

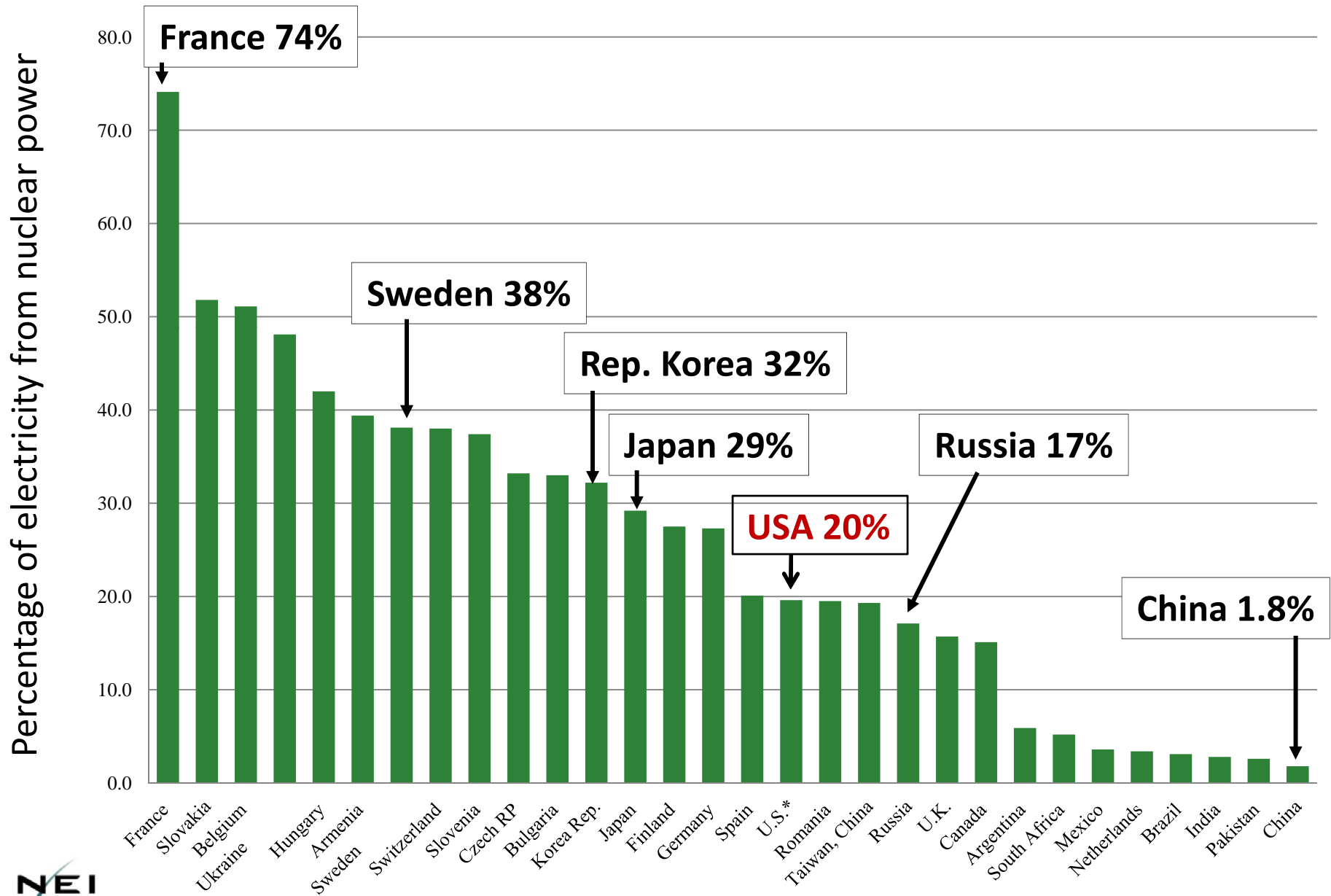
**Prospects and challenges for a global expansion
of Nuclear Energy**

**Siegfried S. Hecker
Stanford University**

**Acta Materialia Award in
Materials and Society Symposium on
“Global R&D Trends – Implications for Materials Science”
San Antonio, TX
March 5, 2013**

Nuclear electricity around the world

Nuclear Share of Electricity – NEI 2010



Global nuclear futures

- **Will there be a nuclear “renaissance?”**
- **Key challenges:**
 - **Safety and security**
 - **Economics**
 - **Waste disposal**
 - **Nuclear proliferation**
 - **Manpower**
- **Public acceptance and governmental control**

These are major challenges for democratic countries



Fukushima Dai-ichi – new concerns about nuclear safety

Nuclear safety is paramount

- Natural disasters
- Human error
- Acts of terrorism

Nuclear Electricity in the United States

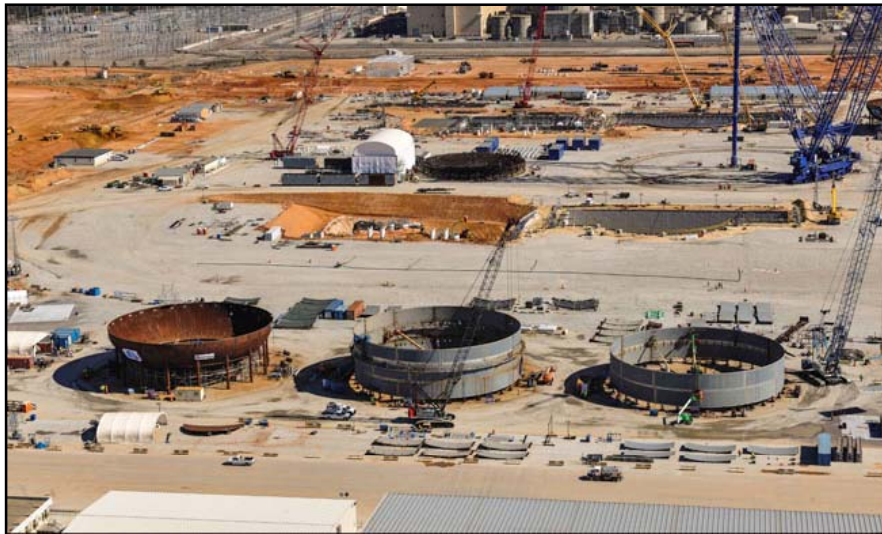
- In the late 1960's, conventional wisdom was the nuclear power industry **was soaring** with extraordinary expectations
- In the late 1980's, conventional wisdom was the domestic fleet would **phase out** with no new builds
- So what happened?
 - 101 utilities in 1991 → 87 utilities in 1999 → Currently 70% of total nuclear capacity is owned by top ten utilities
 - Nuclear assets were bought at bargain prices and plant economics improved



It is important to have a healthy dose of humility when talking about the future of nuclear power

The “nuclear picture” in the United States

- **Construction is continuing on 2 new AP-1000s at Vogtle in Georgia while 2 more units have been approved for V. C. Summer plant in South Carolina**
- **TVA is finishing Watts Bar construction**



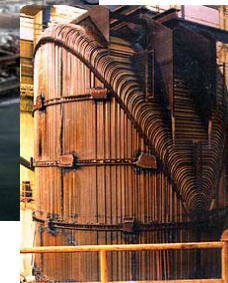
A large, cylindrical industrial pressure vessel is the central focus of the image, positioned in a spacious industrial facility. The vessel's surface is highly reflective, showing bright highlights from overhead lights. It has several large, complex flange-like structures protruding from its top and sides. In the foreground, five men are standing in a line, facing the camera. They are dressed in a mix of business-casual and work-appropriate attire, including light blue shirts, white shirts, and trousers. All five men are wearing white hard hats. The background shows the interior of a large factory with steel beams, other industrial equipment, and a wooden floor. The overall scene conveys a sense of large-scale industrial manufacturing.

Doosan Heavy Industries, South Korea
Pressure vessel for Vogtle AP-1000

Loss of nuclear supply chain in U.S.

2012: a very tough year for US nuclear industry

- U.S. could potentially lose four units at three sites due to long term outages
 - High heat concerns limited power output in US fleet over summer

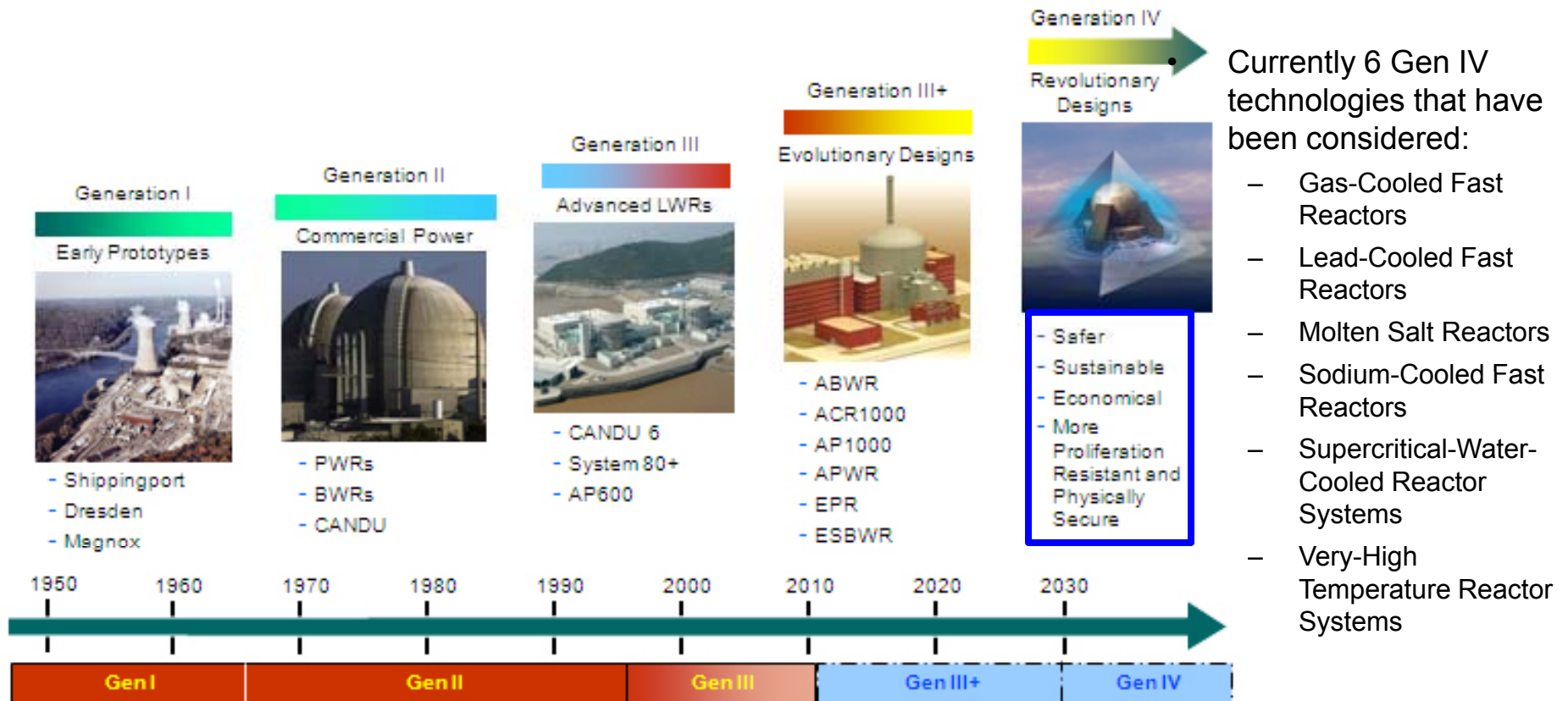


A nuclear winter?

- Aug. 24, 2012 editorial – FINANCIAL TIMES
 - “Cost, not safety, is the biggest challenge for atomic power”
- Jeff Immelt (GE)
 - Nuclear power is really hard to defend financially
 - Especially to gas-fired generation, even some renewables
- Insufficient cost cutting in nuclear industry
 - Fukushima makes it more difficult
 - Tight regulation crimps competition and innovation
- Government role is important – floor price for carbon?

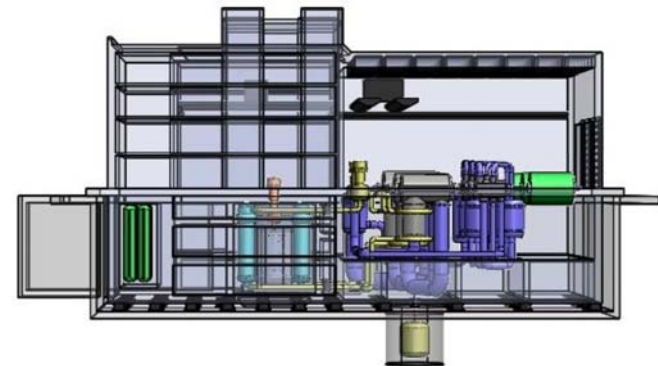
Has nuclear power in U.S. gone from “too cheap to meter”
to “too expensive to matter?”

Evolutionary path for nuclear power



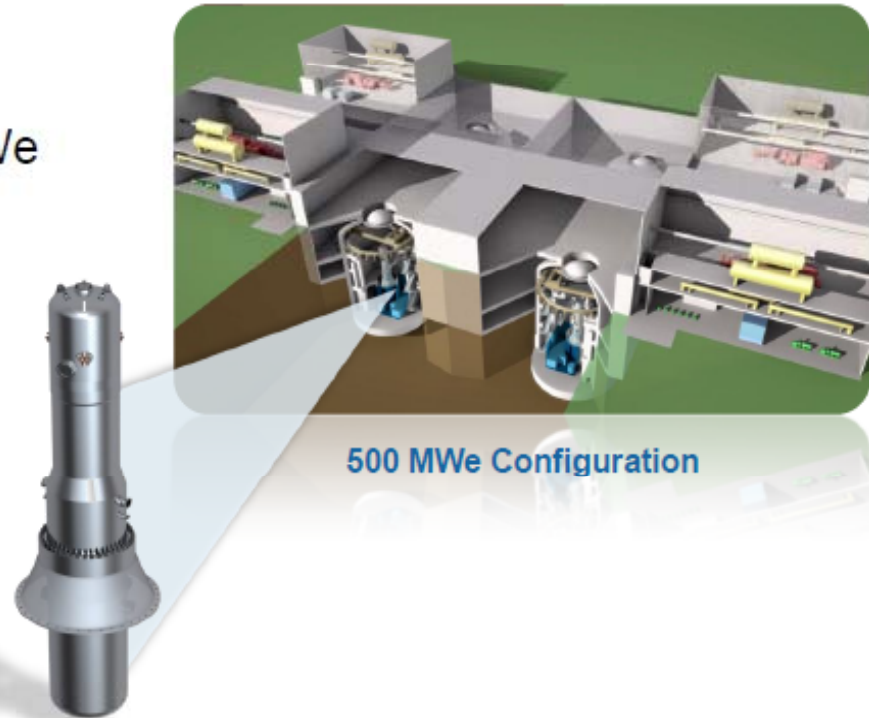
Technical Barriers: Need to accelerate learning

- Nuclear world involves long lead times
 - Fuel demonstration
 - Material performance
 - Reliability data
 - Design inflexibility
- Power of plant demonstration is important but risky
 - Small modular reactors can help minimize risk
- Requires verification and validation of sophisticated computational tools for safety



Scalable Nuclear Plant: Practical, Affordable

- Fully independent reactor modules
- 1-8 modules per plant, 125-1,000 MWe
- Underground containment building
- Low-impact, air-cooled condenser
- Scalable to grid, site, load-growth
- Three-year construction schedule



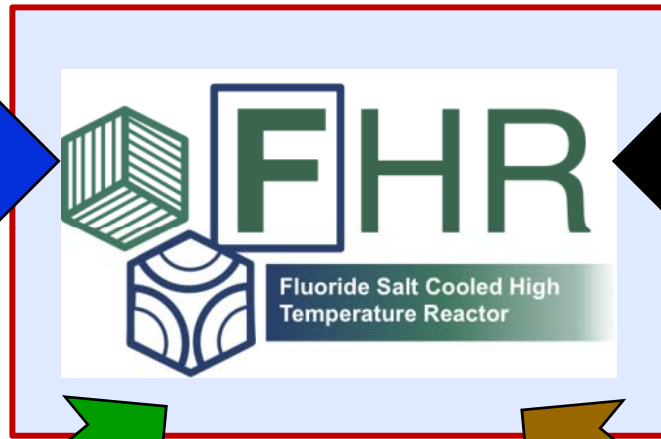
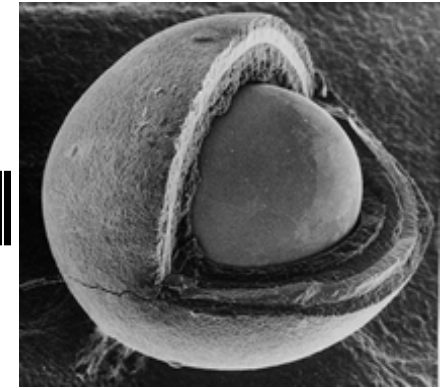
Cost certainty ... Schedule certainty ... Capital efficient.

Renewed Interest in Molten Salt Technology

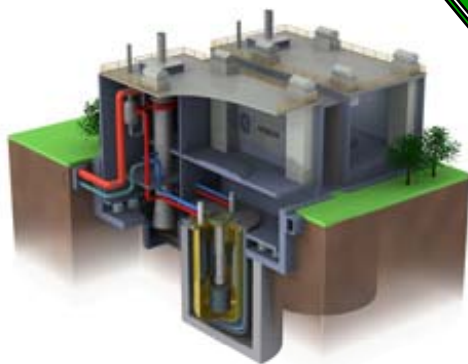
High temperature and low pressure liquid salt coolant



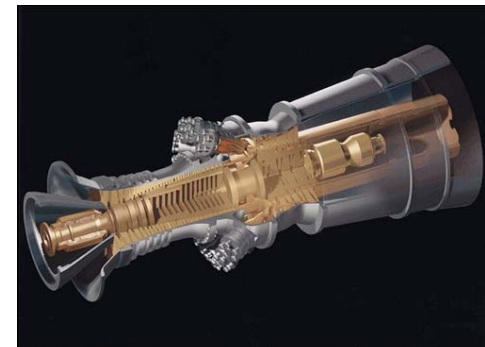
High temperature coated particle fuel



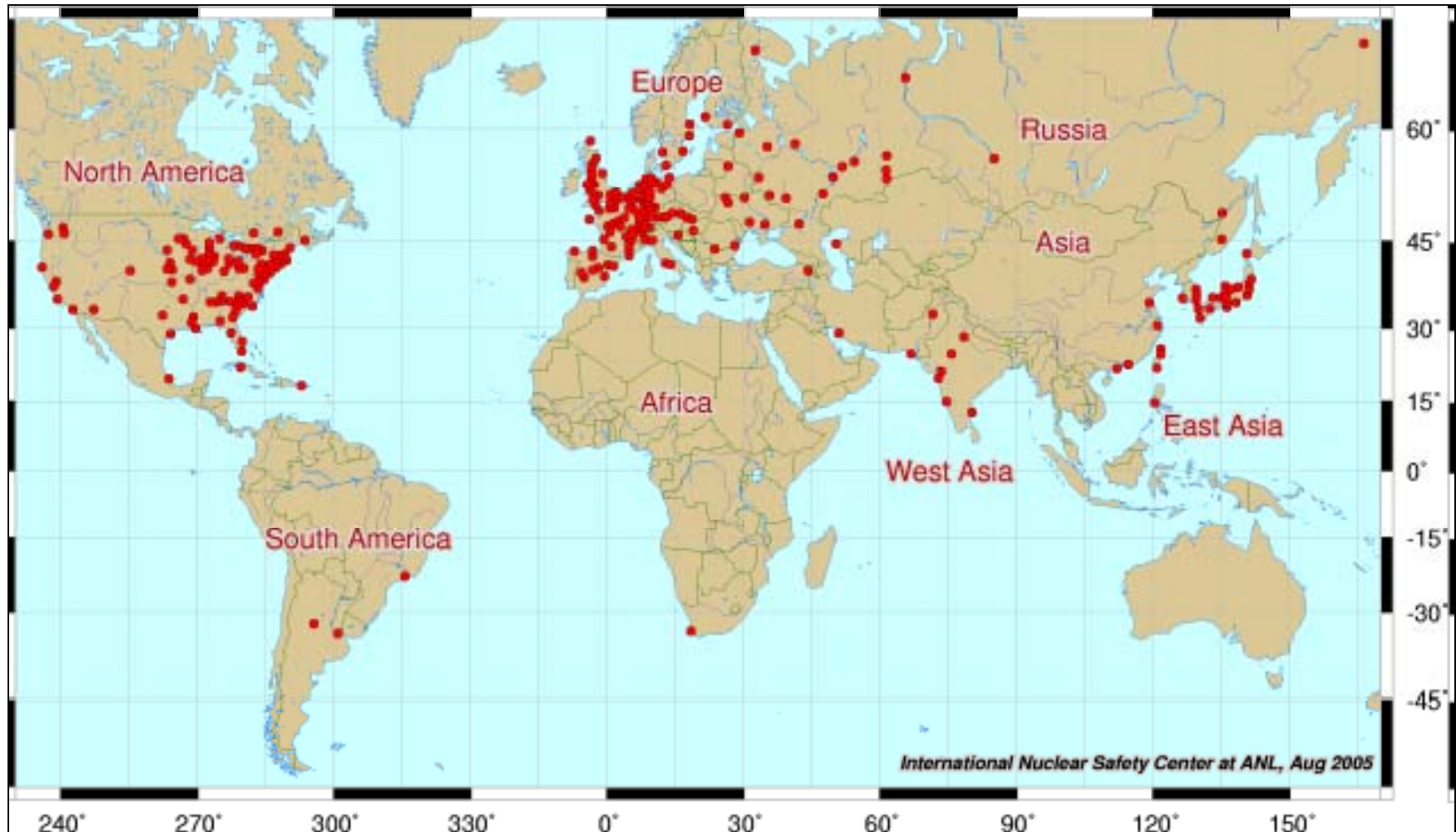
Pool-type passive reactor design



Brayton power cycles



Nuclear power supplies 15% of the world's electricity...



... but it is concentrated heavily in the developed world.

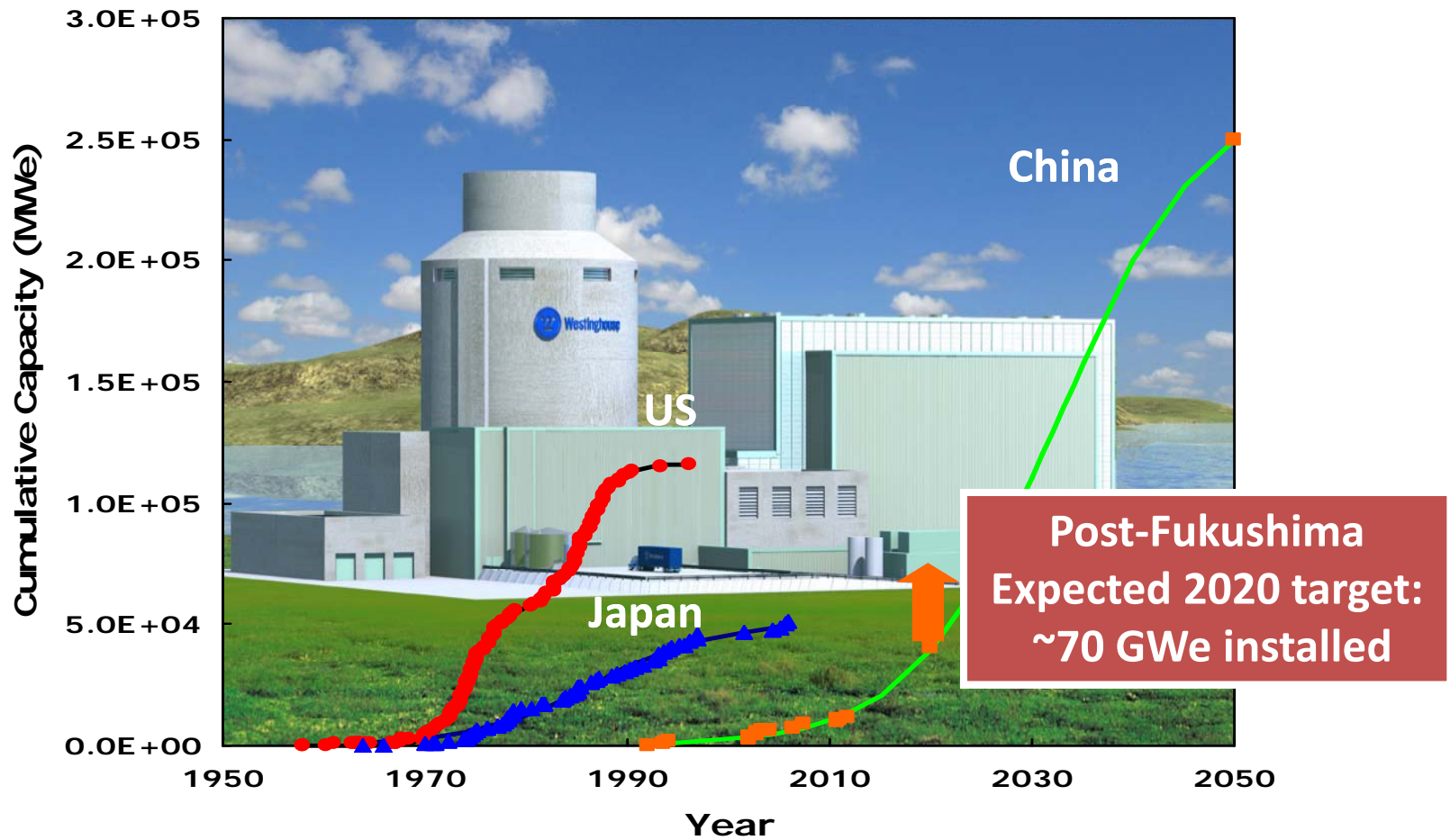
Major expansion will come in the developing world – China & India

Future of global nuclear power

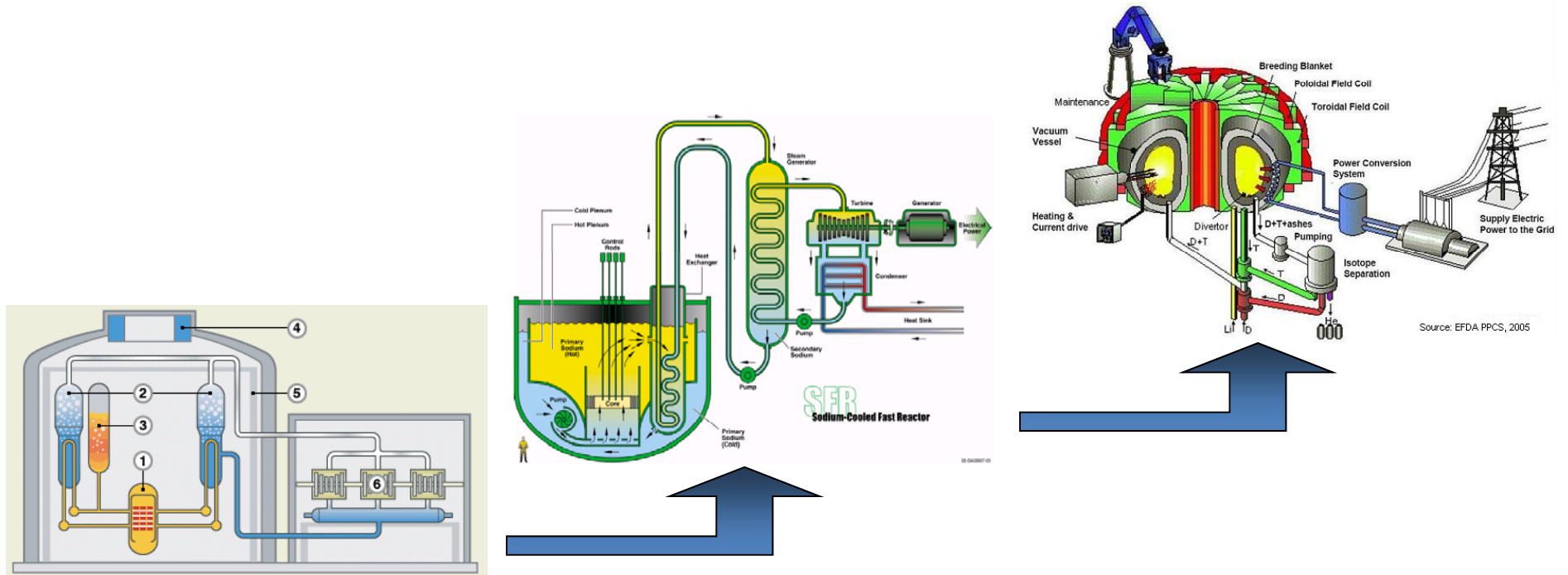
- **Nuclear reactor construction primarily in Asia**
- **Nuclear reactor manufacture shifting to Asia**
 - South Korea emerges as major exporter
 - China is poised to be next major exporter
 - Japan is fading
 - Russia is pushing very hard, French are also
 - Questions of US nuclear supply chain
- **Who will lead the regulatory and operations world?**

We are seeing tectonic shifts in all aspects of global nuclear power to Asia – is it prepared to lead?

China's post Fukushima nuclear plan



Three Stages of Nuclear Power Growth



2020

2030

>2050

~70 GWe (PWR)

FR Commercialized

Fusion

AP-1000 US-China Technology Transfer: Can China Lead in Passive ALWR Technology Export?

- SNPTC currently developing the CAP-1400 based on AP-1000 technology
 - Testing program being developed with assistance from US
- Construction of the first CAP1400, at a site near Weihei in Shandong Province, is officially scheduled to begin in April 2013
- CAP-1400 (or CAP-2100) will not be design certified by the US NRC

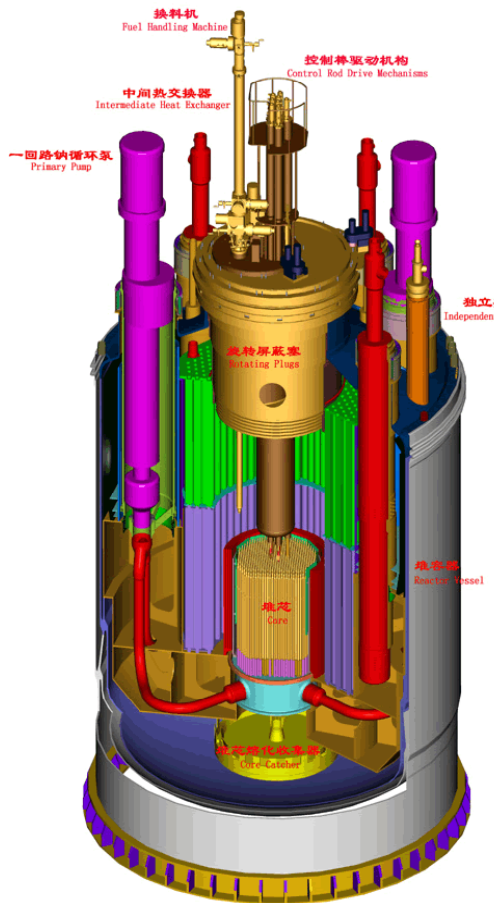


China is currently constructing a high temperature gas reactor demonstration plant called HTR-PM

- HTR-PM demonstration plant features two 250MWth pebble-bed modules driving one 210 MW turbine generator
 - Located in Shidaowan, a coastal site near Rongcheng city on Shandong Peninsula
- In early December 2012, Chinese government approved the HTR-PM project and regulatory authority issued construction permit
- Began pouring concrete on December 9, 2012

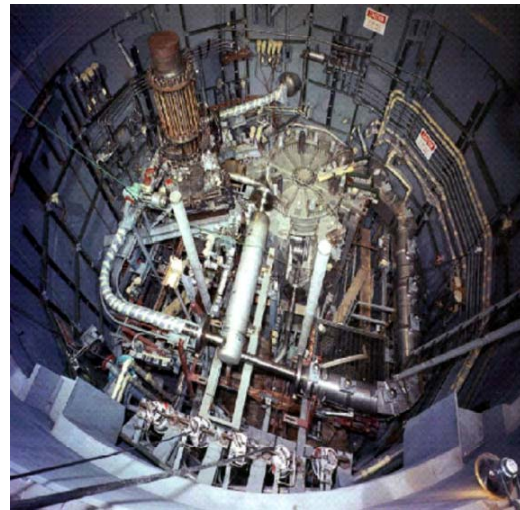


CEFR - 65MWt/25MWe (China Experimental Fast Reactor)

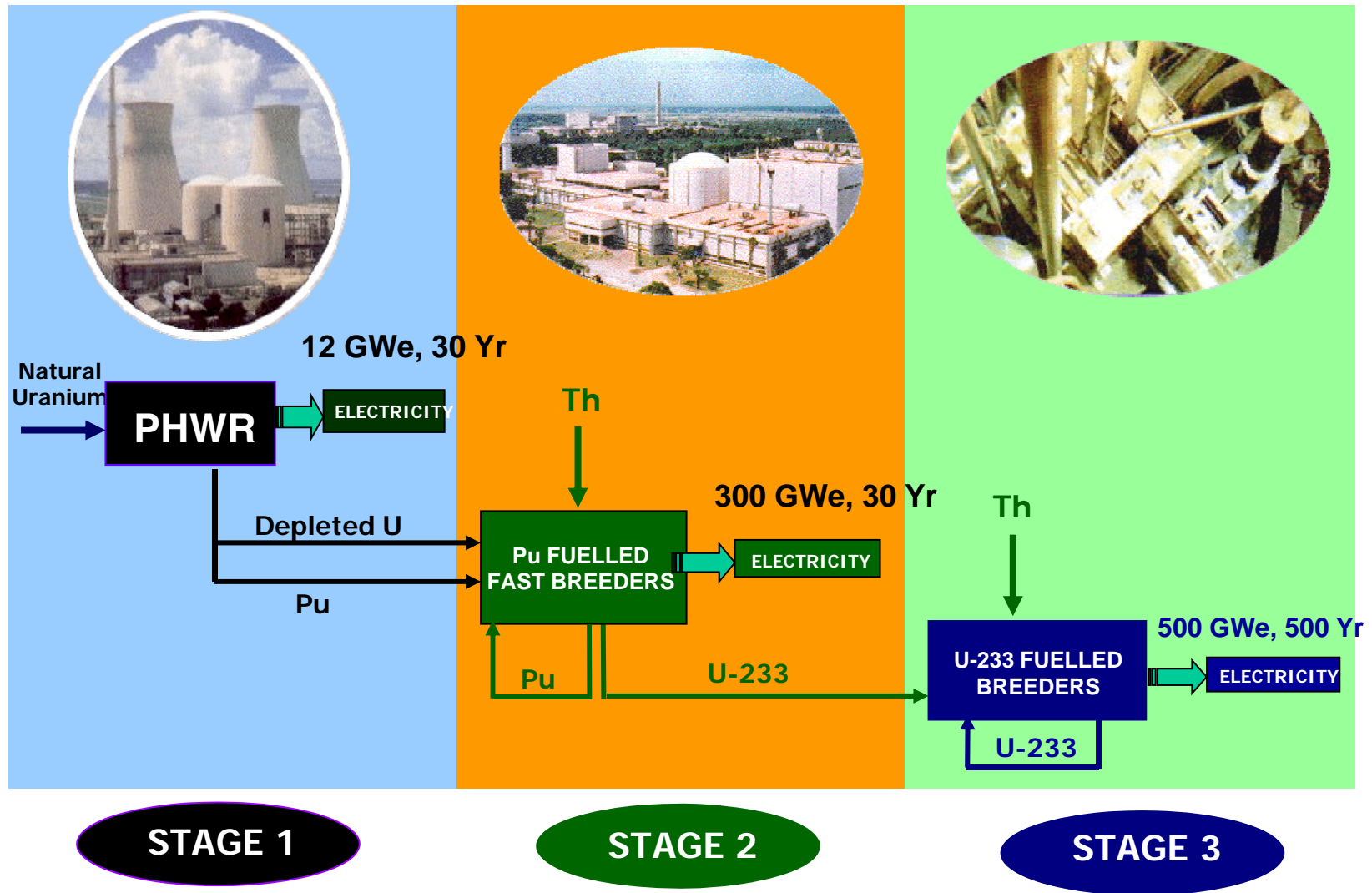


Chinese have recently embarked upon a Thorium Molten Salt Reactor (TMSR) Program

- Jiang Mianheng from the Chinese Academy of Sciences (CAS) and former son of former Chinese president, Jiang Zemin, has recently initiated a large thorium molten salt reactor program
- CAS program is based largely on the Molten Salt Reactor (MSR) program developed under Alvin Weinberg
- Chinese have adopted a similar strategy as the United States with respect to fluoride salt technology



India - pushing the technological envelope



India's nuclear ambitions



ARTIST VIEW OF 500 MWe FAST BREEDER REACTOR PROJECT

South Korea has become a nuclear energy power house



A bird's eye view of Shin-Kori Units 3 & 4
Two APR-1400 plants

South Korea's nuclear export - United Arab Emirates



Korea Electric Power Corporation wins \$20 B bid – Dec. 2009
Ground broken March 14, 2011

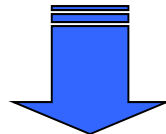


Abu Dhabi

South Korea's SMART Small PWR Plant

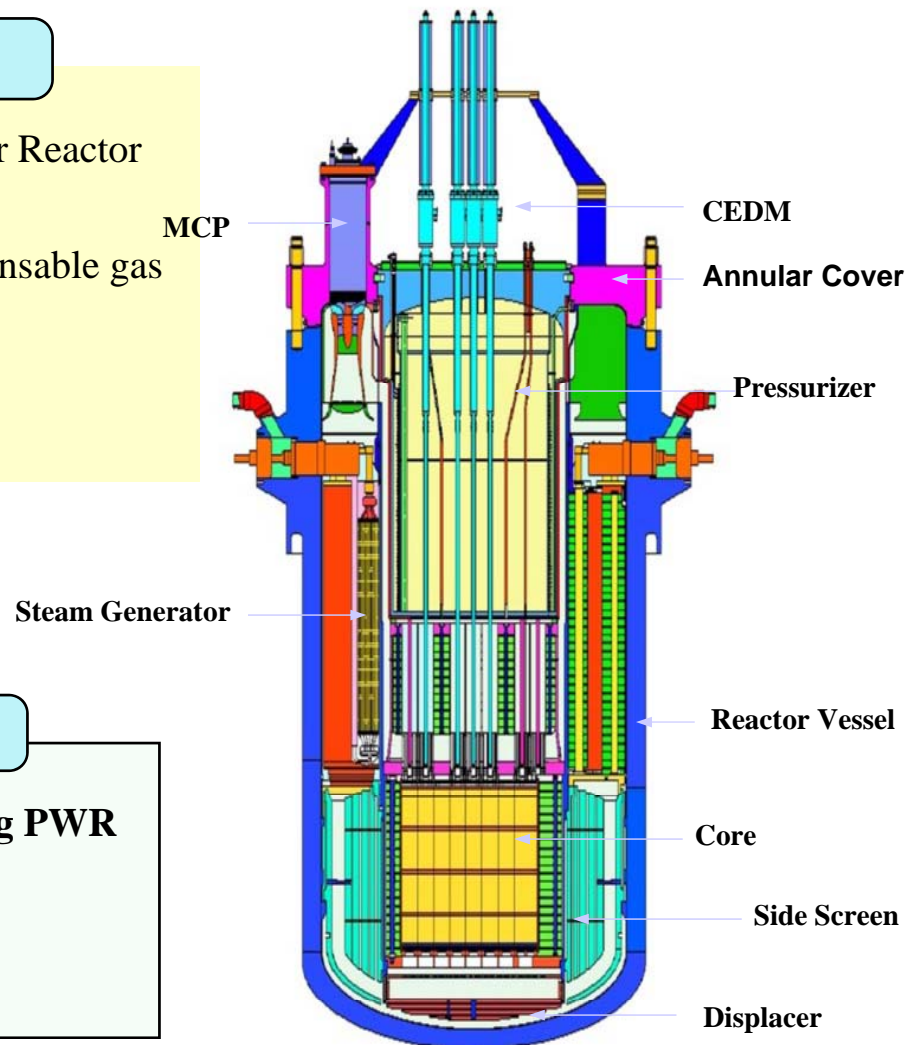
SMART DESIGN

- Small sized integral type Pressurized Water Reactor
- Elimination of the possibility of LBLOCA
- Self controlled pressurizer by a non-condensable gas
- Low power density and Boron free core
- Passive system for the decay heat removal
- Simplification of system/components

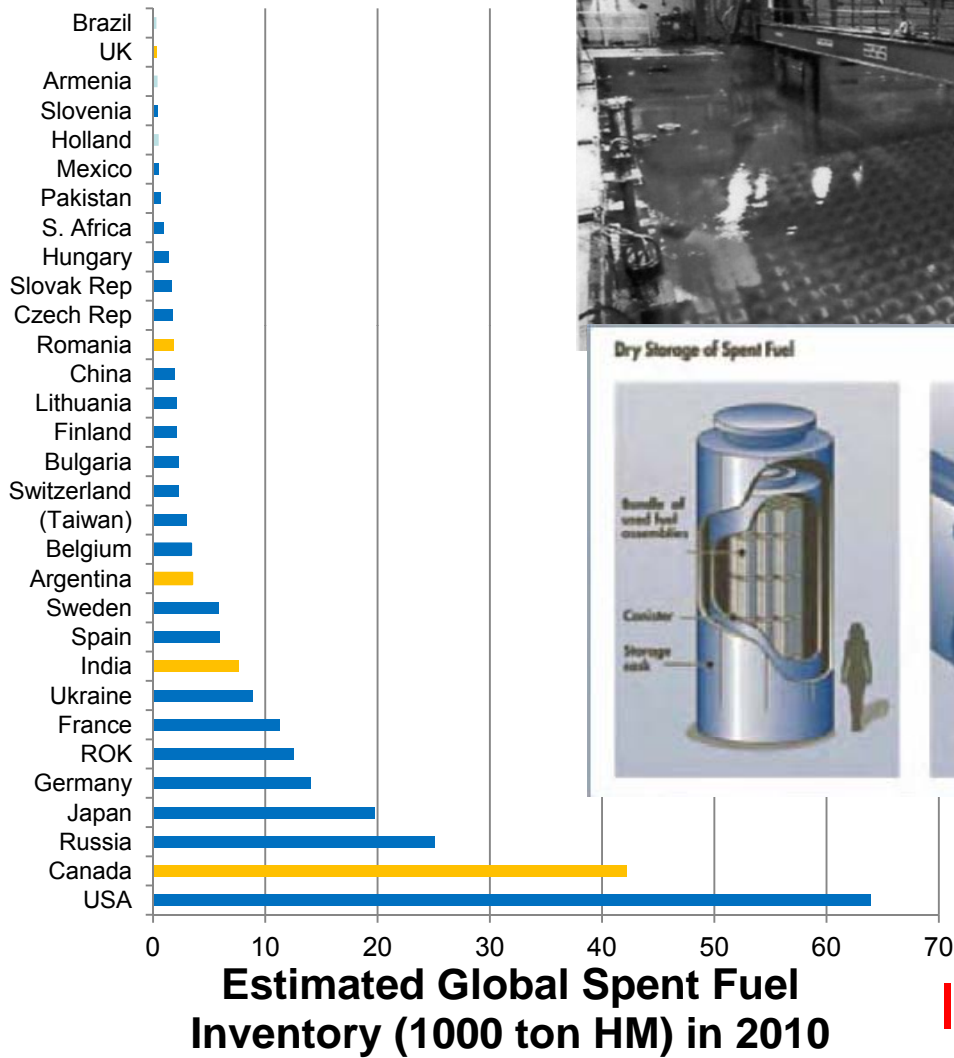


CHARACTERISTICS

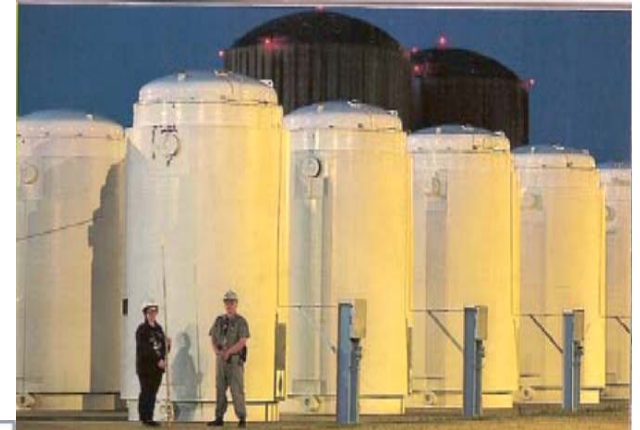
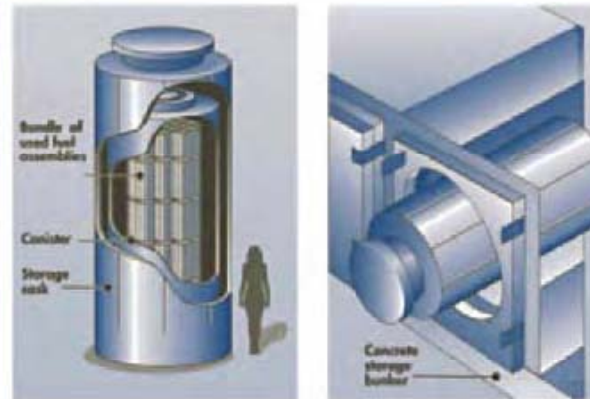
- Enhance safety comparing with existing PWR
- Shorten construction period
- Reduce liquid radioactive wastes



Nuclear waste disposal



Dry Storage of Spent Fuel



Interim Spent Fuel Storage

Nuclear Power: Expansion vs. Spread

States with nuclear power and **aspiring nuclear power states**.

Americas	Western Europe	Eastern Europe	Central and South Asia	East Asia/Oceania	Middle East	Africa
Argentina	Belgium	Armenia	India	China	Iran	South Africa
Brazil	Finland	Bulgaria	Pakistan	Japan	Bahrain	Africa
Canada	France	Czech Republic	Bangladesh	Korea	Egypt	Algeria
United States	Germany	Hungary	Georgia	Indonesia	Israel	Ghana
Mexico	Netherlands	Lithuania	Kazakhstan	Malaysia	Jordan	Kenya
Bolivia	Spain	Romania	Mongolia	Myanmar	Kuwait	Libya
Chile	Sweden	Russia	Sri Lanka	Philippines	Oman	Morocco
Dominican Republic	Switzerland	Slovakia		Singapore	Qatar	Namibia
El Salvador	United Kingdom	Slovenia		Thailand	Saudi Arabia	Nigeria
Haiti		Ukraine		Vietnam	Syria	Sudan
Jamaica		Belarus			Turkey	Tanzania
Peru		Croatia			UAE	Tunisia
Uruguay		Estonia			Yemen	
Venezuela		Greece				
		Latvia				
		Poland				

Sources: the IAEA Power Reactor Information System, www.iaea.org/programmes/a2; Frank N. von Hippel, ed., "The Uncertain Future of Fission Power," review draft, www.fissilematerials.org; Polity IV Project, *Political Regime Characteristics and Transitions, 1800-2007*, www.systemicpeace.org/inscr/inscr.htm

Importance of U.S. influence

- **Regulatory, safety and operations standards**
- **U.S.-origin fuel restrictions**
- **Nonproliferation norms and practices**
 - Congressional Blue Ribbon Committee Report (2012)
 - Bipartisan Policy Center Report (2012)

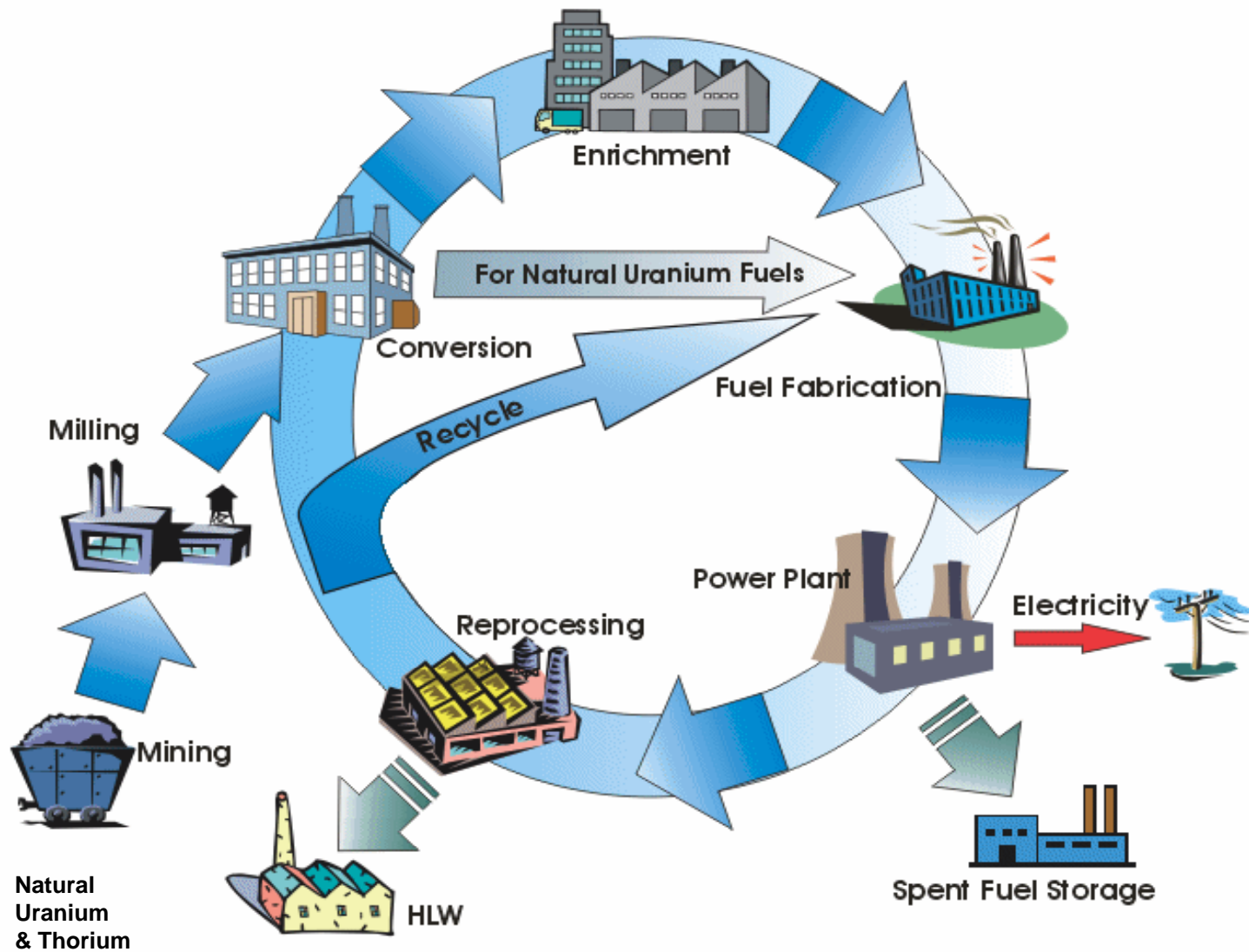
Current economics do not favor nuclear power in U.S.
Growth will come in Asia – U.S. has reasons to stay involved

Early warnings about the inevitability of proliferation

"A Report on the International Control of Atomic Energy". **Acheson-Lilienthal Report, March 28, 1946**

- It is further recognized that atomic energy plays so vital a part in contributing to the military power, to the possible economic welfare, and no doubt to the security of a nation, that the **incentive** to other nations to press their own developments is **overwhelming**.
- The development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their course **interchangeable and interdependent**.

Nuclear Fuel Cycle



North Korea and Iran. Different paths to the bomb



Iran – US Atoms for Peace
 Revolution and retreat
 Covert development
 Discovered, negotiate
 Civilian “peaceful” cover



DPRK - SU Peaceful Atom
 Indigenous “peaceful” cover
 Breakout & freeze
 Breakout, arm and negotiate

26 SEP 2010

Yongbyon LWR North Korea



Source: DigitalGlobe

4 NOV 2010



Source: DigitalGlobe

28 MAY 2011



Source: GeoEye

4 NOV 2011



Source: DigitalGlobe, 38 North

26 JAN 2012



Source: DigitalGlobe

20 MAR 2012



Source: DigitalGlobe

24 JUN 2012



Source: GeoEye

6 AUG 2012



Source: GeoEye

2 JAN 2013



Source: DigitalGlobe

North Korea threatens 'final destruction' of South Korea in UN debate

By Tom Miles, Reuters, Geneva, Feb. 19, 2013



North Korea threatens to scrap armistice ending war

Tue Mar 5, 2013 8:45am EST

Dennis "Diplomat" Rodman to the rescue

