Nuclear Economics & Safety

A Review of the Evidence

April 2017

ENVIRONMENTAL PROGRESS

U.S. vs. France

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U.S. vs. France

Economic study of US and French reactor costs.

Best data.

Advanced economic methods

Lina Escobar Rangel

Michel Berthelemy

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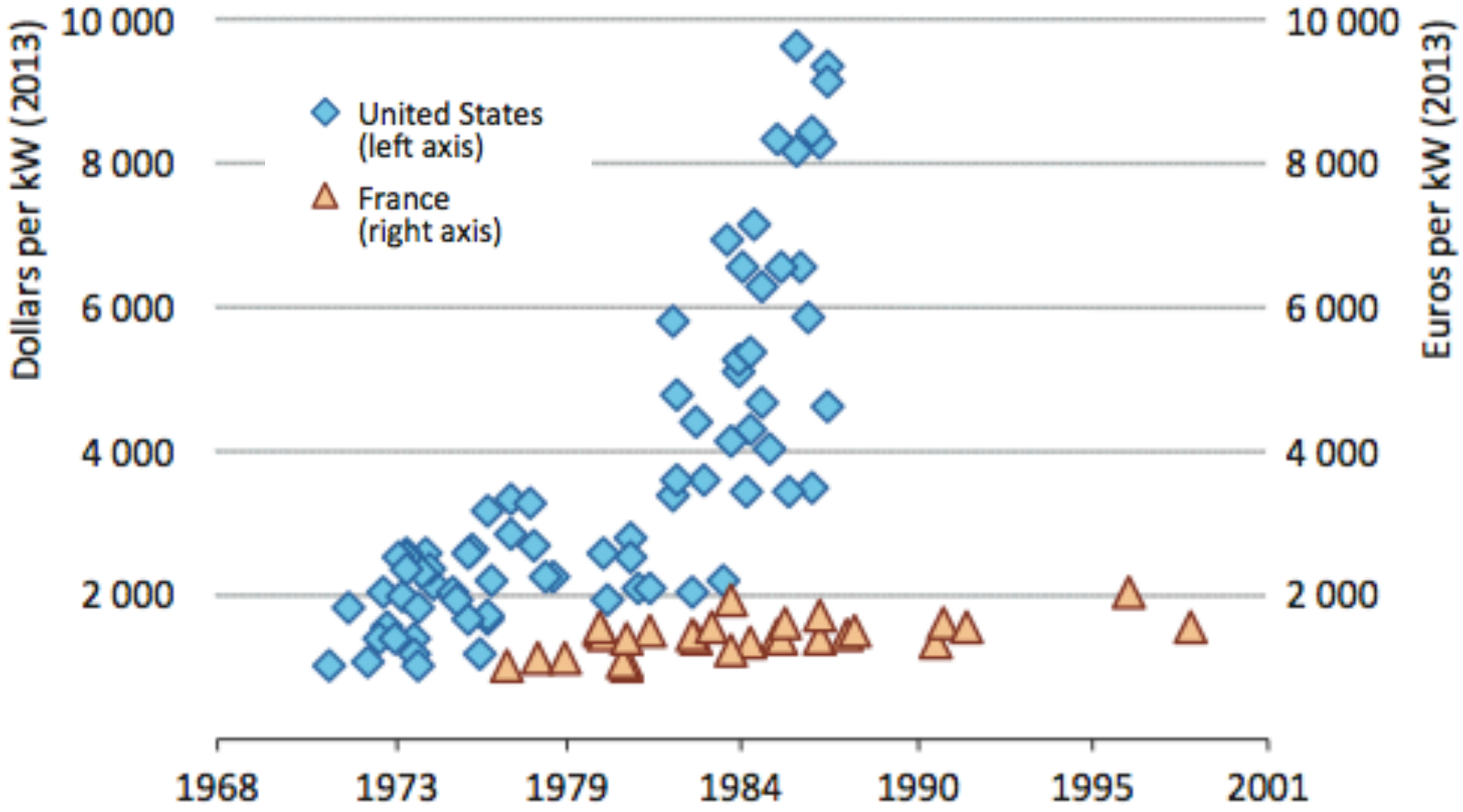
Source: Michel Berthelemy, Lina Escobar Rangel. “Nuclear reactors’ construction costs: The role of leadtime, standardization and technological progress.” *Energy Policy*, 2015



Note: Overnight costs are shown for the year in which plants came online.

Sources: Cour des Comptes (2012), US CBO (2008) and US DOE/EIA (1986).

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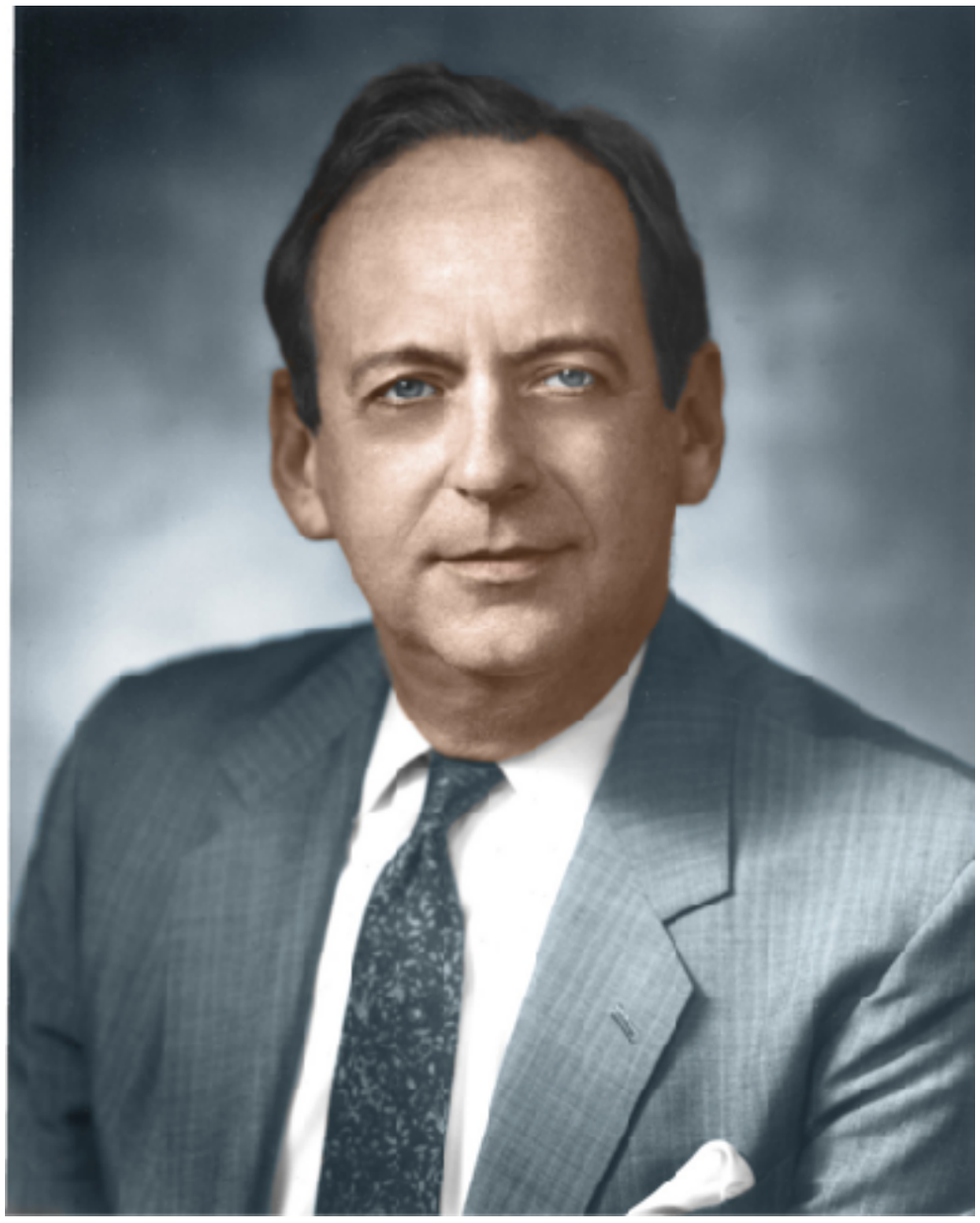

Ivan Selin, former NRC Commissioner

"The French have two kinds of reactors and hundreds of kinds of cheese, whereas in the United States the figures are reversed."

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Source: Washington Post, May 29, 1995

What lowers costs?

- Long-term commitment
- Standard design
- Centralization (Utility management of construction)
- Same Architect-Engineer.
- More reactors on same site.
- Larger reactors

Lina Escobar Rangel

Michel Berthelemy

ENVIRONMENTAL PROGRESS

Source: Michel Berthelemy, Lina Escobar Rangel. “Nuclear reactors’ construction costs: The role of leadtime, standardization and technological progress.” *Energy Policy*, 2015

Centralization reduces costs

"A vertically integrated utility reduces potential asymmetric information problems between the utility and the firms involved in the construction of nuclear reactors, leading to cost reductions."

Lina Escobar Rangel

Michel Berthelemy

ENVIRONMENTAL PROGRESS

Source: Michel Berthelemy, Lina Escobar Rangel. "Nuclear reactors' construction costs: The role of leadtime, standardization and technological progress." *Energy Policy*, 2015

Diverse Designs Increases Costs

"When the diversity of nuclear reactors is high, the nuclear safety authority has to assess the potential risks of different models of reactors which prevents rapid monitoring and licensing procedures, due to the heterogeneity in demand which could lead to supply chain constraints and construction delays."

Lina Escobar Rangel

Michel Berthelemy

ENVIRONMENTAL PROGRESS

Source: Michel Berthelemy, Lina Escobar Rangel. "Nuclear reactors' construction costs: The role of leadtime, standardization and technological progress." *Energy Policy*, 2015

Innovation Increases Costs

"Contrary to other energy technologies, innovation leads to construction costs increases."

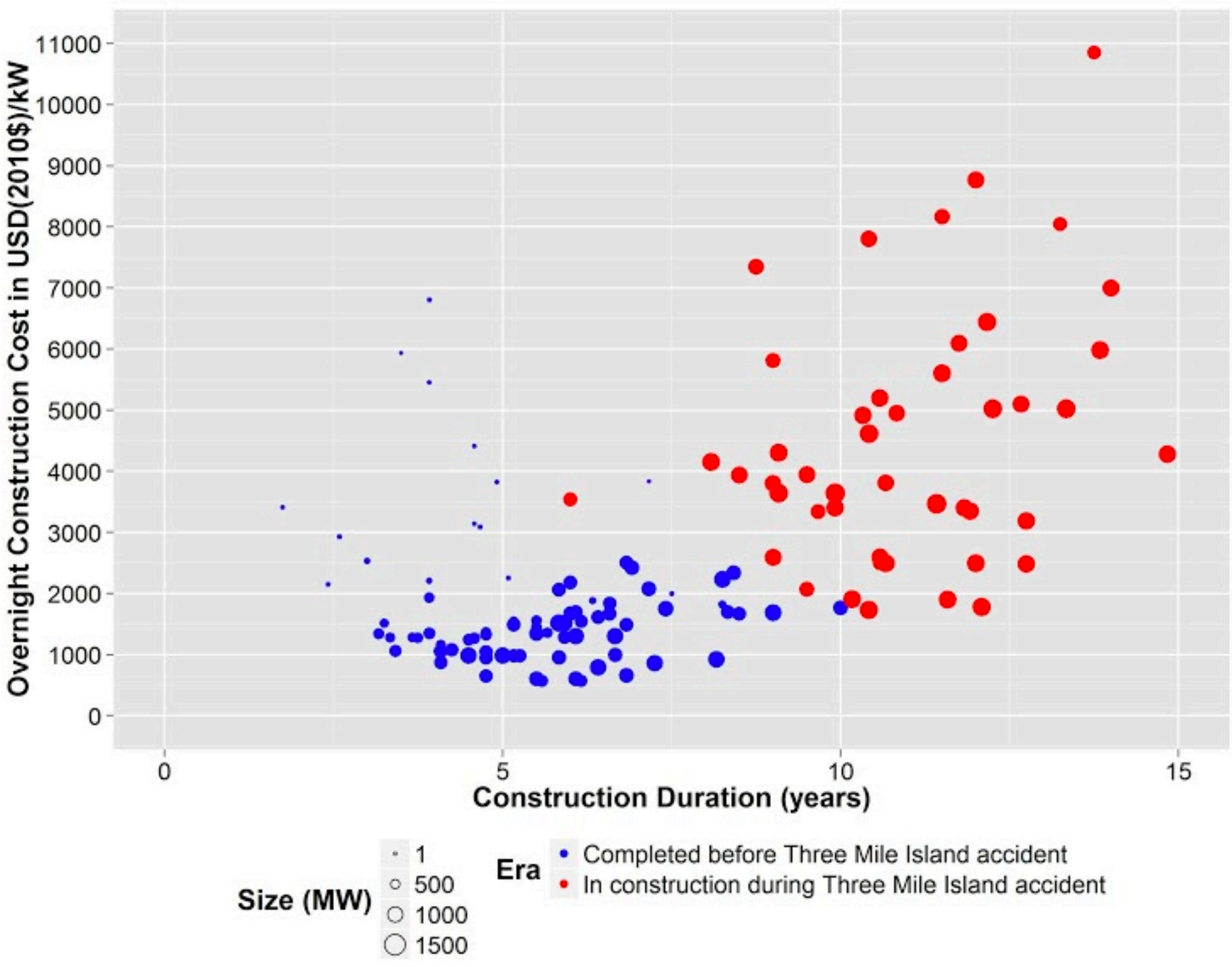
Lina Escobar Rangel

Michel Berthelemy

ENVIRONMENTAL PROGRESS

Source: Michel Berthelemy, Lina Escobar Rangel. "Nuclear reactors' construction costs: The role of leadtime, standardization and technological progress." *Energy Policy*, 2015

Construction delays after TMI



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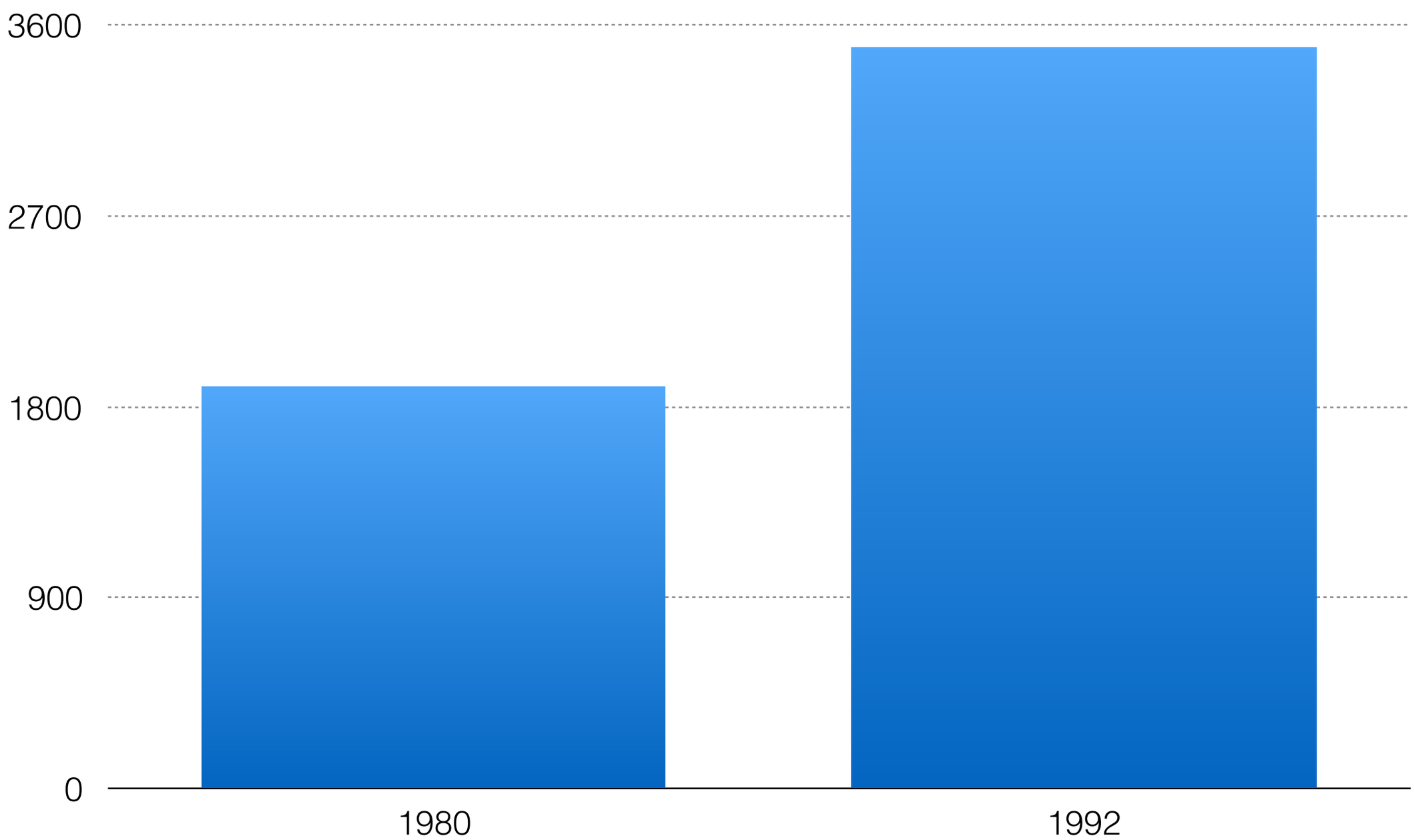
Regulations increased dramatically in 12 Year Period



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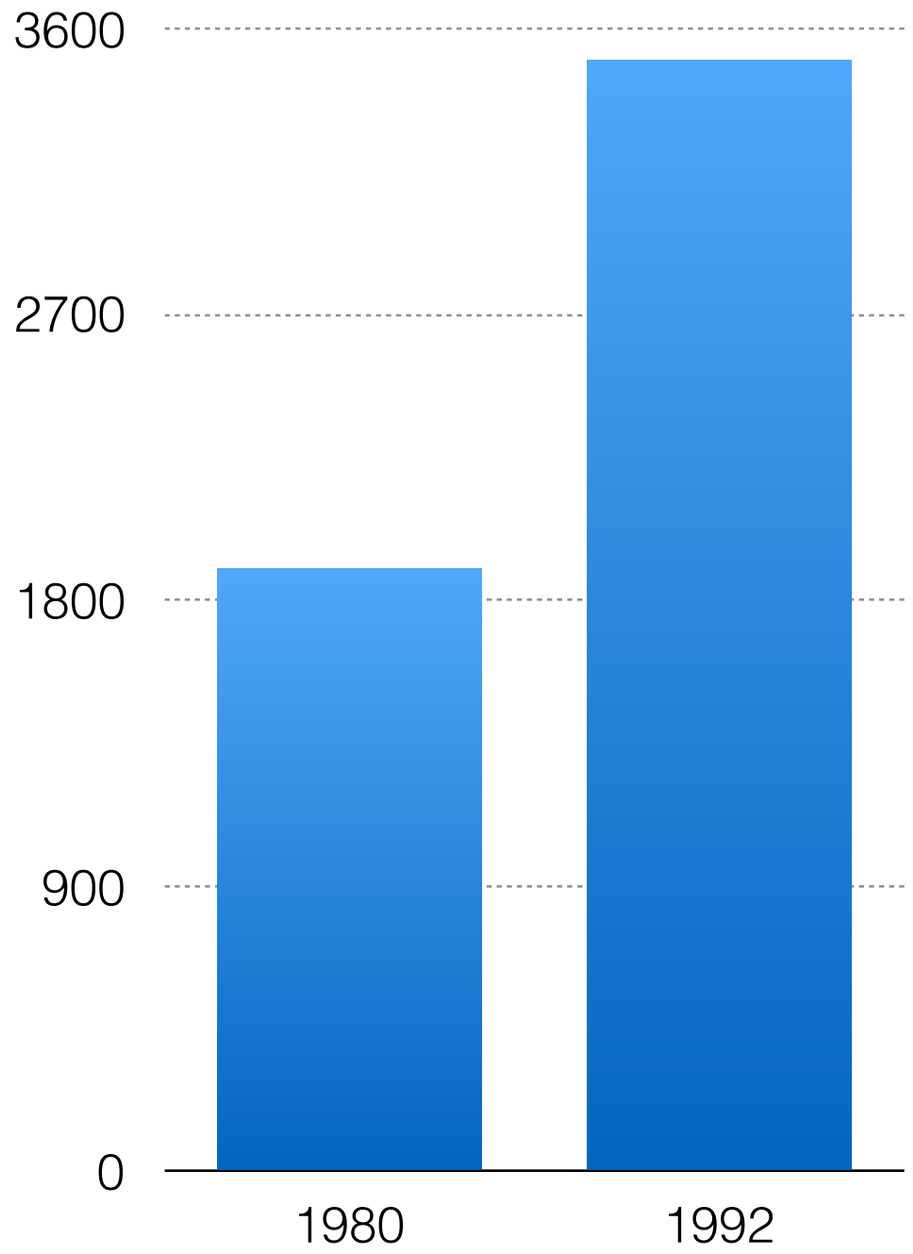
Source: EIA, Operating Costs of Nuclear Power Plants in the U.S., 1994

New regulations & delays behind higher costs

- "A one-year delay in the start of construction results in costs that are higher by 10.6 percent."
- "[T]here was an escalation in real construction costs that was independent of factors such as size and lead-times…attempts to control costs should also focus on the regulatory, and other non-pecuniary factors causing the escalation in overnight costs."



Source: EIA, Operating Costs of Nuclear Power Plants in the U.S., 1994

Source: Cantor & Hewlett, "Economics of Nuclear Power," Resources & Energy, 1988

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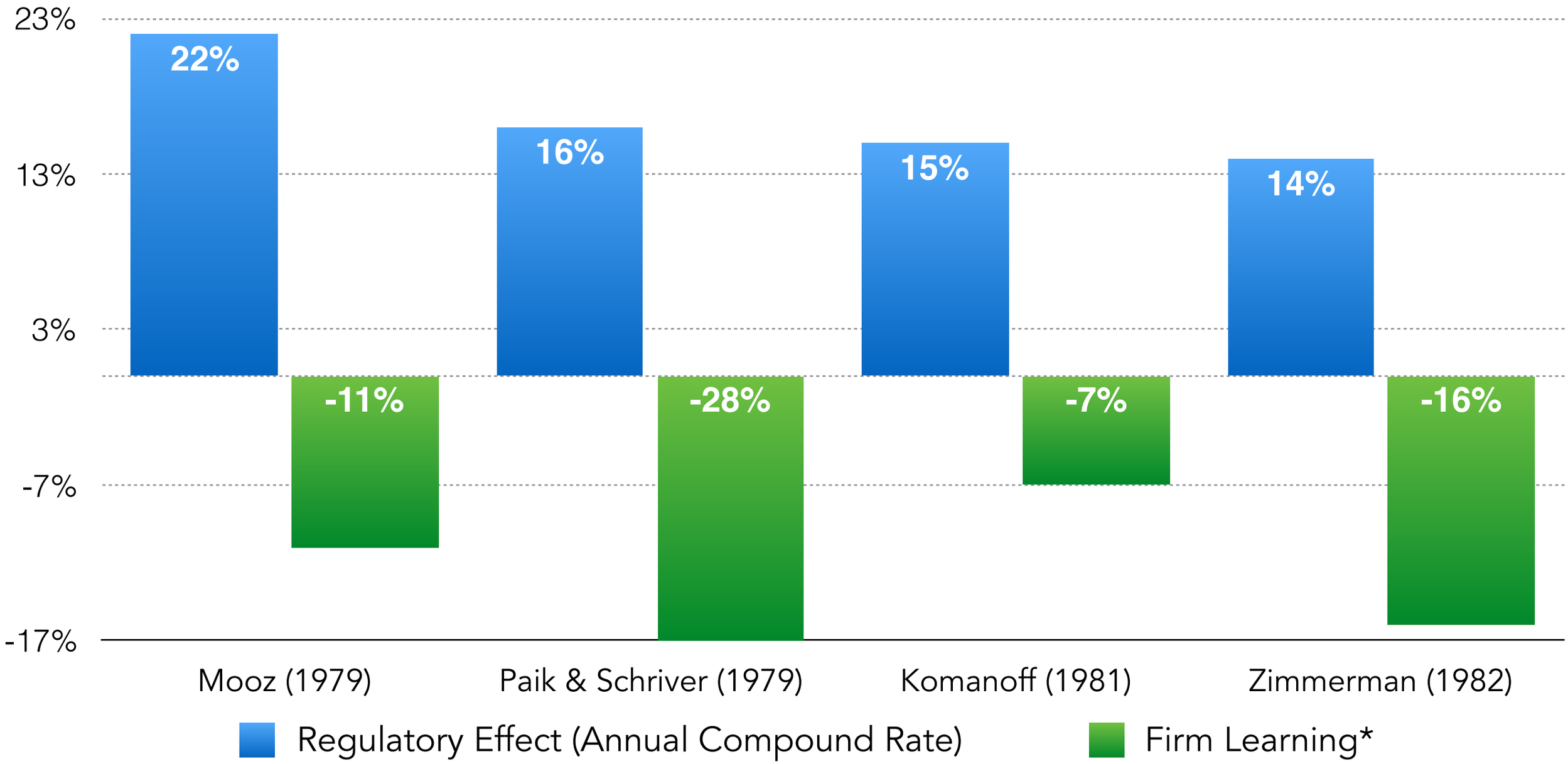
Construction experience *did* drive down costs — but was canceled out by new regulations.



*In all studies except Zimmerman, "firm learning" is a measure of the doubling of experience, either by constructor or architect-engineer. Zimmerman measured completion of first unit (-11.8%) and second unit (-4%)

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Source: Cantor & Hewlett, "Economics of Nuclear Power," Resources & Energy, 1988

Lessons from South Korea

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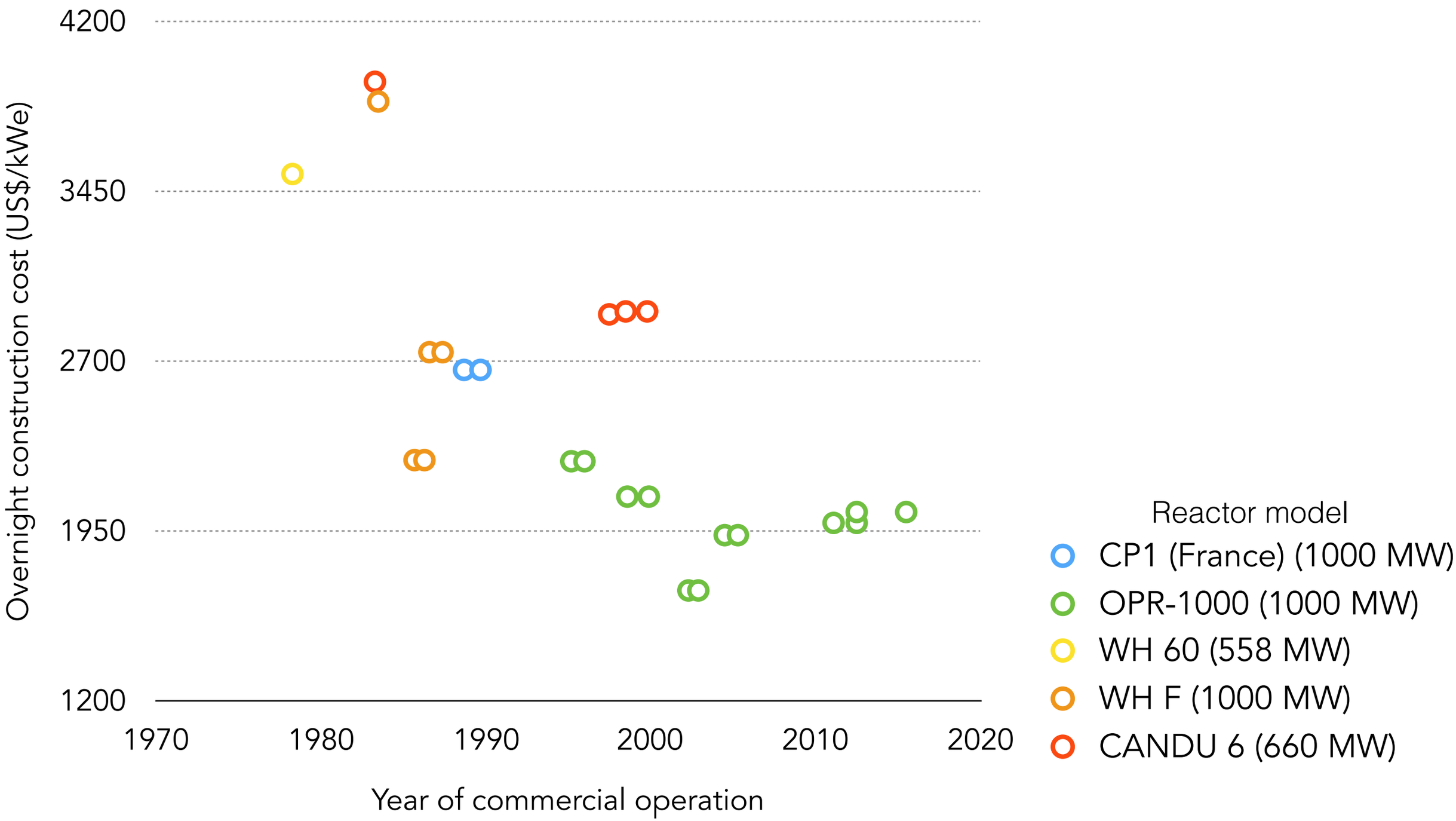
South Korea cost reduction over time



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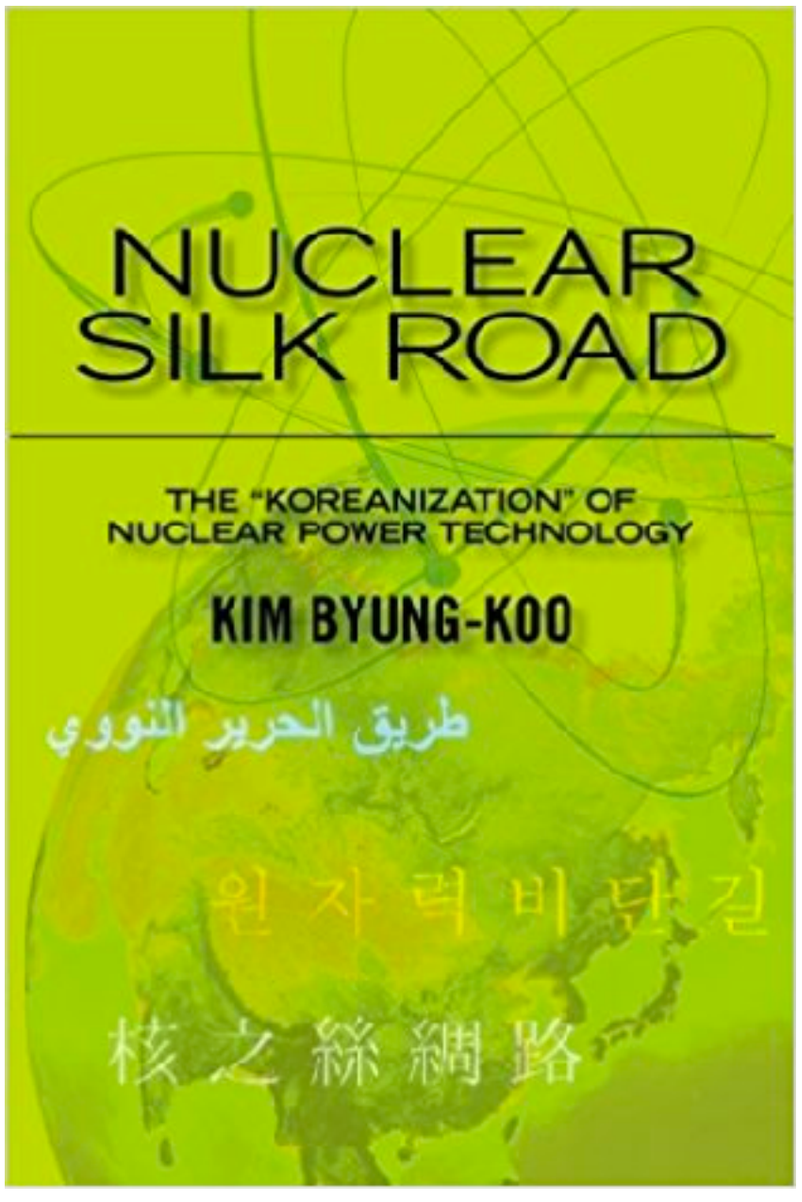
Source: EP Energy Progress Tracker, 2017. Email info@environmentalprogress.org for more information.



"Only when Koreans learned how to replicate and verify it properly after several repeat projects did the time arrive to move on to improving and enhancing the safety and economy without sacrificing the merits of standardization."

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Source: Kim Byung-Koo, *Nuclear Silk Road: The Koreanization of Nuclear Power Technology*, 2011

Will smaller be cheaper?

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"Larger nuclear reactors take longer to build but are also cheaper per MWe."

Lina Escobar Rangel

Michel Berthelemy

ENVIRONMENTAL PROGRESS

Source: Michel Berthelemy, Lina Escobar Rangel. "Nuclear reactors' construction costs: The role of leadtime, standardization and technological progress." *Energy Policy*, 2015

"One of the main factors negatively affecting the capital costs of the SMRs [Small Modular Reactors] is the lack of economy of scale.

As a result, the specific (per MWe) capital costs of the SMR are expected to be tens to hundreds of percent higher than for large reactors."

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Alexi Lokhov, Ron Cameron and Vladislav Sozoniuk, "OECD/NEA Study on the Economics and Market of Small Reactors," Nuclear Engineering and Technology, November 2013

"Since large initial orders SMRs are needed to launch production process it is important to know who could be the first customers, and how many SMR designs will really be deployed in the near future."

ENVIRONMENTAL PROGRESS

Alexi Lokhov, Ron Cameron and Vladislav Sozoniuk, "OECD/NEA Study on the Economics and Market of Small Reactors," Nuclear Engineering and Technology, November 2013

Waste

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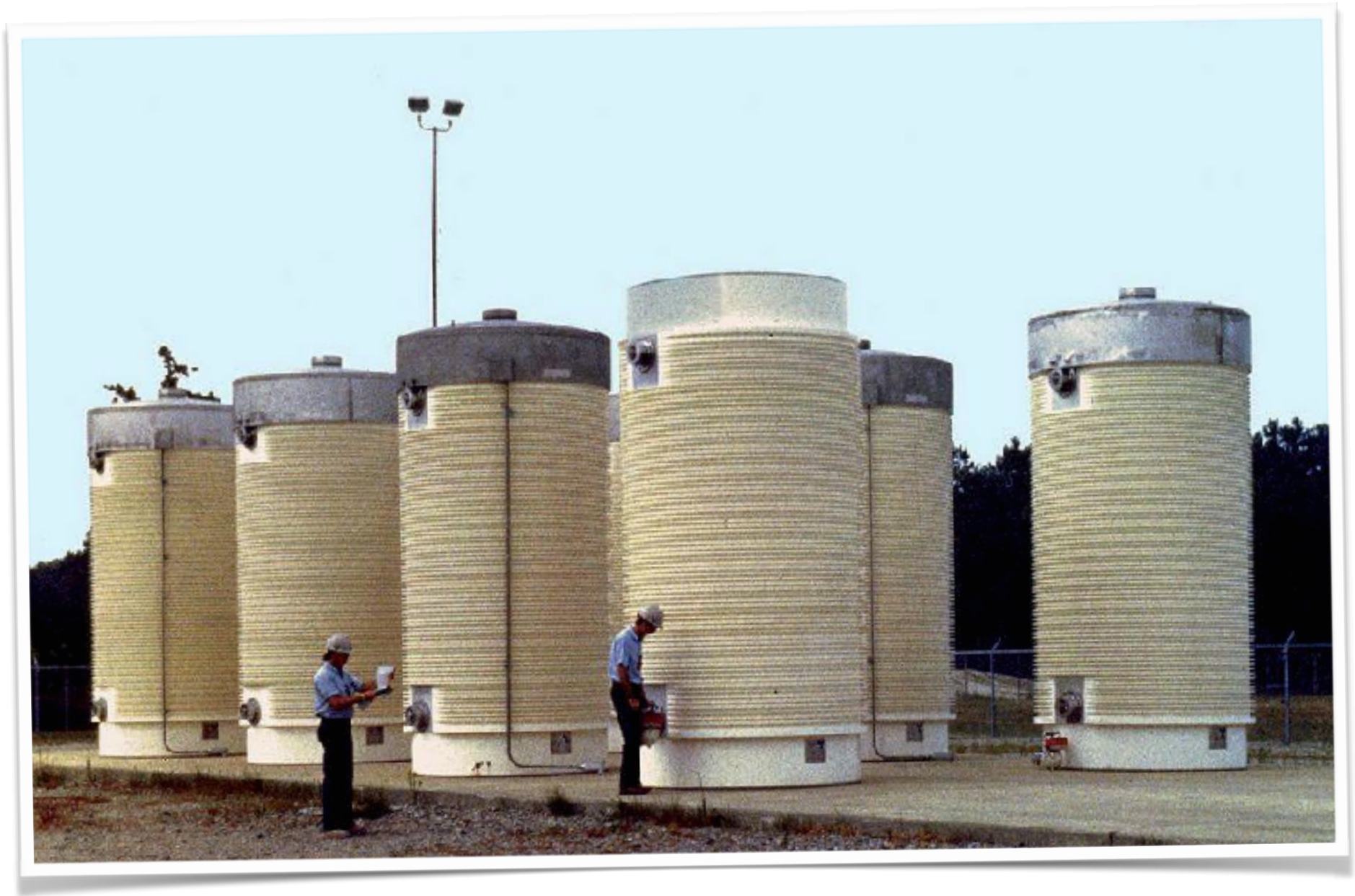
All US “waste” can be stacked 50 ft. high on football field



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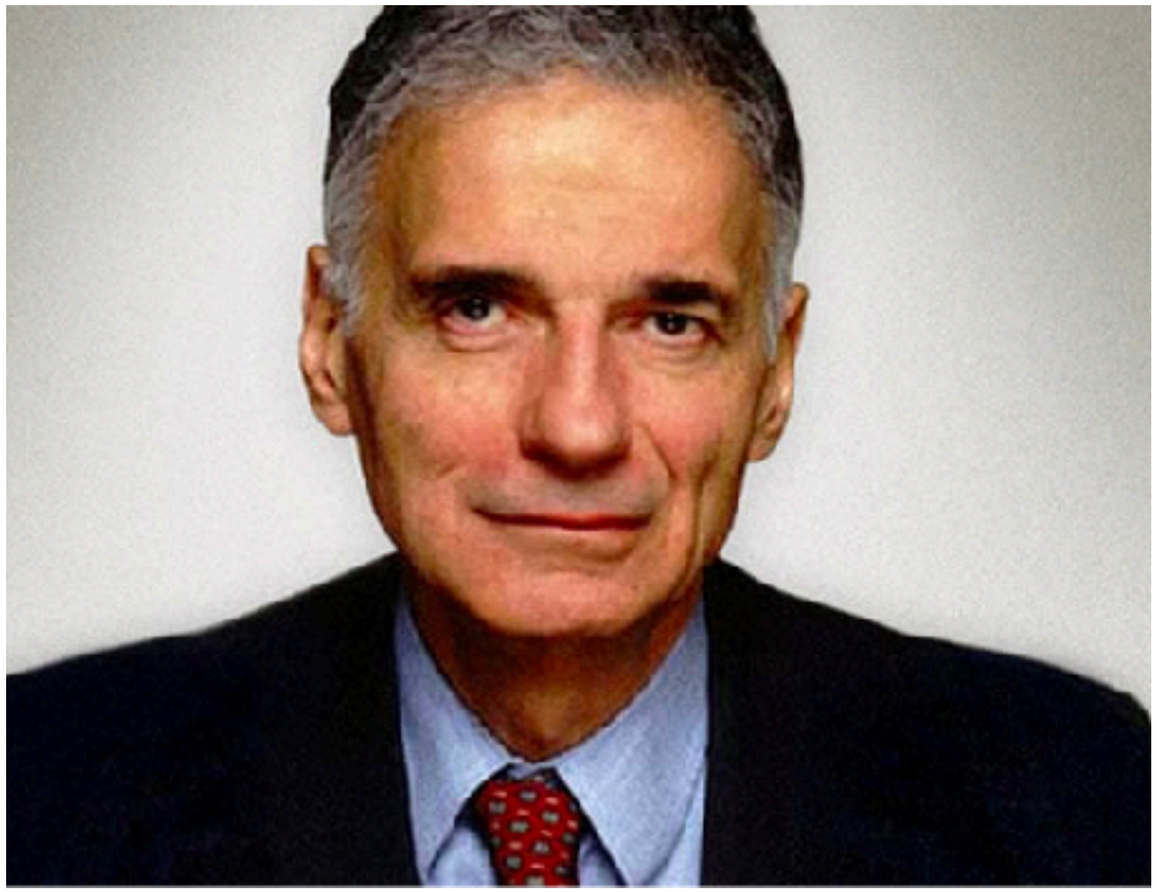

Q: You don't want [the nuclear waste] problem solved until the industry --

A: No, because it'll just try to prolong the industry, and expand the second generation of nuclear plants subsidized by the tax payer.

— Ralph Nader, 1997, PBS Frontline, “Nuclear Reaction”

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"[P]romising to increase the reactor's fuel efficiency by 75 times is the rough equivalent of saying that, in a single step, you'd developed a car that could get 2,500 miles per gallon."

"…overstated promises matter because they run the risk of further undermining those negative public perceptions you mention, and making investors more skeptical of the space."

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James Temple, "Nuclear Energy Startup Transatomic Backtracks on Key Promises,"
MIT Technology Review, February 24, 2017

Will newer designs allay public fears?

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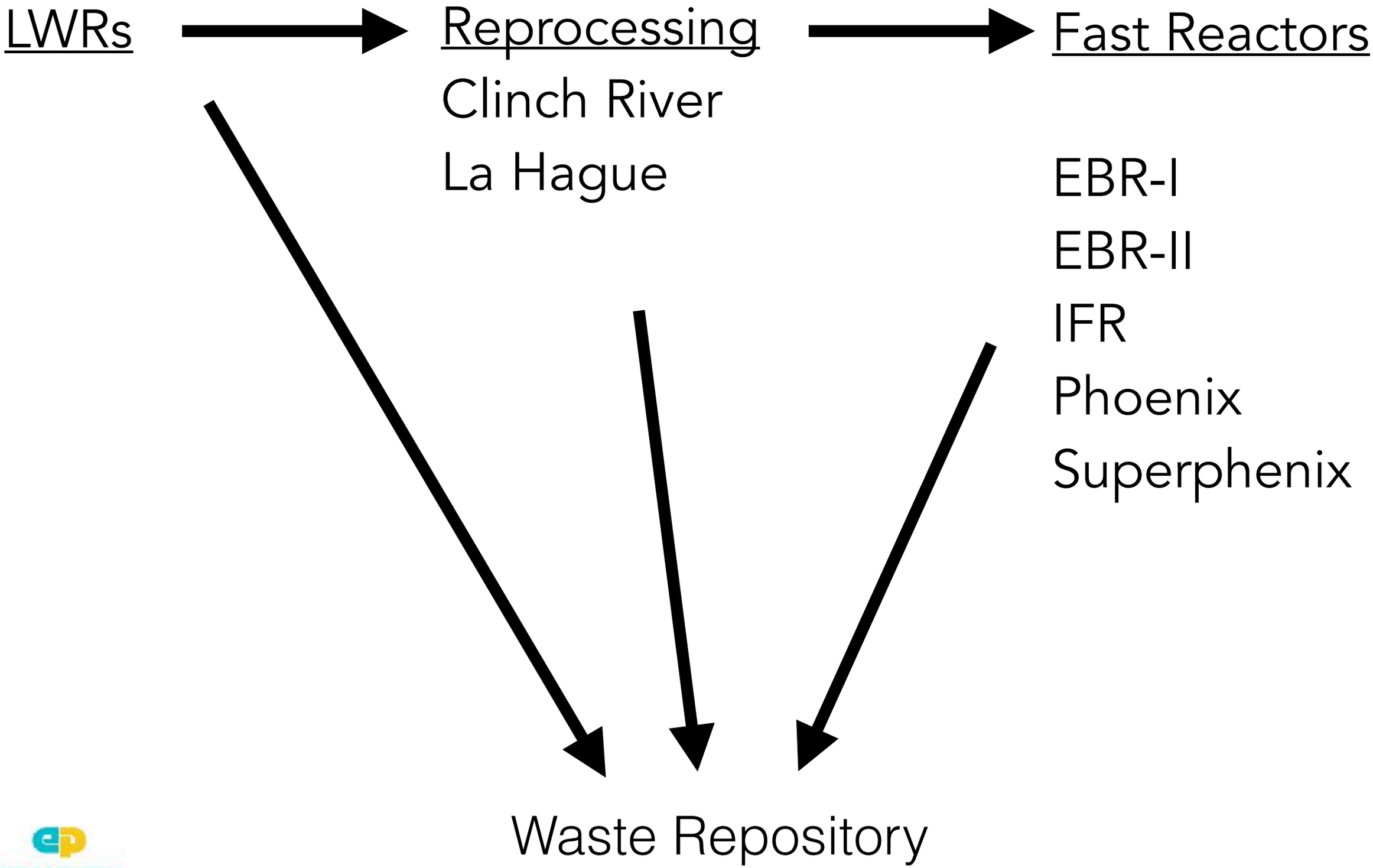
Advanced Nuclear Vision (1950s - 2000s)



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Advanced Nuclear Vision (1950s - 2000s)

LWRs → Reprocessing → Fast Reactors

Clinch River
La Hague

EBR-I+II —> IFR
Phenix —>
Superphenix

"hot particles"!

"can explode with their fast neutrons"!

Waste Repository

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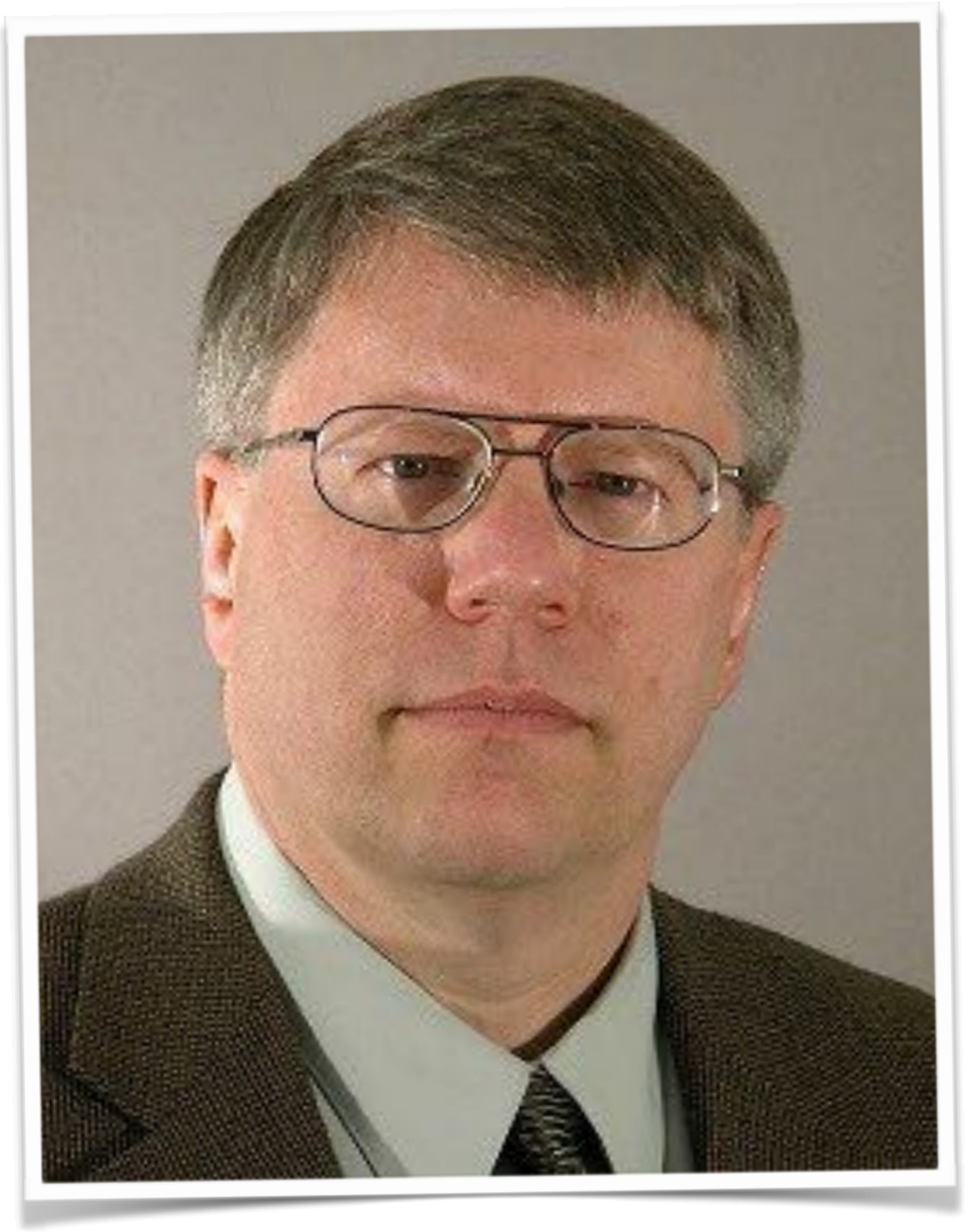

“Imagine the consequences from a fertilizer truck bomb detonated next to a “containment-lite” [molten-salt] reactor with millions of curies of lethal radioactivity to containment the environment for many decades. That would truly be a nuclear nightmare.” (2001)

“[The Liquid Flouride Molten Salt Reactor’s] serious safety issues associated with the retention of fission products in the fuel may not be resolved….LFTRs also present proliferation and terrorism risks… (2012)

— David Lochbaum, Union of Concerned Scientists, 2012

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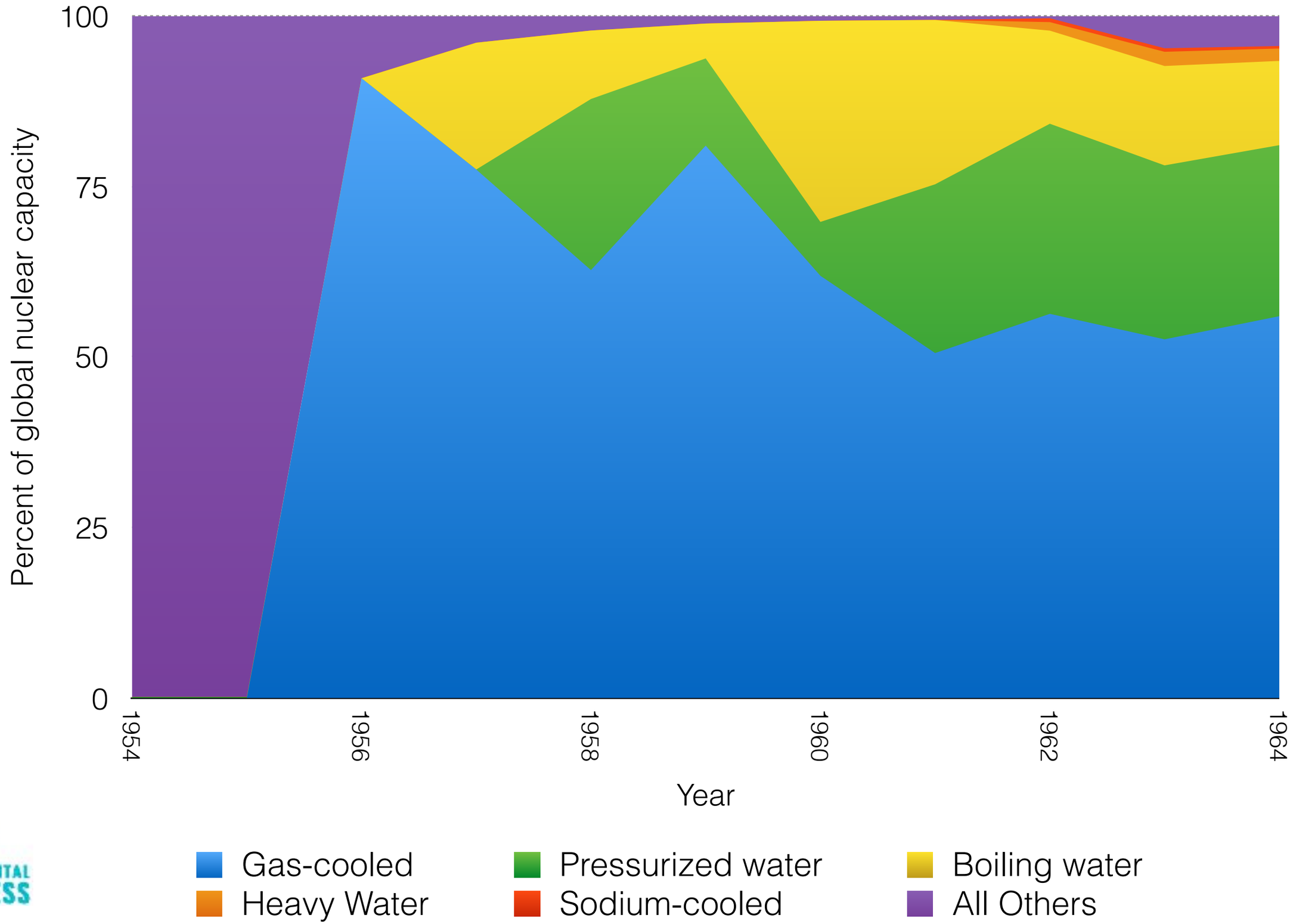
Today's water-cooled reactors were the underdogs…



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Sierra Club’s Mike Brune

NRDC’s Ralph Cavanagh

“This [nuclear innovation] amendment expends taxpayer resources to expand the already heavily subsidized nuclear industry's research arm in clearly uneconomic areas despite its demonstrated risks.

— NRDC, Sierra Club, Earthjustice, Environment America, League of Conservation Voters, Public Citizen, Jan 27, 2016

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Will non-light water designs be cheaper?

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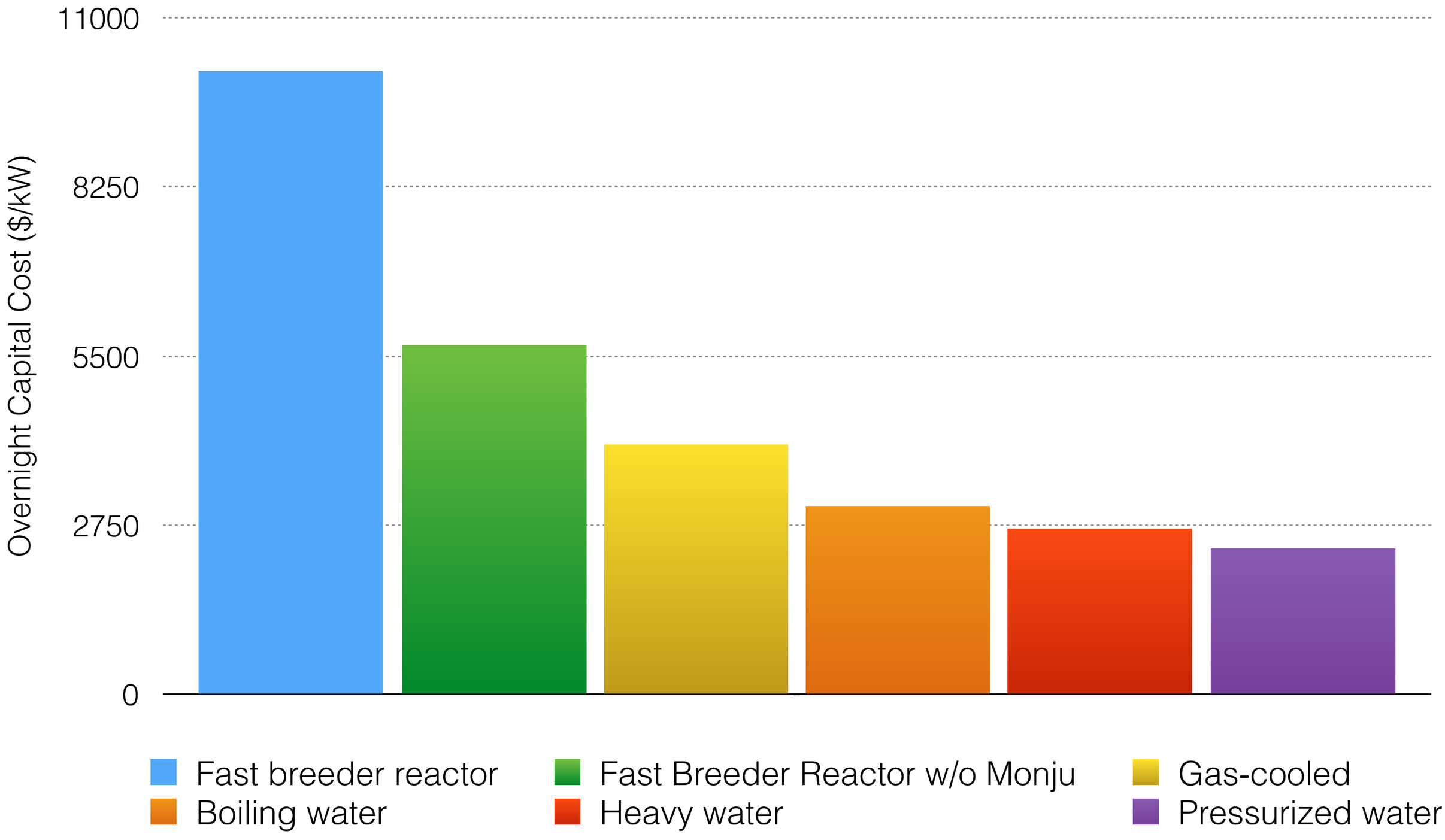
Cost of nuclear by reactor type



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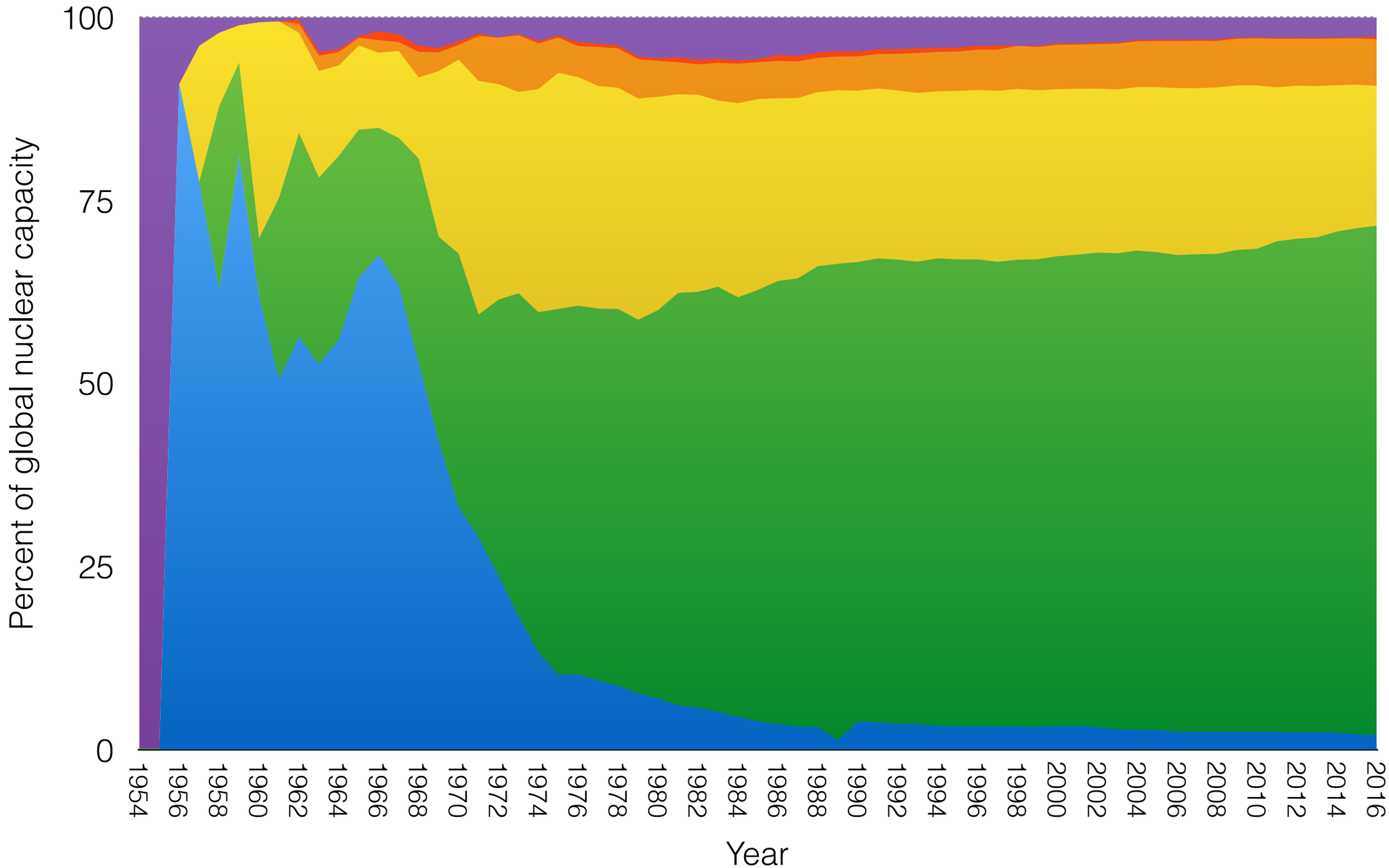
Source: Lovering, J. R., Yip, A., & Nordhaus, T. 2016. Historical construction costs of global nuclear power reactors. *Energy Policy*, *91*, 371-382. Accessed March 7, 2017. http://www.sciencedirect.com/science/article/pii/S0301421516300106

…that came from behind



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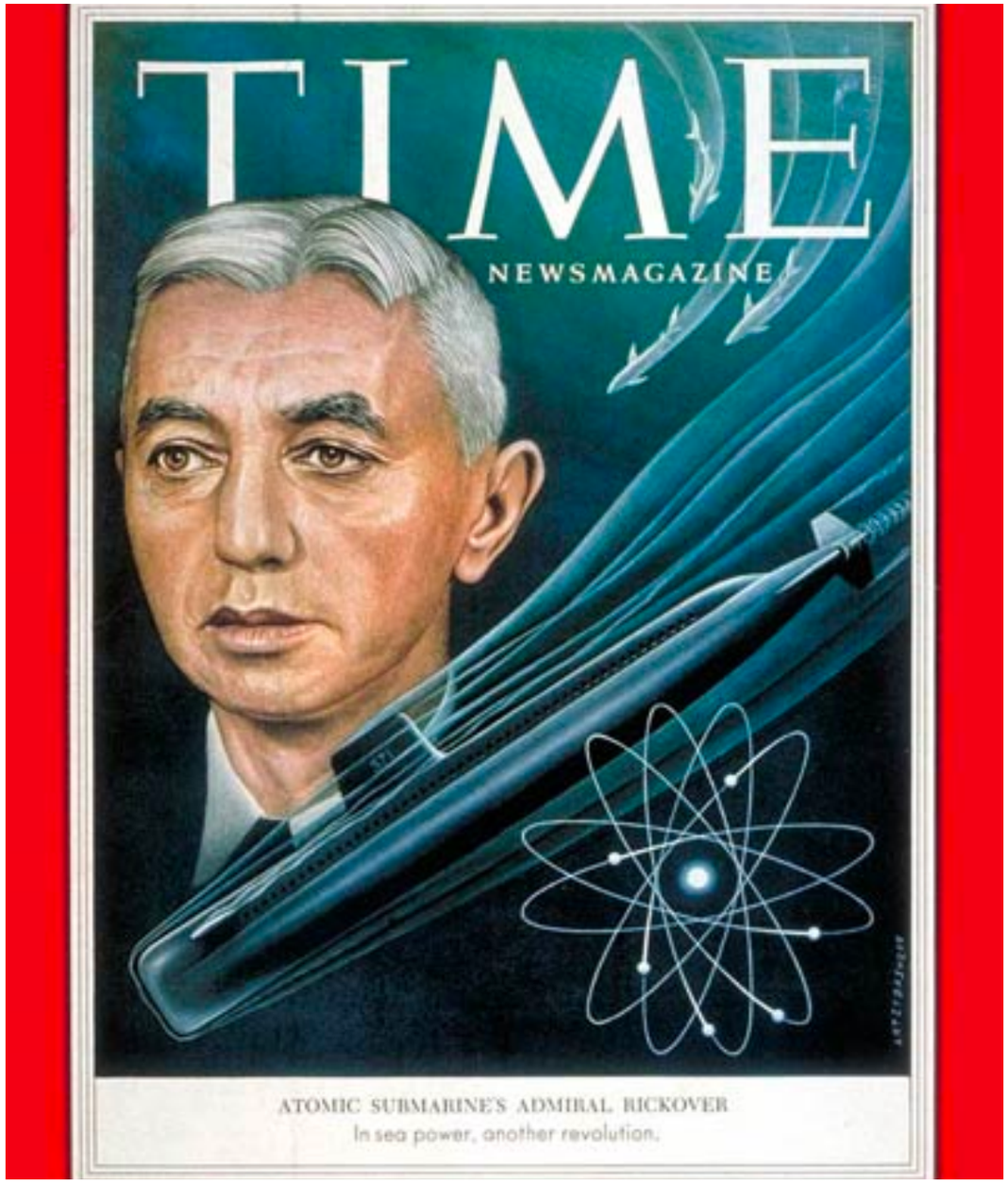
Why light water won

- British and French preferred gas-cooled and resisted light-water throughout 50s and 60s.
- Germans and French utility EdF wanted to benefit from American operational experience.
- EdF pushed for LWR after DeGaulle died.
- Soviets independently chose light water
- South Koreans independently chose light water
- Brits paid heavy price for sticking with gas-cooled designs



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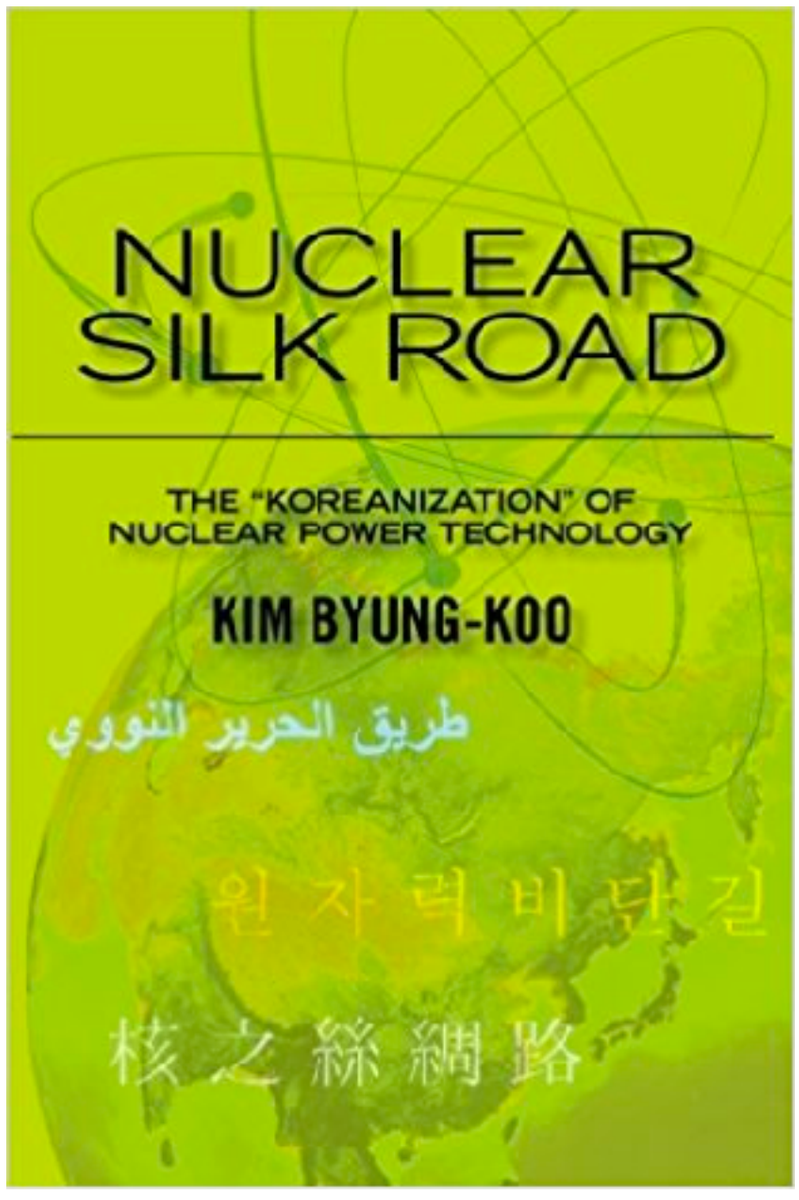

"Three different types of power reactors… were about equally successful commercially in the world market and the Korean nuclear community was split… a technical feasibility study report… recommended the US reactor types (preferably PWR) over the British one for the technical merits and reactor design characteristics."

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Source: Michel Berthelemy, Lina Escobar Rangel. "Nuclear reactors' construction costs: The role of leadtime, standardization and technological progress." *Energy Policy*, 2015

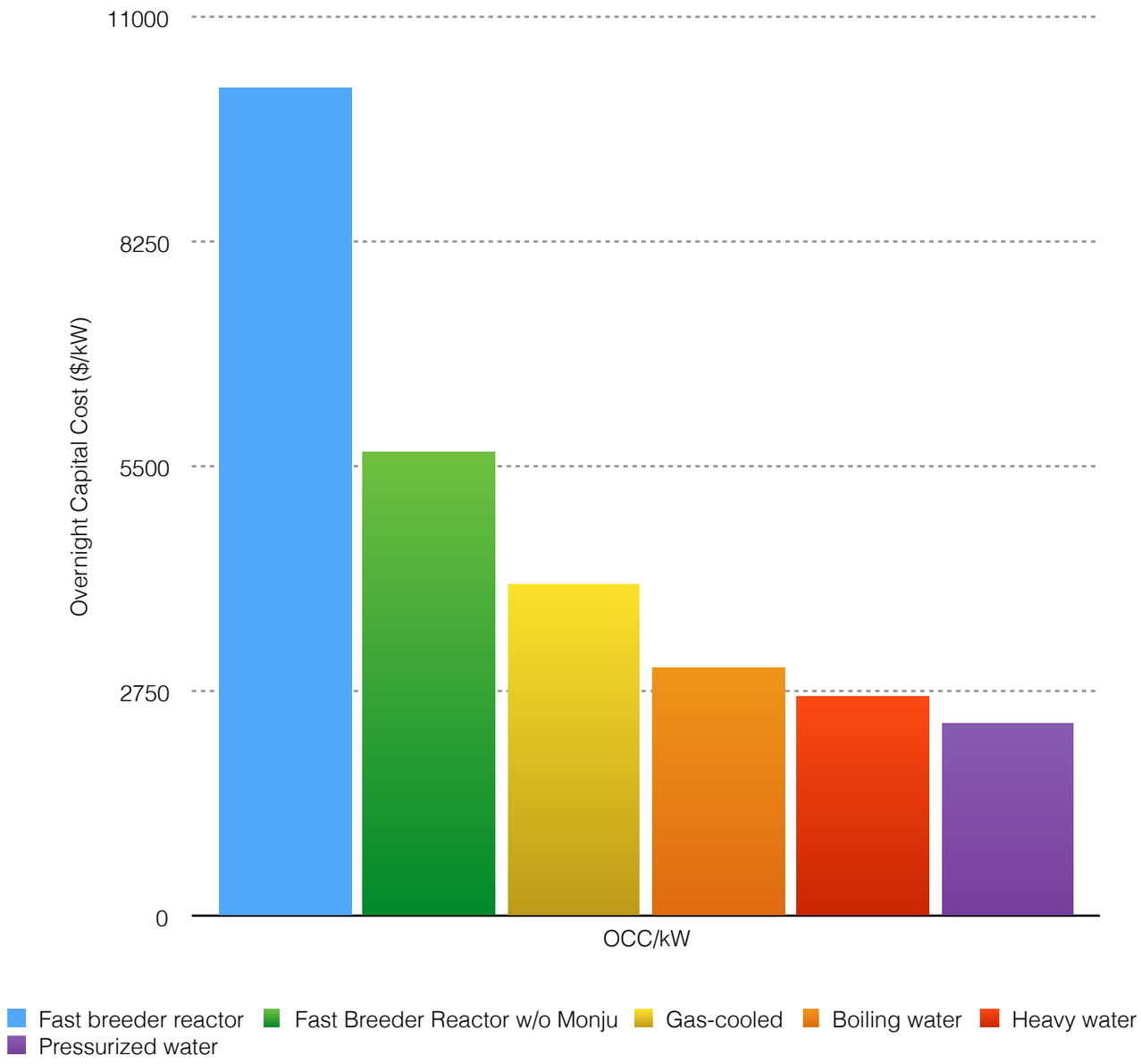
Other reactor designs

Gas-cooled & sodium-cooled fast reactors proved complicated & more expensive than water-cooled.

Sodium-cooled developed at same time as light water and was used in submarine.

Heavy-water makes proliferation easier and was chosen by India and South Korea for that purpose.

US Atomic Energy Commission in 1972 said cost of building molten salt demonstration reactor would be $10-20 billion (2016 dollars)



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What makes nuclear safe and cheap?

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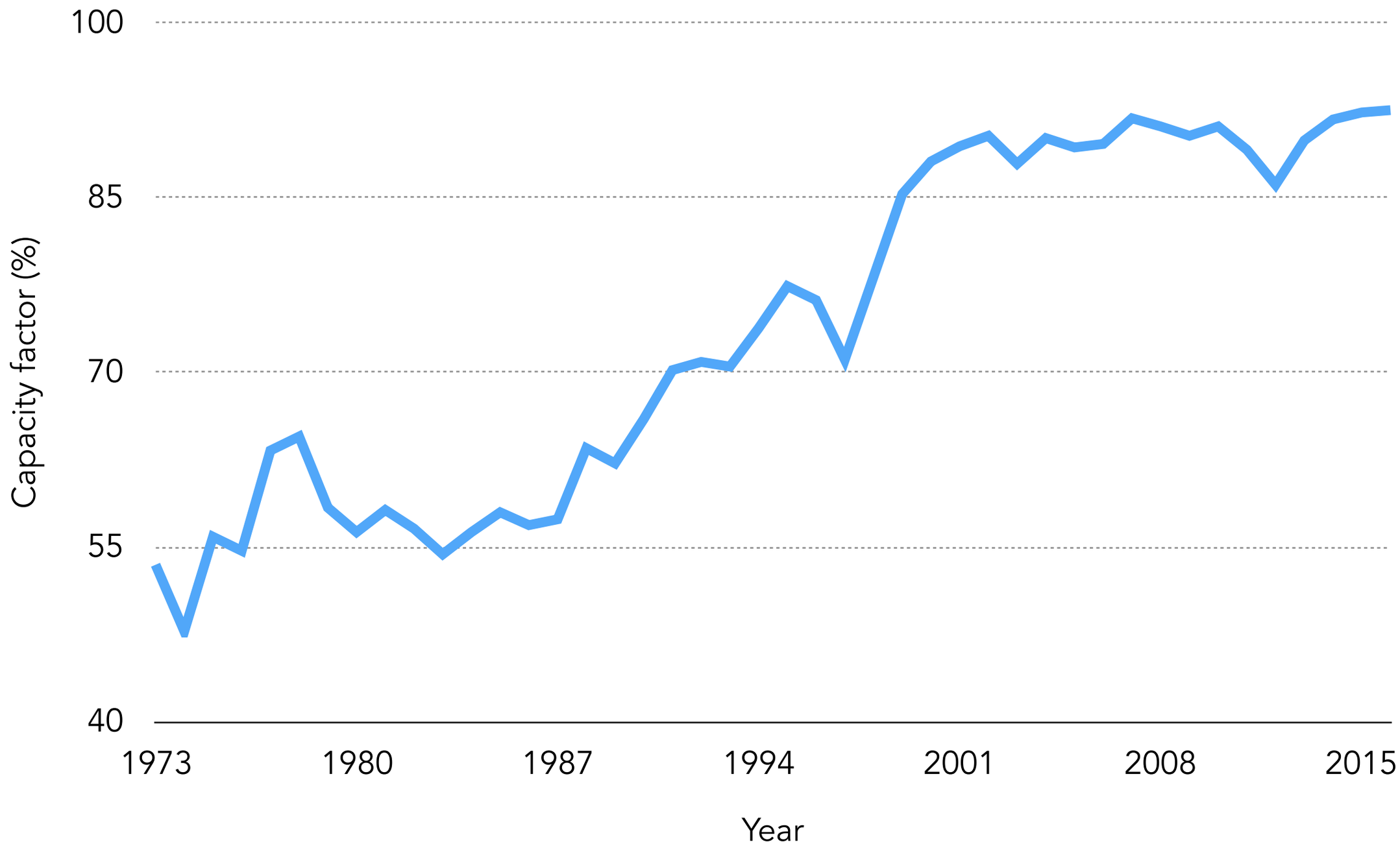
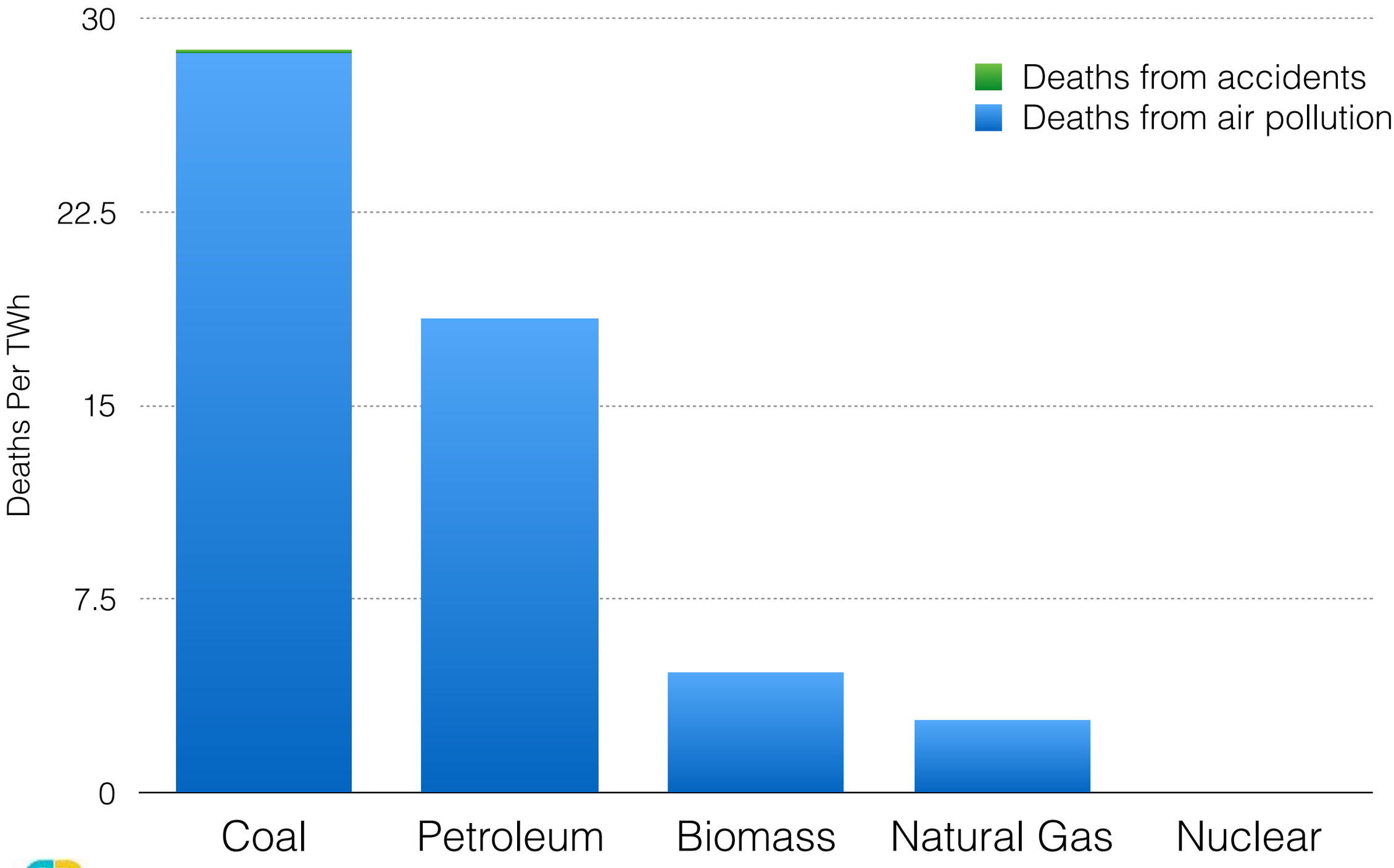
Improved efficiency of U.S. nuclear plants



Source: U.S. Energy Information Administration (EIA). 2017. Monthly Energy Review. https://www.eia.gov/totalenergy/data/monthly/#nuclear.

Can nuclear get any safer?



Health effects of electricity generation in Europe by primary energy source

Source: Markandya, A. & Wilkinson, Electricity generation and health. Lancet 2007; 370:970-90

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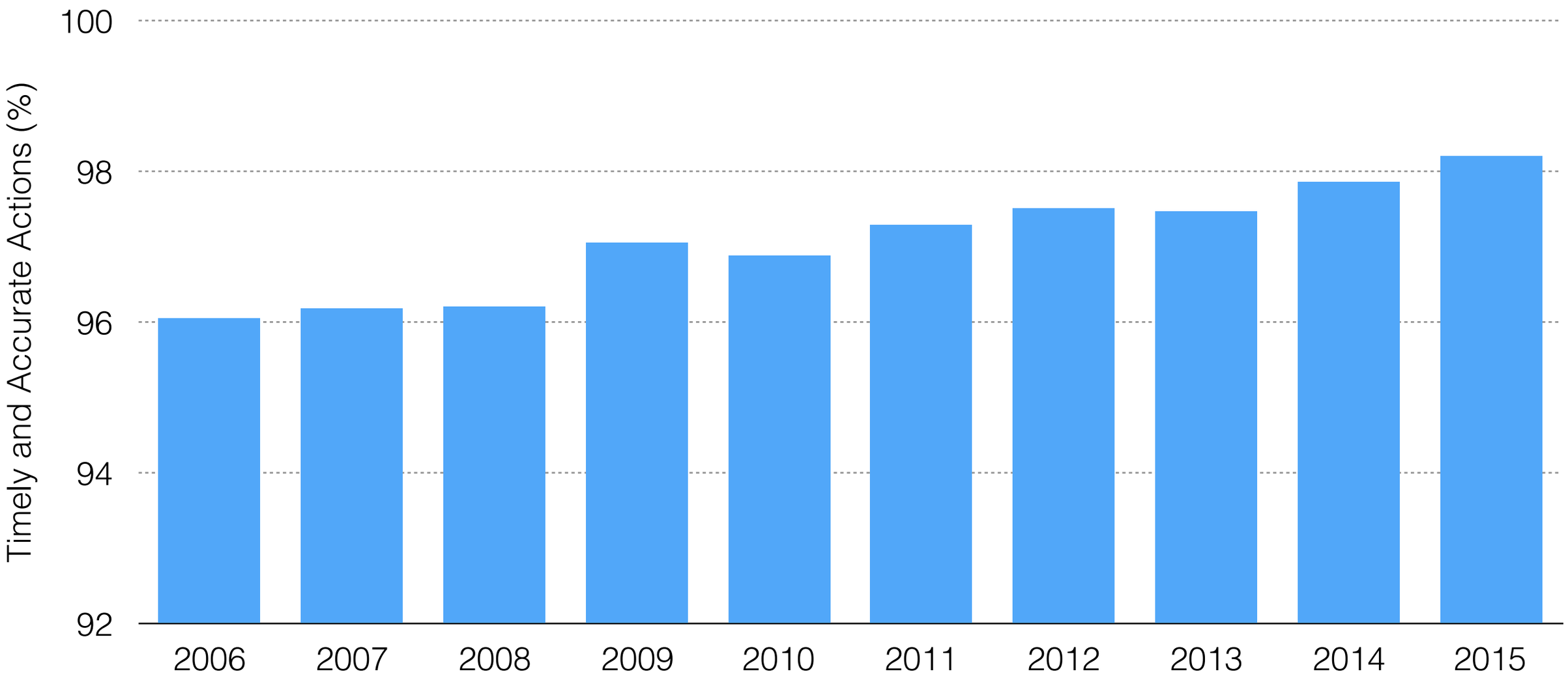
Operator Performance Very High and Still Rising



Timely and accurate actions taken by plant personnel (emergency classifications, protective action recommendations, and notifications to offsite authorities) in drills and actual events.

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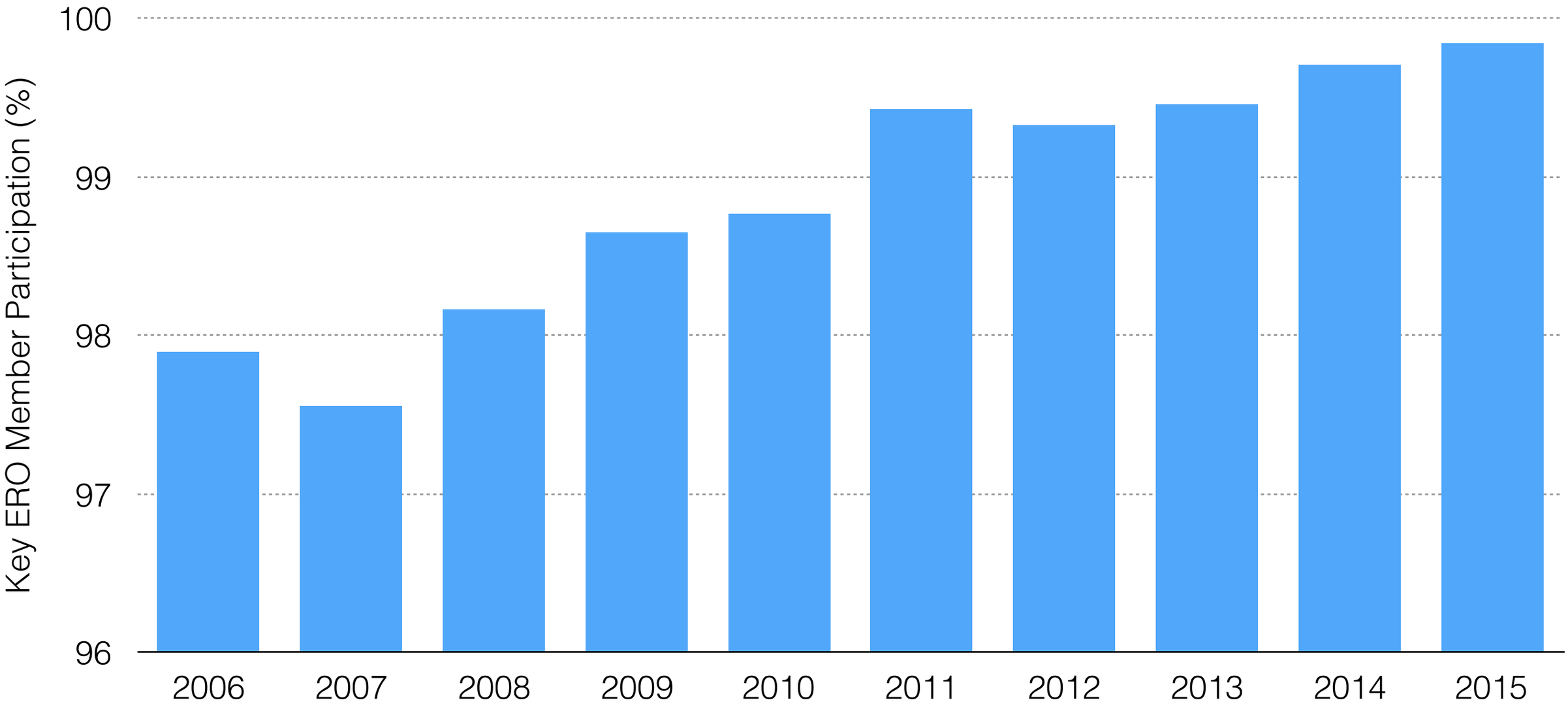
Source: U.S. Nuclear Regulatory Commission (NRC). 2016. Information Digest 2016-2017. NUREG-1350, Volume 28. Accessed March 6, 2017. https://www.nrc.gov/docs/ML1624/ML16243A018.pdf.

Plant workforce participation in key events is high & rising



This indicator is the percentage of participation by key plant personnel in drills or actual events in the previous 2 years, indicating proficiency and readiness to respond to emergencies.

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Source: U.S. Nuclear Regulatory Commission (NRC). 2016. Information Digest 2016-2017. NUREG-1350, Volume 28. Accessed March 6, 2017. https://www.nrc.gov/docs/ML1624/ML16243A018.pdf.

Heather Matteson

Mother, Environmentalist, Reactor Operator

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Kristin Zaitz

"Me inspecting Diablo Canyon containment dome. It is in pristine condition."

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Me: What do you think of Diablo Canyon?

Woody: It's a great plant.

Me. What makes you say that?

Woody: Because the people who work there care!

Woody Epstein, Nuclear Risk Analyst

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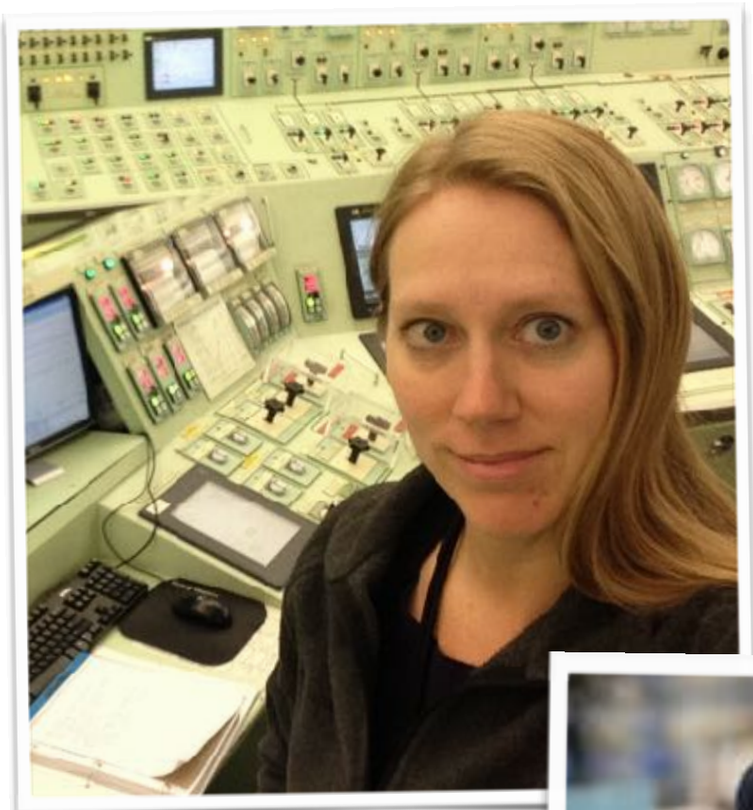
~~What~~ Who makes nuclear safe



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Rickover's Wisdom

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"An academic reactor or reactor plant almost always has the following basic characteristics: (1) It is simple. (2) It is small. (3) It is cheap. (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose. (7) Very little development will be required. It will use off-the-shelf components. (8) The reactor is in the study phase. It is not being built now.

"On the other hand a practical reactor can be distinguished by the following characteristics: (1) It is being built now. (2) It is behind schedule. (3) It requires an immense amount of development on apparently trivial items. (4) It is very expensive. (5) It takes a long time to build because of its engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated."

— Hyman Rickover, 1953

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