U.S. DEPARTMENT OF ENERGY | Nuclear Energy

International Perspective on the Future of Nuclear Power

The 23rd International Conference on Nuclear Engineering

Majuhari Messe, Chiba, Japan

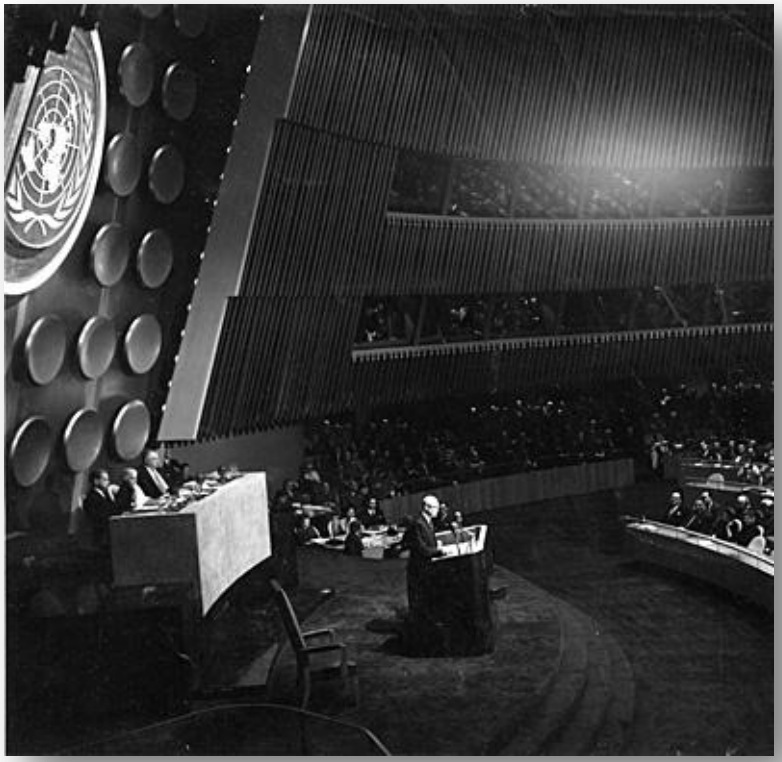
John E. Kelly
Deputy Assistant Secretary for Nuclear Reactor Technologies
Office of Nuclear Energy
U.S. Department of Energy

May 19, 2015

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Atoms for Peace

The First Wave of Nuclear Power Deployment



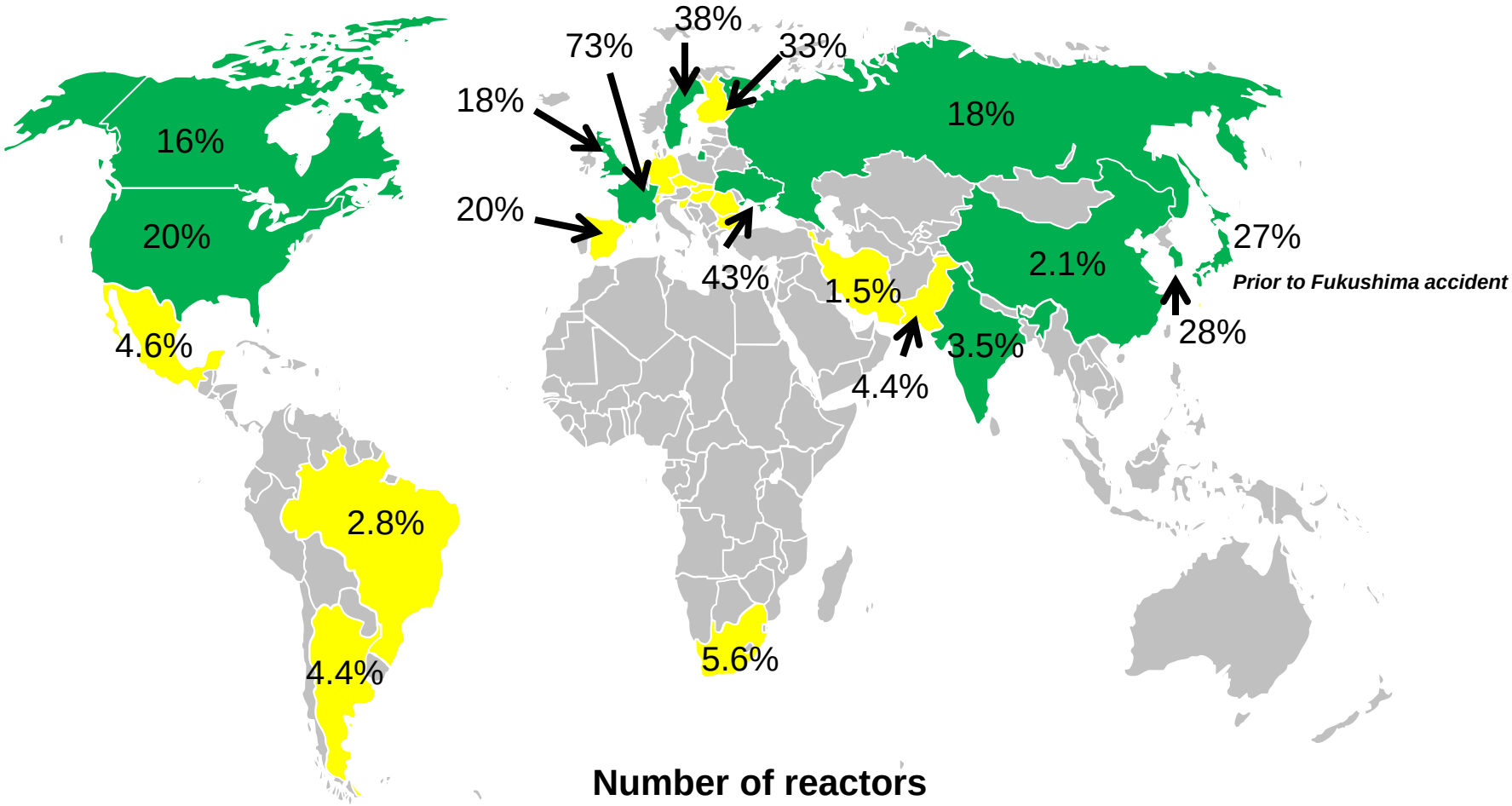
President Dwight D. Eisenhower, December 8, 1953, to the 470th Plenary Meeting of the United Nations General Assembly

"Peaceful power from atomic energy is no dream of the future. That capability, already proved, is here – now – today."

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Existing Nuclear Commercial Power Reactors *(13.8% World Wide / 21.4% OECD)*



~ Source: IAEA information & news reports

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Drivers that Influenced the First Wave of Nuclear Power Deployment

Encouraging drivers

- Post World War II: Re-emerging economies required increased energy
- 1970s - Oil Crisis
- Strong Government Backing

Neutral drivers

- Acid Rain
- Air Pollution
- 1971- **Inadvertent Climate Modification**. *Report of the Study of Man's Impact on Climate*

Discouraging drivers

- High Interest Rates
- Fear of Radiation
- Fear of Nuclear Weapons
- Three Mile Island Accident
- Chernobyl Accident
- Waste Management Impasse

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Today, Worldwide Interest in Nuclear Power is Strong

Energy security
- Nuclear shelters countries from importing costly fossil fuels
- Replacement of retiring nuclear or coal power plants

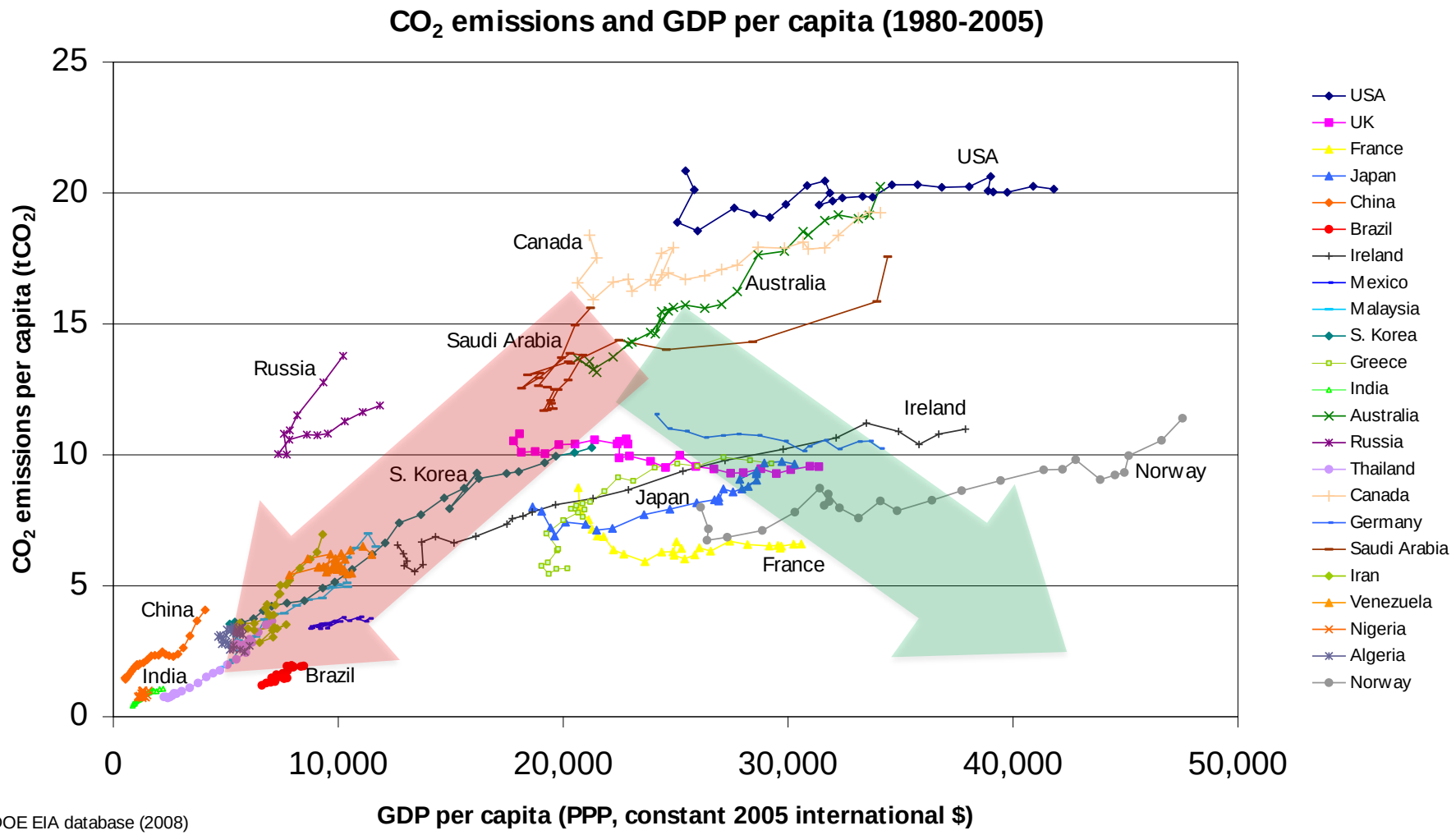
Economic incentives
- Nations rich in fossil fuels would prefer to export those fuels and use nuclear for domestic electricity production

Environmental protection
- Replacing coal with nuclear can alleviate air pollution problems
- Dry condenser cooling possible with SMRs when water usage is restricted

Climate change concerns
- Nuclear is the “Emission-free” base load generation technology

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

CO_2 Emissions and GDP per Capita (1980 – 2005)

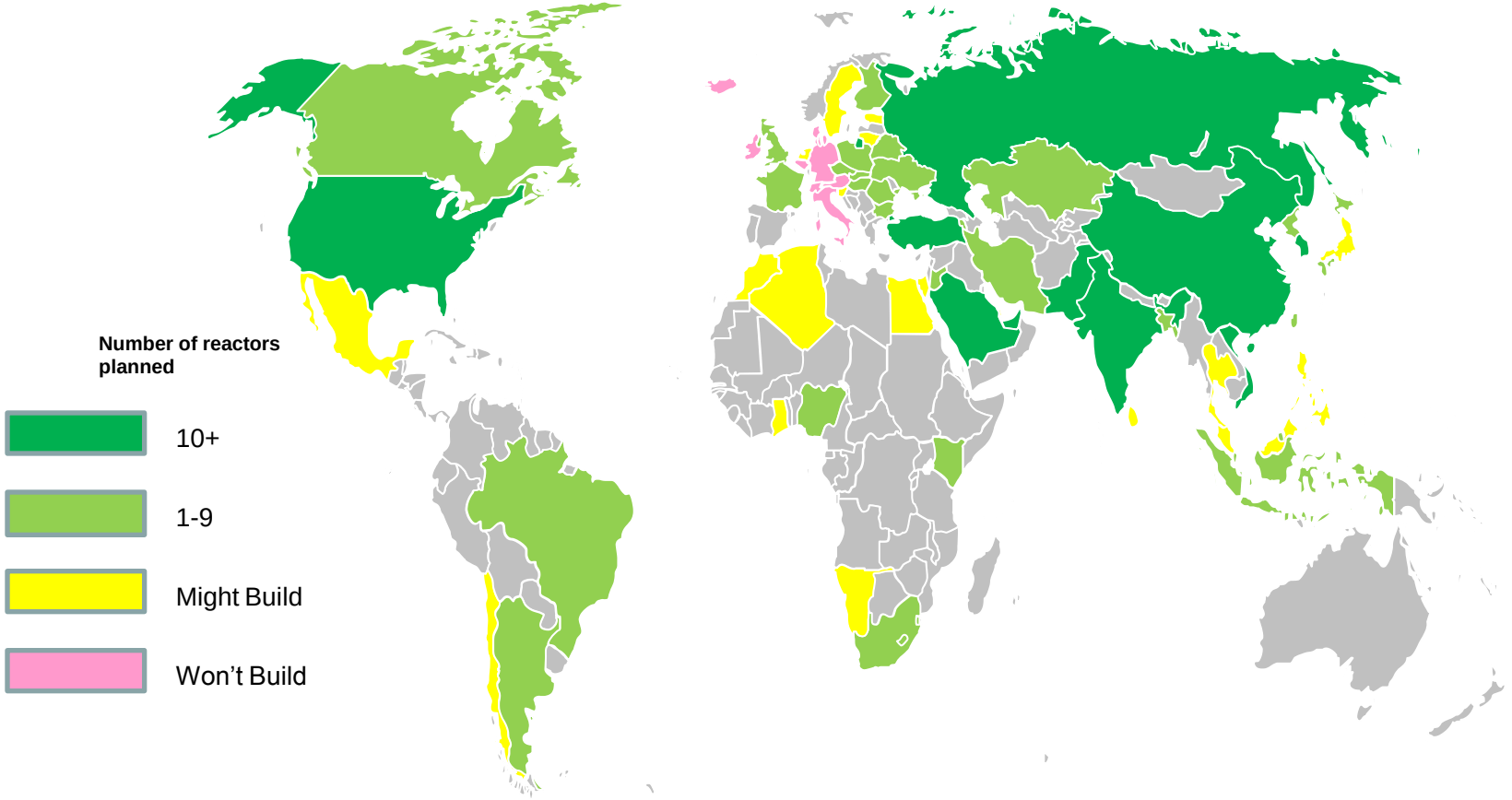


Source: DOE EIA database (2008)
Russia data 1992-2005, Germany data 1991-2005

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Global Nuclear Construction Plans



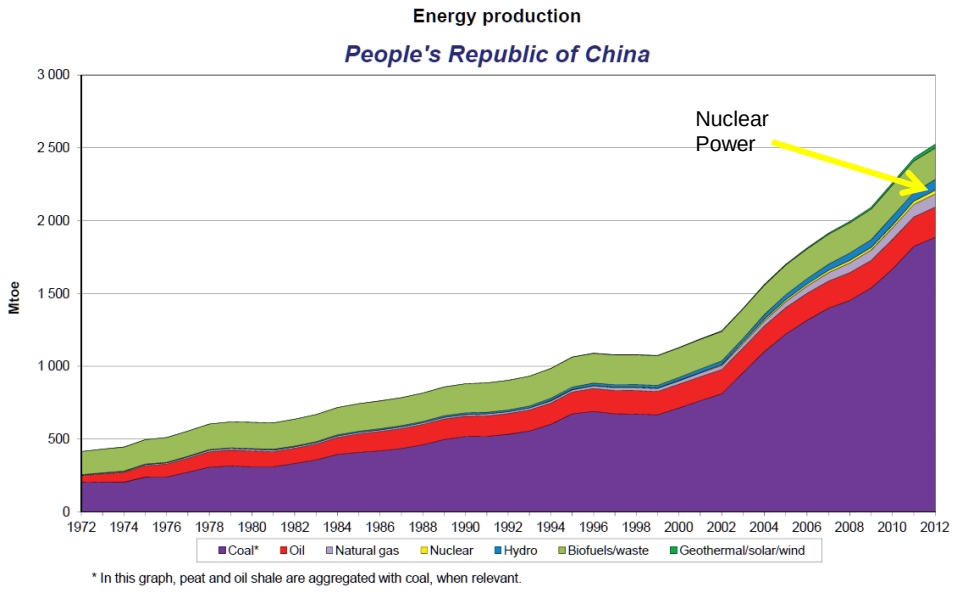
- **443 nuclear reactors operating in 30 countries (372 GWe capacity)**
- **66 reactors currently under construction in 15 countries (23 in China)**
- **164 reactors planned in 27 countries over next 8-10 years**
- **317 reactors proposed in 37 countries over next 15 years**

~ Source: IAEA information & news reports

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

China is Driving the Nuclear Renaissance

- **Most of China's electricity is produced from fossil fuels**
  - 2014 data shows 80% coal, 2% oil, 1% gas, 15% hydropower & 2% nuclear
- **China has 26 nuclear power reactors in operation, 23 under construction, and more about to start construction**
- **Additional reactors are planned to increase nuclear capacity**
  - Goal is for 58 GWe by 2020, 150 GWe by 2030, and much more by 2050
- **China is largely self-sufficient in reactor design and construction, and other aspects of the fuel cycle, but is making full use of western technology to adapt and improve**



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

AP1000 Construction Worldwide

Sanmen
April 2015 © SNPTC

Haiyang
May 2014 © State Nuclear Power Engineering
Feng Qingyi Wang Jinjie.

VC Summer Steam Generator,
January 2015 © SCE&G

Construction of Vogtle Unit 3 Turbine Building,
February 2015 ©Georgia Power Company

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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**
  - Watts Bar 2015
  - Vogtle late 2017
  - V.C. Summer 2018 - 2020
- **Challenges of nuclear deployment**
  - High capital cost
  - Lower electricity demand
  - Low natural gas prices
  - Post – Fukushima safety concerns
  - Waste Management

Vogtle Unit 3 Nuclear Island ,
March 2015 ©Georgia Power Co.

Aerial photograph of SCE&G's V.C. Summer Units 2 & 3,
December 2014.©SCE&G

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

SMRs can be Game Changers

Secretary Moniz addresses the Intermountain Energy Summit, August 20, 2014

"Small Modular Reactors represent a new generation of safe, reliable, low-carbon nuclear energy technology and provide a strong opportunity for America to lead this emerging global industry."

"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

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

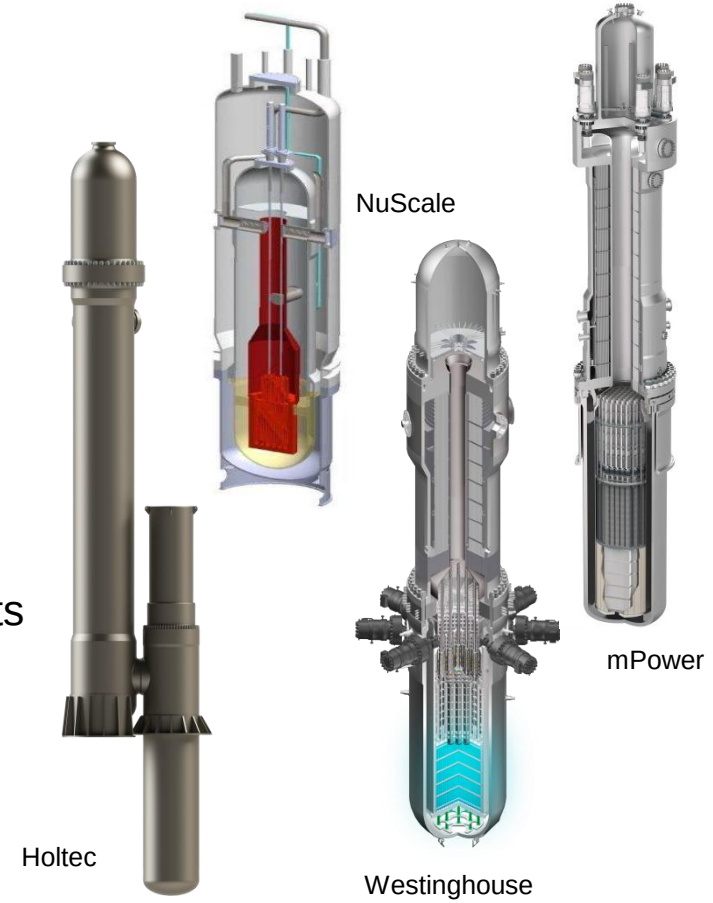
SMR Technologies are of Great Interest

Safety benefits

- Passive decay heat removal by natural circulation
- Simplified design eliminates/mitigates several postulated accidents
- Below grade reactor sites
- Potential for reduction in Emergency Planning Zone

Economic benefits

- Reduced financial risk
- Flexibility to add units
- Right size for replacement of old coal and other plants
- Frees up hydrocarbons for export or reduce need for fuel imports
- Job and skill creation



mPower and NuScale have been selected for the Department of Energy $452M SMR Licensing Technical Support Program

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

SMRs are being Developed Globally

- **Russia**
  - KLT-40S is a 35 MWe barge mounted PWR - Available for commercial deployment
  - Other SMR designs: VBER-150/300, VK-300, ABV & SVBR-100 (lead-bismuth variant)
- **Korea**
  - SMART is a 90-100 MWe PWR
    - Plan to begin operation of a demonstration plant in 2017
    - Could be used for electricity and/or non-electric applications such as desalination
- **China**
  - ACP100 is a 100 MWe PWR
    - Plan to begin construction of a 2 module plant in 2015
    - Could be used for electricity, heat or desalination
  - HTR-PM is a High Temperature Gas-Cooled Reactor
    - First nuclear concrete poured December 2012
- **Argentina**
  - CAREM-25 is a 25 MWe PWR
    - Plan to complete construction of a prototype in 2017
    - Could be used for electricity, desalination or as a research reactor
    - Full scale 200 MWe CAREM reactor to follow in early 2020's

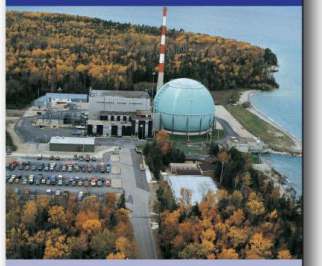
~ CAREM-25's Basemat
February 2014 © Ministry of Federal Planning

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Generation IV International Forum

Generation I



Big Rock Point, GE BWR

Early prototypes

- **Calder Hall** (GCR)
- **Douglas Point** (PHWR/CANDU)
- **Dresden-1** (BWR)
- **Fermi-1** (SFR)
- **Kola 1-2** (PWR/VVER)
- **Peach Bottom 1** (HTGR)
- **Shippingport** (PWR)

Generation II

Diablo Canyon, Westinghouse PWR

Large-scale power stations

- **Bruce** (PHWR/CANDU)
- **Calvert Cliffs** (PWR)
- **Flamanville 1-2** (PWR)
- **Fukushima II 1-4** (BWR)
- **Grand Gulf** (BWR)
- **Kalinin** (PWR/VVER)
- **Kursk 1-4** (LWGR/RBMK)
- **Palo Verde** (PWR)

Generation III / III+

Kashiwazaki, GE ABWR

Olkiluoto 3 AREVA PWR

Evolutionary designs

- **ABWR** (GE-Hitachi; Toshiba BWR)
- **ACR 1000** (AECL CANDU PHWR)
- **AP1000** (Westinghouse-Toshiba PWR)
- **APR-1400** (KHNP PWR)
- **APWR** (Mitsubishi PWR)
- **Atmea-1** (Areva NP -Mitsubishi PWR)
- **CANDU 6** (AECL PHWR)
- **EPR** (AREVA NP PWR)
- **ESBWR** (GE-Hitachi BWR)
- **Small Modular Reactors**
  - B&W mPower PWR
  - CNEA CAREM PWR
  - India DAE AHWR
  - KAERI SMART PWR
  - NuScale PWR
  - OKBM KLT-405 PWR
- **VVER-1200** (Gidropress PWR)

Generation IV

Safe
Secure
Sustainable
Competitive
Versatile

Arriving ~ 2030

Innovative designs

- **GFR** gas-cooled fast reactor
- **LFR** lead-cooled fast reactor
- **MSR** molten salt reactor
- **SFR** sodium-cooled fast reactor
- **SCWR** supercritical water-cooled reactor
- **VHTR** very high temperature reactor

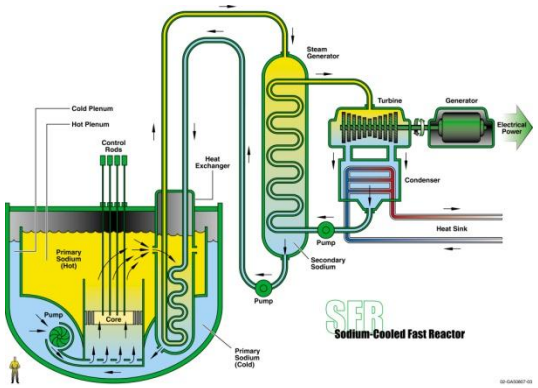
09-508898-01n

1950 1970 1990 2010 2030 2050 2070 2090

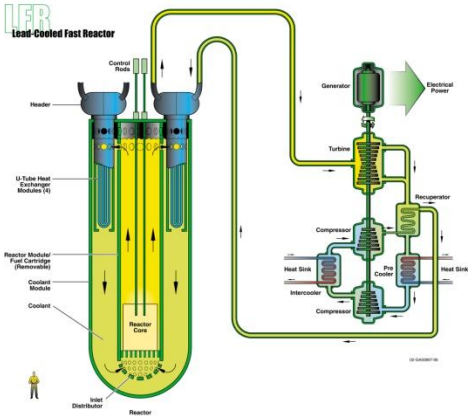
U.S. DEPARTMENT OF ENERGY

Nuclear Energy

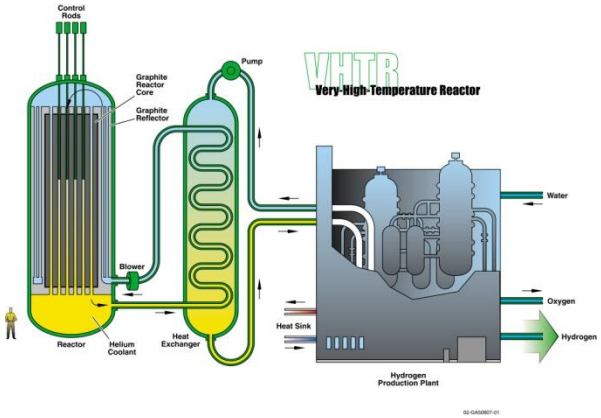
Generation IV Reactor Concepts



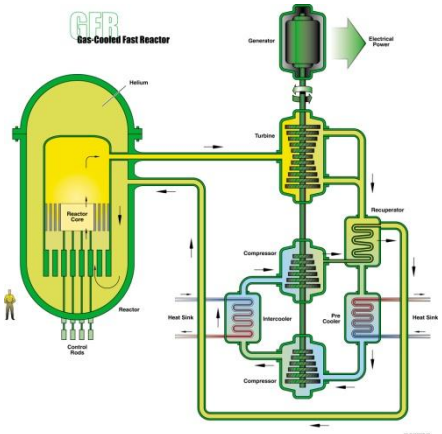
Sodium Fast Reactor



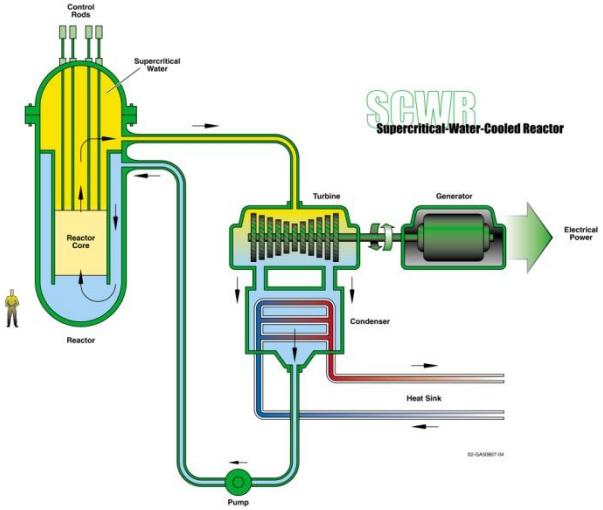
Lead Fast Reactor



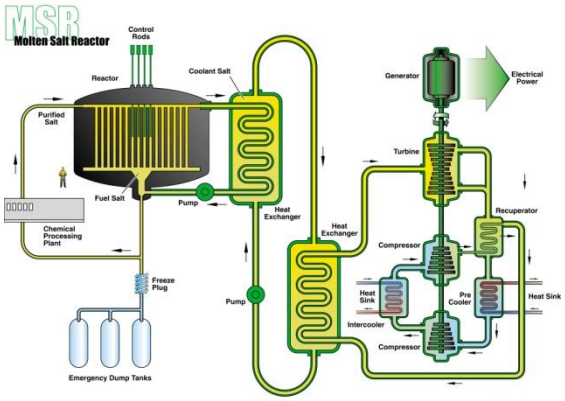
Very High Temperature Reactor



Gas Cooled Fast Reactor



Supercritical Water Cooled Reactor



Molten Salt Cooled Reactor

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Gen IV Systems Moving to Early Phase Demonstration

- **Very High Temperature Gas Reactor**
  - Chinese HTR-PM
- **Sodium Fast Reactor**
  - Operation of Chinese Experimental Fast Reactor
  - Start-up of BN-800 in Russia
  - Active design efforts in China, Korea, Japan, India, France, Russia, and U.S.
- **Lead Fast Reactor**
  - BREST and SVBR-100 in Russia
- **Molten Salt Cooled Reactor**
  - Demonstration reactor planned in China

China's HTR-PM, Shidao Bay-1

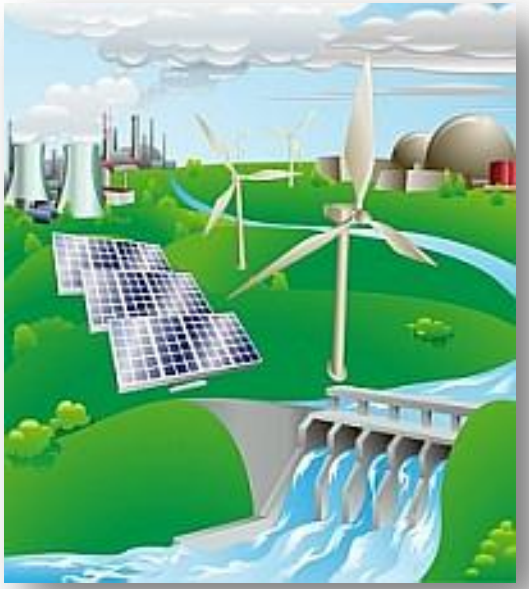
Beloyarsk-4 July 2014

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Summary

- **Strong international interest**
  - Energy Security
  - Climate & Environment concerns
  - Economic incentives
- **Current construction**
  - China is leading the nuclear renaissance
  - USA is making good progress in new builds
- **SMRs can be game changers**



- **Early Generation IV demonstration reactors are likely in the next decade**

"Investing in clean energy <u>isn't</u> a decision that limits our economic potential; it's an opportunity to lead the global clean technology markets that are forming right now."

~ Secretary Moniz at National Press Club, February 1, 2014