US Development of Advanced Nuclear Technologies

American Nuclear Society

Andrew C. Klein, PhD, PE

ANS President
Editor, *Nuclear Technology*
Professor of Nuclear Science and Engineering
Oregon State University

June 2016

Nuclear Energy: Still Going Forward

The Importance of Nuclear Energy

Evolution of Nuclear Power

Small Modular Reactors

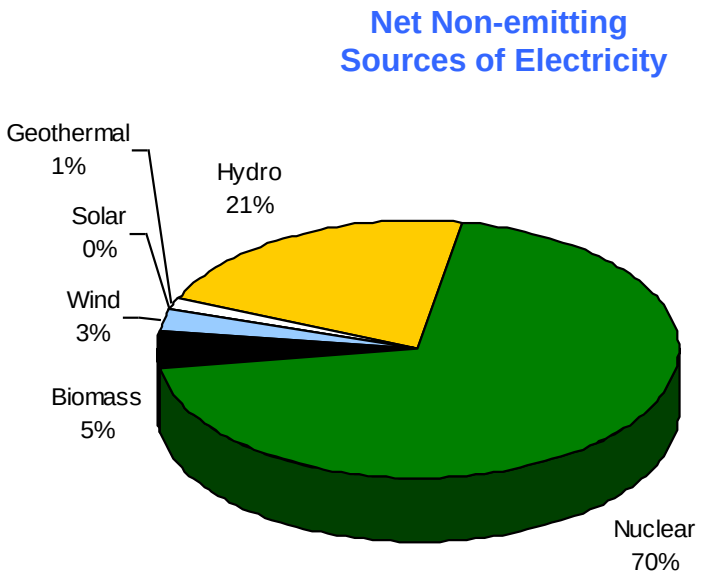
Advancing Advanced Reactors

ANS Nuclear Grand Challenges

Objectives for 2016-2017

Nuclear – Important, Clean Energy Source

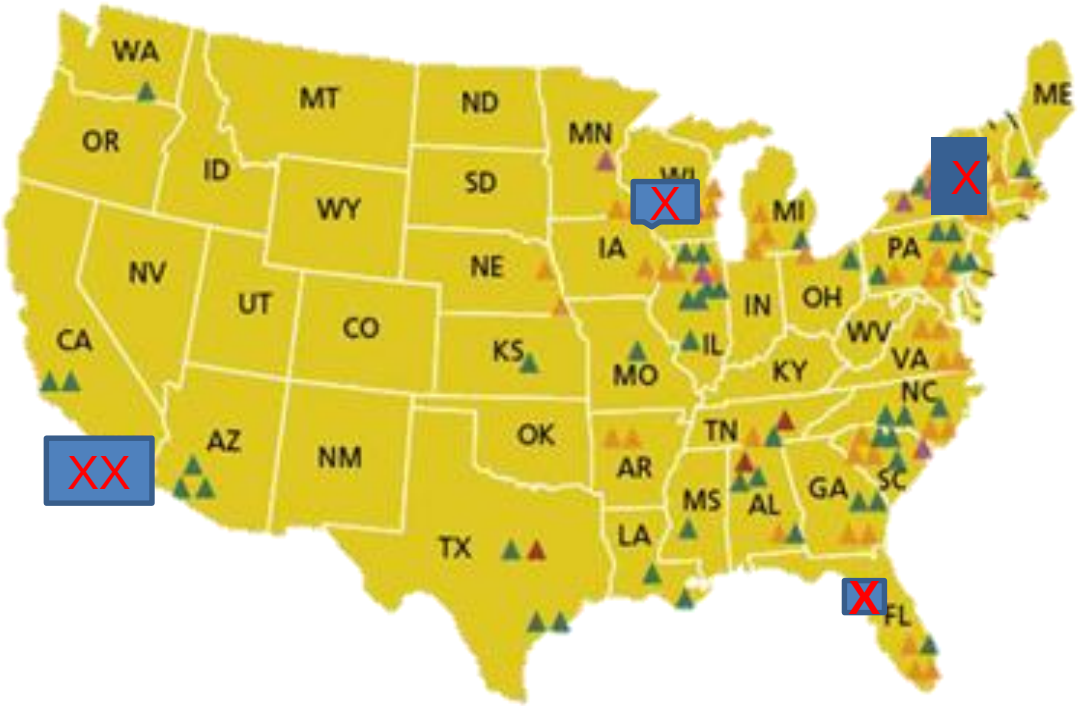
- **Nuclear power is the clean, reliable, expandable base load energy source**
  - **Provides over 70% of U.S. emission-free electricity**
  - **Avoids about 600 MMTCO$_2$ each year**
  - **Helps reduces overall NOx and SOx levels**



So, What's Happening?

- Deregulated markets in US do not recognize emissions reduction or even capacity factors
- Price of natural gas
- Overall slow demand growth
- Five units in US shut down since 2013
- As many as five more scheduled by end of 2018
- More operating units at risk, but a few have announced license extensions to 80 years
- No credit for operating plants in the EPA CPP
- Only five new units presently under construction
- Little to no recognition of the vital role nuclear plays in reducing emissions

US nuclear units shut down since 2013



Fitzpatrick scheduled to close January 2017
Pilgrim to shut down in 2019
Oyster Creek scheduled to close in 2019

Fight to Save US Nuclear Plants

- ANS Nuclear In the States Toolkit
- DOE-NE Workshop – May 19th
- Save US Nuclear activities
  - Environmental Progress
  - Third Way
  - Breakthrough Institute
  - Clean Air Task Force
  - Others

Nuclear In the States Toolkit

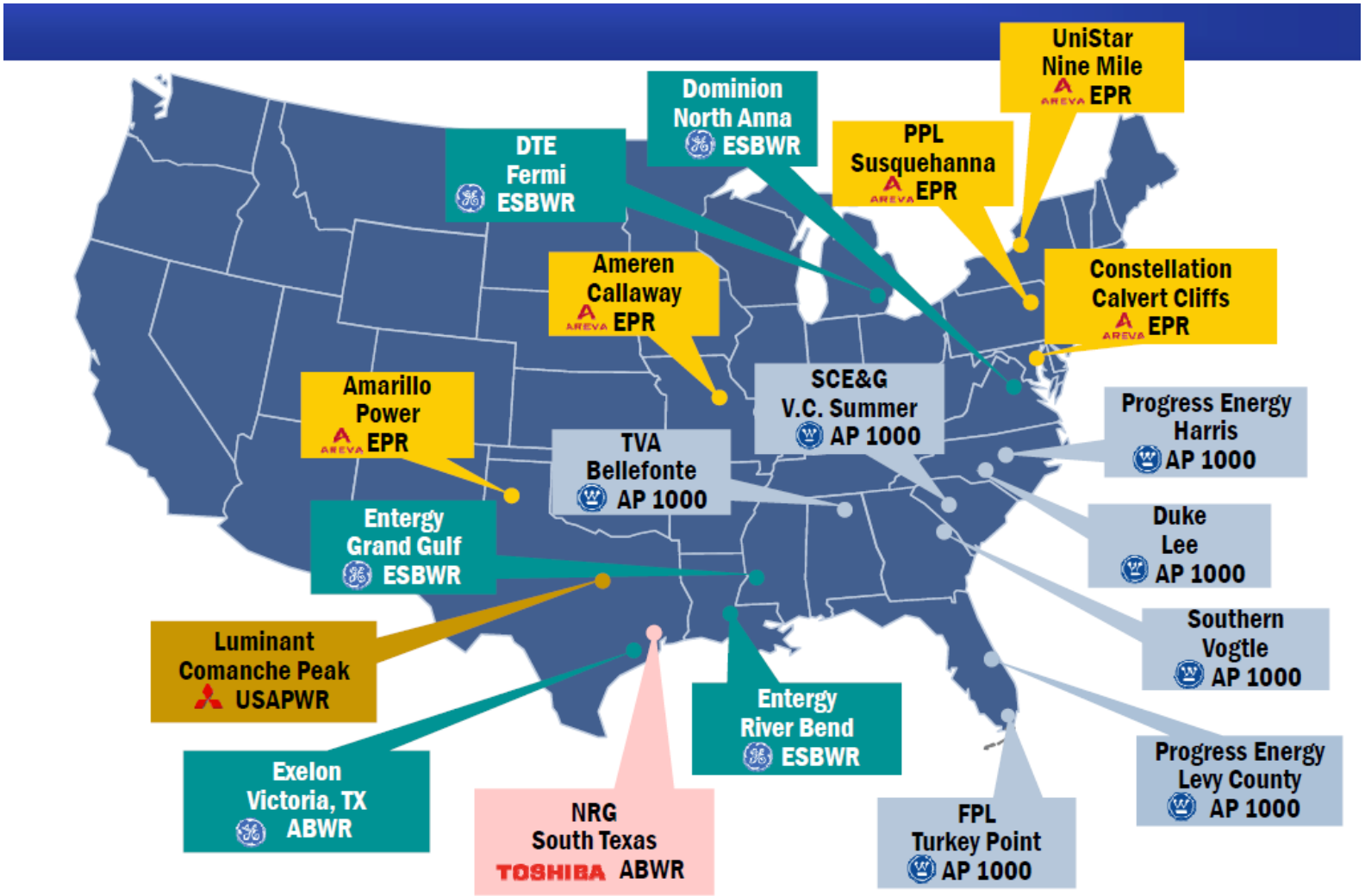
Policy options for States considering the role of nuclear power in their energy mix

- Policy pathways to support the current nuclear fleet
- Goal is to prevent early plant retirements
- Comprehensive overview of a wide range of policy and other options
  - Federal-level initiatives such as federal tax credits
  - Community-level options like public hearings
  - Policy tools
  - Market-based tools
- State policymakers determine methods to best fit their goals
  - Policy
  - Environmental
  - Energy
  - Economic
- Each State faces a different set of circumstances regarding nuclear power

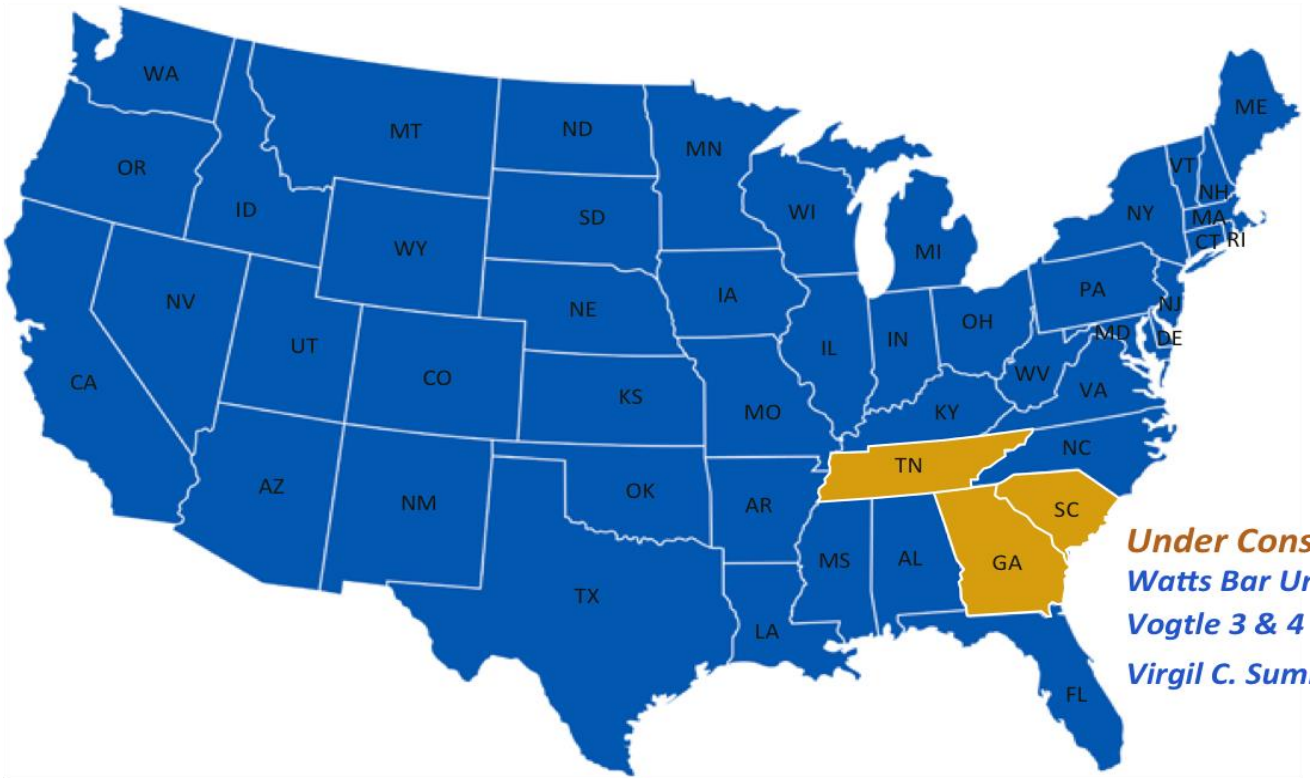
Toolkit Elements

- **Increase Nuclear Plant Revenue/Revenue Certainty**
  - **Power Contracts**
  - **Low-Carbon Portfolio Standard**
  - **Carbon Tax**
  - **Nuclear Portfolio Standard**
  - **Clean Air Portfolio Standard**
- **Public Hearings/Meetings**
- **Clean Power Plan Implementation**
- **Industry Consolidation**
- **Public/Government Ownership**
- **Lower Costs**
- **Capacity Markets**
- **Electricity Markets**
- **Return to Economic Regulation**
- **Others**

Outlook on New Construction



Five New Units Under Construction



Source: NEI - Nuclear Units Under Construction Worldwide

Challenges to New Construction

- High capital costs ($8-12 billion)
- Used fuel issues
- Availability of nuclear qualified components
- Availability of skilled personnel
- Lengthy licensing and construction schedule
- Cost and schedule performance
- Public concerns/misunderstandings
- Price/availability of natural gas

Advanced Nuclear Technologies

Opportunities

- Highly Efficient Technologies
- New Instrumentation and Control Strategies
- Modular Construction
- Preapproved Sites
- Dramatically Reducing Waste Production
- Proliferation Resistant
- New Markets

Challenges

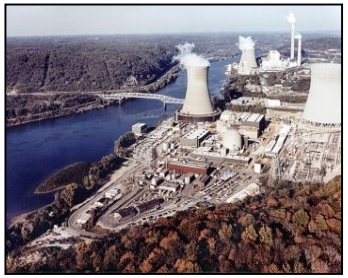
- Different Operations and Industry Comfort?
- New Licensing Strategies/Requirements?
- Inexperience with New Technologies?
  - Industry?
  - Regulator?
  - Workforce?
- Turning the Economy of Scale on it's Head?

Evolution of Nuclear Power

ANS

Generation I

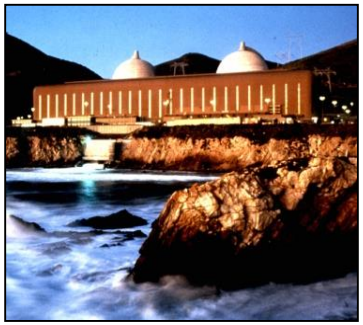
Early Prototype Reactors



- Shippingport
- Dresden
- Fermi I
- Magnox

Generation II

Commercial Power Reactors



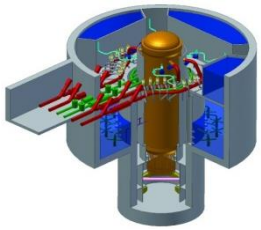
- LWR-PWR, BWR
- CANDU
- VVER/RBMK

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- EPR

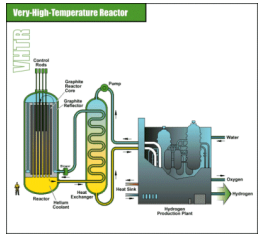
Generation III+



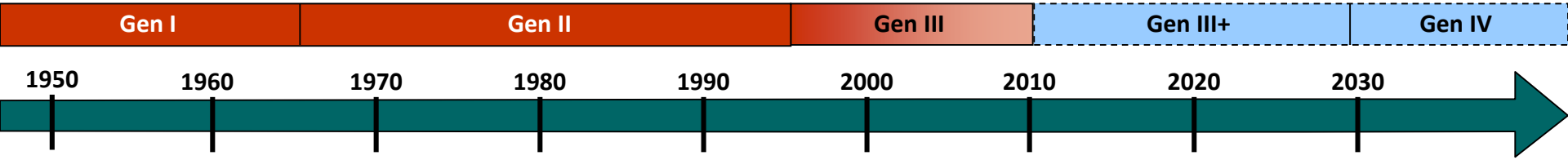
Near-Term Deployment

- AP1000
- PBMR
- SWR-1000
- ABWR-II

Evolutionary Improved Economics



- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant



1. U.S. Department of Energy Gen-IV Roadmap Report

U.S. DEPARTMENT OF ENERGY

Advanced Nuclear Technologies

Many recent new and old ideas

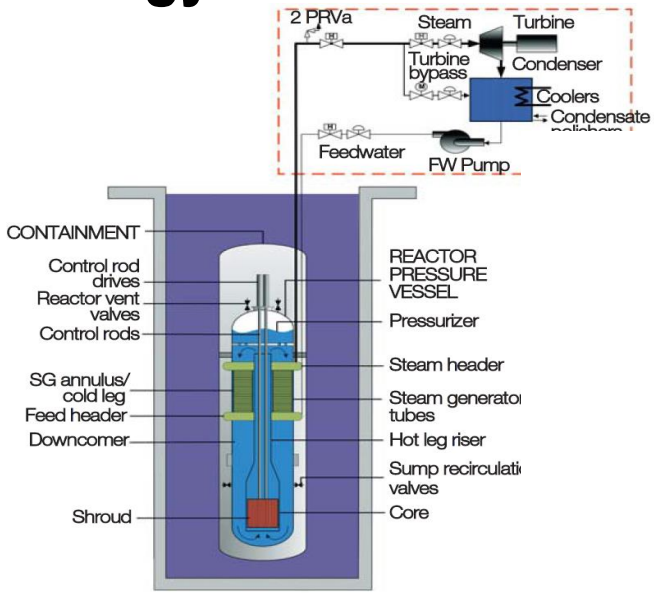
- ❑ Small Modular Reactors
- ❑ Advanced Reactors
- ❑ Innovative Nuclear Concepts
- ❑ Innovative Development Constructs
- ❑ Innovative Nuclear Business Models

Small Modular Reactors

- Small Modular Reactors (SMRs) are being developed for deployment around the world
  - Offer enhanced passive safety features and promise lower construction and financing costs
  - Domestic market focused on replacement of 600+ smaller, aging coal fired plants
  - Export market focused on emerging economies with smaller grids

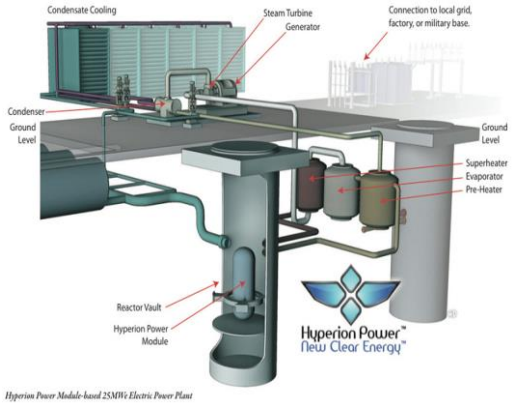
Benefits of SMRs

- **SMRs potential for changing social and energy supply paradigms is compelling**
  - **Jobs**
  - **US goods and services**
  - **National Security and energy policy**
  - **Climate change benefits**
  - **Complement large reactor programs**

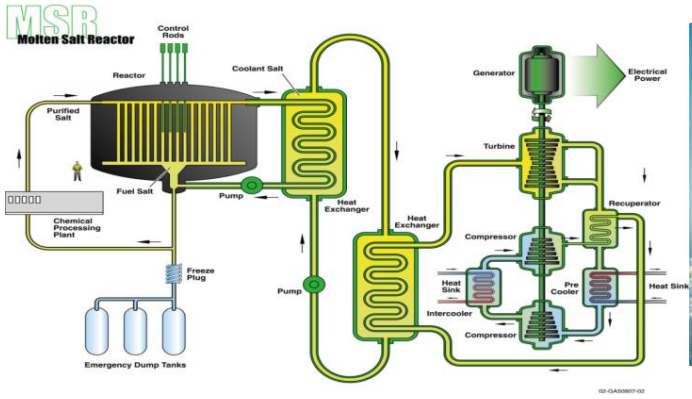


NuScale Integral PWR

SMR licensing must address technology-neutral Issues

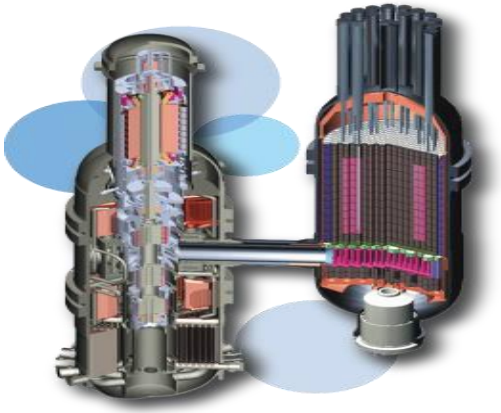


Hyperion Reactor

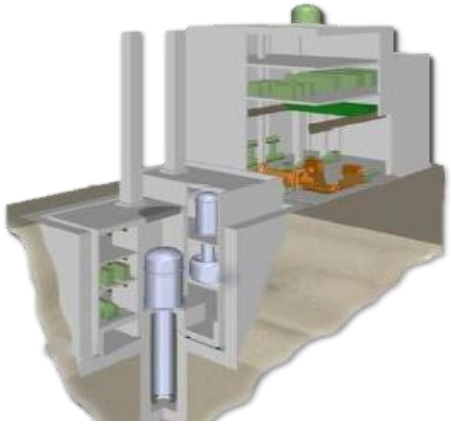


Molten Salt Reactor

KLT-40 Icebreaker Reactor
(35 Mwe floating nuclear power plant)



General Atomics MHR

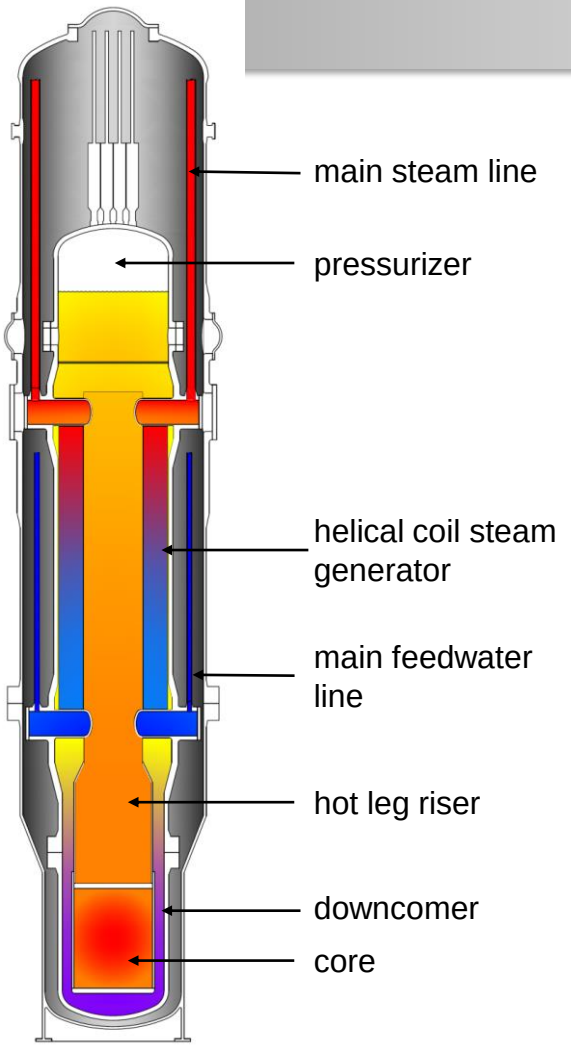


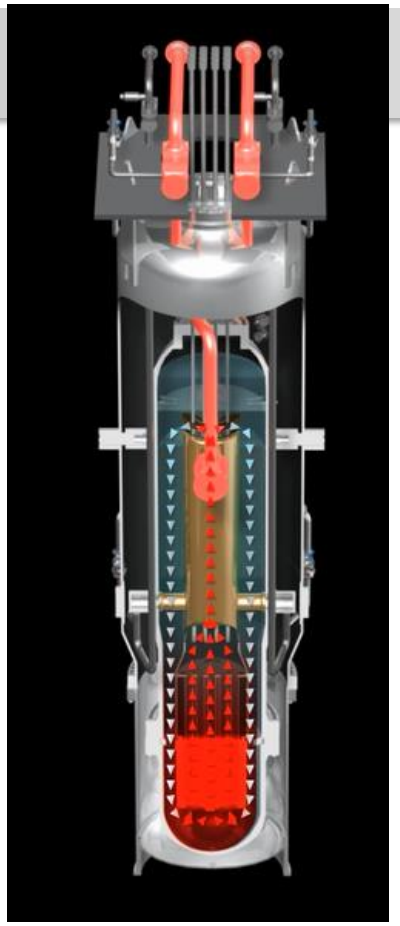
Toshiba 4S (10 to 50 MWe) Sodium-cooled

PBMR (165 MWe)

NuScale Reactor Design Features

- Primary side
  - Natural circulation
  - Integral pressurizer
  - No Reactor Coolant Pumps
- Secondary side
  - Feedwater plenums
  - Two helical steam generators with large surface area per volume to maximize thermal efficiency
  - Steam plenums



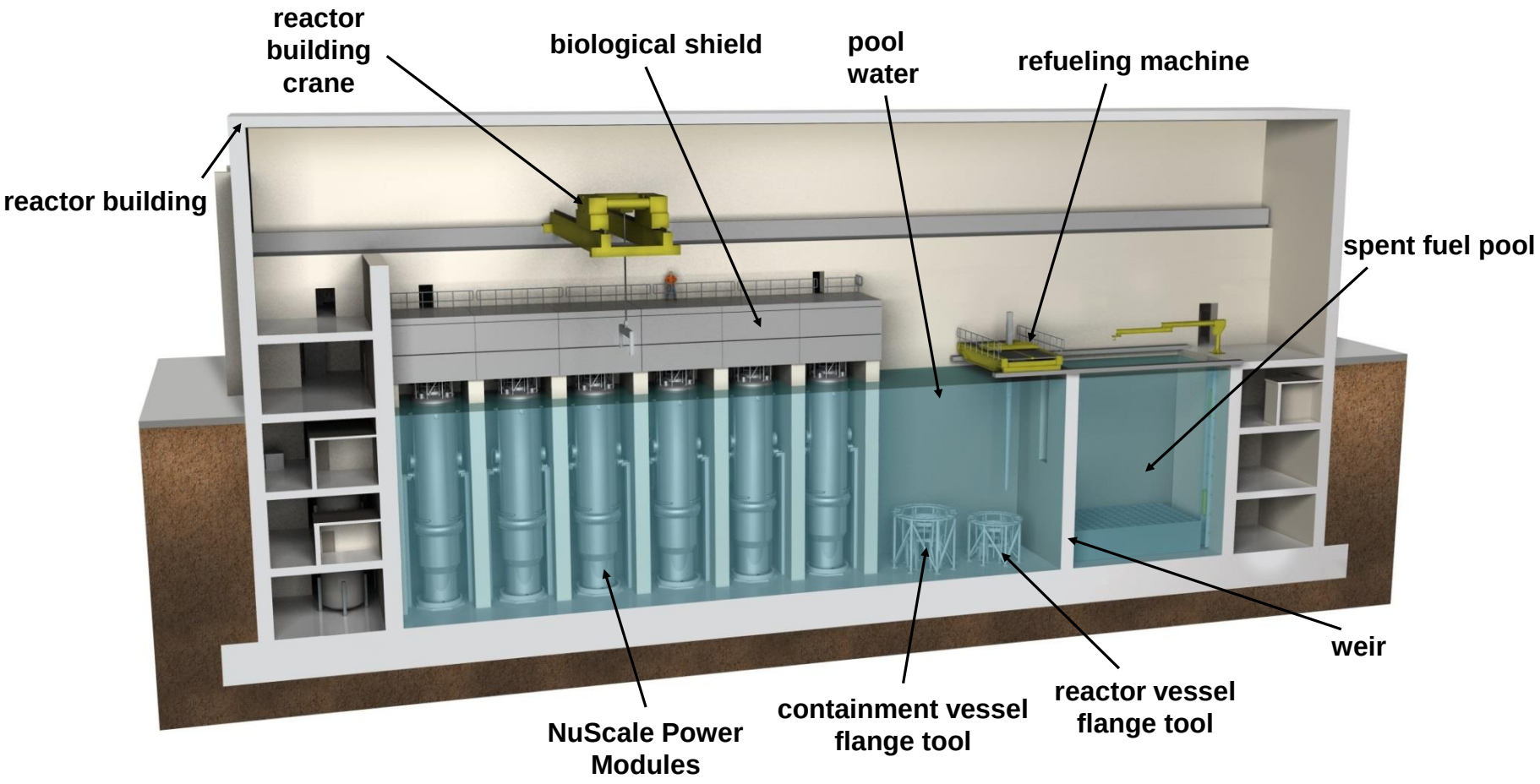


primary coolant flow path

NuScale Power™

Reactor Building Cross-Section

Reactor building houses reactor modules, fuel pool, and reactor pool

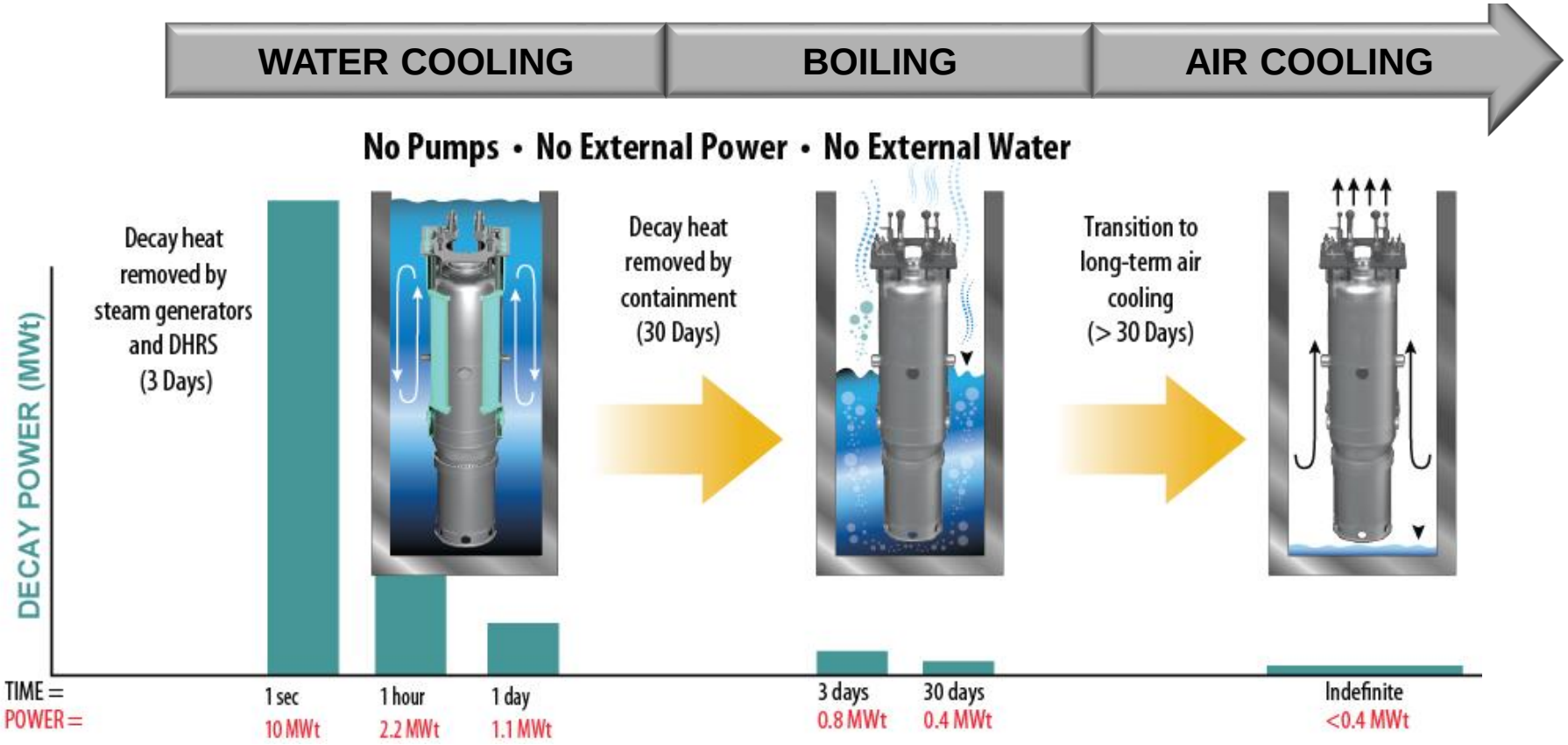


NuScale Power™

Response to Loss of All Power

Stable Long-Term Cooling Under all Conditions

Reactor and nuclear fuel cooled indefinitely without pumps or power



** Based on conservative calculations assuming all 12 modules in simultaneous upset conditions and reduced pool water inventory*

NuScale Integral System Test Facility @ Oregon State University

NuScale Power™

Advancing Advanced Reactors

Generation IV Designs and Concepts

- US Department of Energy
- International Development
- Large Companies – Private Investments
- Startup Companies – Venture Capital

Advanced Reactor Missions

- Process heat applications including cogeneration
- Actinide management to extend fuel resource utilization
- Reduce the nuclear waste burden
- Integration of with intermittent energy sources for reliable energy systems
  - Hybrid Energy Systems

Technology Innovations

- Reduction of capital cost and improvement of thermal energy conversion
- Incorporation of passive safety features
- Advanced fuels
  - Dissolved
  - Particle
  - Metallic
  - Ceramic
- Cladding innovations enabling high burnup, extensive actinide destruction, and enhanced accident tolerance
- Advanced power conversion systems (Brayton, supercritical CO_2) to improve overall energy conversion efficiency and reduce water usage

Gateway for Accelerated Innovation in Nuclear (GAIN)

GAIN Gateway for Accelerated Innovation in Nuclear

ANS

U.S. DEPARTMENT OF ENERGY | Office of Nuclear Energy

- New DOE-NE approach
- Provide the nuclear community with access to the technical, regulatory, and financial support necessary to move innovative nuclear energy technologies toward commercialization
- Ensure continued safe, reliable, and economic operation of the existing nuclear fleet

DOE-NE Demonstration & Test Reactor Assessment Program

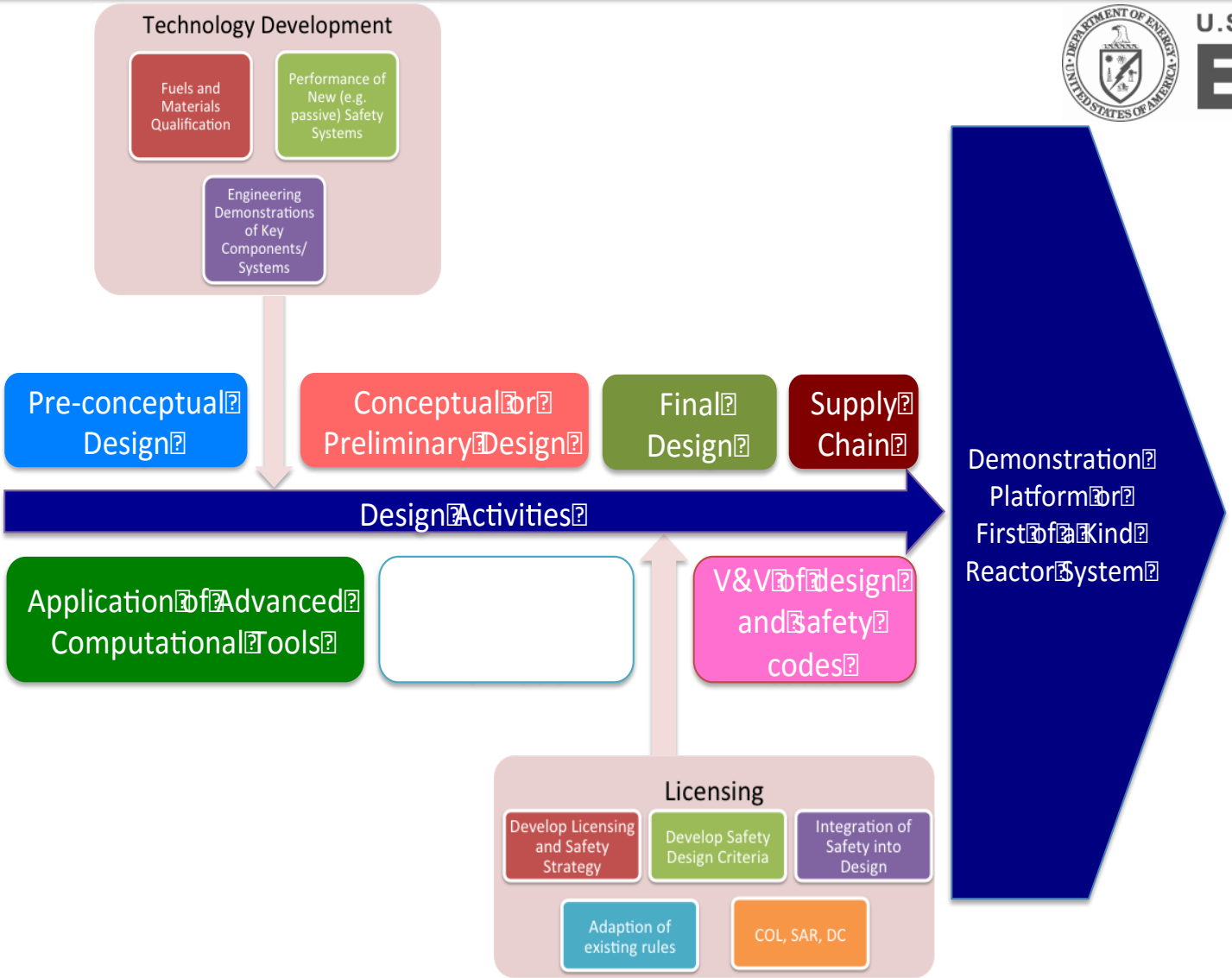
Demonstration Reactor Concepts

- Sodium-Cooled Fast Reactor
- High Temperature Gas-Cooled Reactor
- Lead-Cooled Fast Reactor
- Molten Salt-Cooled Reactor

Test Reactor Concepts

- Sodium-Cooled Fast Test Reactor
- Helium-Cooled Thermal Test Reactor

Technical, Licensing and Design Readiness



International Advanced Reactor Developments

Sodium fast reactor demonstration reactor projects

- Russia (880 MWe BN-800)
- India (500 MWe PFBR)
- China (Experimental Fast Reactor (CEFR) in operation since 2010)
- Japan (restart of Japan Experimental Fast Reactor (JOYO) test reactor and Monju demonstration reactor)

Sodium fast reactor design projects

- Korea (150 MWe PGSFR)
- France (300 MWe ASTRID)

High temperature gas-cooled reactor projects

- China (building two-unit 250 MW pebble bed)
- Eastern Europe (ALLEGRO fast-spectrum gas-cooled reactor study)

International Advanced Reactor Developments

Lead-cooled fast reactor project

- Russia (BREST-300 design project, aiming for 2020 operation)

Subcritical accelerator-driven test projects

- Belgium (85MWth Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) design project)
- Russia (study phase)
- European Union (study phase)

Molten salt reactor projects

- China (2 to 10 MW molten salt pebble bed reactor)
- Europe (study phase)
- Russia (study phase)

ANS Nuclear Grand Challenges

Andrew Klein
ANS President

June 2016

American Nuclear Society

Objectives

- Identify, accumulate, analyze, vet, select, release and promote a set of technical ANS Nuclear Grand Challenges that need to be addressed by 2030
- Professional/Technical focus to improve economic/political/public acceptance of the various nuclear technologies

- Mobilize and energize ANS membership around a Society-wide project

ANS Nuclear Grand Challenges

An all-ANS, grass-roots activity utilizing ANS Division Structure and ANS Collaborate

Process in a Nutshell:

- Identify and select 1-3 Division Grand Challenges
- Select 6-10 ANS Nuclear Grand Challenges from all of the Division Grand Challenges
- Announce/promote/publicize/utilize all ANS Nuclear Grand Challenges and Division Grand Challenges
  - US Congress
  - US DOE, US NRC and other federal agencies
  - ANS topical meetings, publicity, etc.
  - Nuclear Industry, National Laboratories, Academia, others
  - International audiences, as appropriate

ANS Nuclear Grand Challenges

Schedule/Timeline

June 2016 – Kick off conversations in New Orleans with Professional Divisions and select ANS members for the ANS Nuclear Grand Challenges Steering Committee.

June – September 2016 – Divisions organize themselves to identify methods for analysis and vetting of contributed Division Grand Challenges.

October 2016 – Open ANS main website for external collection of ideas, open ANS Collaborate for internal collection of ideas and announce process to ANS members and general public.

November 2016 – Brief the ANS membership on the ANS Nuclear Grand Challenges Project at the Opening Plenary of the ANS Winter Meeting in Las Vegas. Conduct ANS Nuclear Grand Challenges brainstorming session during ANS President's Special Session on Monday afternoon.

ANS Nuclear Grand Challenges

Schedule/Timeline (continued)

November 2016 – March 2017 – Divisions identify, analyze and select their 1-3 Division Grand Challenges.

April – May 2017 – Division Chairs collectively determine the top 6-10 Division Grand Challenges to be identified as the ANS Nuclear Grand Challenges.

June 2017 – Announce the ANS Nuclear Grand Challenges and the Division Grand Challenges at the Opening Plenary Session at the 2017 ANS Annual Meeting in San Francisco. Stimulating discussion of the top ANS Nuclear Grand Challenges during ANS President's Special Session on Monday afternoon.

Post June 2017 – Promote/discuss ANS Nuclear Grand Challenges with US Congress, US DOE (Leadership, Nuclear Energy, Science, Fusion Energy, Science, and others), NSF, professional societies (ASME, IEEE, HPS, INMM, ASEE, NAE, NAS, etc.) and others to gain support for solving the identified Challenges.

Presidential Objectives for 2016-2017

- Promote and Implement Board approved recommendations from last year's Special Committee on the Future of ANS
  - Establish relevant task forces and, if needed, Special Committees
  - Develop appropriate business cases and strategic recommendations for Board consideration and approval
- Develop and complete the Nuclear Grand Challenges Project by June 2017
  - Mobilize and energize ANS membership
  - Utilize Division structure and ANS Collaborate
  - Generate/Analyze/Vet/Prioritize/Release/Promote set of technical grand challenges for nuclear technologies to tackle and solve by 2030

Presidential Objectives for 2016-2017

Further Objectives

- Explore enhanced fundraising models for the Society
  - ANS programs and projects
  - Center for Nuclear Science and Technology Information (CNSTI)
  - Local Sections
- Engage communities related to ANS, both nationally and internationally
- Support our Local Sections and others to utilize the Nuclear in the States Toolkit developed in 2016
- Build and energize ANS membership – and communicate better with our members

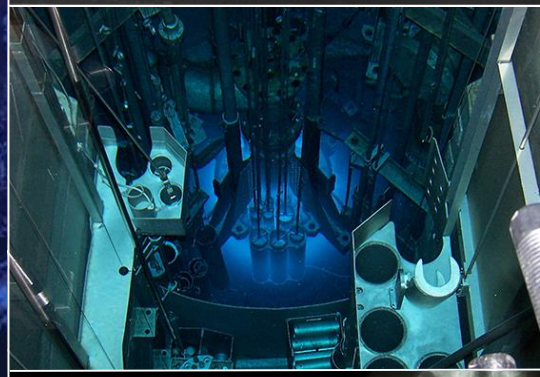
What Can You Do?

- Share the message: social media, letters to editor, etc.
  - The World Needs Nuclear!
- Share the link: www.nuclearconnect.org
- Be involved
- Be a part of the public discussion:
  - Why is your energy future not part of the current election debate?
- Challenge bad science wherever you encounter it
- Be proud of who you are and what you do
- Join, renew and recruit for ANS!

The WORLD needs NUCLEAR

NUCLEAR needs the American Nuclear Society

ANS



American Nuclear Society

ans.org