U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Nuclear Reactor Technologies Program

Trinity ANS Chapter Presentation

John E. Kelly
Deputy Assistant Secretary for Nuclear Technologies
Office of Nuclear Energy
U.S. Department of Energy

August 21, 2013

"All of the Above" Clean Energy Strategy

"With rising oil prices and a warming climate, nuclear energy will only become more important. That's why, in the United States, we've restarted our nuclear industry as part of a comprehensive strategy to develop every energy source."

Seoul, Korea - March 26, 2012

I'm announcing a new national climate action plan…
….We're building the first nuclear power plants in more than three decades…
…A low-carbon, clean energy economy can be an engine of growth for decades to come. And I want America to build that engine.

Georgetown University - June 25, 2013

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Meeting Clean Energy Goals will Require a Shift

Source	2010 Elect (TWhr)	2010 CO_2 (Gton)	2035 Elect (TWhr)	2035 CO_2 (Gton)
Natural Gas	1000	0.4	1520	0.5
Coal	1730	1.7	1800	1.8
Coal (CCS)	0	0	0	0
Nuclear (Large)	790	0	870	0
Nuclear (SMR)	0	0	0	0
Hydro	325	0	300	0
Renewable	200	0	440	0
Petroleum/Other	50	0.04	40	0.03
TOTAL	**4095**	**2.2**	**4970**	~~**2.3**~~ 1.0

2010 U.S Electricity Consumption and CO_2 Emissions. *EIA CE=42%*

EIA Reference Projections 2035 CE=43%

Source: EIA, Annual Energy Outlook 2013

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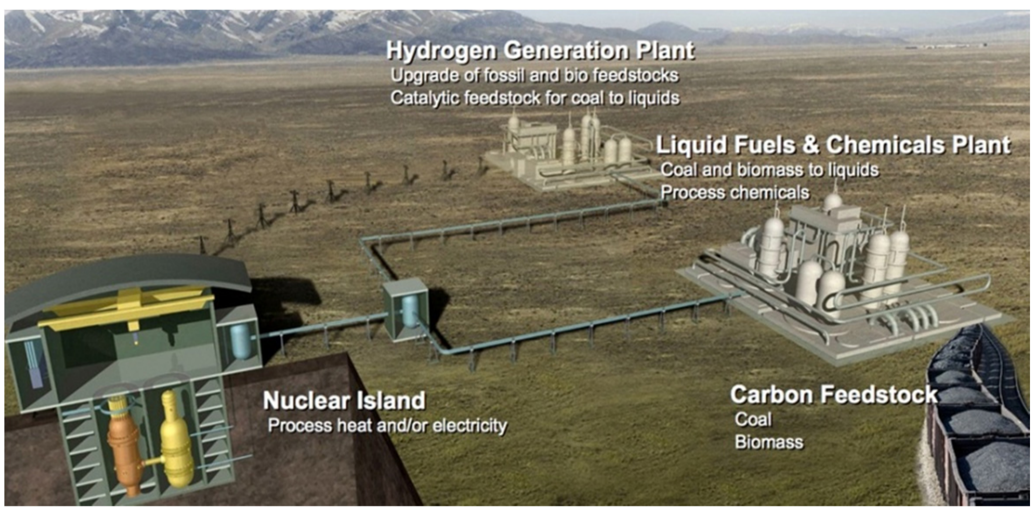
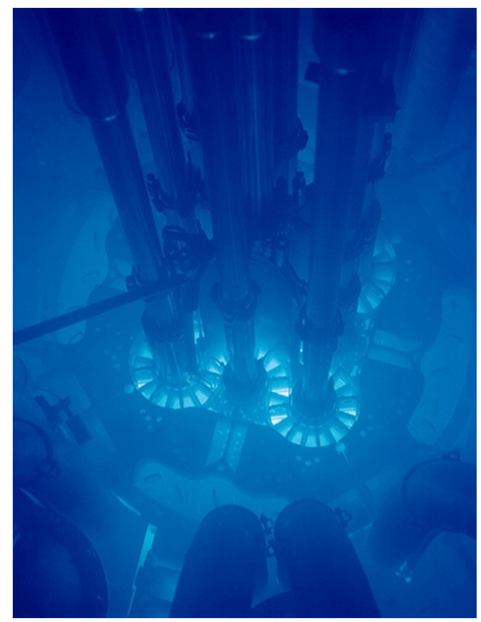
Office of Nuclear Energy Mission

The primary mission of NE is to advance nuclear power as a resource capable of making major contributions in meeting the nation's energy supply, environmental, and energy security needs by resolving technical, cost, safety, security and regulatory issues, through research, development, and demonstration (RD&D).





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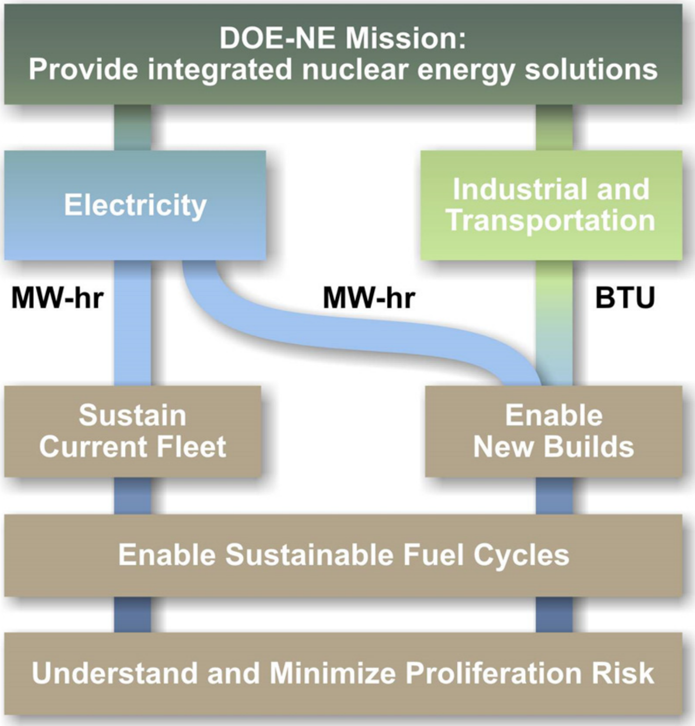
Nuclear Energy Roadmap Objectives

- Develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors
- Develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals
- Develop sustainable nuclear fuel cycles
- Understand and minimize the risks of nuclear proliferation and terrorism



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Office of Nuclear Energy Organization Chart

- NE-1/2 **Assistant Secretary for Nuclear Energy**
  Dr. Peter B. Lyons, Assistant Secretary
  Dennis Miotla, Acting Principal Deputy Assistant Secretary
  - Nuclear Energy Advisory Committee
  - Senior Advisors
  - NE-20 Chief Operating Officer, Dennis Miotla
    - NE-21 Office of Human Capital & Business Services, Deborah Sharpe
    - NE-22 Office of Budget & Planning, Patrick Edgerton
  - NE-3 Deputy Assistant Secretary for Nuclear Facility Operations, *Tracey Bishop, Acting*
    - Idaho Operations Office, Richard Provencher, Manager
    - Oak Ridge Site Office, Larry Perkins, Acting Manager
    - NE-31 Office of Facilities Management, Tracey Bishop
  - NE-4 Deputy Assistant Secretary for Science and Technology Innovation, *Shane Johnson, Acting*
    - NE-41 Office of Advanced Modeling & Simulation, Trevor Cook, Acting
    - NE-42 Office of Innovative Nuclear Research, Mike Worley, Acting
  - NE-5 Deputy Assistant Secretary for Fuel Cycle Technologies, *Monica Regalbuto*
    - NE-51 Office of Systems Engineering & Integration, John Herczeg, Acting
    - NE-52 Office of Fuel Cycle Research & Development, Andy Griffith
    - NE-53 Office of Used Nuclear Fuel Disposition Research & Development, William Boyle
    - NE-54 Office of Uranium Management and Policy, William Szymanski
  - NE-6 Deputy Assistant Secretary for International Nuclear Energy Policy and Cooperation, *Ed McGinnis*
    - NE-61 Office Bilateral Cooperation, Sarah Lennon, Acting
    - NE-62 Office of Multilateral Cooperation, John Gross, Acting
    - NE-63 Office of International Commercial Activities, Alan Brownstein
  - NE-7 **Deputy Assistant Secretary for Nuclear Reactor Technologies**, *John Kelly*
    - NE-72 **Office of Light Water Reactor Technologies**, Rebecca Smith-Kevern
    - NE-74 **Office of Advanced Reactor Technologies**, Tom O'Connor
    - NE-75 **Office of Space & Defense Power Systems**, Alice Caponiti

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Nuclear Reactor Technologies Program Elements

- **Small Modular Reactor Licensing Technical Support**
- **Reactor Concepts R&D includes four reactor technology sub-programs:**
  - Light Water Reactor Sustainability Program (LWRS)
  - Next Generation Nuclear Plant Demonstration Project (NGNP)
  - Advanced Small Modular Reactors (SMR)
  - Advanced Reactor Concepts (ARC)
- **Space and Defense Power Systems**

~ Courtesy of Department of Energy

Nuclear Energy Plays an Important Role in US Energy Supply

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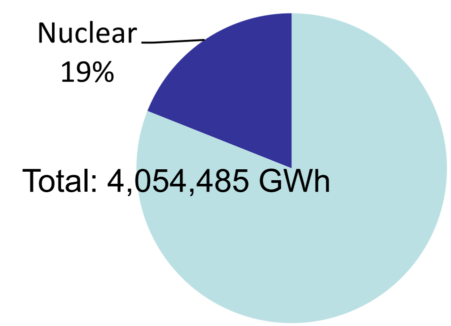
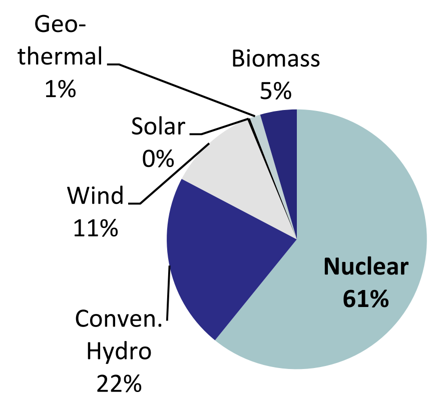
- **Nuclear power is a clean, reliable base load energy source**
  - Provides 19% of U.S. electricity generation mix
  - Provides 61% of U.S. emission-free electricity
  - Avoids about 700 MMTCO2 each year
  - Helps reduces overall NOx and SOx levels
- **U.S. electricity demand projected to increase ~28% by 2040 from 2011 levels**
- **100 GWe nuclear capacity - 100 operating plants**
  - Fleet maintaining close to 90% average capacity factors
  - Most expected to apply for license renewal for 60 years of operation

Electricity Production, 2012



Net Non-Carbon Emitting Sources of Electricity, 2012



Source: Energy Information Administration

Light Water Reactor Sustainability (LWRS)

LWRS Program Goals

- Develop fundamental scientific basis to allow continued long-term safe operation of existing LWRs (beyond 60 years) and their long-term economic viability

Benefits

- Current fleet provides >60% of non-greenhouse gas emitting electricity
- Existing reactors reduce burden of new clean electricity that will need to come online

Key R&D areas

- Materials Aging and Degradation
- Systems Analysis and Emerging Issues (includes research to support post-Fukushima lessons learned)
- Advanced Instrumentation and Controls
- Risk-Informed Safety Margin Characterization

Materials R&D Collaboration with Industry

- **A multi-year partnership between EPRI, Constellation Energy Group, and DOE has yielded key data from Ginna and Nine Mile Point NPPs on materials aging and provided a test-bed for several new innovative monitoring technologies**
  - Strain measurements on containment reinforcing tendons
  - Digital image correlation measurement of strain in containment during pressure testing
  - Observations of cable aging
  - Joint harvesting of high fluence baffle bolts
- **Working with Zion Solutions to obtain aged materials samples during decommissioning**
- **Recent partnerships with Areva and EPRI have focused on joint studies of irradiation-embrittlement in high strength bolting materials**

Pilot Projects with Industry on Instrumentation and Controls

- Human factors engineering studies with licensed operators for control room upgrades at Harris, Brunswick, and Robinson plants
- Conducting field trials of mobile nuclear worker technologies at the Catawba and Palo Verde plants
- With EPRI, conducting initial tests of on-line monitoring technology at the Braidwood (emergency diesel generator) and Harris (power transformers)
- Completed outage coordination technologies with Byron plant. Now developing Advanced Outage Control Center technologies with Palo Verde

~ Human Systems Simulation Laboratory at Idaho National Lab

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Status of New Builds in U.S.

- **Gen III+ designs are a major evolutionary step in large reactor technology**
- **First new reactors being built in U.S. in 30 years**
- **Nuclear construction (Commercial Operation Date)**
  - Vogtle 2017- 2018
  - V.C. Summer 2017- 2018
  - Watts Bar 2015
  - Turkey Point 2022 - 2023
- **Challenges of nuclear deployment**
  - High capital cost
  - Lower electricity demand
  - Low natural gas prices
  - Post – Fukushima safety concerns

Vogtle 3 & 4, Courtesy of Georgia Power

Construction at Vogtle

- **NRC issued COL on Feb 10, 2012**
- **Two Westinghouse AP1000 units**
  - 1,117 MWe PWRs
- **$14B capital investment**
  - Will create ~5,000 construction jobs & 800 high paying permanent jobs
- **Vogtle units 3 and 4 expected in service in 2017 and 2018 respectively**

Vogtle Unit 3 Nuclear Island showing nuclear island basemat pour & Containment Vessel with exterior rebar installed
~Courtesy of Southern Company

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Construction at V.C. Summer

- **NRC issued COL on March 30, 2012**
- **Two Westinghouse AP1000 units**
- **Represent $10B capital investment**
  - Will create 3,000 construction jobs & 800 high paying permanent jobs
- **Units 2 & 3 expected to be in service 2017 and 2018 respectively**

VC Summer Unit 2 Lower Bowl Assembly and nuclear island concrete placement
~Courtesy of SCANA

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SMRs can be Game Changers

"I believe small modular reactors could represent the next generation of nuclear energy technology, providing a strong opportunity for America to lead this emerging global industry."

U.S. Senate Committee on Energy & Natural Resource
Confirmation Hearing
April 9, 2013

"We are committed to fostering the safe and secure contribution of nuclear power to the global energy mix."

~ IAEA International Conference on Nuclear Security – July 1, 2013

SMR Technologies are of Great Interest

- **Further improve passive safety technology**
- **Reduce capital cost and project risk**
- **Regain technical leadership and advance innovative reactor technologies and concepts**
- **Create high-quality domestic manufacturing, construction, and engineering jobs**
- **Become global leader in SMR technology based on mature nuclear infrastructure and NRC certified designs**

Challenge to SMR fleet deployment:
Prove economy of mass production is competitive with economy of scale

SMR Licensing Technical Support Program

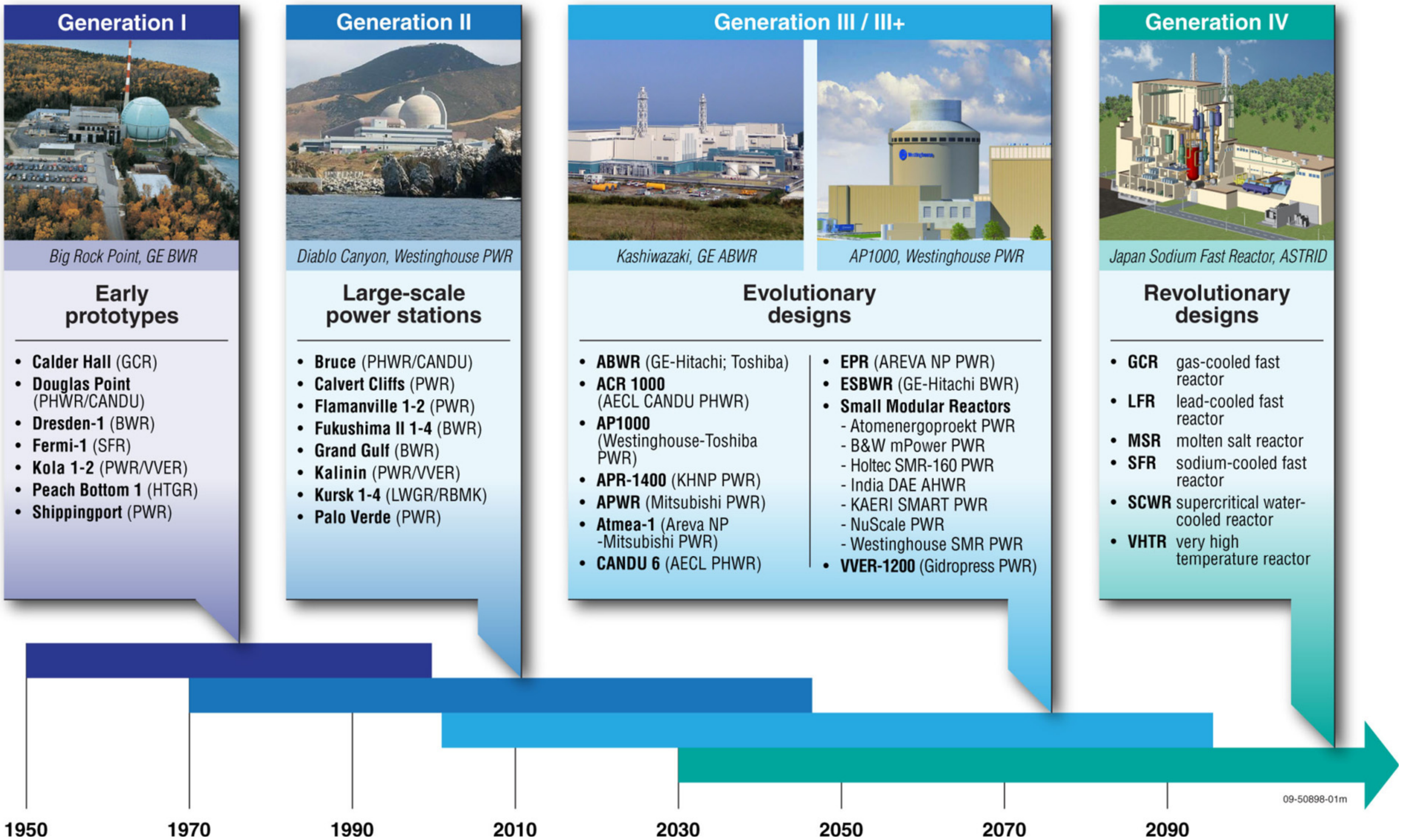
- **Facilitate and accelerates commercial development and deployment of near term U.S. SMR designs at domestic locations**
- **$452 M in cost-share program over 6 years**
  - FY12 funding is $67M and FY14 request is $70M
- **DOE has selected one awarder under the first SMR funding opportunity announcement**
  - Babcock and Wilcox mPower Design selected
- **DOE issued a second FOA that placed more emphasis on innovation in improved safety attributes and further reduction regulatory risk**
  - Proposals under review

Genesis of Generation IV Concept

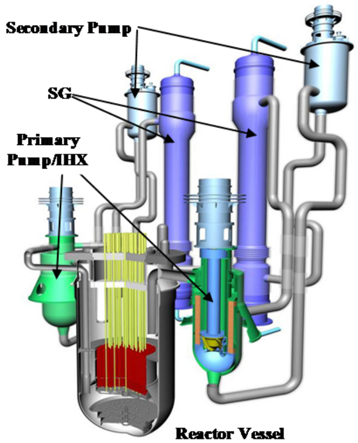
- **In 1999, low public and political support for nuclear energy**
  - Oil and gas prices low
  - Over 50 GWe of natural gas electricity installed in the 90's
- **DOE proposed a bold initiative in 2000**
  - Leapfrog beyond LWR technology and collaborate with international partners to share R&D
  - 9 Countries and EU joined in
  - Oil prices jumped soon thereafter
- **Gen IV concept defined via ambitious goals and Technology Roadmap**
  - Goals: sustainability, economics, safety and reliability, and proliferation resistance
  - Technology Roadmap released in 2002
    - 2yr study with over 100 experts worldwide
    - Nearly 100 reactor designs evaluated and down selected to 6 most promising concepts

> *"This may have been the first time that the world came together to decide on a fission technology to develop together."*
>
> *~William Magwood IV*

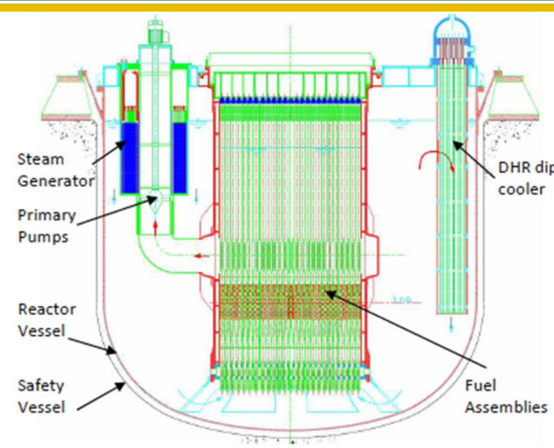
Generation IV International Forum



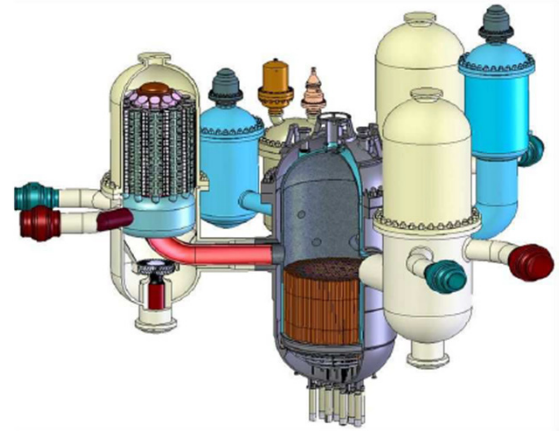
Generation IV Reactor Concepts



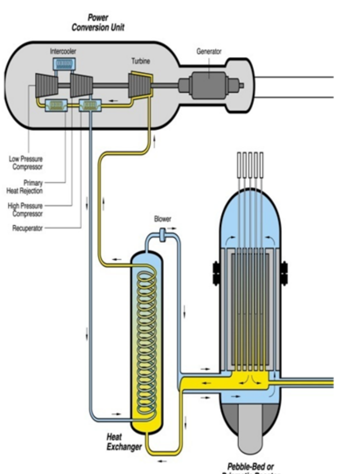
Sodium Fast Reactor (JSFR Loop Configuration)



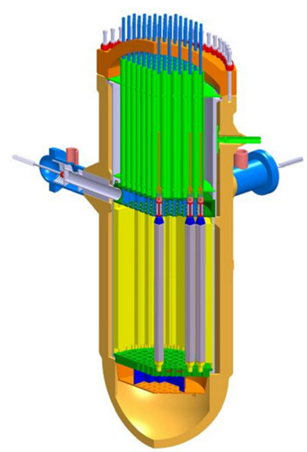
Lead Fast Reactor



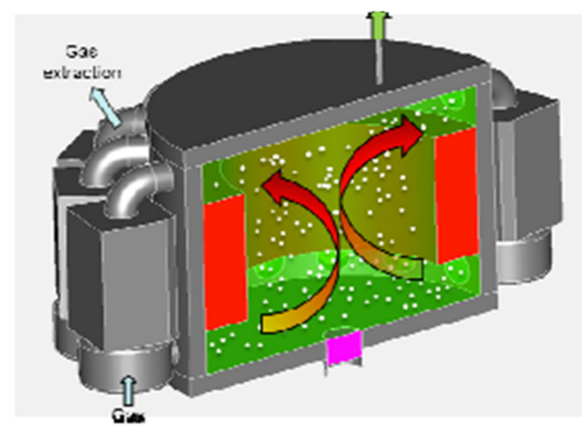
Gas Cooled Fast Reactor



Very High Temperature Reactor



Supercritical Water Cooled Reactor



Molten Salt Cooled Reactor

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Generation IV System Development

Generation IV Systems	Argentina	Brazil	Canada	China	France	Japan	Korea	Russia	South Africa	Switzer-land	U.K.	U.S.A.	EU
Sodium-cooled Fast Reactor (SFR)				○	○	●	○	○				○	○
Very-high Temperature Gas-cooled Reactor (VHTR)			○	○	○	○	○		▲	○		○	●
Gas-cooled Fast Reactor (GFR)					●	○				○			○
Supercritical-water cooled Reactor (SCWR)			○			○		○					●
Lead-cooled Fast Reactor (LFR)						○		○				▲	○
Molten Salt Reactor (MSR)					○			▲				▲	○

● Chairing member ○ Participating member ▲ Observer member

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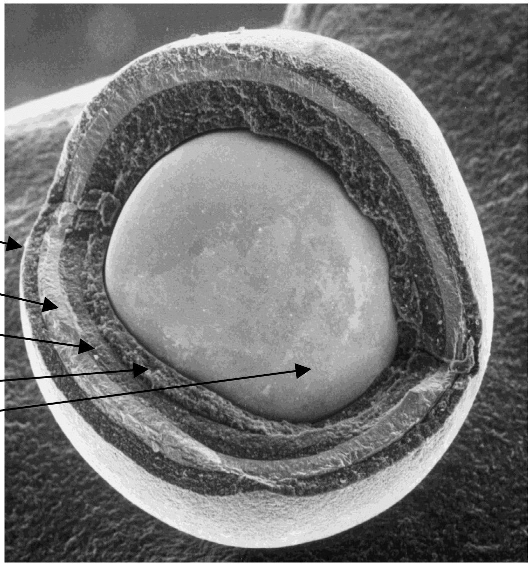
U.S. VHTR Program – Fuels R&D

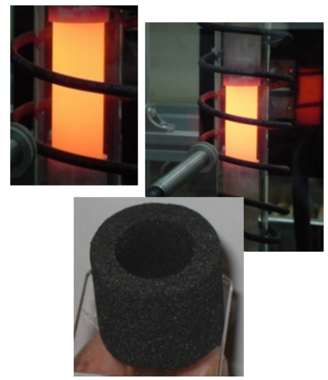
- **R&D to design and fabricate high performance fuels with very low failure rates**
  - Establish credible fission product transport mechanisms and mechanistic source term under normal, off-normal, and accident conditions
  - Improved quality control techniques for fabrication
  - Develop innovative fuel designs for higher outlet temperatures and increased fuel margins relative to existing concepts

1000 micron coated fuel particle

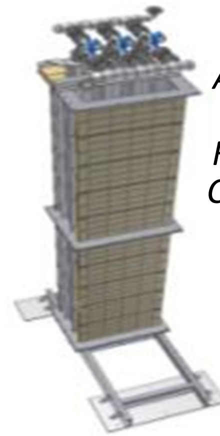


US VHTR Program - Analysis Methods R&D

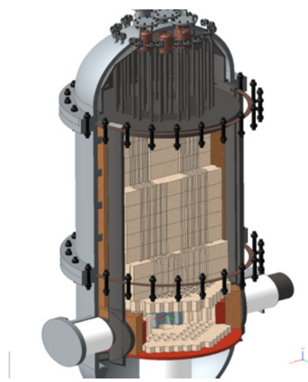
- **R&D focused on developing practical tools to analyze neutronics, thermal-hydraulics, and safety**
  - Experimental planning of phenomena (Scaling, experimental design, fundamental phenomena identification and PIRT)
  - Modeling and simulation of core phenomena (neutronics, thermal-hydraulics, and multiphysics)
  - Plant simulation and safety analysis, (source term, uncertainty and sensitivity analysis, licensing approaches)



Graphite/Air Reaction Rate Testing



ANL Facility to Validate Reactor Cavity Cooling System Behavior

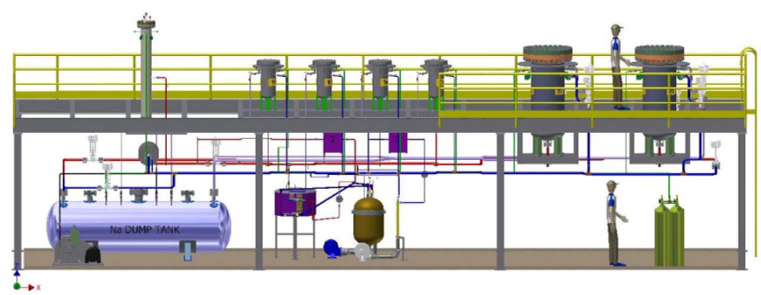


OSU's High Temperature Test Facility to Model Depressurized Cooldown

INL's Matched Index of Refraction (MIR) Facility to Study 3-D Flow Effects in Plena

U.S. SFR Program R&D Activities

- **Reactor Concept Development**
  - Evaluate and compare alternative coolants and develop optimal integrated reactor system designs
- **Mechanisms Engineering Test Facility Project**
  - Establish a platform for testing of innovative systems and components in high temperature liquid sodium
- **Advanced Materials**
  - Advanced structural alloy development and testing
  - Support development of codes and standards
- **Advanced Energy Conversion Systems**
  - Supercritical CO_2 Brayton cycle machinery performance, Computational Fluid Dynamics modeling, corrosion chemistry

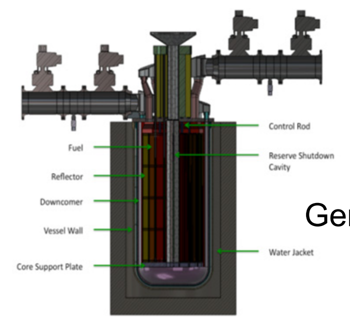


METL Facility

Advanced SMR R&D

Advanced SMR R&D Program Goals

- Develop advanced SMR technologies with emphasis on technologies that
  - Are manufactured in a factory and shipped to the site
  - Offer simplified operation and maintenance for distributed power applications
  - Achieve greater levels of safety and resilience, flexibility of use, sustainability and construction or operational affordability



Gen4 Energy

Benefits

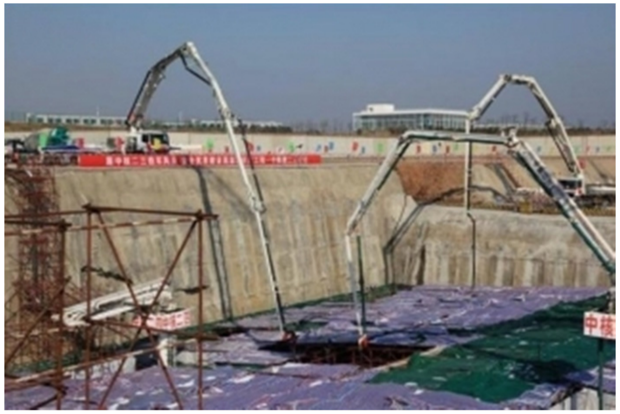
- Inherent/passive safety features
- Increased flexibility
- Lower initial construction costs

Key activities

- Develop innovative concepts that utilize advanced technologies to achieve expanded functionality; Instrumentation, Control, Human, Machine Interface (ICHMI) and Materials
- Evaluating technologies that further reduce costs; Economic Analysis
- DELTA (Pb) loop on-line
- SMR site suitability and screening tools

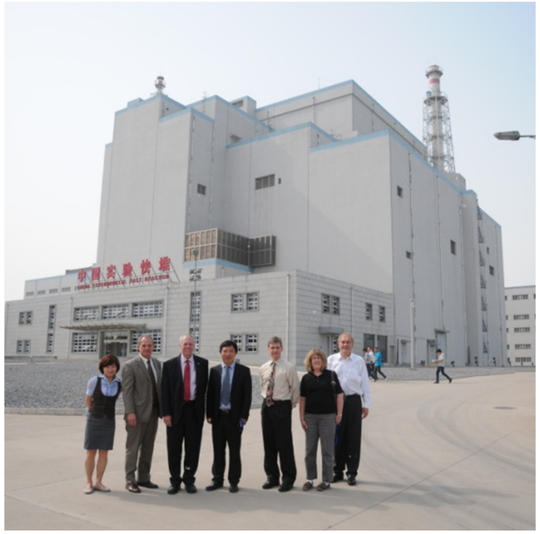
Gen IV Nuclear Construction in China

- **Operation of CEFR 20 MWe Test Reactor**
  - Startup in 2010-2011, power operations start in 2013
  - Design of Demonstration Reactor
- **Construction of demonstration HTGR**
  - 200 MW Pebble Bed design
  - Scheduled to start electricity generation by the end of 2017
- **Design of a small Fluoride Salt Cooled Reactor**



First Concrete poured for China's HTR-PM

CEFR construction



CEFR Finished

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Gen IV Nuclear Construction in Russia

- **Completion of BN-800 Reactor**
  - Startup in 2014
- **Design of BN-1200 Gen-IV SFR**
  - Goal is to be competitive with LWRs
- **Design of MBIR test reactor to replace BOR-60**
- **Demonstration project on lead-bismuth LFR**

Turbine Hall

Reactor Compartment of Main Building

Steam Generator Compartment of Main Building

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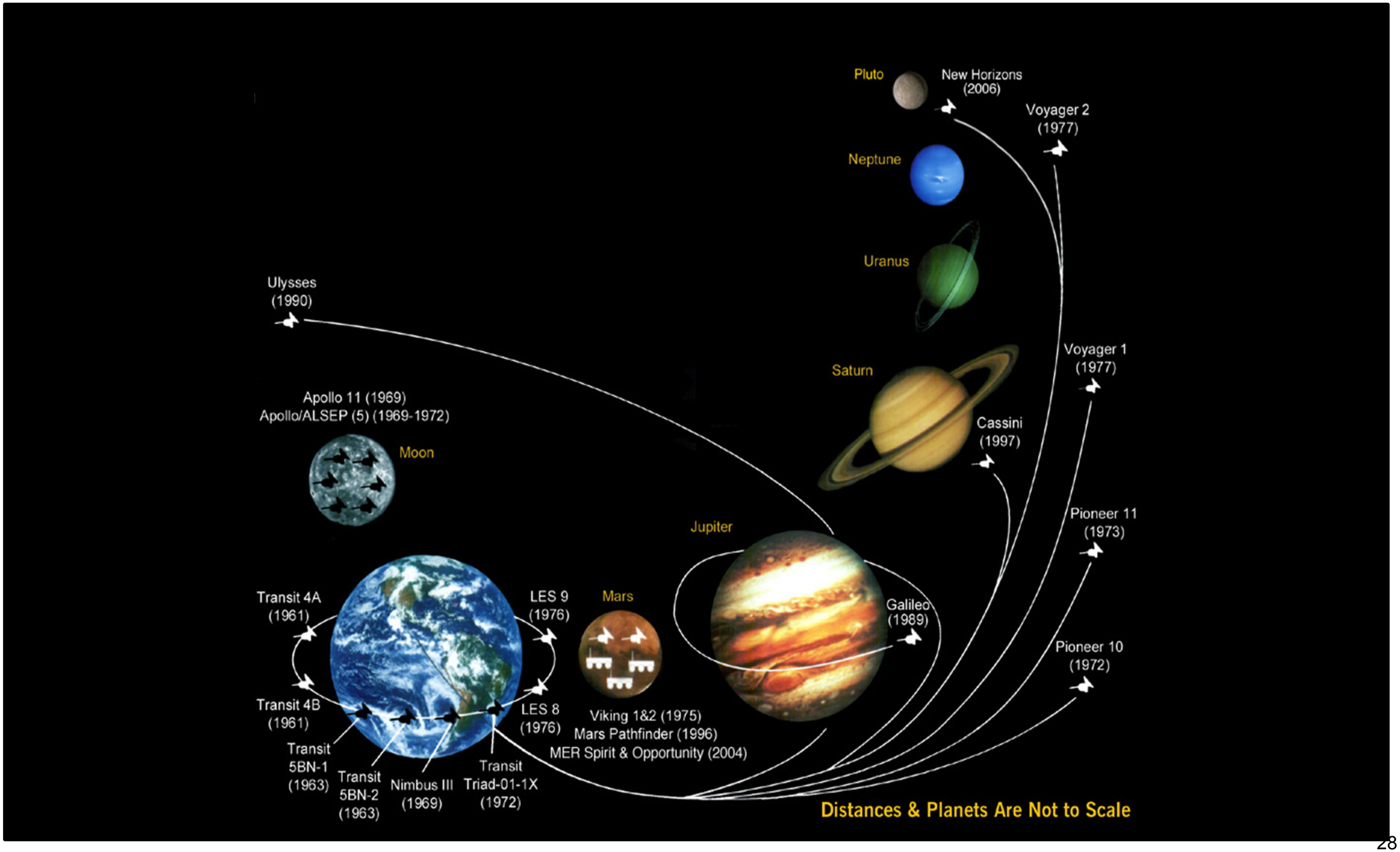
50 Years of Nuclear Power in Space



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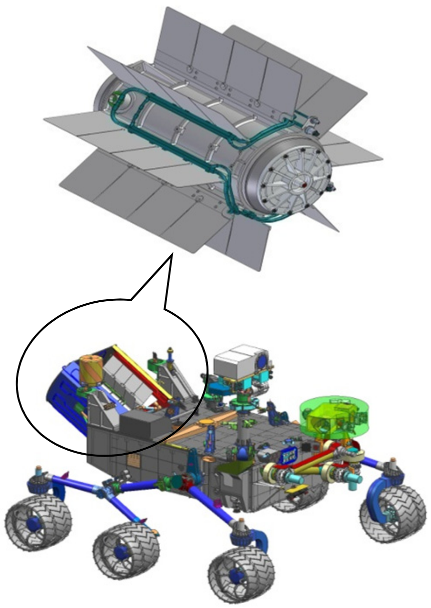
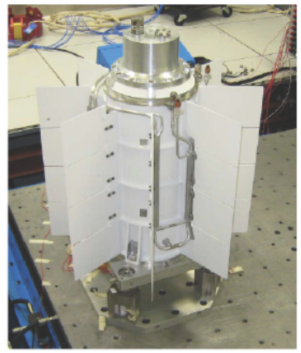
Space and Defense Current Projects

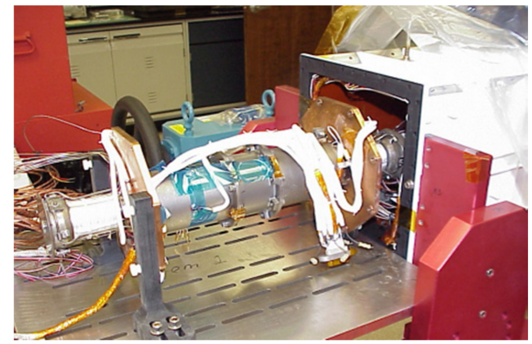


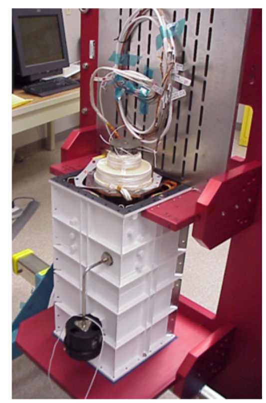
Mars Science Laboratory

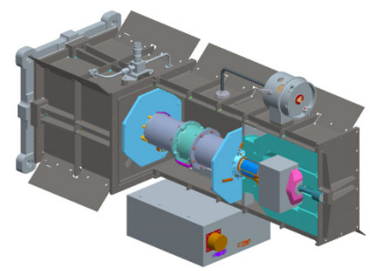


Multi-Mission Radioisotope Thermoelectric Generator for NASA with proven performance, but low conversion efficiency (5-7%)

Nuclear Thermal Propulsion Technology for NASA







Advanced Stirling Radioisotope Generator (ASRG) for NASA with high efficiency (25-30%) under development

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Summary

- Nuclear Power is important for clean energy
- Current plants needs life extension
- SMRs are the near term future
- Generation IV is are longer term
- Nuclear Power enables space exploration