The Future of Nuclear Power After the Fukushima Accidents

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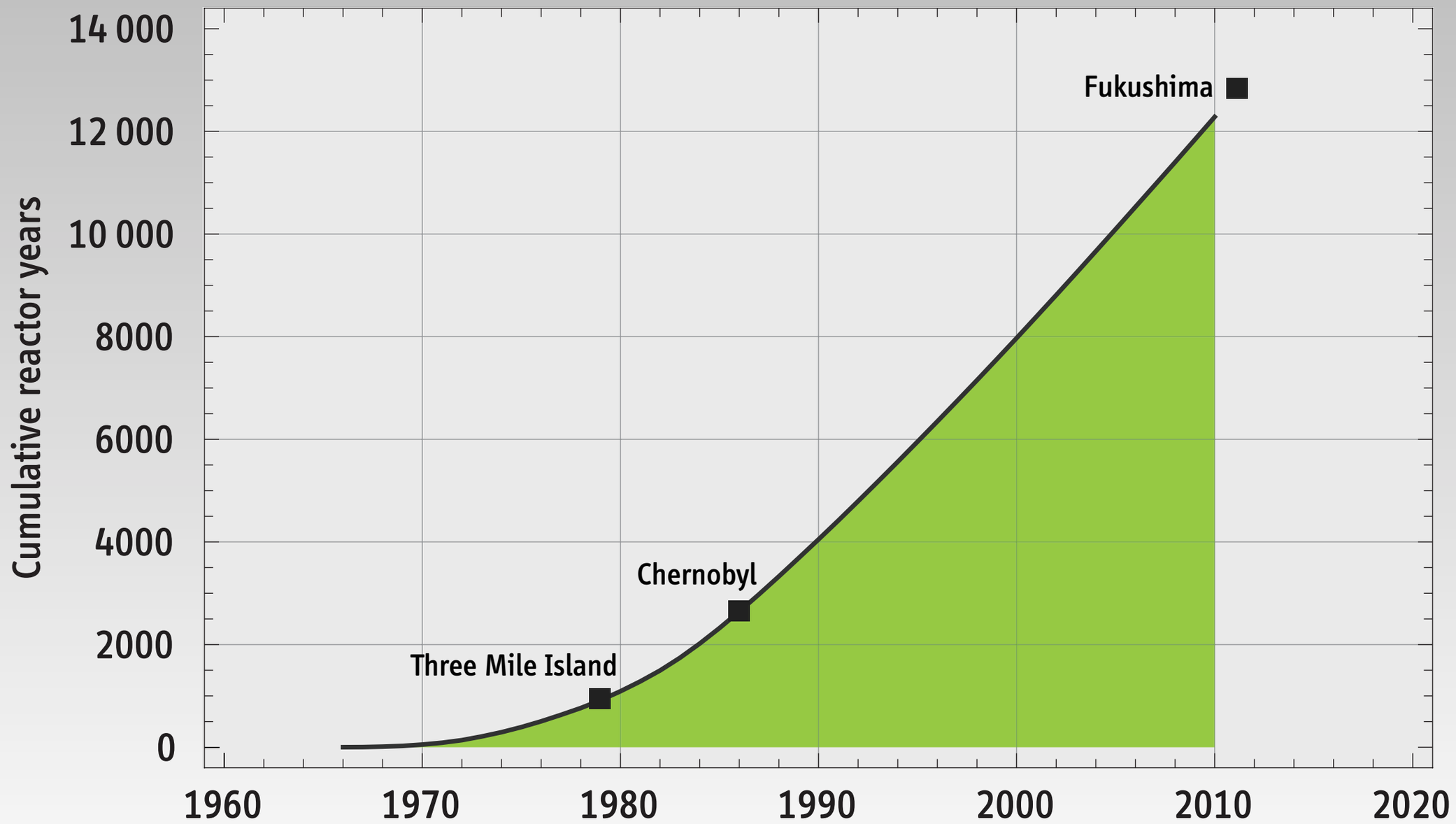
Rutgers Energy Institute, 6th Annual Energy Symposium, May 4, 2011

Revision 4

Nuclear Power: Years of Uneventfulness Interrupted by Moments of Sheer Terror?

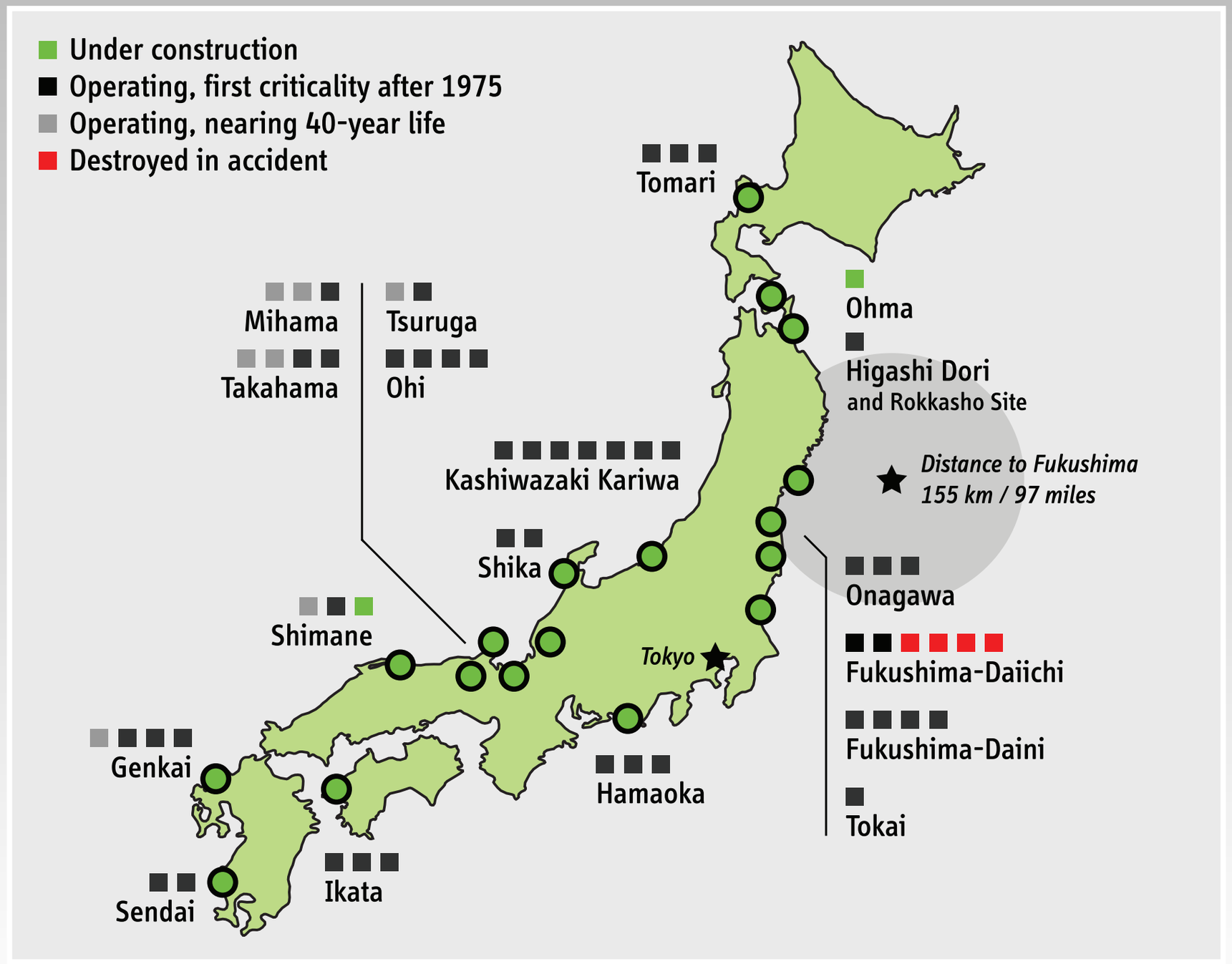


Low estimate based on the number of operating reactors by age, IAEA Power Reactor Information System
(actual value for 2010 closer to 14,000 reactor years)

The March 2011 Fukushima Accidents

(Quick Review)

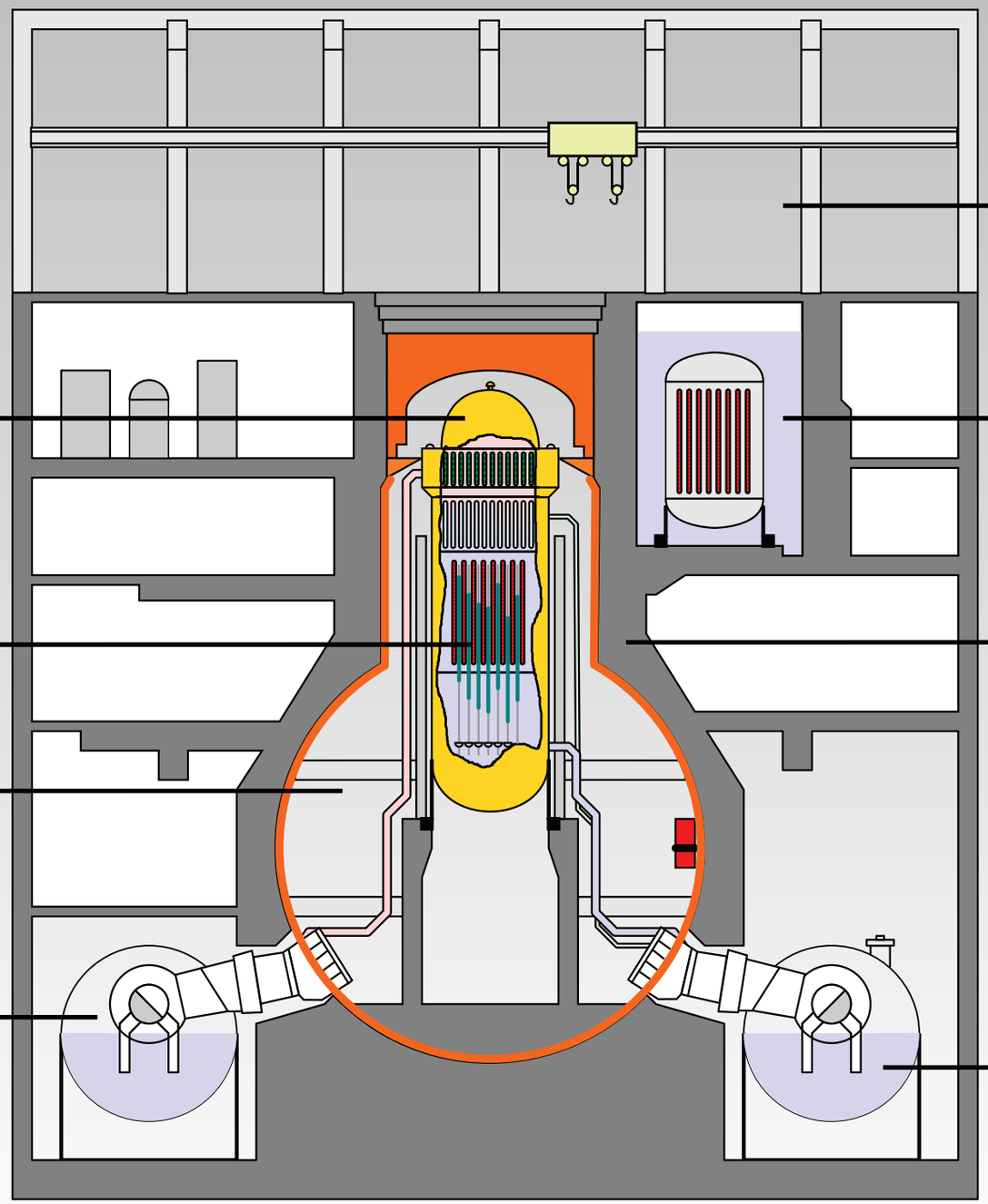
Nuclear Power Plants in Japan, 2011



Fukushima-Daiichi Plant

Source: TEPCO, undated

Layout of MK-I Boiling Water Reactor



Refueling bay
Secondary containment

Reactor pressure vessel

Spent fuel pool

Reactor core

Primary containment
("light bulb")

Drywell

Wetwell (torus)

Suppression pool

Source: MovGP0, General Electric

Explosions of Secondary Containment Buildings of Units 1 and 3

Unit 1, March 12, 2011, 3:36 p.m.

Unit 3, March 14, 2011, 11:01 a.m.

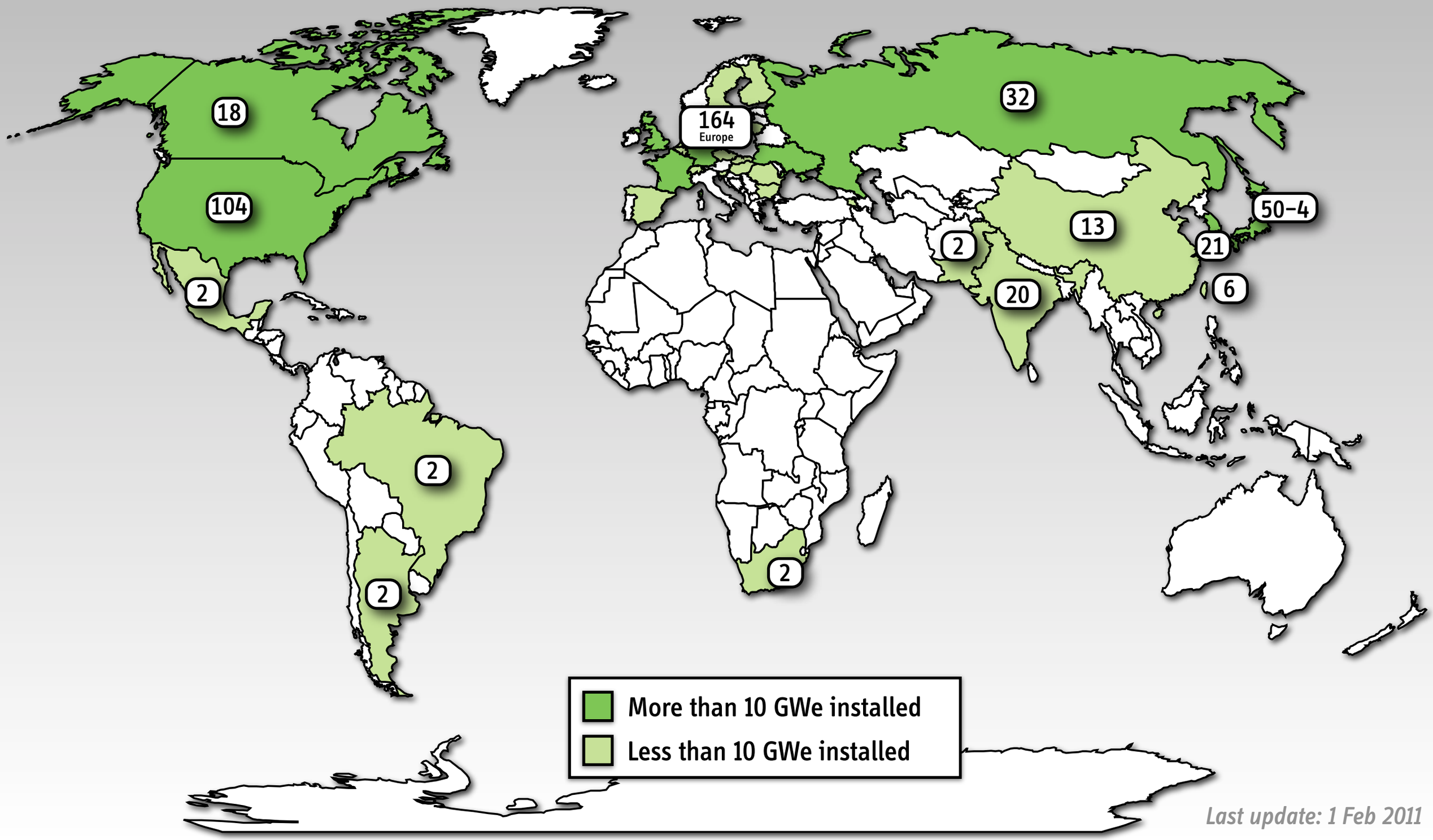
March 14, 2011 - DigitalGlobe

Lessons (to be) Learned

What To Do With the Existing Fleet?

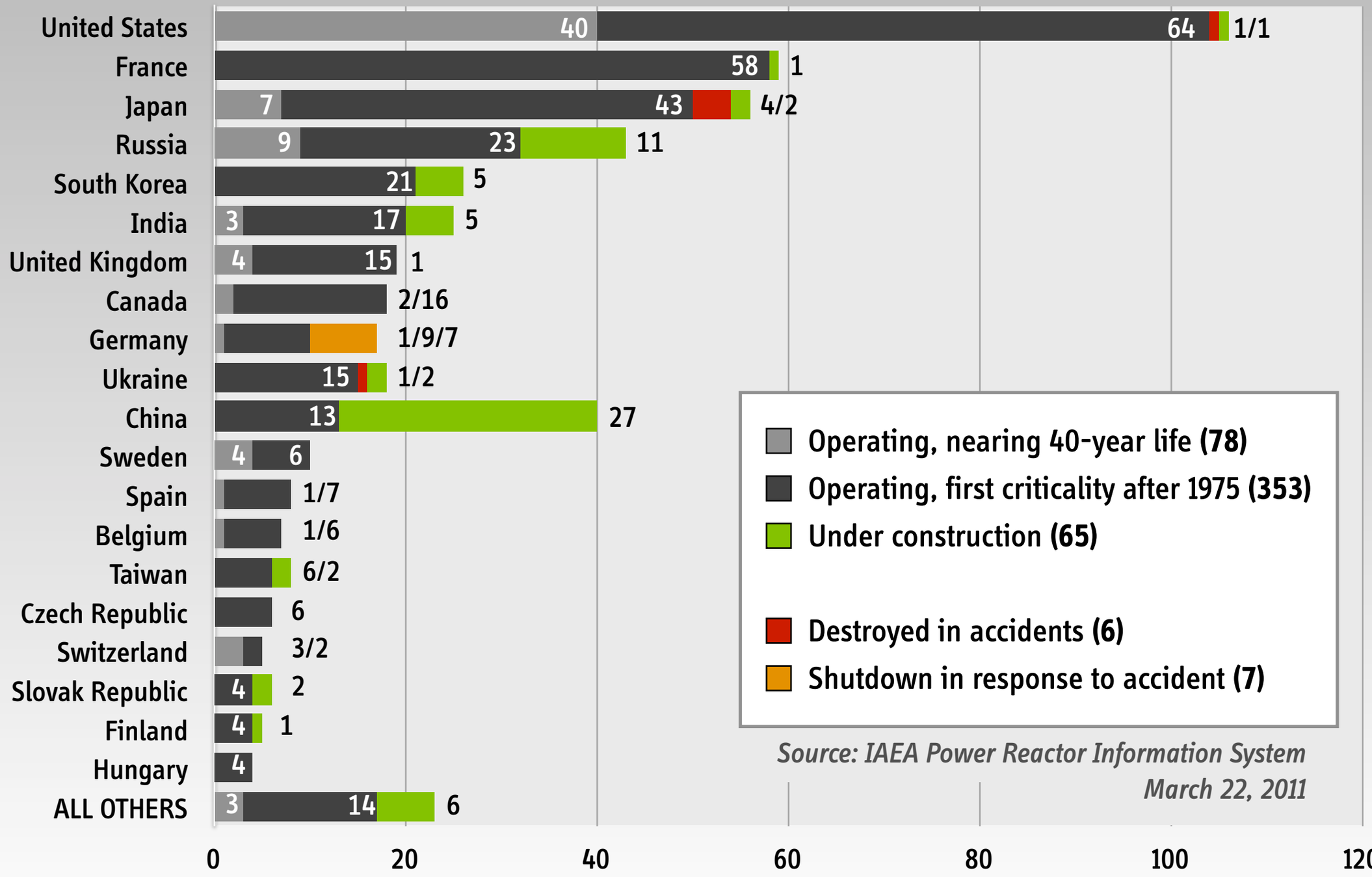
Nuclear Power Reactors in the World, 2011

(442 minus 4 reactors in 30 countries, providing about 14% of global electricity)



Last update: 1 Feb 2011

The Existing Fleet of Power Reactors is Aging



Source: IAEA Power Reactor Information System
March 22, 2011

Weaknesses of Old Reactor Designs Have Been Known for Decades

"Steve's idea to ban pressure suppression containment schemes is an attractive one in some ways. ... However, the acceptance of ... [these] containment concepts ... is firmly embedded in the conventional wisdom. Reversal of this hallowed policy ... could well be the end of nuclear power. It would throw into question the operation of licensed plants, would make unlicensable the ... plants now under review, and would generally create more turmoil than I can stand."

Joseph Hendrie, 1972
Then Deputy Director for Technical Review
U.S. Atomic Energy Commission

Most New Construction is Underway in China

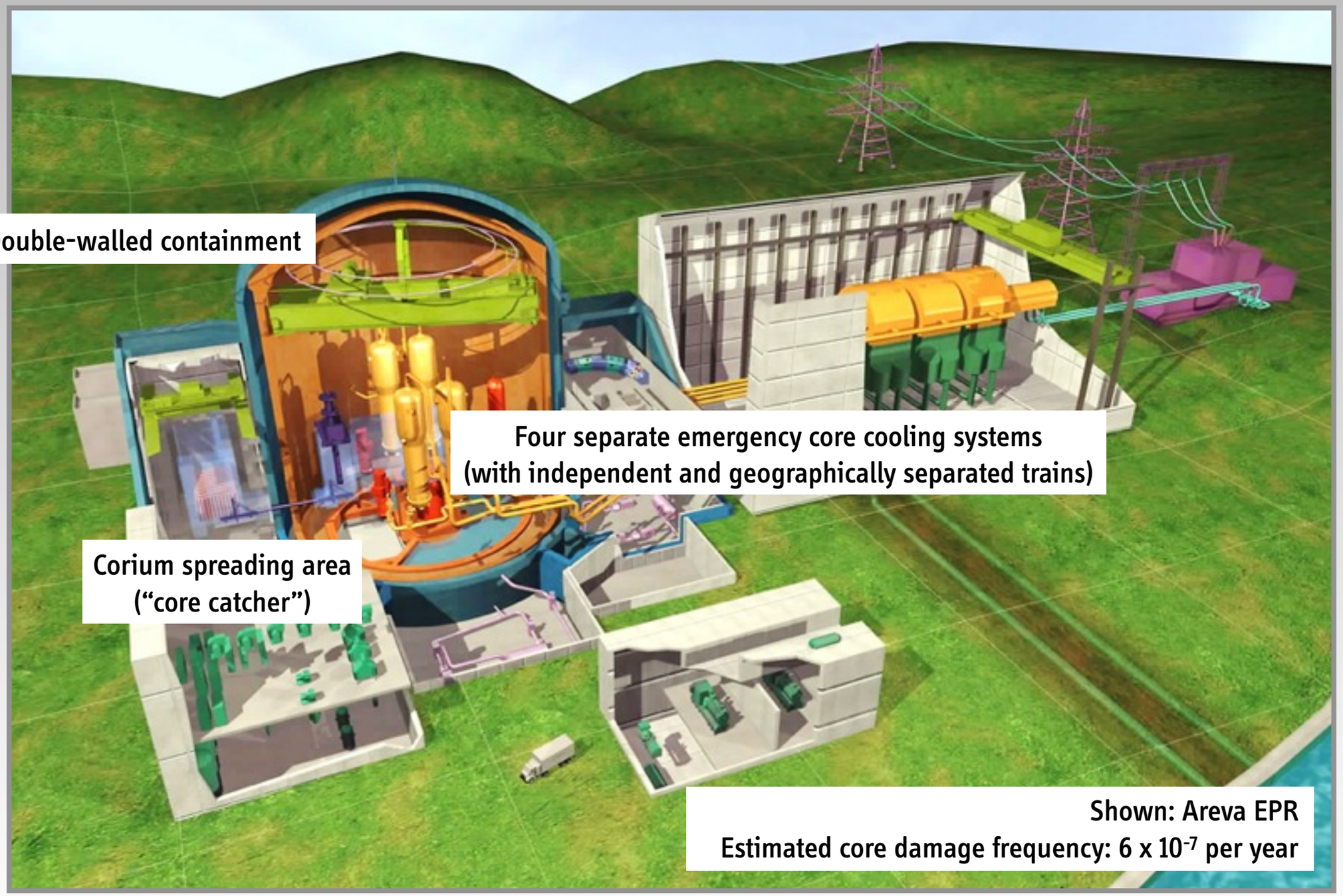
Lock-in of China's Fleet with GEN II Technology?

ReactorDesign	China	France	Japan	South Korea	Russia	Other	Total
GENERATION II							
CPR-1000	18	-	-	-	-	-	19.4 GW
CNP Series	3	-	-	-	-	-	2.0 GW
OPR-1000	-	-	-	4	-	-	4.0 GW
VVER	-	-	-	-	7	4	12.3 GW
GENERATION III							
APR-1400	-	-	-	2	-	-	2.7 GW
ABWR	-	-	2	-	-	2	5.4 GW
APWR	-	-	2	-	-	-	3.1 GW
GENERATION III+							
AP-1000	4	-	-	-	-	-	4.8 GW
EPR	2	1	-	-	-	1	6.6 GW
TOTAL	27	1	4	6	7	7	60.3 GW

Source: Robert Rosner and Steve Goldberg, Nuclear Power post-Fukushima, University of Chicago, March 29, 2011

What About Advanced Reactor Designs?

Advanced Reactors Promise Enhanced Safety



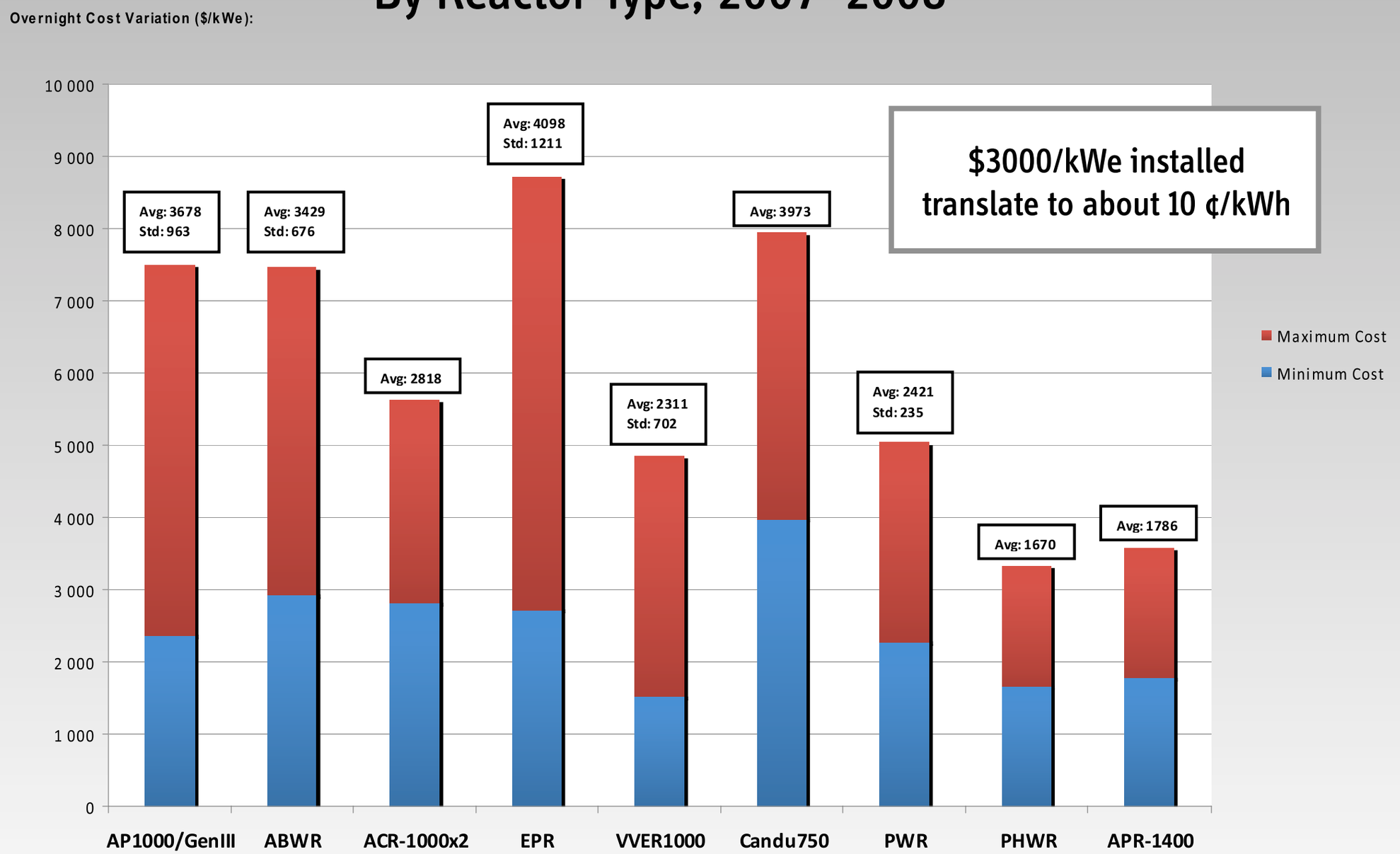
Advanced Reactors Are Also Expensive

Olkiluoto 3 (Finland, Areva): Four years behind schedule (2013 vs 2009)
Turnkey agreement ($4.3 billion), currently estimated loss for Areva: $3.8 billion

Source: Francois de Beaupuy, "Areva's Overruns at Finnish Nuclear Plant Approach Initial Cost," *Bloomberg Businessweek*, June 24, 2010

Overnight Capital Cost Variation

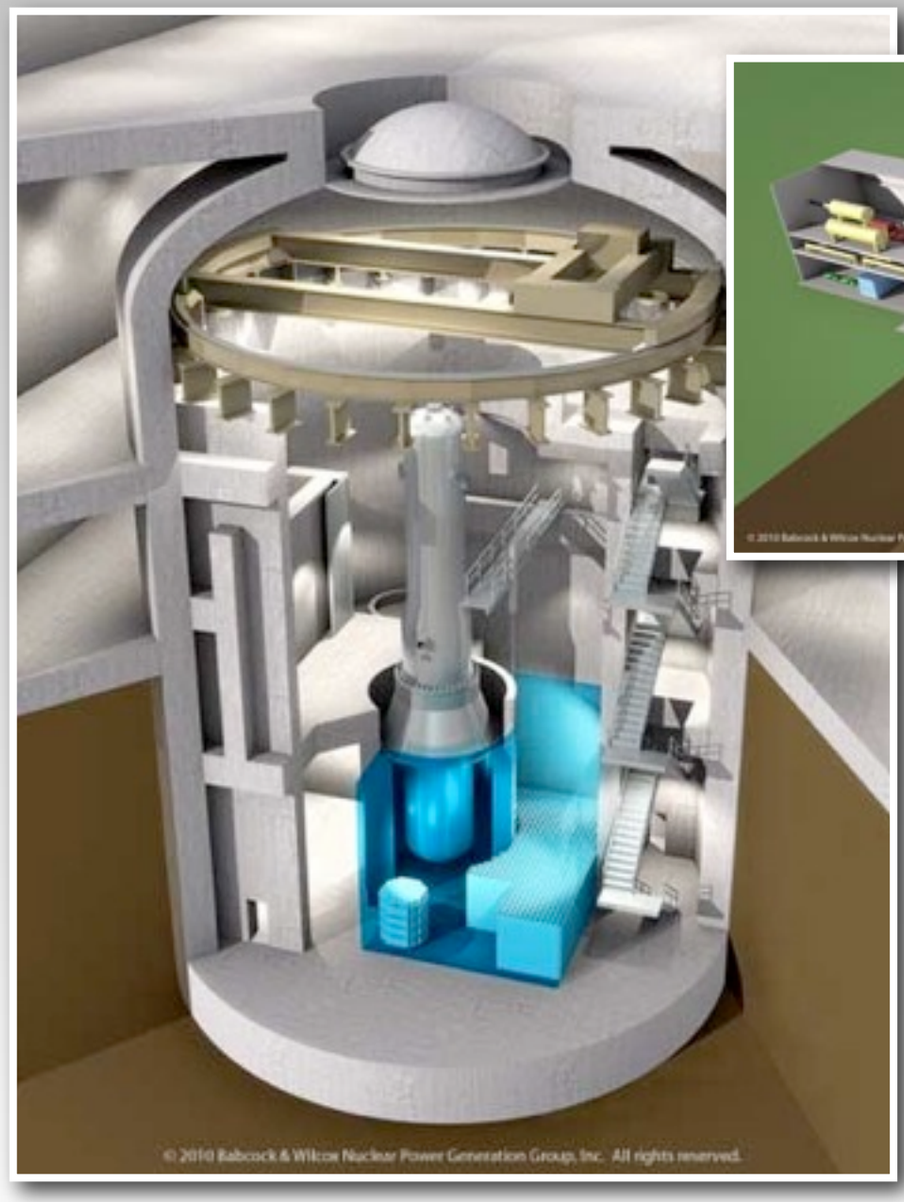
By Reactor Type, 2007–2008

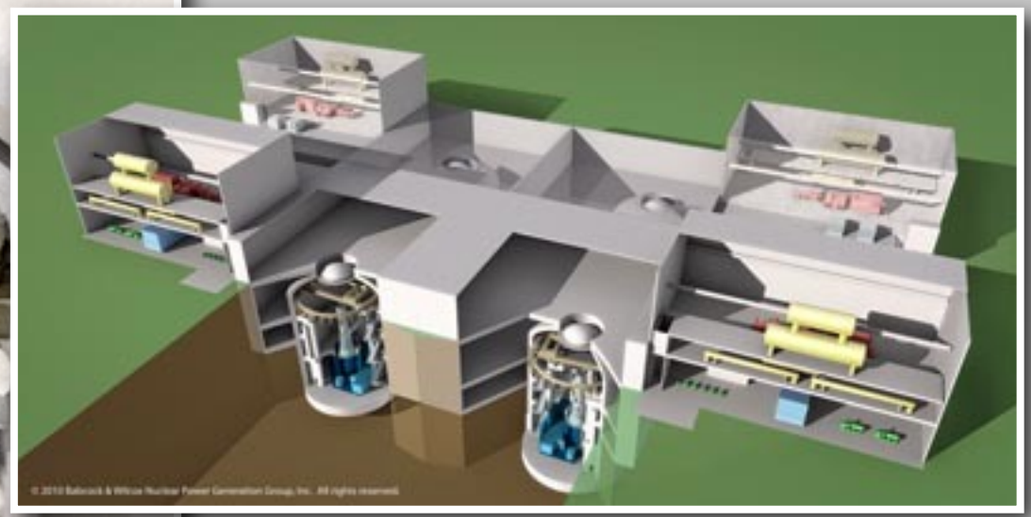


Source: Nuclear Technology Review 2009, Uncertainties and Variation in Nuclear Power Investment Costs
International Atomic Energy Agency, Vienna, 2009 (DRAFT)

Could Small Nuclear Reactors Play a Role?

Some concepts are based on proven reactor technology





Babock & Wilcox mPower Concept

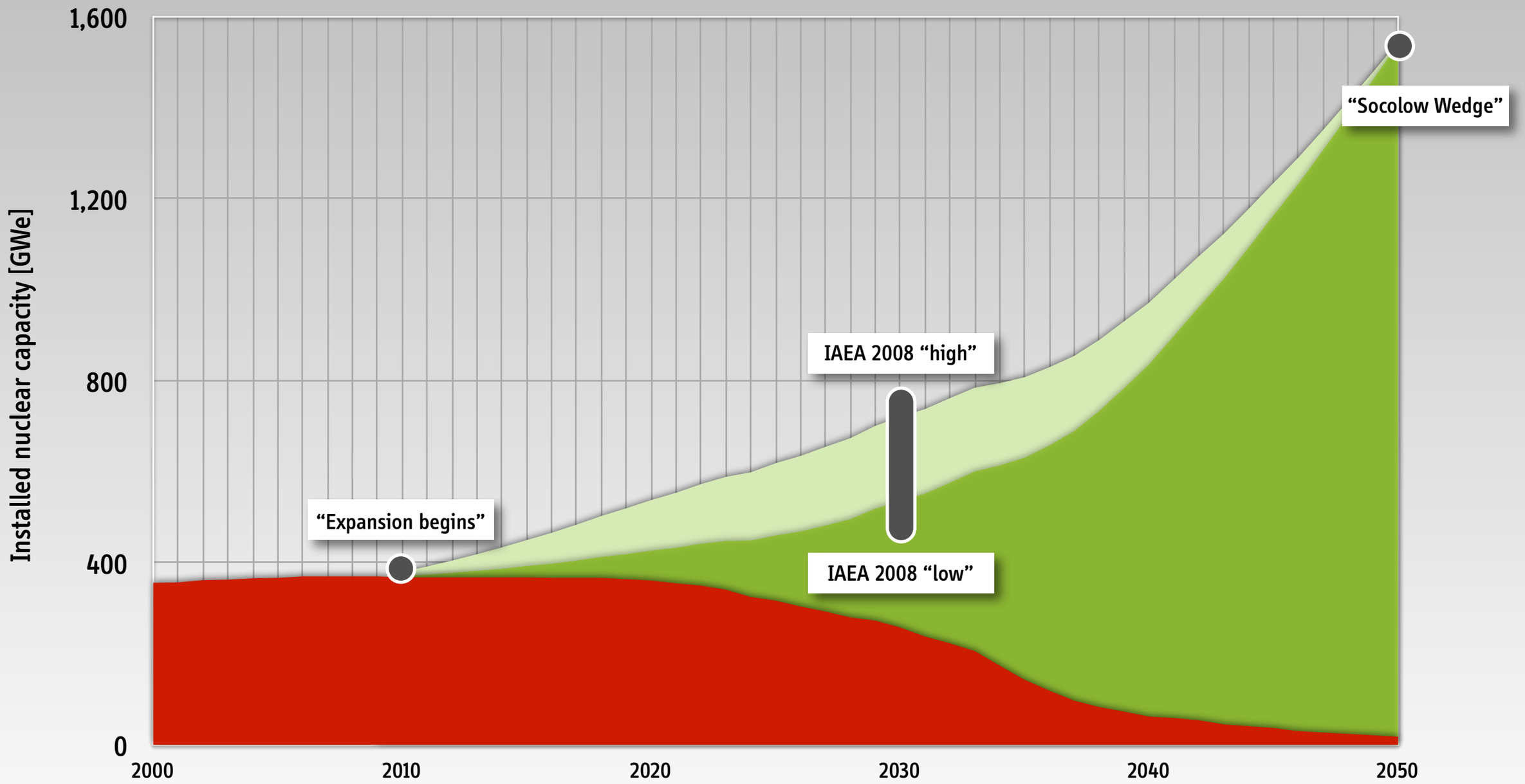
- Light-water cooled
- 125-750 MWe
- Underground construction
- 60-year spent fuel storage onsite
- Quasi-standard LWR fuel

Source: www.babcock.com/products/modular_nuclear/

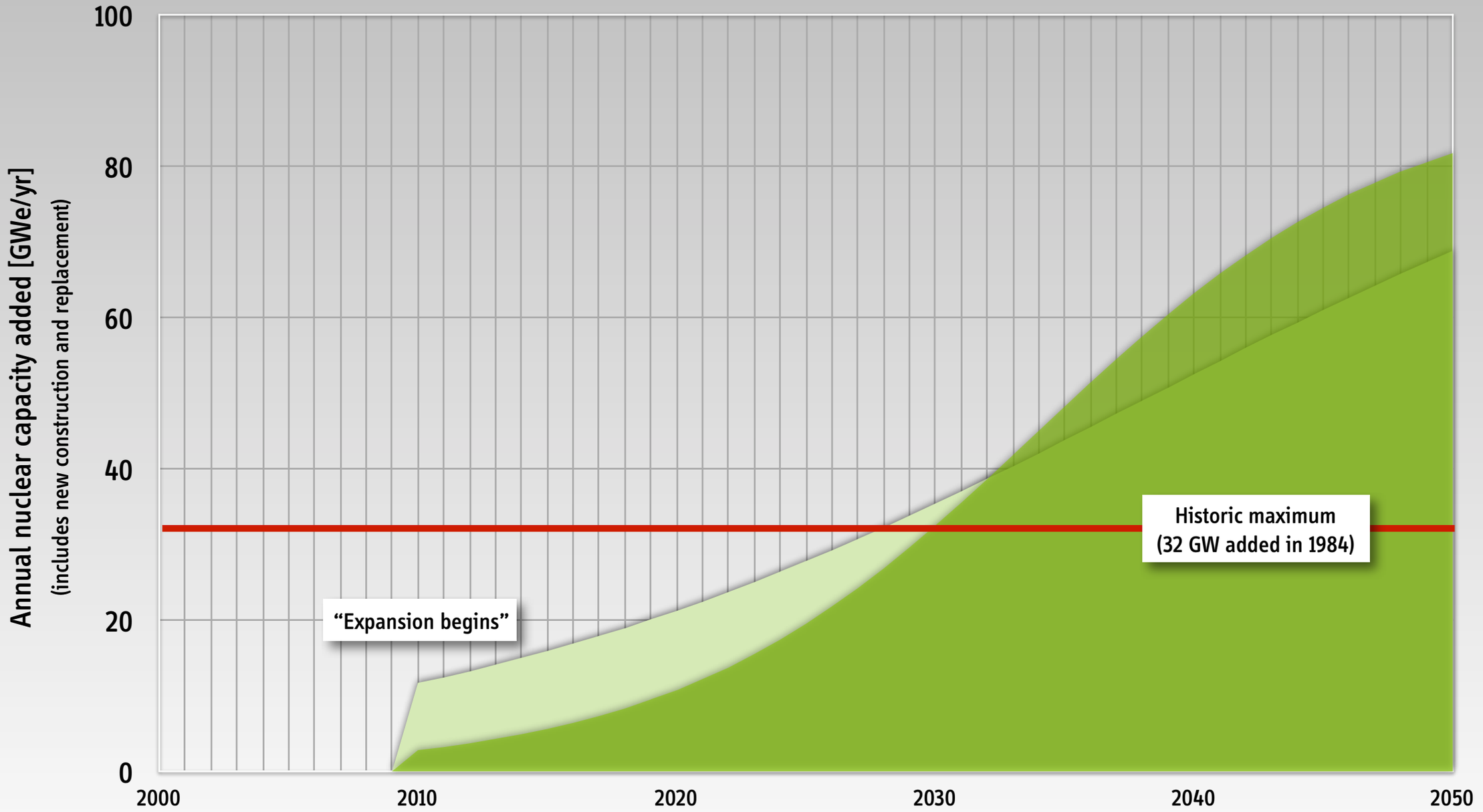
Looking Ahead

Achieving One “Socolow Wedge” By 2050

Notional Buildup of Nuclear Capacity



Achieving One "Socolow Wedge" By 2050 Would Require Unprecedented Construction Rates



America's Energy Future: Technology and Transformation
National Academy of Sciences; National Academy of Engineering; National Research Council
Washington, DC, July 2009
www.nap.edu/catalog.php?record_id=12091

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Nuclear Energy

Utilities in the United States ha
in adding new nuclear powe
tion sources. As of July 200
(USNRC) had received 17 applicati
licenses[1] for 26 units, and it expec
units by the end of 2010.[2] The 1
constructed in the 1970s and 19
supply: nuclear power provides
70 percent of electricity produ
tions. These plants provide el
with capacity factors greater
remain, and no new nuclear
than 30 years.

This chapter discusse
the United States, includi

[1]Previously, the licensin
required a different licens
part of the USNRC's new
[2]The USNRC's lists
reactors/new-reactors/
expected-new-rx-appl
[3]The net capacity

America's Energy Future

National Research Council, July 2009, Executive Summary

"The deployment of existing energy efficiency technologies is the nearest-term and lowest-cost option for moderating our nation's demand for energy, especially over the next decade. The potential energy savings available from the accelerated deployment of existing energy efficiency technologies in the buildings, transportation, and industrial sectors could more than offset the U.S. Energy Information Administration's (EIA's) projected increases in energy consumption through 2030."

America's Energy Future

National Research Council, July 2009, Executive Summary

"The viability of two key technologies must be demonstrated during the next decade to allow for their widespread deployment starting around 2020:

- Demonstrate whether CCS technologies ... are technically and commercially viable for application to both existing and new power plants. [...]

- Demonstrate whether evolutionary nuclear plants are commercially viable in the United States by constructing a suite of about five plants during the next decade."

The Next Decade

Little (if any) new capacity will be added in the United States

Western Europe is walking away from new build

Little (if any) capacity will come online in “newcomer” countries

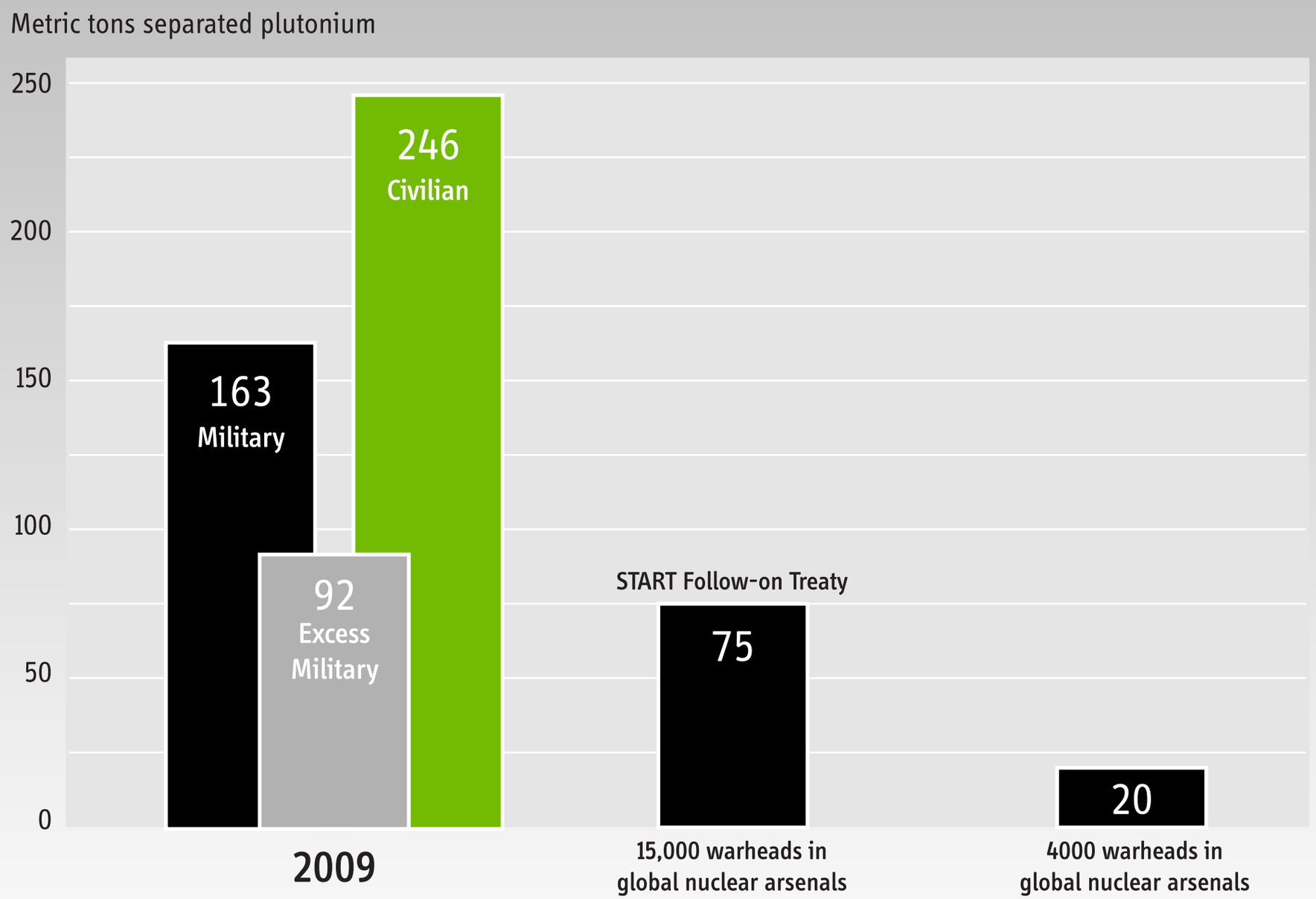
By the end of the decade, we may NOT understand much better the economics and some other constraints of nuclear power

What Should Be Done In the Meantime?

Refrain From Reprocessing and Move Toward Dry-Cask Storage

Stocks of Civilian Plutonium are Growing

and dwarf military stockpiles in a disarming world



R. Socolow and A. Glaser, "Balancing Risks: Nuclear Energy and Climate Change," *Daedalus*, 2009.

Dry Cask Storage of Spent Fuel

is a simple and proven strategy for the next decades

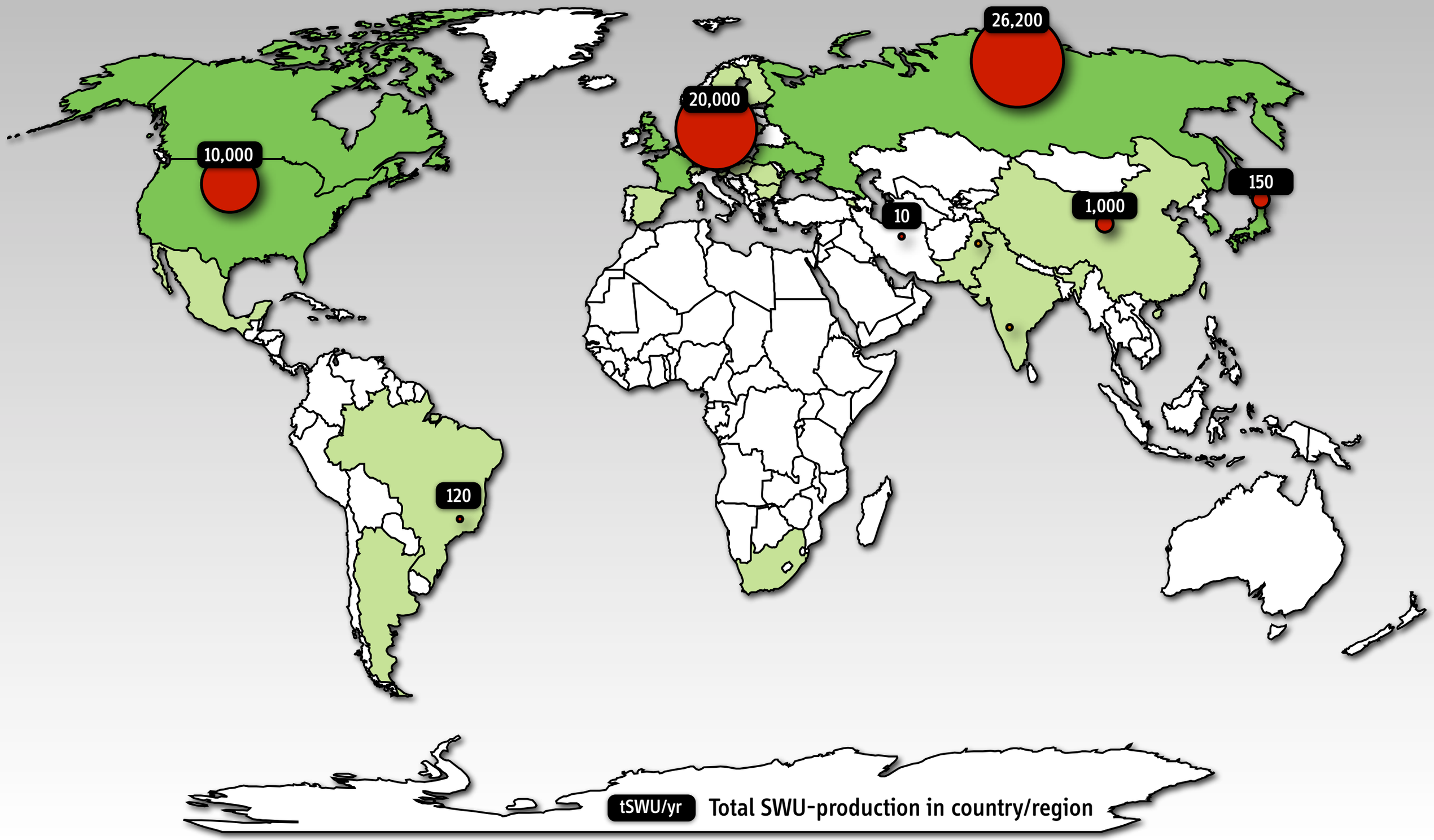
Source: Department of Energy

See for example: www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.pdf

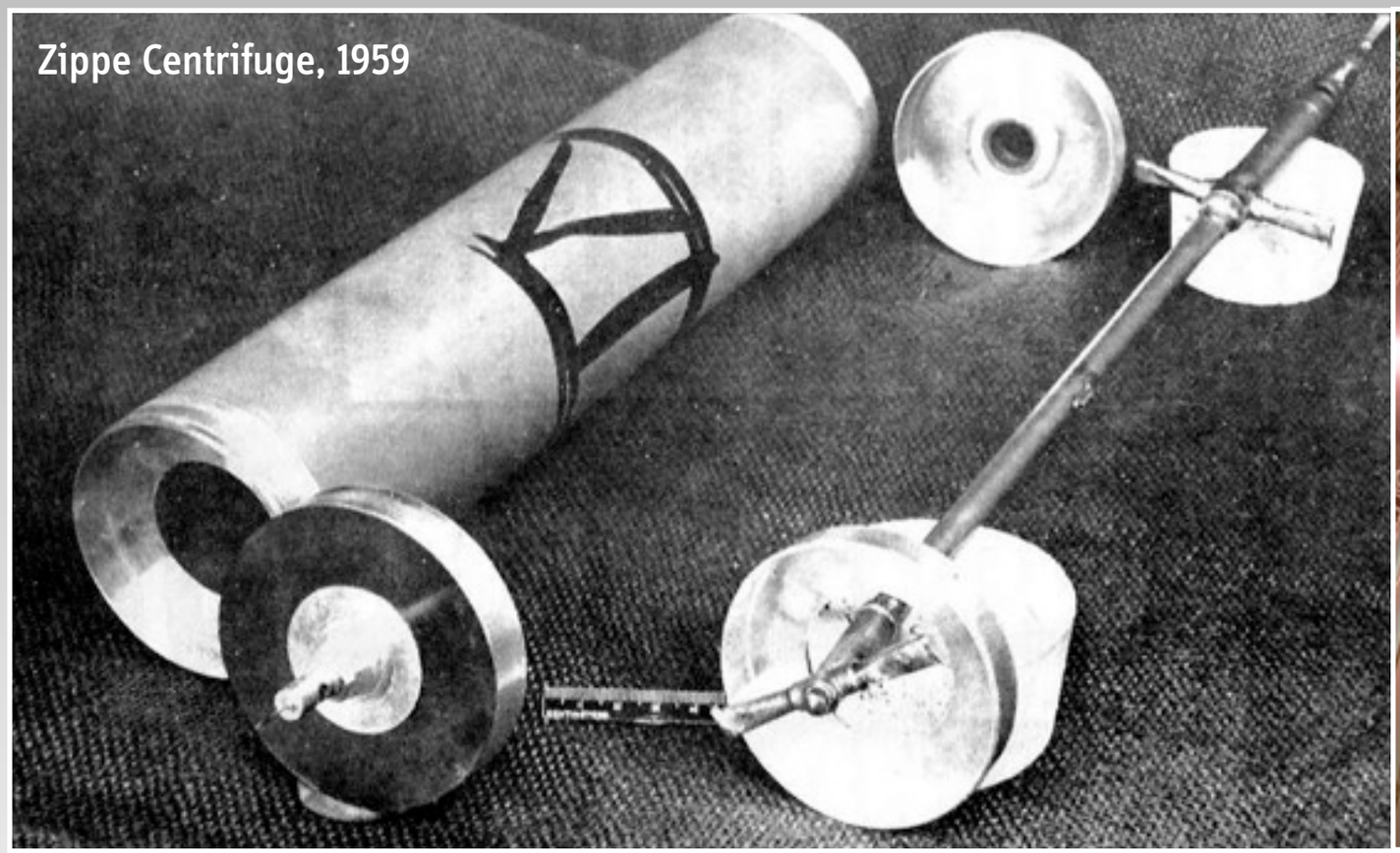
Build a New Framework for the Nuclear Fuel Cycle

Global Enrichment Capacities, 2010

(14 operational plants in 10 countries, not including two military plants)



Why Centrifuges Are Different



Characteristics of centrifuge technology relevant to nuclear proliferation

Rapid Breakout and Clandestine Option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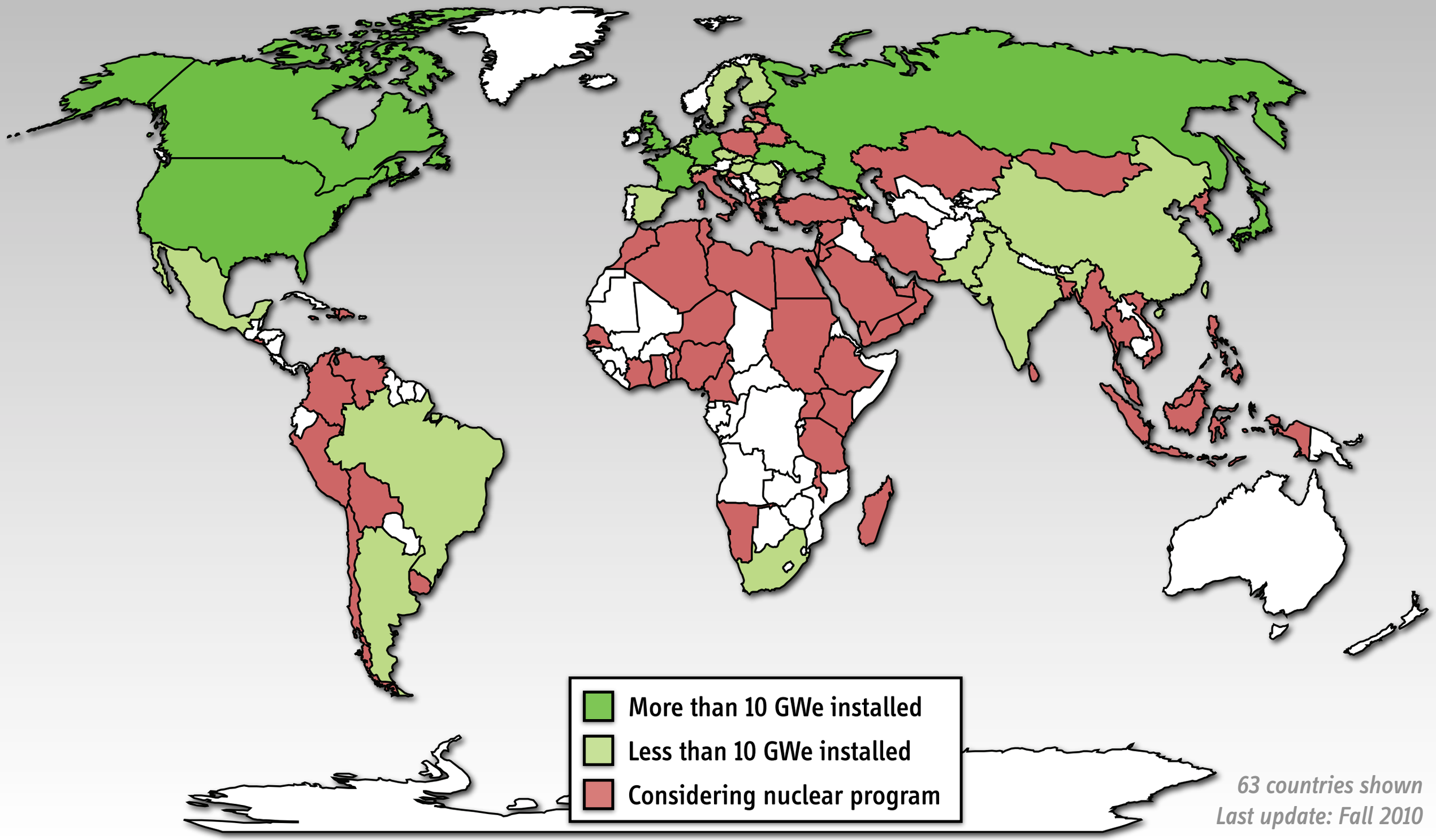
www.President.ir

Newcomer Countries, 2010

According to the IAEA, 60+ countries are currently considering nuclear programs



63 countries shown
Last update: Fall 2010

Preventing the Further Spread and Assuring Peaceful Use

Preventing Further Spread

- Tighten export controls (further)
- Delegitimize enrichment in today's "non-enrichment" states
- Increase the ability to detect undeclared facilities
- Encourage multilateral approaches to the nuclear fuel cycle

Assuring Peaceful Use

- Increase the effectiveness of IAEA safeguards
- Revisit alternative "proliferation-resistant" technologies

Concluding Remarks

The Fukushima accidents have reminded us that we continue to rely on a reactor technology that is not "state-of-the-art"

Critical debate needed about life-extensions and safety objectives for future reactors

The economics of nuclear power are bleak

Advanced reactors promise enhanced safety but are also more expensive

Small modular reactors would have to be "mass-produced" to overcome "economy-of-scale" penalty

The next decade is critical

Not much new nuclear capacity will be added in the United States and Europe

Time to establish adequate technologies and new norms of governance