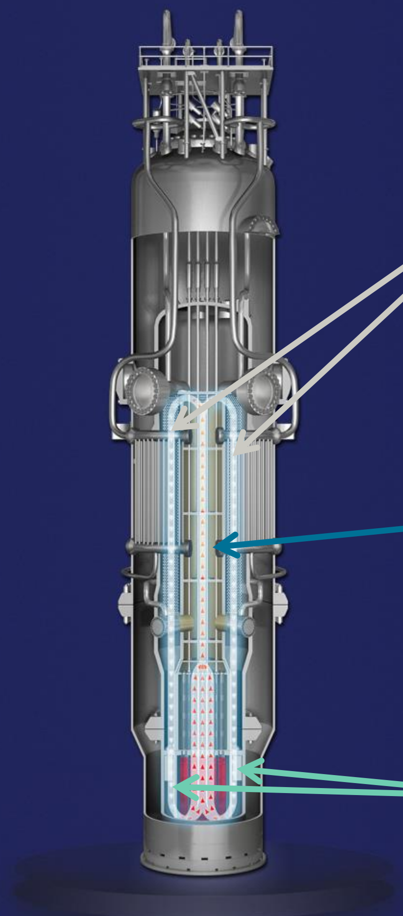
- System submerged in a below-grade pool of water in an earthquake and aircraft impact resistant building.

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.**

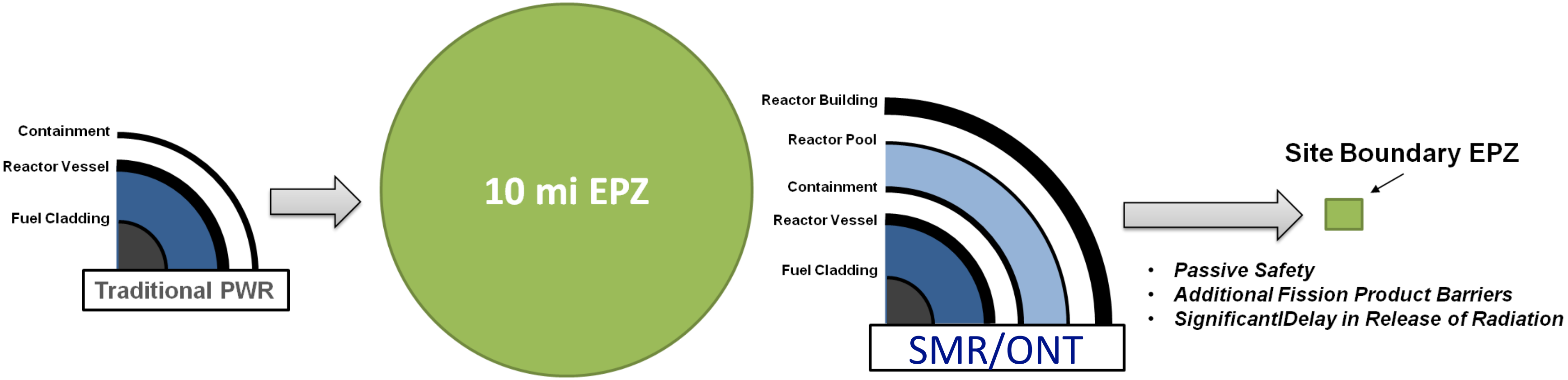
Convection **– energy from the nuclear reaction heats the primary water causing it to rise by convection and buoyancy through the riser, much like a chimney effect.**

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

No Operator Actions, no AC/ DC power, and no addition of water needed for safe shutdown and cooling of reactors – site boundary Emergency Planning Zone capable

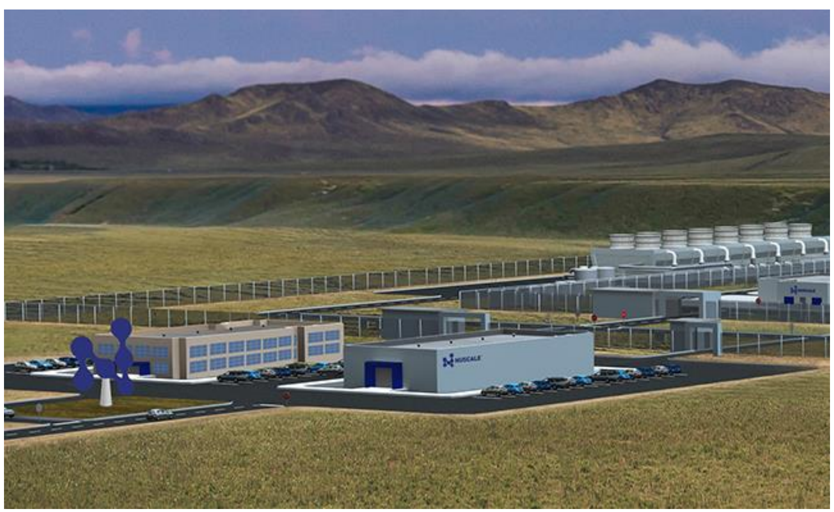
Emergency Preparedness for SMRs and ONTs

- The U.S. Nuclear Regulatory Commission (NRC) is proposing to amend its regulations to include new alternative emergency preparedness (EP) requirements for small modular reactors (SMRs) and other new technologies (ONTs), such as non-light-water reactors (non-LWRs) and certain non-power production or utilization facilities (NPUFs)
- Issued Proposed Rule for Public Comment on May 12, 2020
- Comments due July 27, 2020



https://www.federalregister.gov/documents/2020/05/12/2020-09666/emergency-preparedness-for-small-modular-reactors-and-other-new-technologies

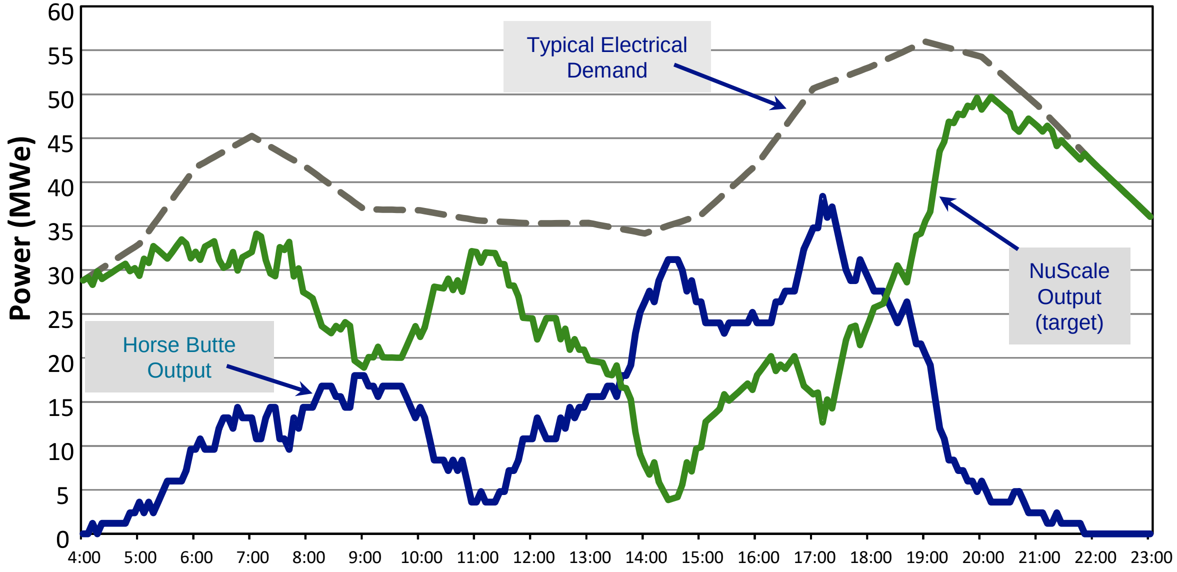
SMR Plants for Repurposing U.S. Coal Power Plant Sites



- By 2030, the U.S. will see 73 coal power plants retire, resulting in a loss of 38 GW of capacity and creating a significant economic downturn for the communities that host these plants
- Repurpose some coal plant infrastructure such as cooling water delivery systems, demineralized water, potable water, site fire protection, switchyard, and buildings (e.g., administrative, training, warehouse)
- Continue to use the site for power generation and keep economic benefits within the community
- Existing coal plant workforce can be retained and cross-trained to operate an SMR plant

Flexible Power for Load Following Wind

- The increased penetration of wind and solar variable power generators create challenges to maintaining constant frequency on the grid, as well as providing baseload power when wind or sunshine is not available



- <u>Horse Butte Study</u>: Commissioned in 2012, 32 Vestas V100 turbines, 1.8 MWe capacity per turbine, 57.6 MWe total capacity on 17,600 acres

SMRs and Integrated Energy Systems

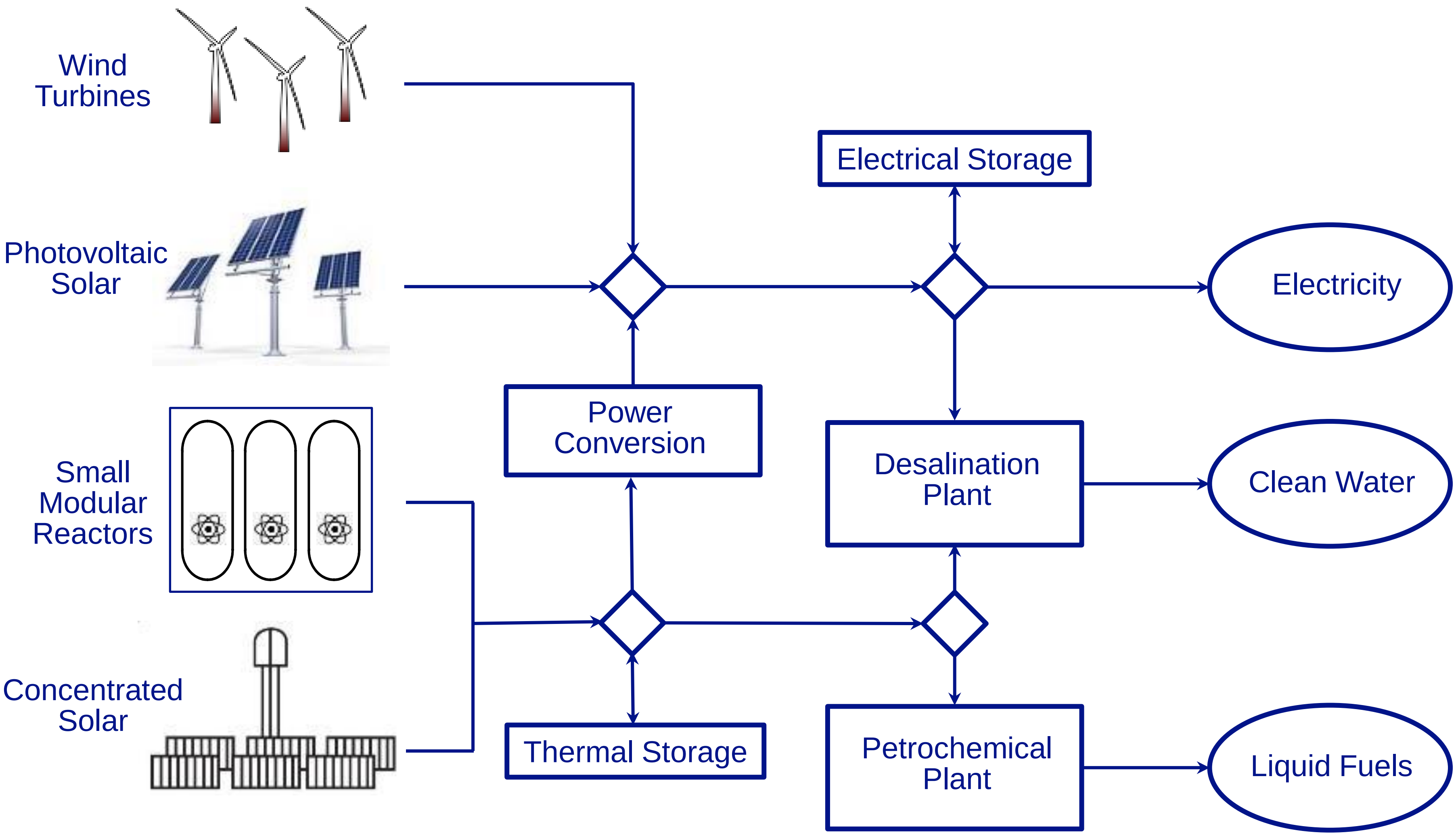


Image Source: Ingersoll, D. (2017) Small Modular Reactors Economics and Applications

SMRs and Integrated Energy Systems – DOD Needs

- In FY 2018, the Department of Defense (DoD) consumed over 85 million barrels of fuel to power ships, aircraft, combat vehicles, and contingency bases at a cost of nearly $9.2 billion
- Further, recent research shows that the U.S. military consumes more liquid fuels and emits more CO2e (carbon-dioxide equivalent) than most countries
- At over 500 worldwide military installations, the DoD spent $3.4 billion in FY 2018 on energy to power over 585,000 facilities and 160,000 non-tactical vehicles
- In FY20, the DoD requested more than $3.6 billion for the execution of operational energy initiatives

SMRs for Co-Generation Applications

- Scalable in small power increments
  - Low initial commitment and cost
  - Easily expandable as IES grows
  - High reliability and continuous power output
- Flexible for multi-product outputs
  - Co-generation of individual modules
  - Whole-module dedication to different products
- Reduced risk yields simplified emergency planning (reduced emergency planning zone—EPZ)

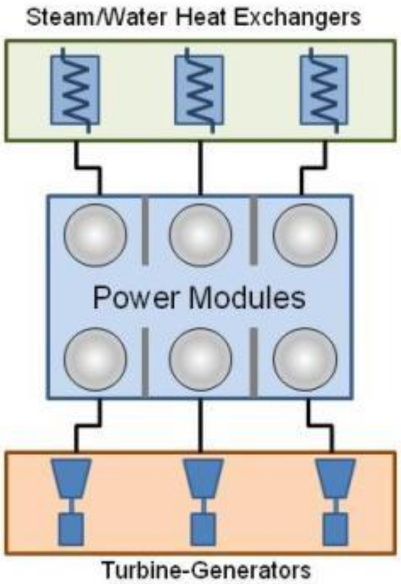


Image Source: Ingersoll, D. (2017) Small Modular Reactors Economics and Applications

Co-Generation Research Results

Oil Refinery Study Reducing Carbon Emissions *(Fluor)*

10-Module Plant coupled to a 250,000 barrels/d refinery, thus avoiding ~230 MT/hr CO_2 emissions

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

8-Module Plant producing 60 Mgal per day of clean water plus ~400 MWe to the grid

High-Temp Steam Electrolysis for Carbon-Free Hydrogen Production *(INL)*

6-Module Plant producing ~240 tons per day carbon-free hydrogen for ammonia plant

Nuclear Power for the Modern Grid - A New Level of Plant Resiliency

Climate Adaptation

Black-Start and Island Mode Following Loss of Offsite Power

A single module can be Black-Started and 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.

SMRs for Powering Remote Operating Bases

- Eliminate Grid Vulnerability
  - Island Mode Operations for multi-module site
  - Safety without Operator Actions, AC or DC Power or additional water - Unlimited coping time

- Provide Highly Reliable Electric Power
  - Module Sizes and Portability
  - Long-Lived Fuel
  - Simplified and Automated Controls
  - Cybersecure Nuclear I&C Systems
  - Reduced Maintenance Requirements
  - Water Usage and Air Cooled Condensers

Research on Reliable Power for Mission Critical Facilities

UTILITY MACROGRID

- Connection to a micro-grid, Island Mode capability, and the ability for 100% turbine bypass allows a 720 MWe (gross) NuScale plant to assure **120 MWe net power at 99.95% reliability over a 60 year lifetime**
  - 60 MWe at 99.98% availability
- Using highly robust power modules and a multi-module plant design can provide **clean, abundant, and highly reliable power** to customers
- Completed study with TVA demonstrating greater than “Six 9s”

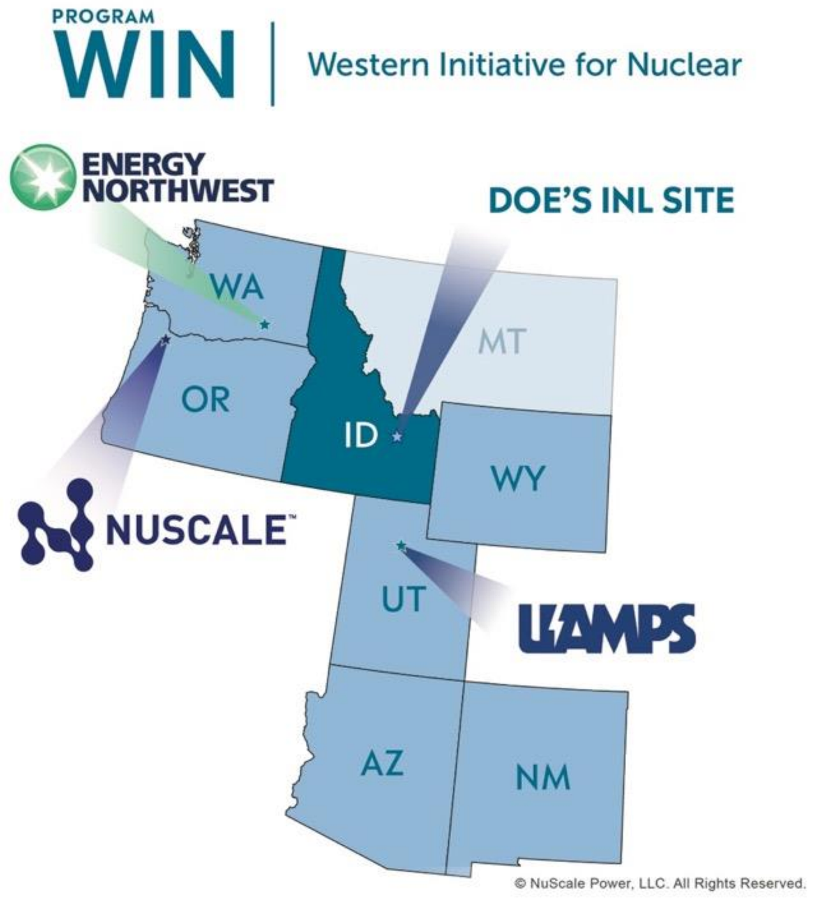
684 MWe (net)
> 95% Capacity

12-Module SMR Plant

DEDICATED MICROGRID
120 MWe (net)
> 99.95% Availability

MISSION CRITICAL FACILITY

1st SMR Deployment: UAMPS Carbon Free Power Project



- Utah Associated Municipal Power Systems (UAMPS) provides energy services to community-owned power systems throughout the Intermountain West
- First deployment will be a 12-module plant (720 MWe) within the Idaho National Laboratory (INL) site, slated for commercial operation in 2027
- DOE awarded $63.3 million in matching funds to perform site selection, secure site and water, and prepare combined operating license application to NRC and advance the site specific design

Conclusions

- Small modular reactors can be a tremendous asset to building a reliable modern grid
- They can help address key challenges:
  - Baseload and grid stability challenges
  - Repurposing coal power plant sites
  - Helping state governments meet clean energy mandates
  - Mitigating climate change
  - Responding to external threats
  - Using for non-electrical applications

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