Advancing Advanced Nuclear Technologies

American Nuclear Society

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

Northeastern Local Section
3 April 2017

Advancing Advanced Nuclear Technologies

About ANS
The Importance of Nuclear Energy
Evolution of Nuclear Power
Small Modular Reactors
Advancing Advanced Reactors
ANS Nuclear Grand Challenges
Benefits of ANS Membership
What Can You Do?

About ANS

An international professional organization of engineers, scientists, educators, and others devoted to peaceful applications of nuclear science and technology.

About ANS

More than 10,000 individual members

More than 100 organizational members

International alliances, bilateral agreements with 25 nuclear societies outside the U.S.

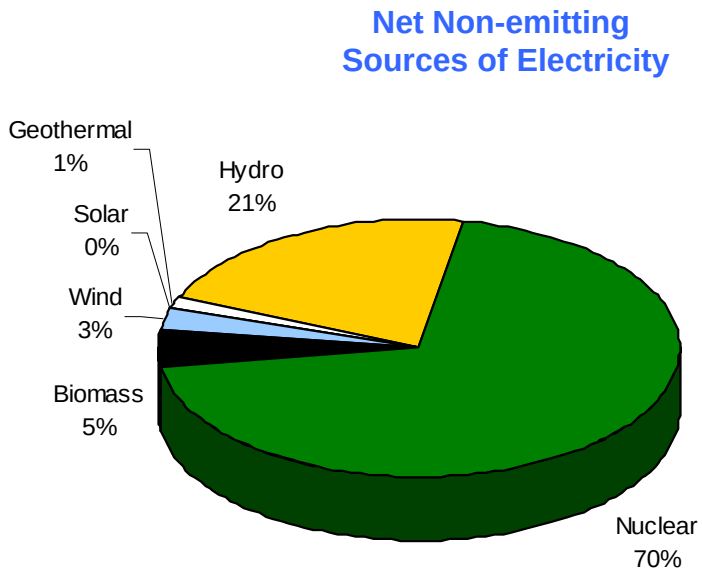
51 Local Sections (including 9 outside the U.S.)

53 Student Sections

20 specialty Professional Divisions

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**



Current Issues – United States

Keeping Current Plants Operating

- Full Value for Reliable & Clean Generation

Building New/Replacement Plants

- Opening Generation III+ Plants
- Enabling Small Modular Reactors
- Advancing Advanced Reactors

Managing Used Nuclear Fuel

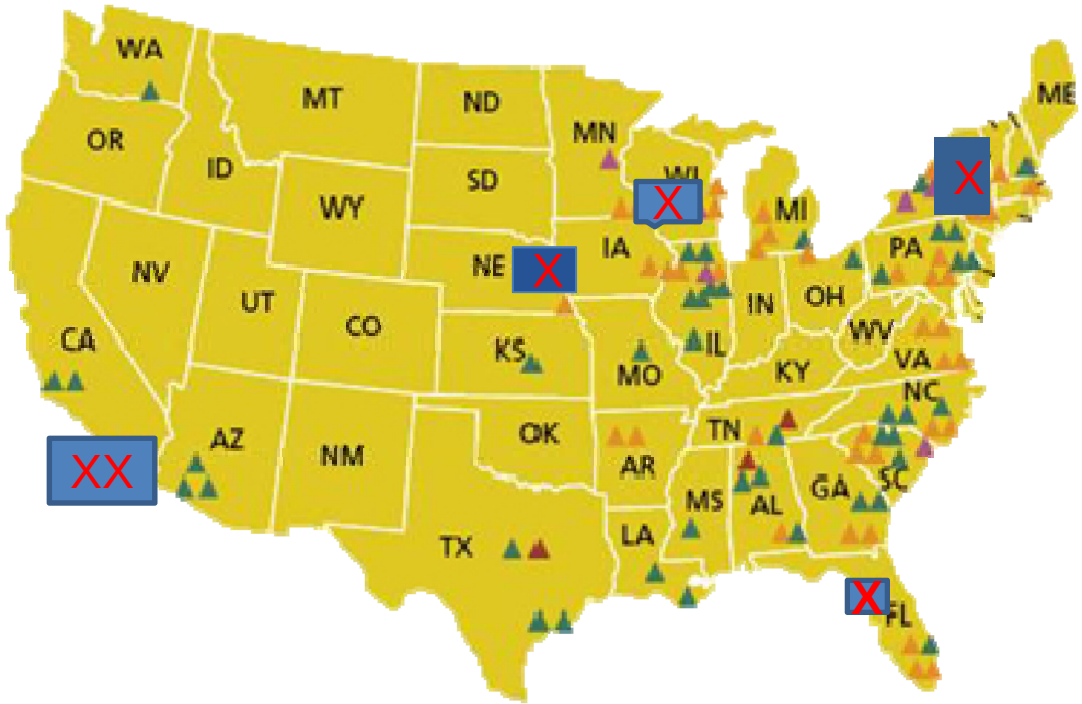
Educated, Trained & Dedicated Workforce

ANS Nuclear Grand Challenges

Currently Operating Plants

- Deregulated markets in US do not recognize emissions reduction or even capacity factors
- Low price of natural gas
- Overall slow demand growth
- No credit for operating plants in the EPA CPP
- Only four new units presently under construction
- Little recognition of vital role nuclear plays in reducing emissions
- **Good news**:
  - August 1, 2016, New York Public Service Commission enacted **Clean Energy Standard (CES)** including provisions to prevent closure of emissions-free nuclear facilities
  - December 1, 2016, Illinois Legislature approved the **Future Energy Jobs Bill** to keep Clinton and Quad Cities nuclear power plants open
  - **License extensions** to 80 years

US nuclear units shut down since 2013



Fort Calhoun shut down in October 2016
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 2.0
  - Policy Options for States
- DOE-NE Workshop
- Save US Nuclear activities
  - Third Way
  - Environmental Progress
  - Mothers for Nuclear
  - Breakthrough Institute
  - Clean Air Task Force
  - Others

Nuclear In the States Toolkit

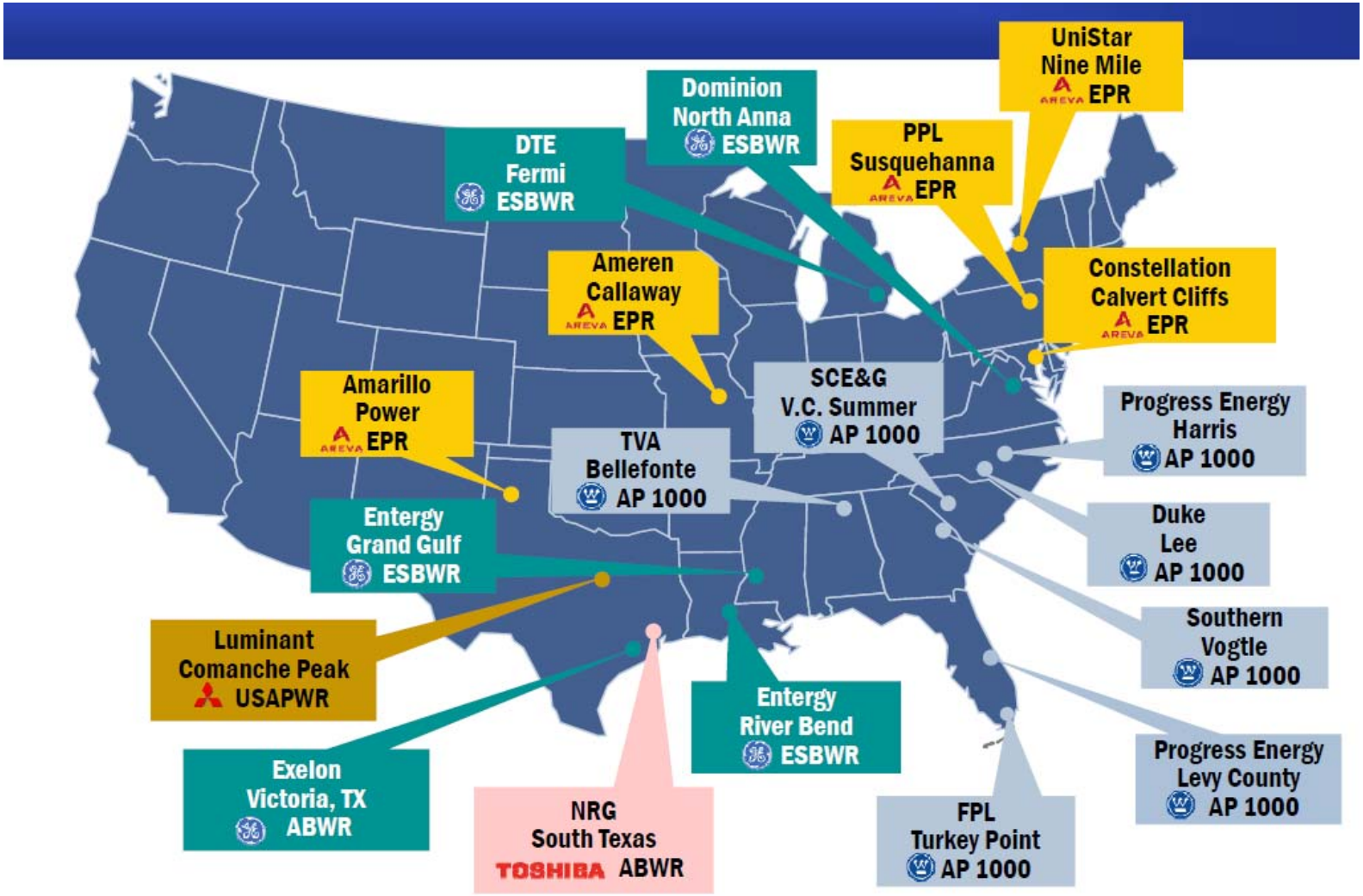
Policy options for States considering the role of nuclear power in their energy mix

- 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

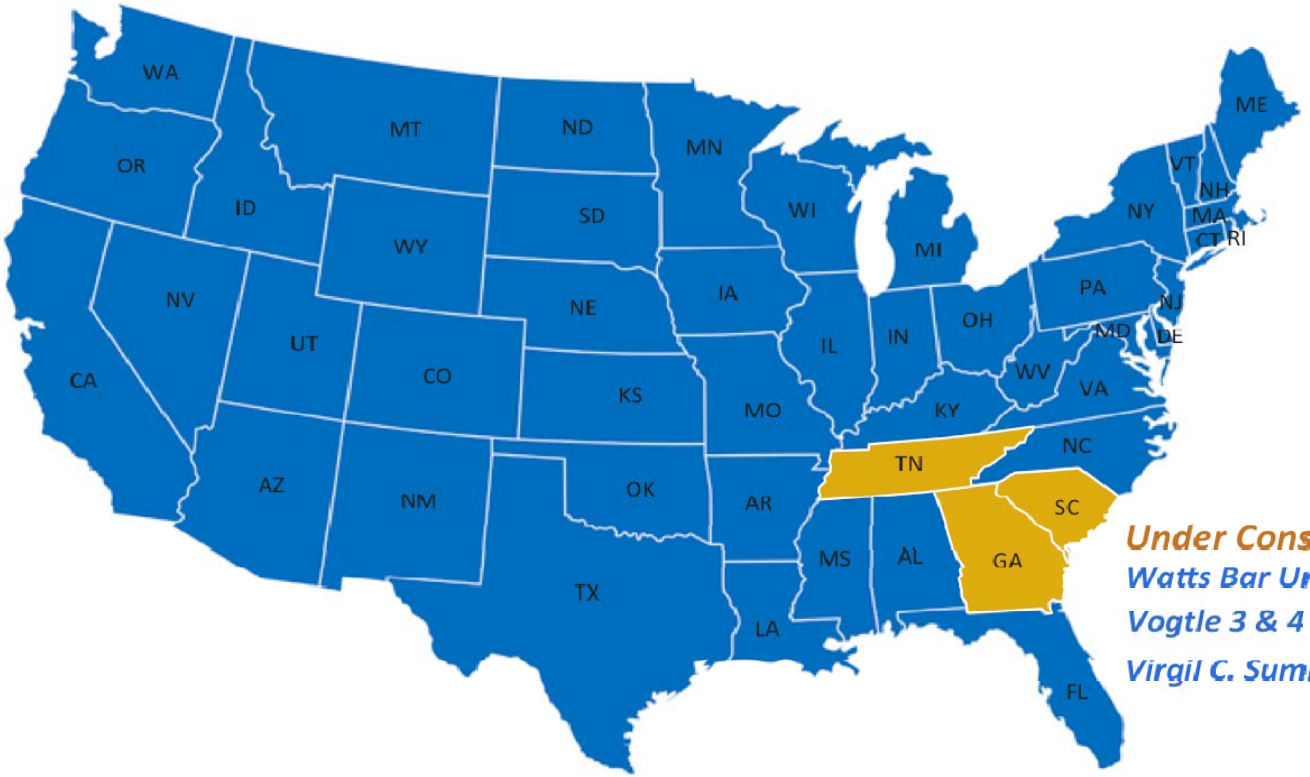
ANS Nuclear in the States Special Committee Focus for 2016-2017

- Identify specific states for focus
  - States with plants that are under the greatest challenge
  - States considering new plant construction
- Identify constituents and stakeholders to provide sustainability
- Engage local and student ANS Sections
- Refine and develop the tools already developed
- Provide constituents and stakeholders with tools & training

Outlook on New Construction



~~Five~~ Four New Units Under Construction



Under Construction:

Watts Bar Unit 2 ← **Operating!**

Vogtle 3 & 4

Virgil C. Summer 2 & 3

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

Managing Used Nuclear Fuel

More open questions than answers

Process stalled, but all fuel safely stored

Uncertain future of

- Long-term storage (distributed/central/other)
- Intermediate storage
- Repository identification
  - Blue Ribbon Commission Report in January 2012
  - Yucca Mountain
- Recycling?

Evolution of Nuclear Power

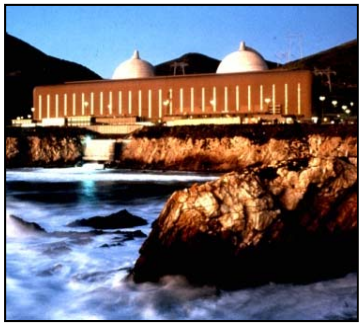
Generation I

Early Prototype Reactors

- Shippingport
- Dresden
- Fermi I
- Magnox

Generation II

Commercial Power Reactors



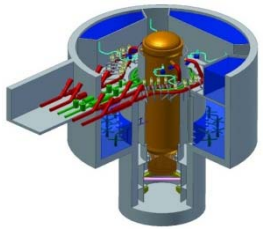
- LWR-PWR, BWR
- CANDU
- VVER/RBMK

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- EPR

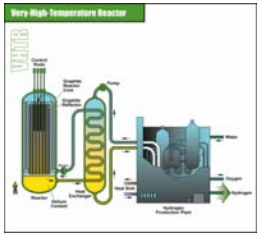
Generation III+



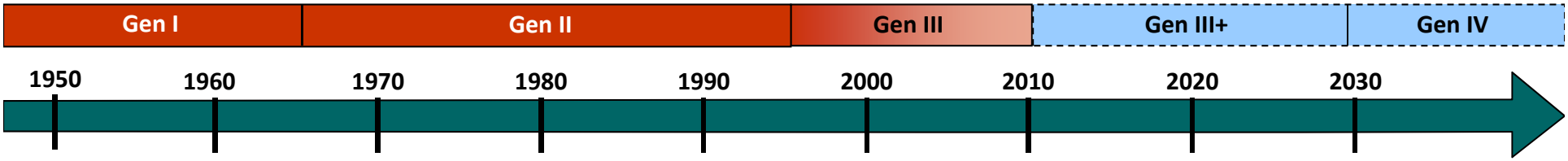
Near-Term Deployment

- 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

Advanced Nuclear Technologies

Opportunities

- Highly Efficient Technologies
- New Instrumentation and Control Strategies
- Modular Construction
- Dramatic Reduction of Waste Production
- Proliferation Resistant
- New Markets, Grids (Small & Large)
- New Missions

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?

Advanced Nuclear Technologies

Many recent new and old ideas

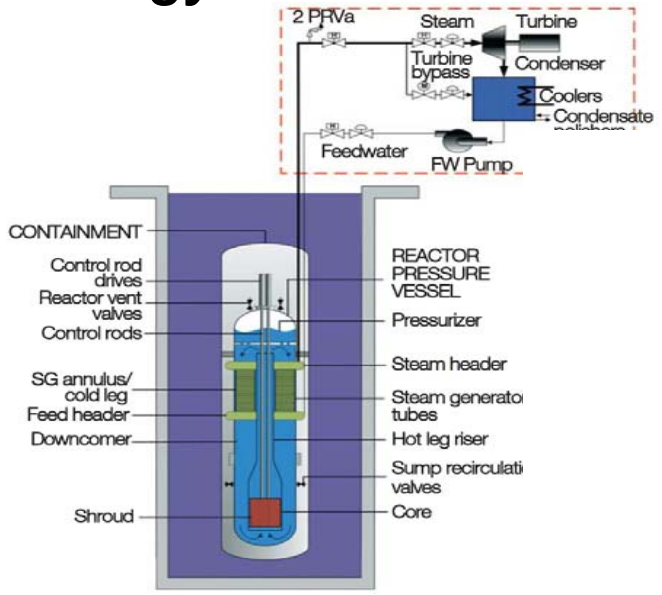
- Small Modular Reactors
- Advanced Reactors
- Innovative Nuclear Concepts
- Innovative Development Constructs
- Innovative Nuclear Business Models

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

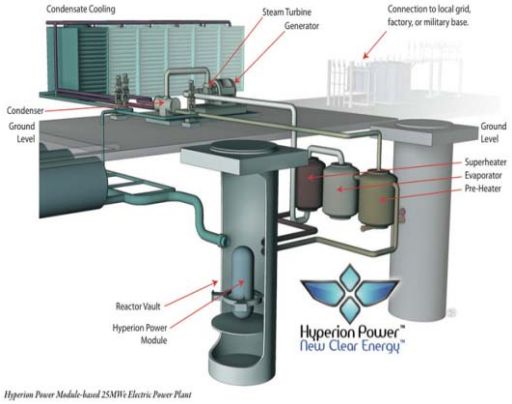
Benefits of SMRs

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

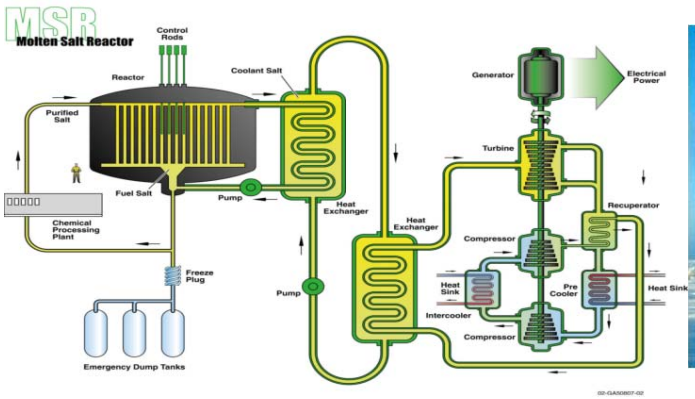


NuScale Integral PWR

SMR licensing must address technology-neutral Issues

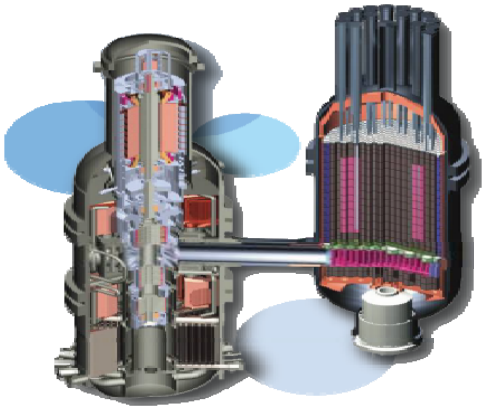


Hyperion Reactor

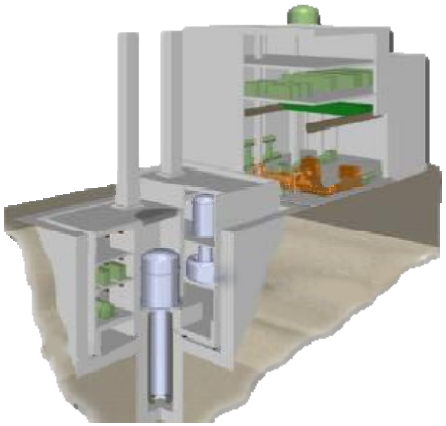


Molten Salt Reactor

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



General Atomics MHR

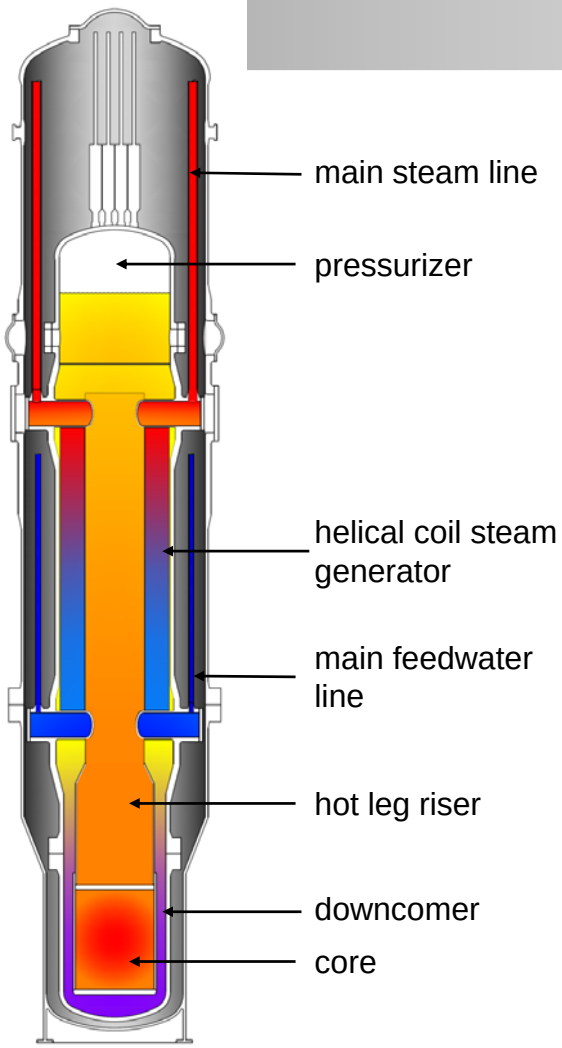


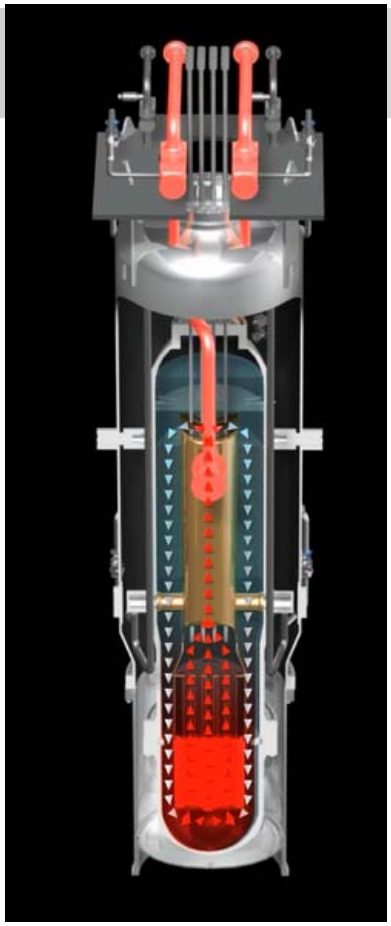
Toshiba 4S (10 to 50 MWe) Sodium-cooled

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



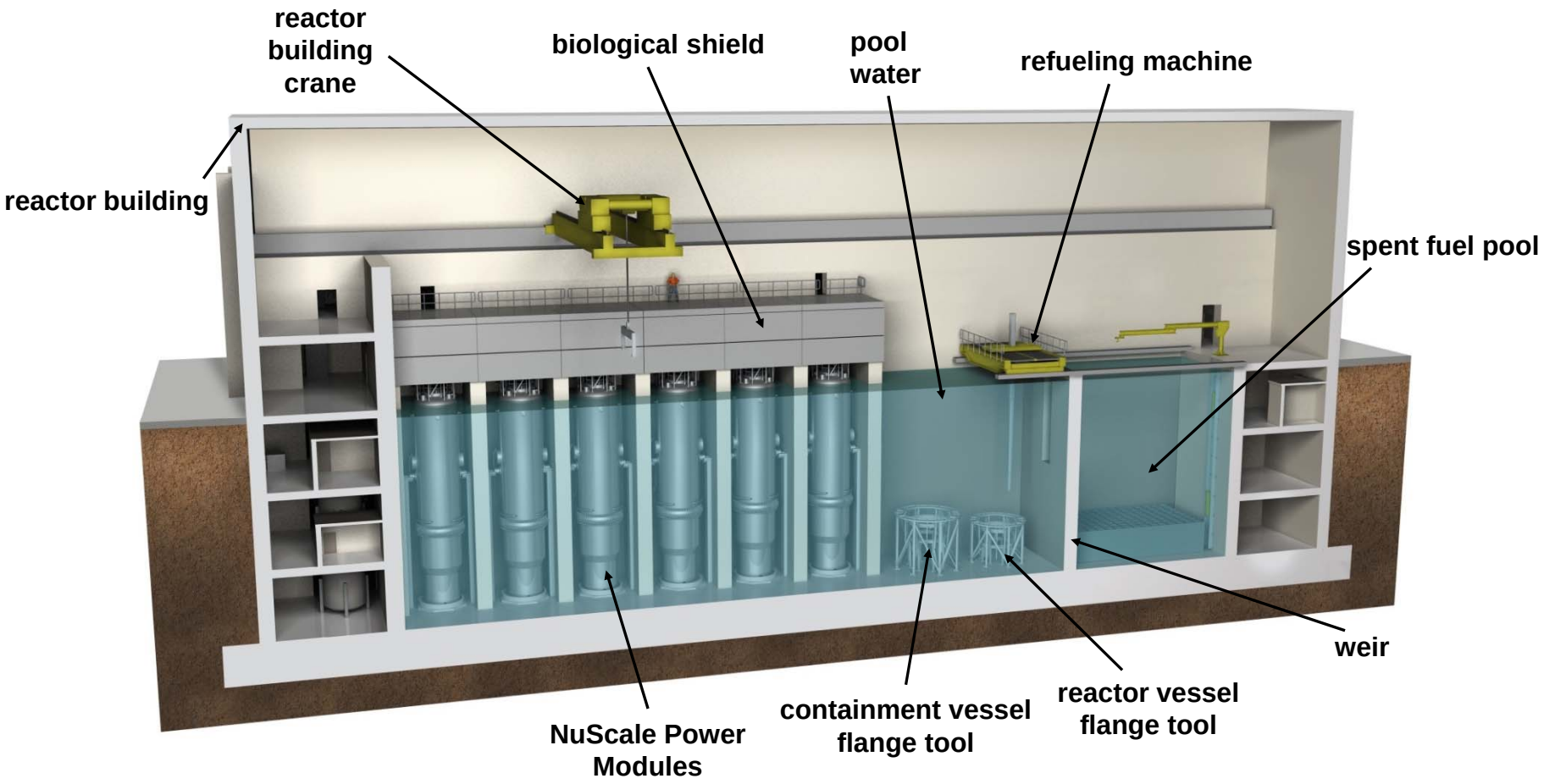


primary coolant flow path

NuScale Power™

Reactor Building Cross-Section

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

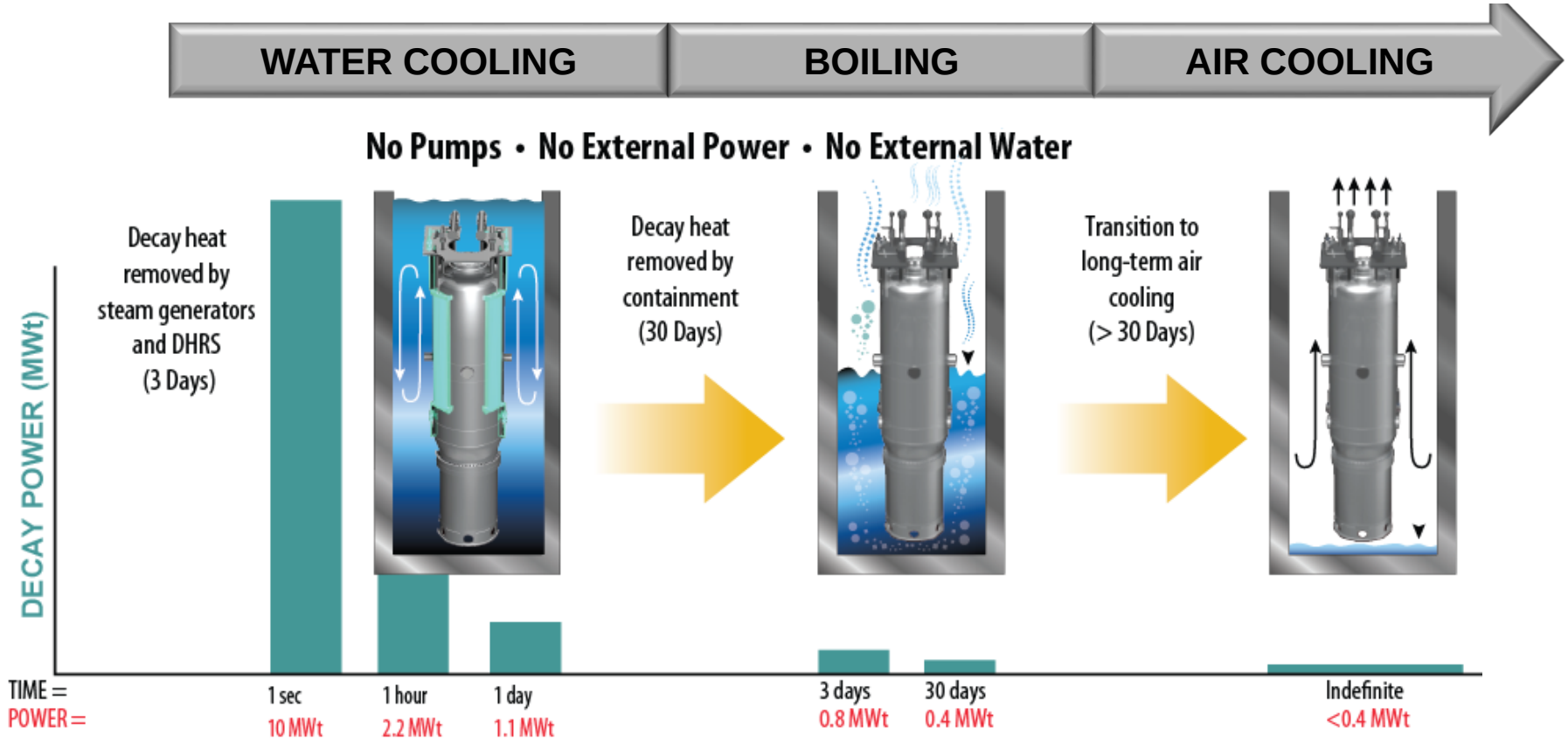


NuScale Power™

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 Power™

NuScale Integral System Test Facility @ Oregon State University

NUSCALE POWER™

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
  - Fusion
- 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

Advancing Advanced Reactors

Generation IV Designs and Concepts

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

Gateway for Accelerated Innovation in Nuclear (GAIN)

GAIN Gateway for Accelerated Innovation in Nuclear

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

Advancing Advanced Reactors

High Temperature Gas Reactors

General Atomics http://www.ga.com/energy-multiplier-module

Areva http://us.areva.com/EN/home-3225/areva-inc-areva-htgr.html

Hybrid Power Technologies
http://www.hybridpowertechnologies.com/

Molten Salt Reactors

Transatomic Power http://www.transatomicpower.com/

Terrestrial Energy http://terrestrialenergy.com/

Oklo (formerly UPower) http://oklo.com/

ThorCon Power http://thorconpower.com/

Liquid Metal Reactors

TerraPower http://terrapower.com/

General Electric http://gehitachiprism.com/

Advanced Reactor Concepts
http://www.arcnuclear.com

Gen4 Energy http://www.gen4energy.com/

Westinghouse http://www.westinghousenuclear.com/

Fusion Reactors

Helion Energy http://www.helionenergy.com/

Tri Alpha Energy http://www.trialphaenergy.com/

General Fusion http://www.generalfusion.com/

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

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

IMSR – INNOVATION FOR INDUSTRIAL USE

Key innovation is the integration of primary reactor components

- Reactor core
- Primary heat exchanger
- Pumps

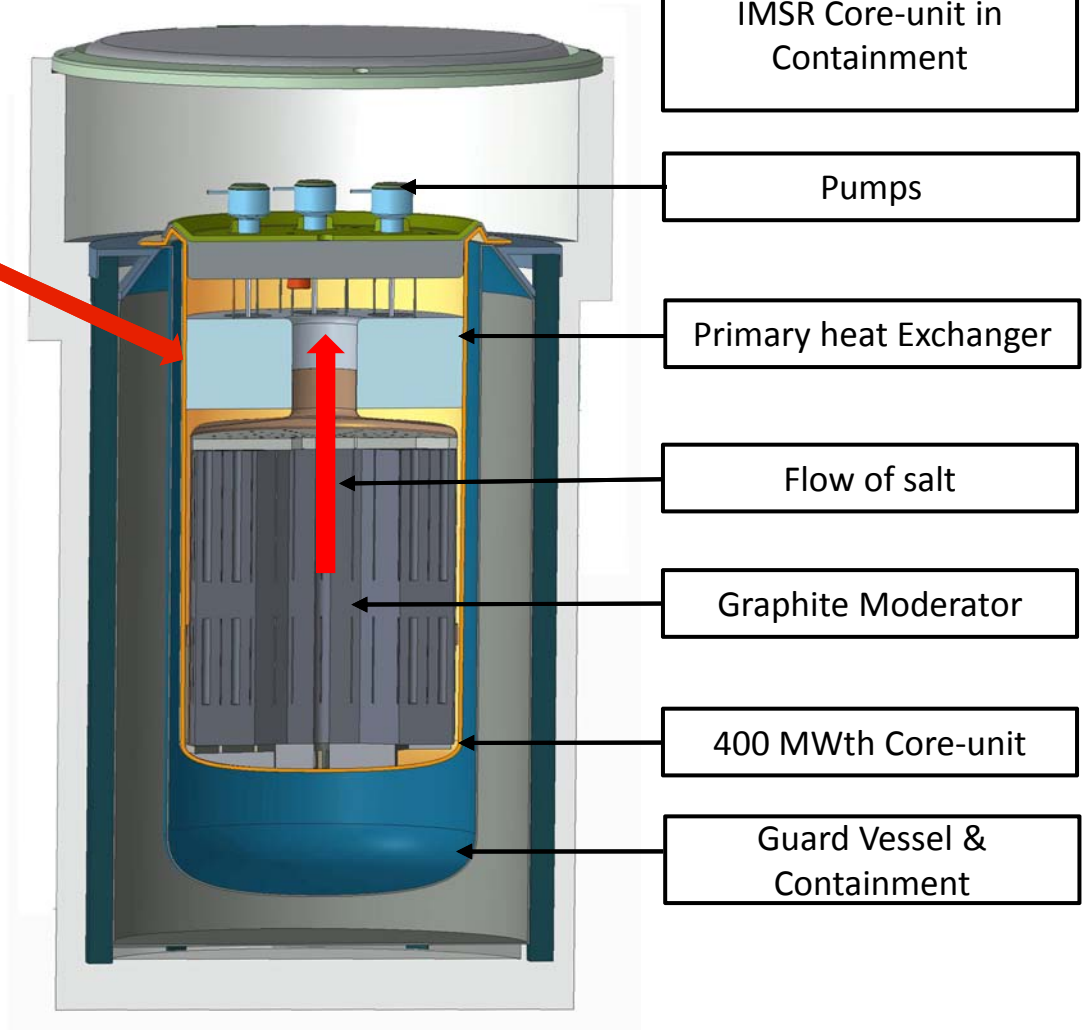
..into a sealed reactor vessel within a compact and replaceable unit

- For a 7-year operational life

This integral design promises high industrial value through

- Inherent safety
- Operational simplicity
- Cost innovation

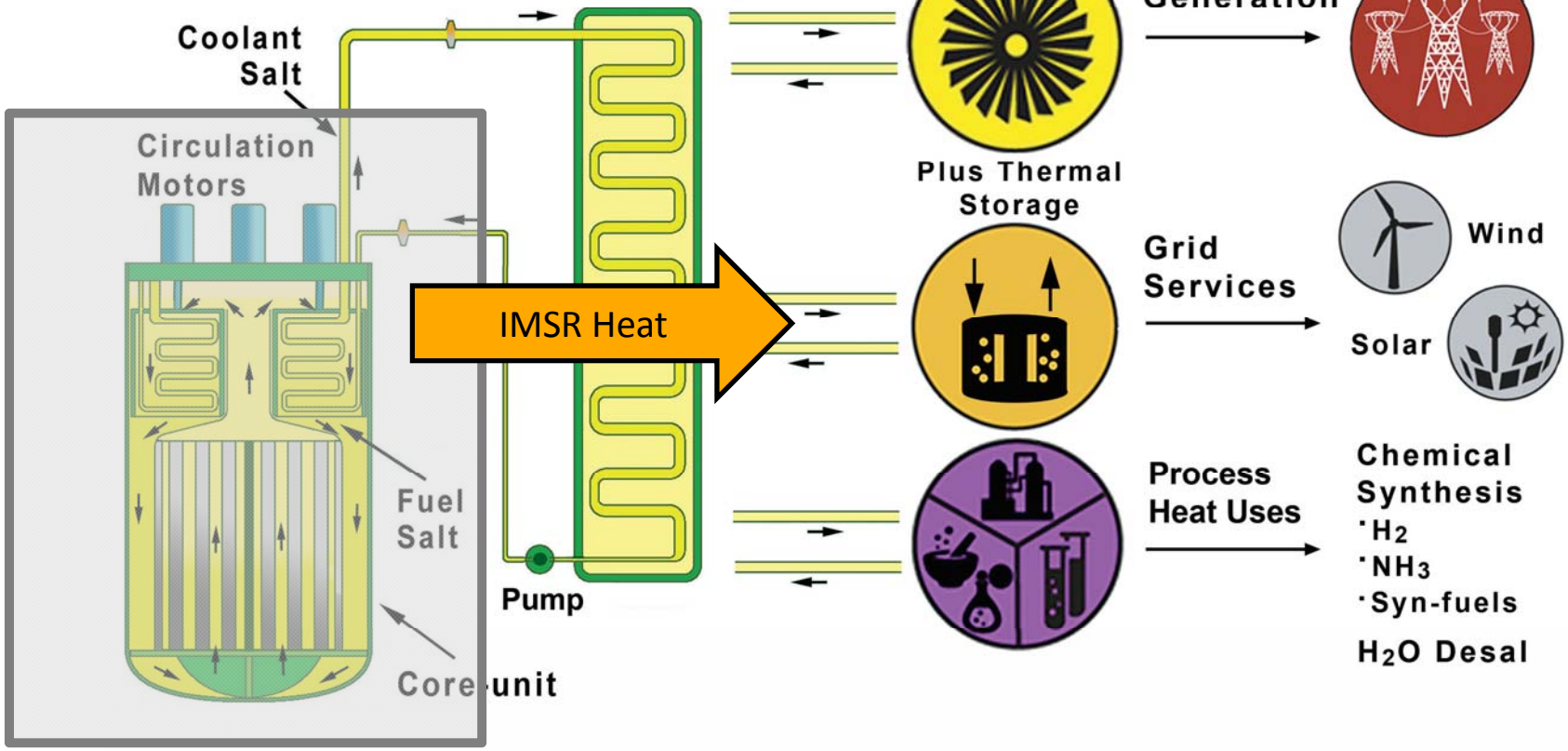
Patent applications filed



TERRESTRIAL ENERGY

IMSR™ 400 MWth (192 MWe) FOR INDUSTRIAL HEAT USE

Dispatchable, clean convenient, cost-competitive heat for industrial use



IMSR™ heat has many industrial uses

TERRESTRIAL ENERGY

Workforce Issues

Continuous requirement for a well educated, trained and dedicated workforce – facilities last much longer than individual careers!

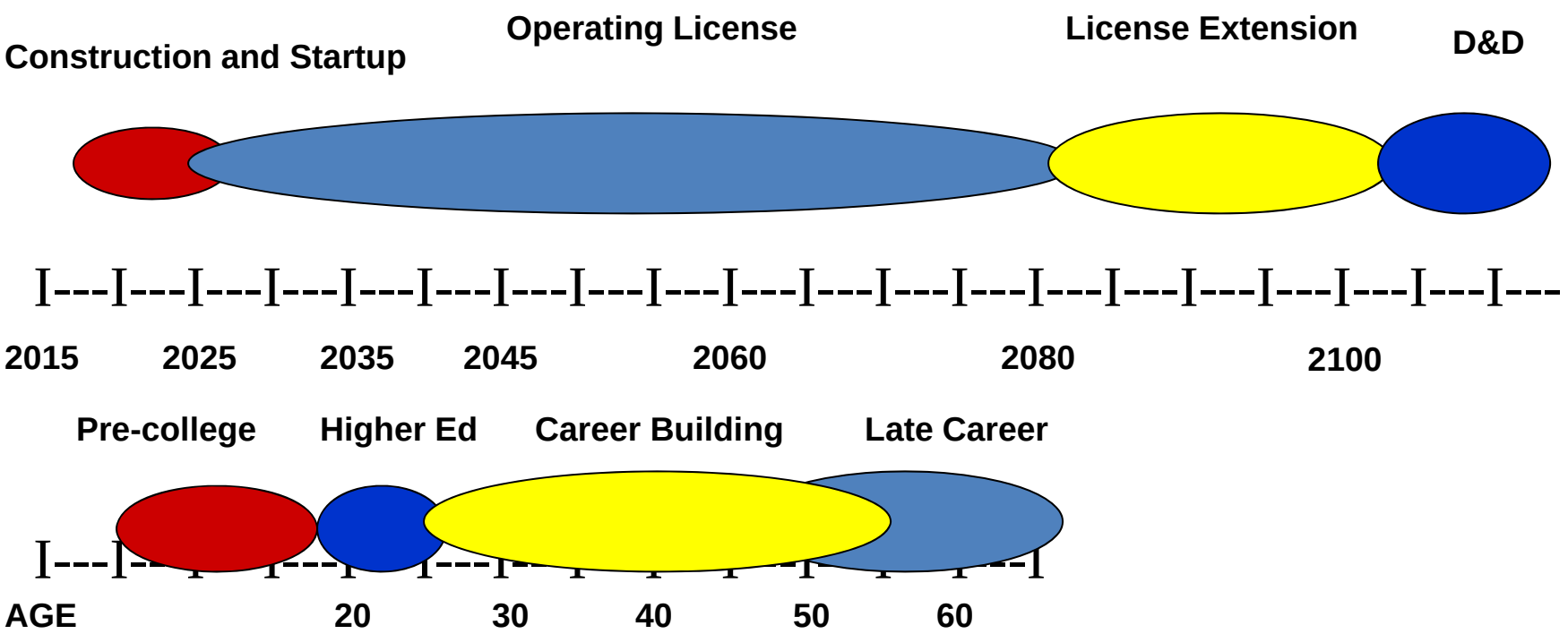
Engineers (Nuclear and other); Health physicists; Radiation protection specialists; Operators (licensed and non-licensed); Chemists; Technicians; Others

Important facets to maintain:

- Interested and engaged students
- Faculty and research support
- Training, teaching & research facilities

Generic Time-line and Activities

Projects



People

Dr. Andrew Klein
ANS President

November 2016

American Nuclear Society

ANS Nuclear Grand Challenges

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
- Technical, community identified focus areas for future activities

Key Benefits of ANS Membership

Knowledge

- Gain a professional edge
- Journals, Digital Nuclear Library, Nuclear News, Conference Proceedings, Books

Credible voice supporting nuclear

- Strengthen ANS's ability to support and advance nuclear science and technology with public and policy makers

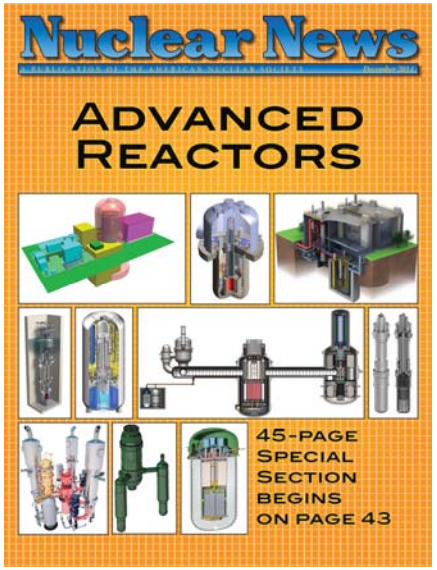
Networking and collaborating

- Personal connections with key nuclear professionals
- Professional advancement
- Members only online communities

ans.org/join

Your Membership Includes:

- Subscription to Nuclear News monthly magazine
- ANS News, bi-monthly newsletter
- Two Professional Division memberships
- Exclusive access to members-only resources
- Member discounts: publications, ANS conferences
- Student Program: conference registration, reimbursement & travel assistance for selected students



ans.org/join

See ANS website to learn about even more benefits

The Center makes the complex nuclear world easier to understand for the general public.

It encourages nuclear education for K-12.

Helps the public and policy makers learn the many benefits that nuclear science and technology bring to their lives.

Is funded entirely through donations.

Center for Nuclear Science and Technology Information

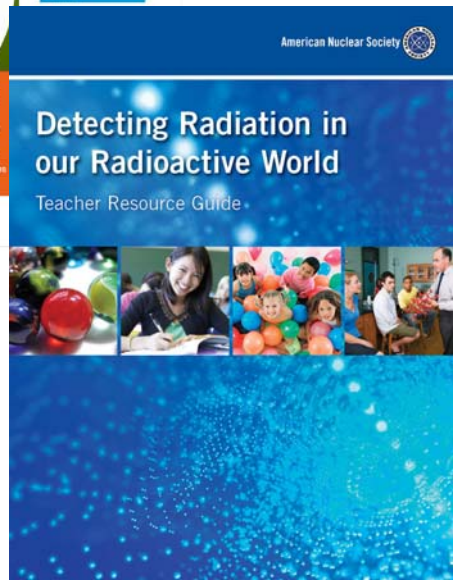
An initiative of the American Nuclear Society

nuclearconnect.org

A Lead Partner at COP21 in Paris

In Schools

Teacher Newsletter



Classroom Materials

Teacher Workshops

In Communities

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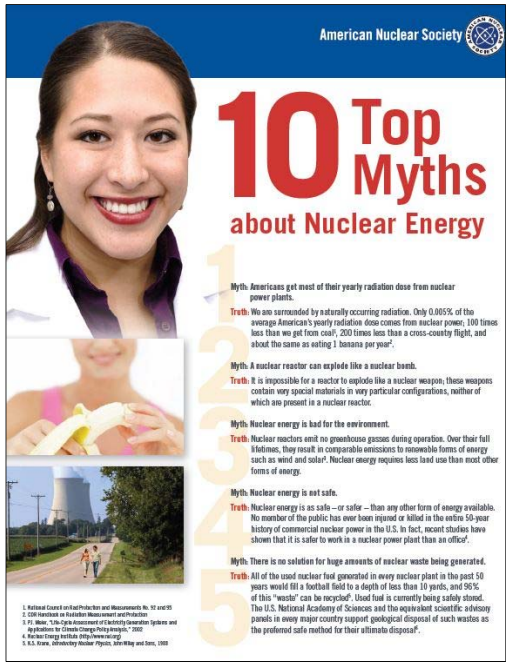

Easy to understand handouts

Bookmarks

In Government

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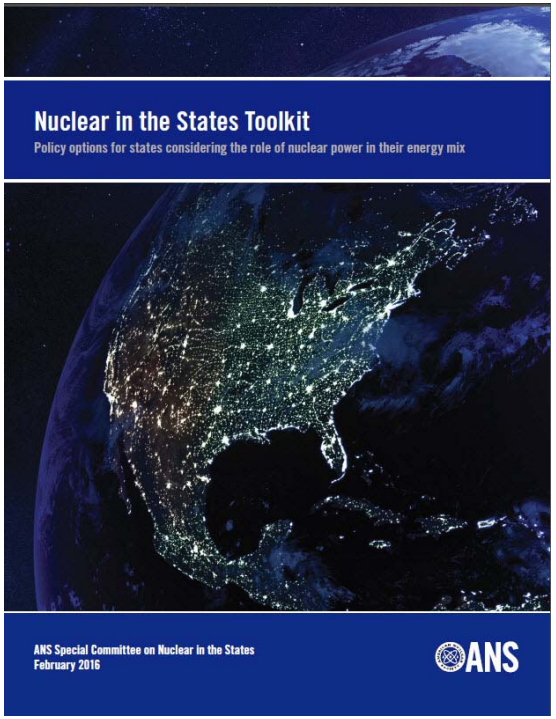

Nuclear in the States

Congressional Seminar Series

In Media

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POWER Engineering

Videos Webcasts Whitepapers Events Magazine

HOME ENERGY STORAGE COAL GAS RENEWABLES NUCLEAR ONSITE POWER O&M EMISSIONS BUSINESS

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Incoming ANS president says group must inform public, policy makers

SAN ANTONIO, Texas

Jun 10, 2015

By Sharryn Dotson
Editor of Nuclear Power International

The American Nuclear Society (ANS)'s 61st president said the organiza
how everyone's lives are affected by it.

Gene Grecheck does not officially begin his role as ANS president until
is the principal of his own consulting group, spent more than 30 years
world needs nuclear.

"Nuclear affects everyone's lives and, in so many ways, people's lives c
educate and provide information and help to influence public policy de

INDUSTRY NEWS : ENERGY

Are new EPA regulations an opportunity for nuclear energy?

Jun 8, 2015, 3:56pm CDT

INDUSTRIES & TAGS Energy, Energy Inc., Solar Energy

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Sergio Chapa
Reporter
San Antonio Business Journal

The Environmental Protection Agency is expected to toughen the nation's air pollution standards in the fall giving nuclear energy a possible opportunity to grow in the United States.

Hundreds of nuclear energy professionals are gathering at the Grand Hyatt in downtown San Antonio for the American Nuclear Society's annual meeting all this week.

Southern Company CEO Tom Fanning said it may take a new administration to pass new energy... more

CARLOS JAVIER SANCHEZ

THE HILL

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October 16, 2015, 04:00 pm

Nuclear energy must be part of the COP21 climate change solution

By Eugene Grecheck

299 50 COMMENTS 179

In December, representatives of world governments will take on one of the most daunting technological challenges of our time: ratifying an agreement to reduce carbon dioxide (CO_2) emissions by 80 percent by 2050. They will meet in Paris for the 21st Conference of the Parties to the UN Framework Convention on Climate Change (COP21).

Improving Nuclear Communications with the Public

Center for Nuclear Science and Technology Information
An initiative of the American Nuclear Society

Speakers Bureau

Improving Nuclear Communications with the Public

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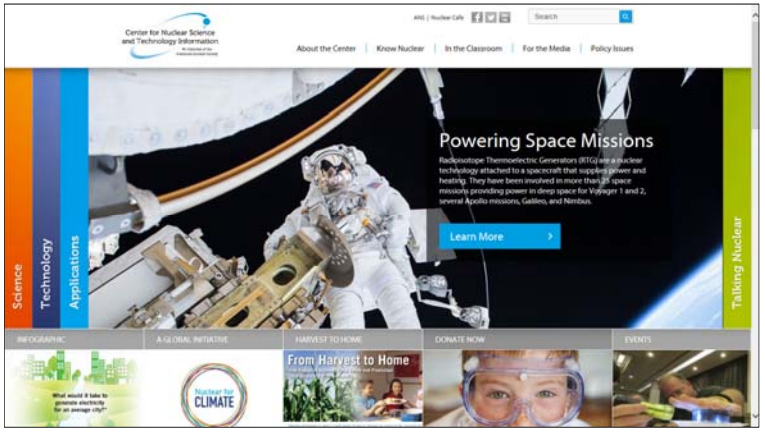
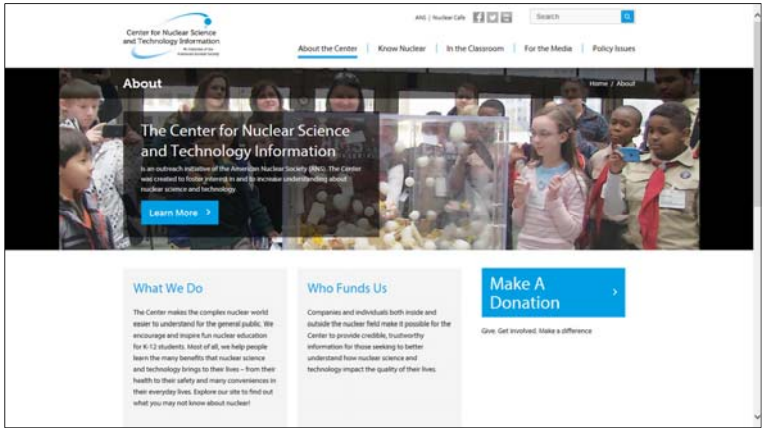
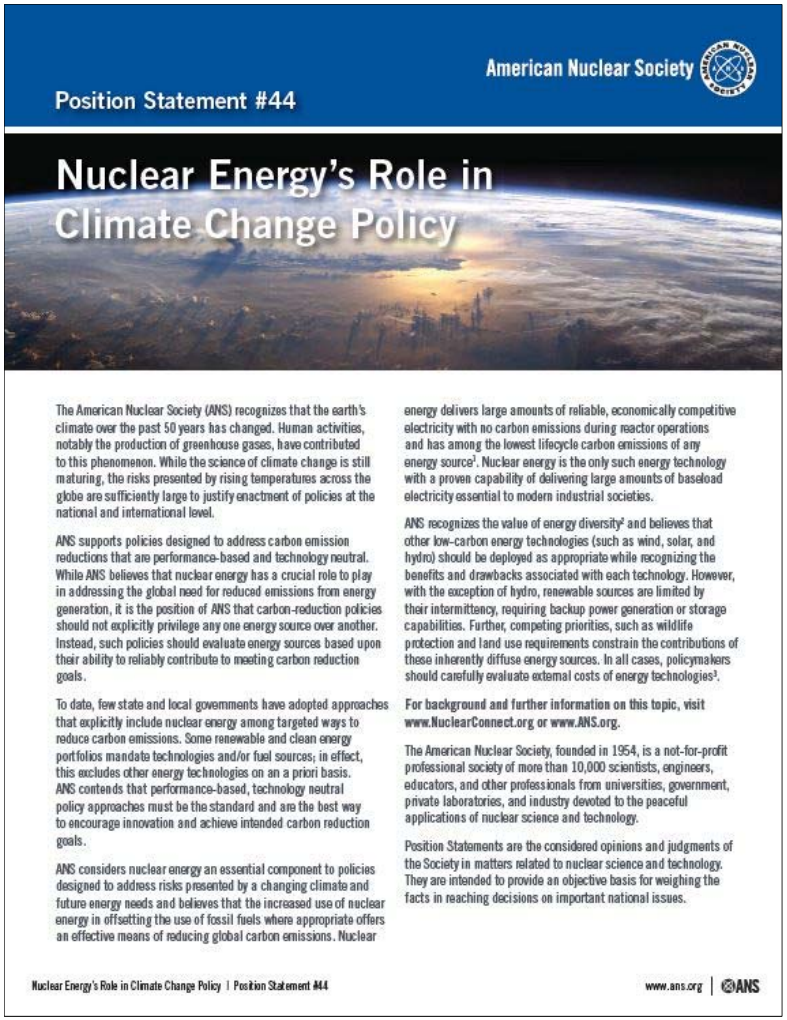




nuclearconnect.org - Website for public audiences

Position Statements



American Nuclear Society

Position Statement #44

Nuclear Energy's Role in Climate Change Policy

The American Nuclear Society (ANS) recognizes that the earth's climate over the past 50 years has changed. Human activities, notably the production of greenhouse gases, have contributed to this phenomenon. While the science of climate change is still maturing, the risks presented by rising temperatures across the globe are sufficiently large to justify enactment of policies at the national and international level.

ANS supports policies designed to address carbon emission reductions that are performance-based and technology neutral. While ANS believes that nuclear energy has a crucial role to play in addressing the global need for reduced emissions from energy generation, it is the position of ANS that carbon-reduction policies should not explicitly privilege any one energy source over another. Instead, such policies should evaluate energy sources based upon their ability to reliably contribute to meeting carbon reduction goals.

To date, few state and local governments have adopted approaches that explicitly include nuclear energy among targeted ways to reduce carbon emissions. Some renewable and clean energy portfolios mandate technologies and/or fuel sources; in effect, this excludes other energy technologies on an a priori basis. ANS contends that performance-based, technology neutral policy approaches must be the standard and are the best way to encourage innovation and achieve intended carbon reduction goals.

ANS considers nuclear energy an essential component to policies designed to address risks presented by a changing climate and future energy needs and believes that the increased use of nuclear energy in offsetting the use of fossil fuels where appropriate offers an effective means of reducing global carbon emissions. Nuclear energy delivers large amounts of reliable, economically competitive electricity with no carbon emissions during reactor operations and has among the lowest lifecycle carbon emissions of any energy source[1]. Nuclear energy is the only such energy technology with a proven capability of delivering large amounts of baseload electricity essential to modern industrial societies.

ANS recognizes the value of energy diversity[2] and believes that other low-carbon energy technologies (such as wind, solar, and hydro) should be deployed as appropriate while recognizing the benefits and drawbacks associated with each technology. However, with the exception of hydro, renewable sources are limited by their intermittency, requiring backup power generation or storage capabilities. Further, competing priorities, such as wildlife protection and land use requirements constrain the contributions of these inherently diffuse energy sources. In all cases, policymakers should carefully evaluate external costs of energy technologies[3].

For background and further information on this topic, visit www.NuclearConnect.org or www.ANS.org.

The American Nuclear Society, founded in 1954, is a not-for-profit professional society of more than 10,000 scientists, engineers, educators, and other professionals from universities, government, private laboratories, and industry devoted to the peaceful applications of nuclear science and technology.

Position Statements are the considered opinions and judgments of the Society in matters related to nuclear science and technology. They are intended to provide an objective basis for weighing the facts in reaching decisions on important national issues.

Nuclear Energy's Role in Climate Change Policy | Position Statement #44

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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 view of the energy future not part of the current energy discussions?
- 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

and ANS needs you!

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