

# Can Nuclear Power and Small Modular Reactors help Mitigate Climate Change?

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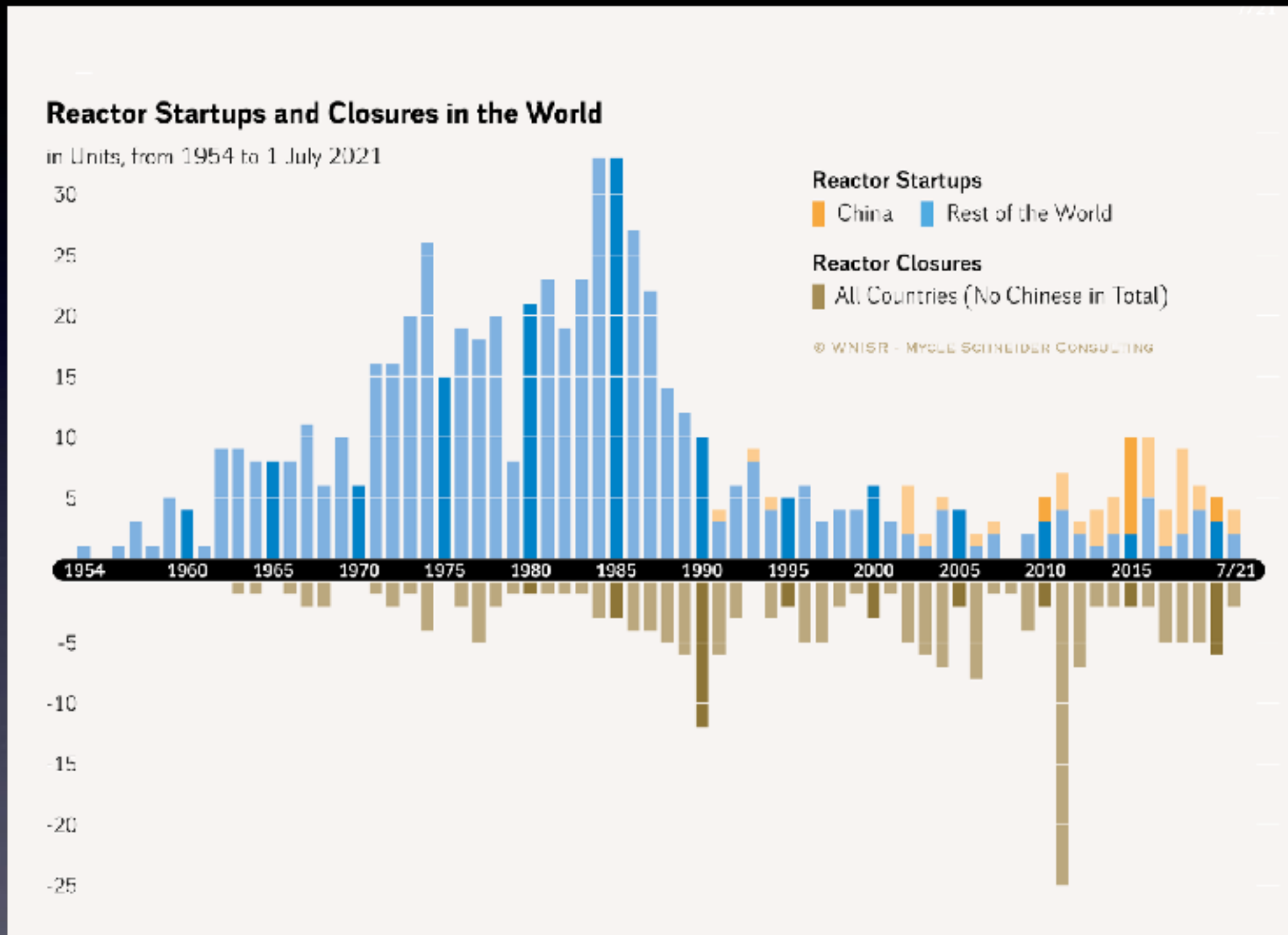
Webinar hosted by  
Institute for Essential Services Reform, Jakarta  
March 2022



# Nuclear energy today

Source: [https://media.farsnews.ir/Uploaded/Files/Images/1400/12/16/14001216000113\\_Test\\_PhotoN.jpg](https://media.farsnews.ir/Uploaded/Files/Images/1400/12/16/14001216000113_Test_PhotoN.jpg)

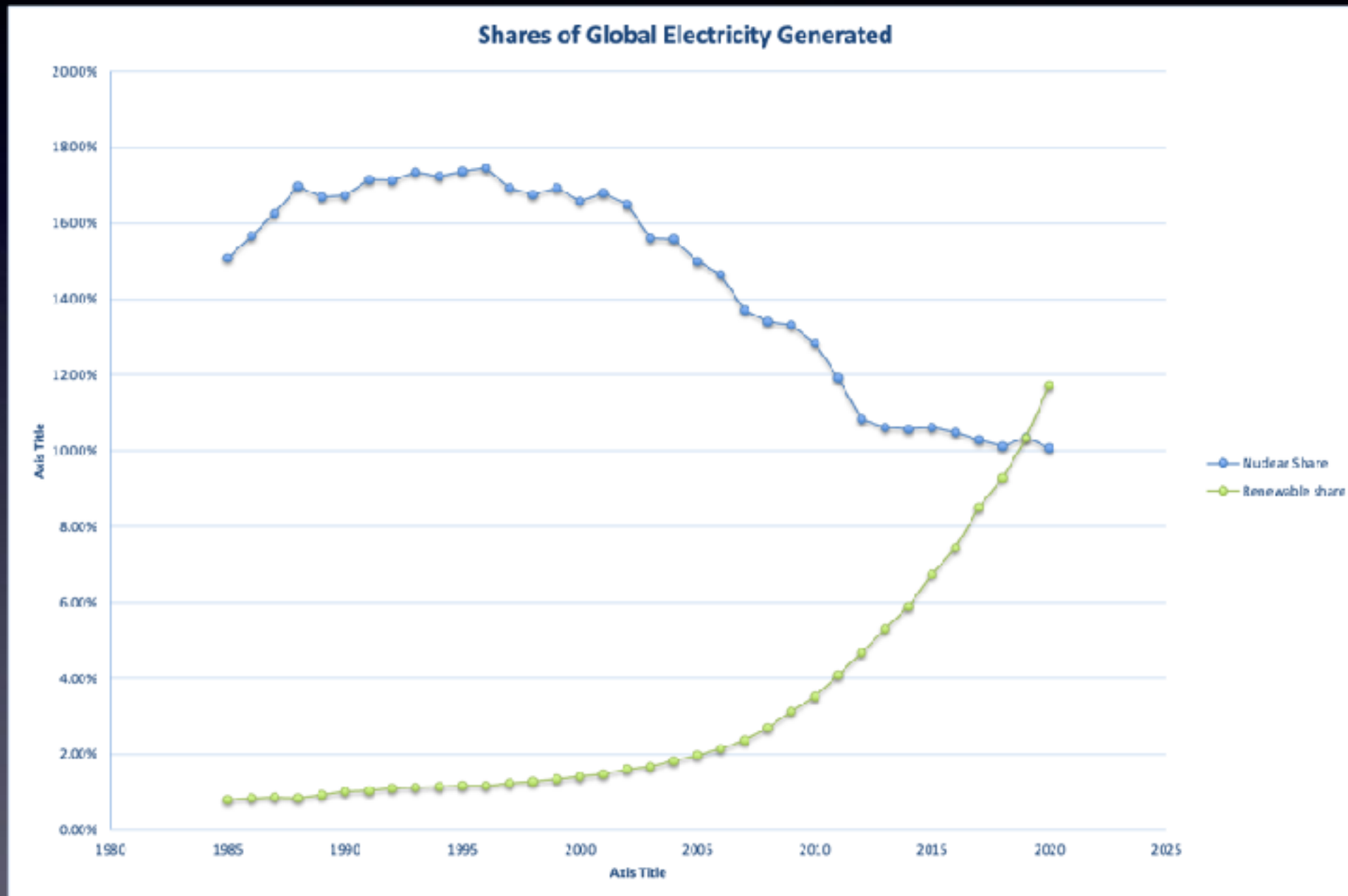
# The best days of nuclear construction are over three decades ago



Source: World Nuclear Industry Status Report, 2021, Mycle Schneider Consulting.

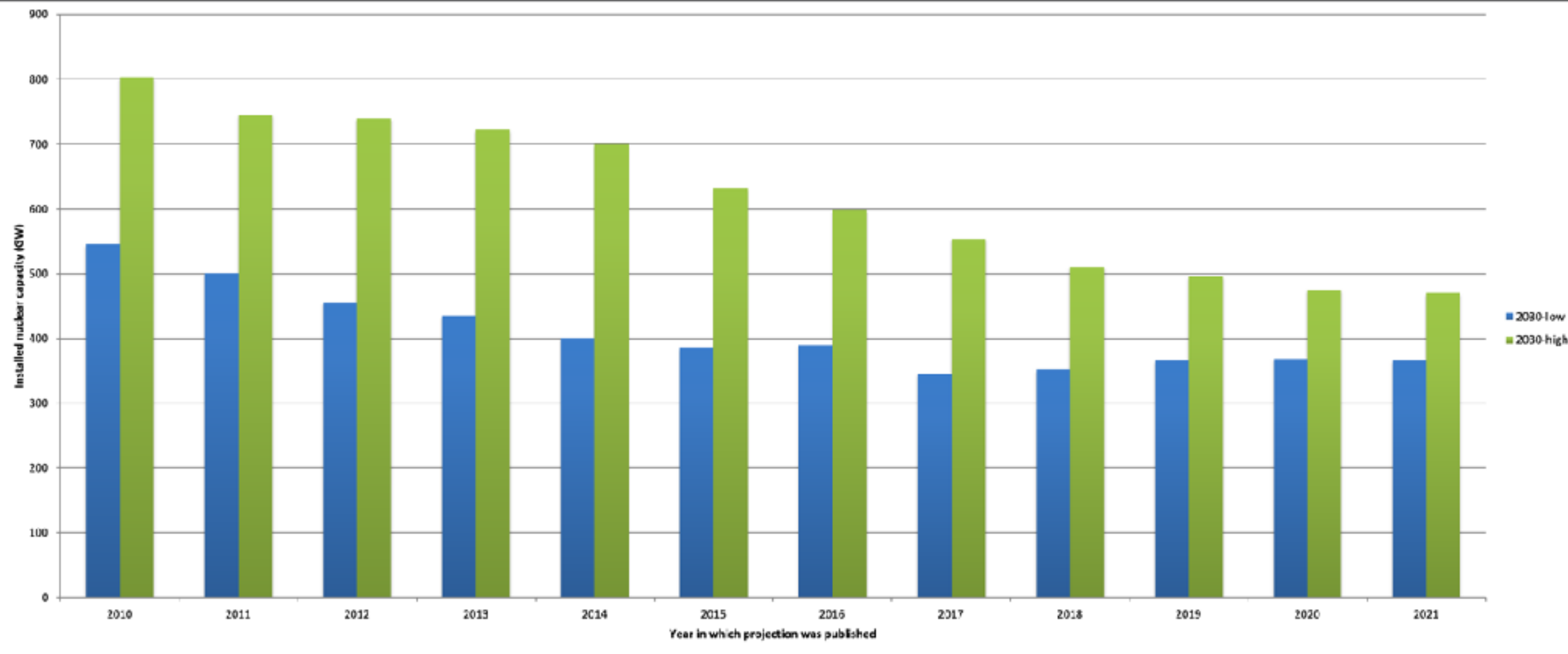
# Share of Electricity

About 40 percent below historical maximum of 17.5 percent in 1996



Source: Calculations using data from BP's Statistical Review of World Energy 2021

# IAEA Projections



IAEA (2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021) Energy, Electricity and Nuclear Power Estimates for the Period up to 2050. Vienna, International Atomic Energy Agency.

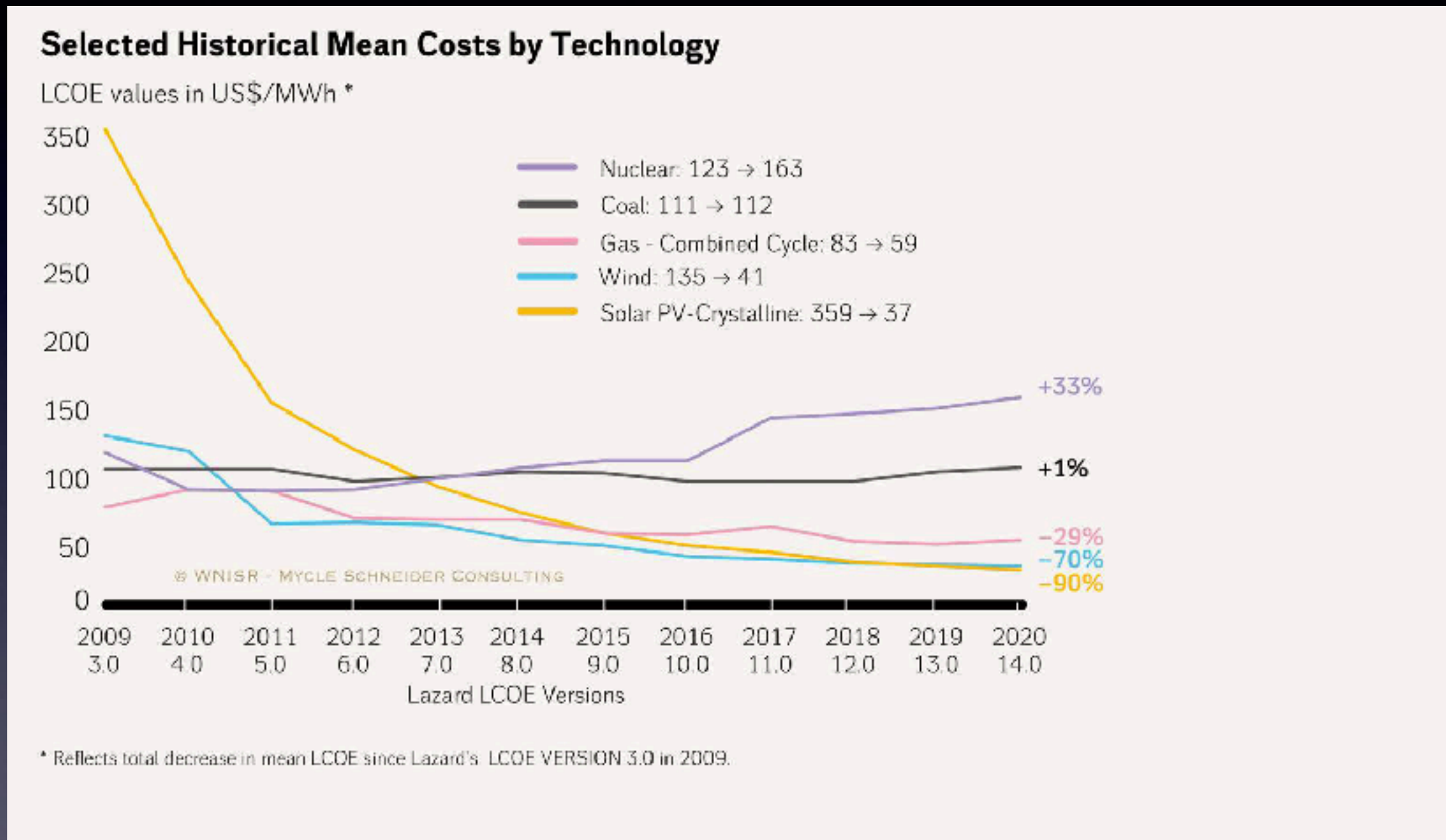


Why this trend?

Nuclear power is not economically competitive:  
reactors cost too much to build



# Other sources of electricity are cheaper... and becoming cheaper



Source: data from Lazard, as plotted in World Nuclear Industry Status Report 2021



# Several reactors shutting down because of high operational costs and cheap alternatives

## Another Reactor Closes, Punctuating New Reality for U.S. Nuclear Power

As Vermont Yankee shuts down, the U.S. has yet to address industry issues that span decades.

By **Christina Nunez**, [National Geographic](#)

PUBLISHED JANUARY 01, 2015



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## Sweden's Oskarshamn 1 and 2 reactor units to close

14 October 2015

German utility E.ON has decided that units 1 and 2 of the Oskarshamn nuclear power plant in Sweden will be shut down permanently. Unit 3 is unaffected by the decision, which was announced today by OXG AB, of which the E.ON group is the major shareholder.



The three-unit Oskarshamn plant. (Image: OXG)

### Related Stories

- E.ON supports early closure of Oskarshamn units
- Court leaves Swedish nuclear tax unchanged

### WNA Links

- Oskarshamn 1
- Oskarshamn 2
- Oskarshamn 3
- Nuclear Energy in Sweden

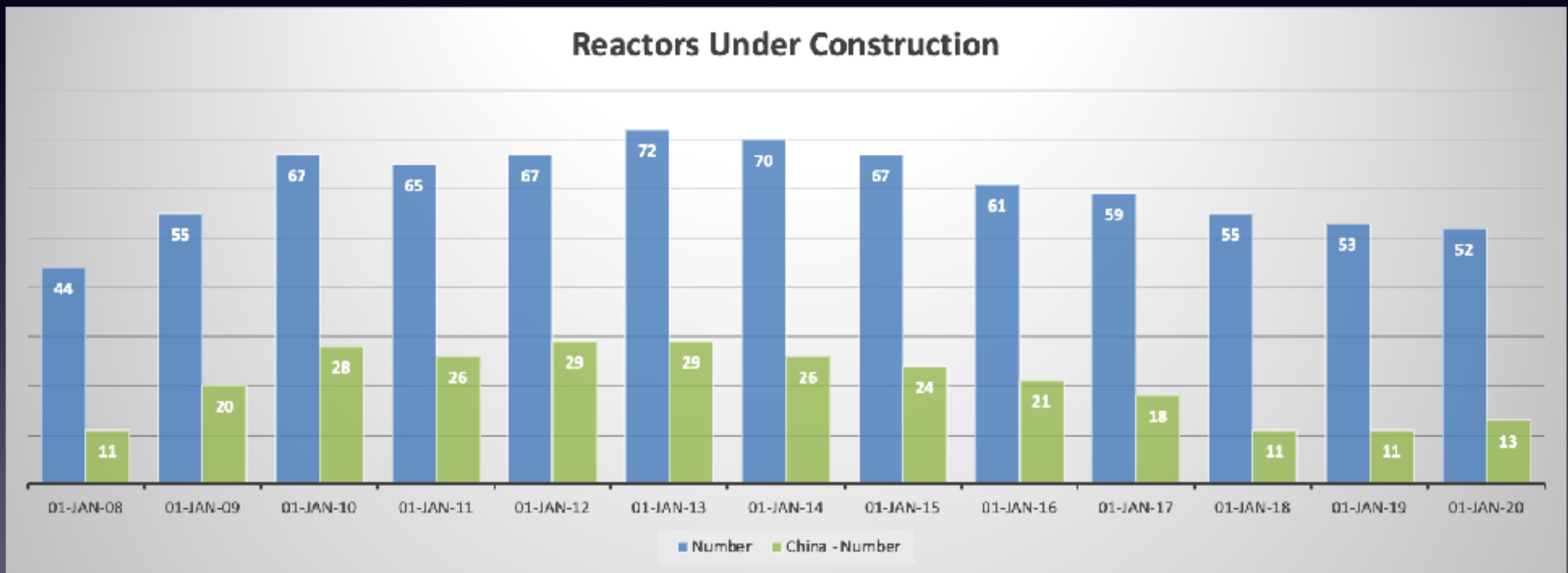
### Related Links

- E.ON
- OXG

<http://news.nationalgeographic.com/news/energy/2015/01/150101-vermont-yankee-shutdown-us-nuclear-issues/>



# Nuclear Renaissance



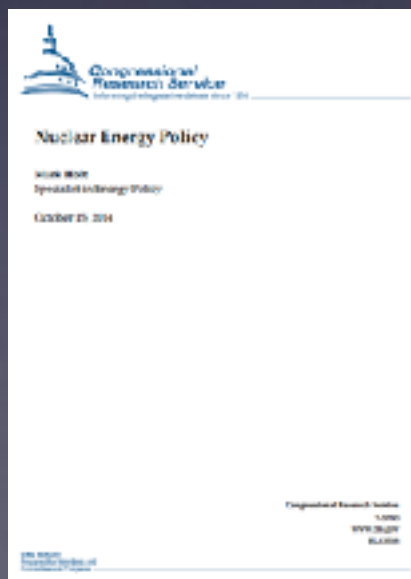
Source: My calculations, based on IAEA PRIS data

# Nuclear Renaissance - USA

## ***What was expected***

Around 30 reactors ordered

Nearly 15 GW of new capacity before 2021



## ***What Materialized***

Only 4 reactors began construction

2 reactors abandoned after \$9 billion spent

What's left?




# Will Small Modular (Nuclear) Reactors solve the problems of nuclear power?

JOURNAL OF THE ATOMIC SCIENTISTS  
2021, VOL. 77, NO. 4, 267-214  
<https://doi.org/10.1080/00963402.2021.1941600>

## OTHER FEATURES

**Can small modular reactors help mitigate climate change?**

Arjun Makhijani and M. V. Ramana 

 **Routledge**  
Taylor & Francis Group

 Check for updates

**IEEE Access**  
Multidisciplinary | Rapid Review | Open Access Journal

Received February 28, 2021, accepted March 5, 2021, date of publication March 9, 2021, date of current version March 22, 2021.

Digital Object Identifier: 10.1109/ACCESS.2021.3094948

## INVITED PAPER

# Small Modular and Advanced Nuclear Reactors: A Reality Check

**M. V. RAMANA** 

Lia Institute for Global Issues, School of Public Policy and Global Affairs, The University of British Columbia, Vancouver, BC V6T 1Z2, Canada

e-mail: m.v.ramana@ubc.ca

# What are Small Modular Reactors?

	Capacity
Small	< 300 MWe
Medium	300 to 700 MWe



Assembled from factory-fabricated modules

Each module represents a portion of finished plant



# All properties will not be realizable in a single design

Energy Research & Social Science 2 (2014) 115–124

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**Energy Research & Social Science**

journal homepage: [www.elsevier.com/locate/erss](http://www.elsevier.com/locate/erss)



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Original research article

**One size doesn't fit all: Social priorities and technical conflicts for small modular reactors**

M.V. Ramana\*, Zia Mian

*Nuclear Futures Laboratory and Program on Science and Global Security, Princeton University, United States*

 CrossMark

# Small also means...

More cost

$$\frac{K_1}{K_2} = \left( \frac{S_1}{S_2} \right)^{0.6}$$

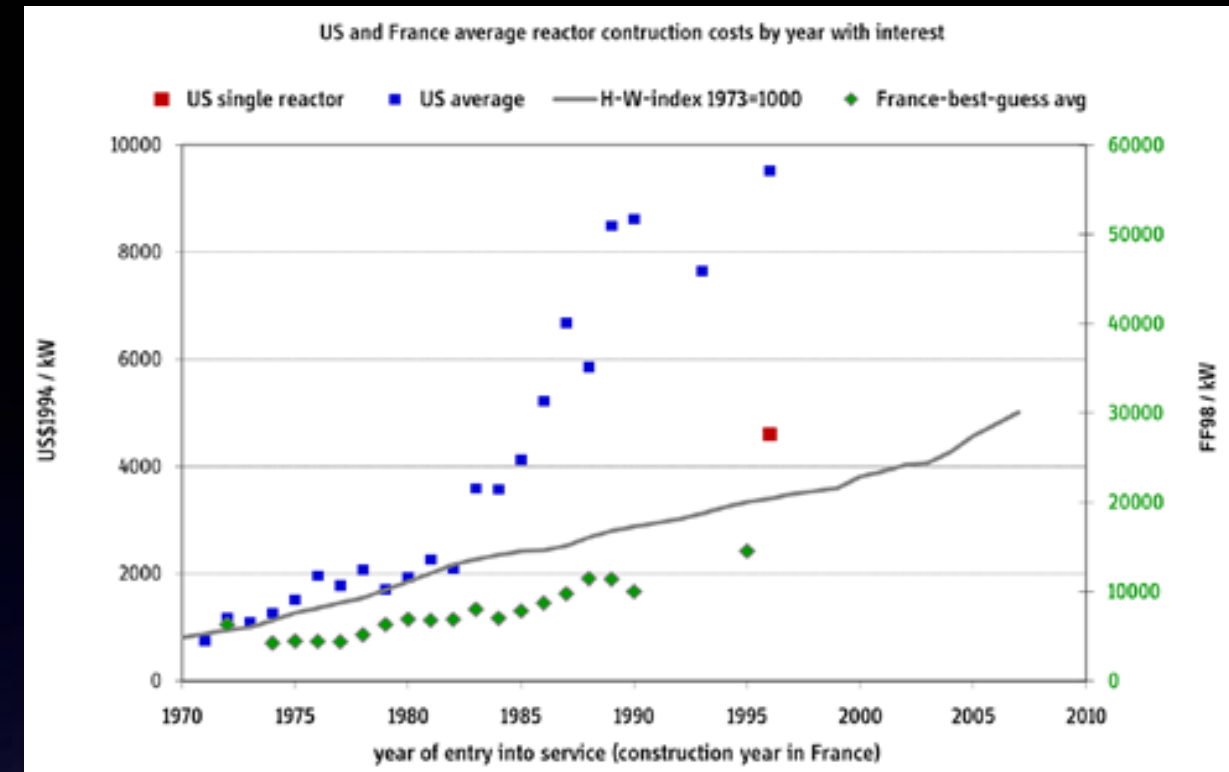
More spent fuel/waste/  
proliferation risk

RESOURCE REQUIREMENTS AND  
PROLIFERATION RISKS ASSOCIATED  
WITH SMALL MODULAR REACTORS

ALEXANDER GLASER,\* LAURA BERZAK HOPKINS, and M. V. RAMANA

NUCLEAR TECHNOLOGY VOL. 184 OCT. 2013

“Learning” might make plants more expensive

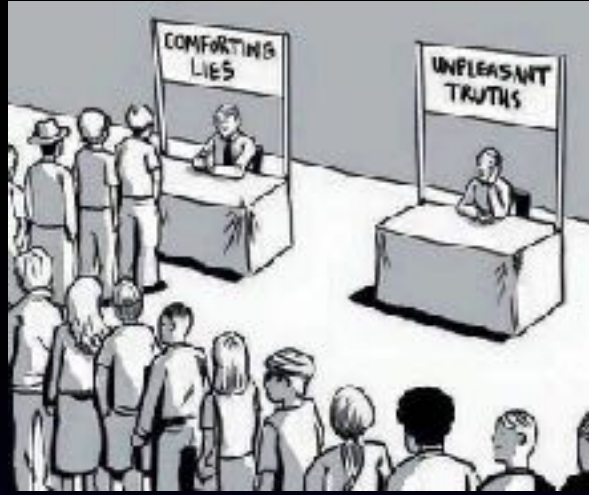


Grubler, Arnulf. 2010. “The Costs of the French Nuclear Scale-up: A Case of Negative Learning by Doing.” *Energy Policy* 38 (9): 5174–88.

Even if there was learning, too many “loss leaders” have to be built

Diseconomies of Scale Exponent		
	0.6	0.8
Learning Rate 10%	700	80
Learning Rate 5%	60,000	780

Glaser, Alexander, M.V. Ramana, Ali Ahmad, and Robert Socolow. 2015. “Small Modular Reactors: A Window on Nuclear Energy.” *An Energy Technology Distillate*. Princeton, N.J.: Andlinger Center for Energy and the Environment at Princeton University. <http://acee.princeton.edu/distillates/distillates/small-modular-reactors/>.



The Experience so far:  
More of the same



# Actual projects are delayed or performing poorly

Argentina: Carem-25 construction start 2014; November 2020 report: “physical completion of Carem 25 is at 70%”; No completion date

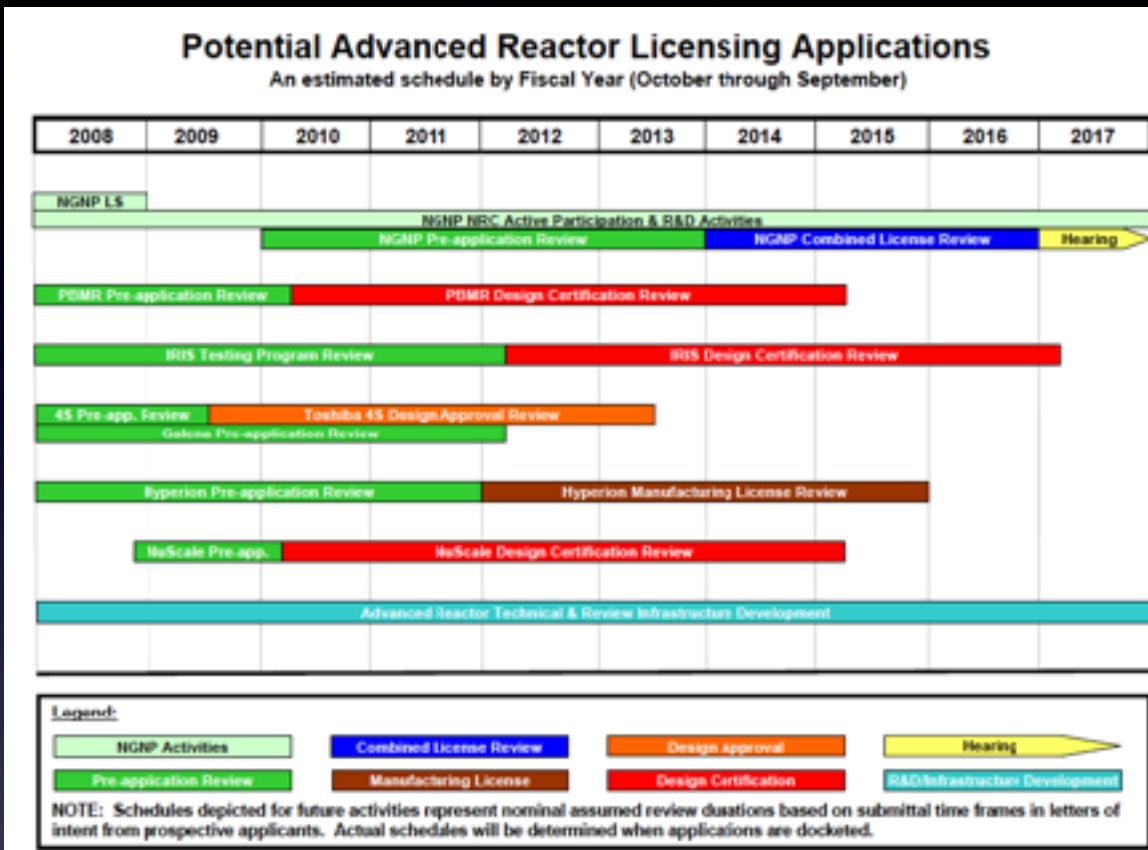
China: HTR-PM construction start 2012; projected to generate electricity in 2017; recently became critical (four years late)

Russia: KLT-40S construction start 2007; projected to start operations in October 2010; commissioned in May 2020; 2020 load factors for twin units just 29 and 16 percent according to IAEA PRIS database

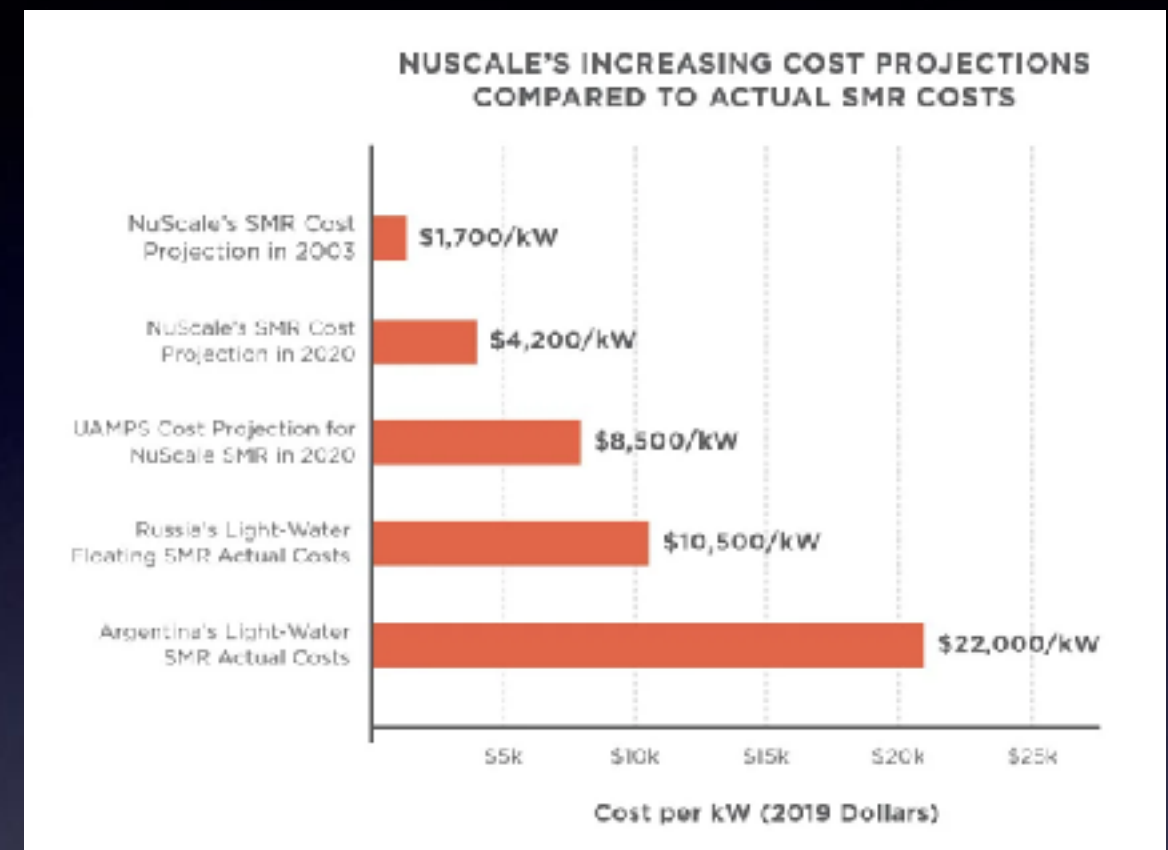
Source: <https://zh-prod-1cc738ca-7d3b-4a72-b792-20bd8d8fa069.storage.googleapis.com/s3fs-public/inline-images/190626175935-arctic-nuclear-2-exlarge-169.jpg>



# NuScale



Source: Edward Baker, "NRC's Advanced Reactor Program," 16 October 2008, <http://web.mit.edu/ans/www/documents/seminar/F08/baker.pdf>, accessed 19 May 2015



"Without clarity on the steam generator integrity, it would be **premature to conclude that the NuScale design ensures adequate protection of public health and safety.**"

Advisory Committee on Reactor Safeguards Member Vesna B. Dimitrijevic, March 2020

We identified a boron dilution issue that remains open. We are concerned that this class of events **could lead to a potential reactivity insertion accident and core damage.**"

Advisory Committee on Reactor Safeguards letter, June 2020

Ramana, M. V. "Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors." Portland, OR: Oregon Physicians for Social Responsibility, September 2020. [https://www.oregonpsr.org/small\\_modular\\_reactors\\_smrs](https://www.oregonpsr.org/small_modular_reactors_smrs).

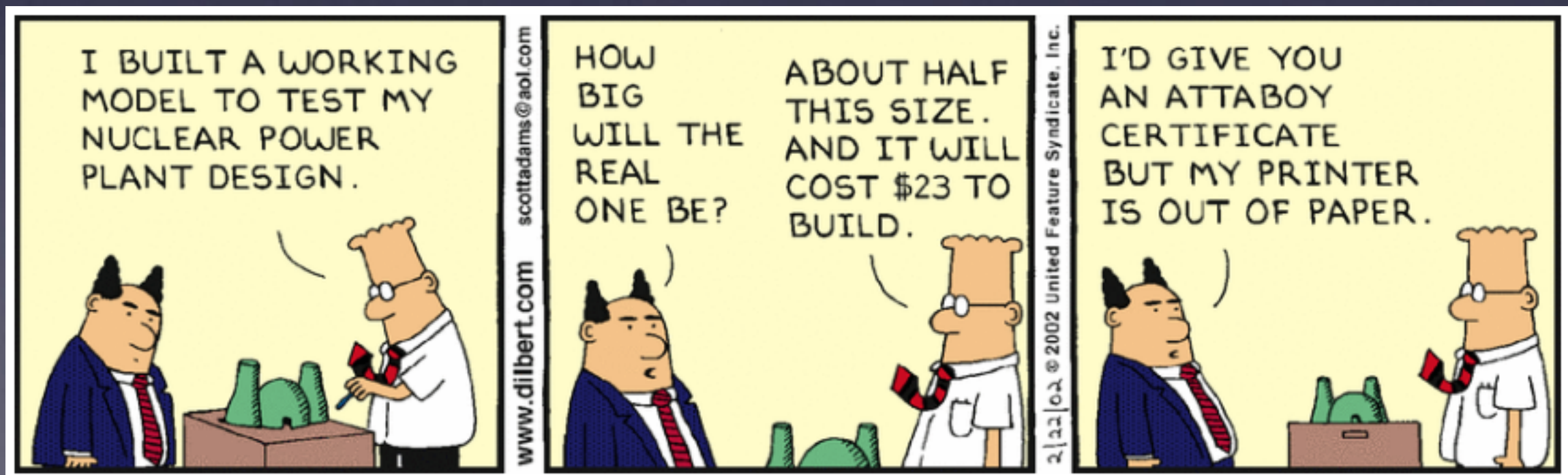
**Douglas O. Hunter: Why the world is watching Utah's Carbon Free Power Project**

[sltrib.com/opinion/commentary/2021/11/23/douglas-o-hunter-why](https://sltrib.com/opinion/commentary/2021/11/23/douglas-o-hunter-why)

November 23, 2021

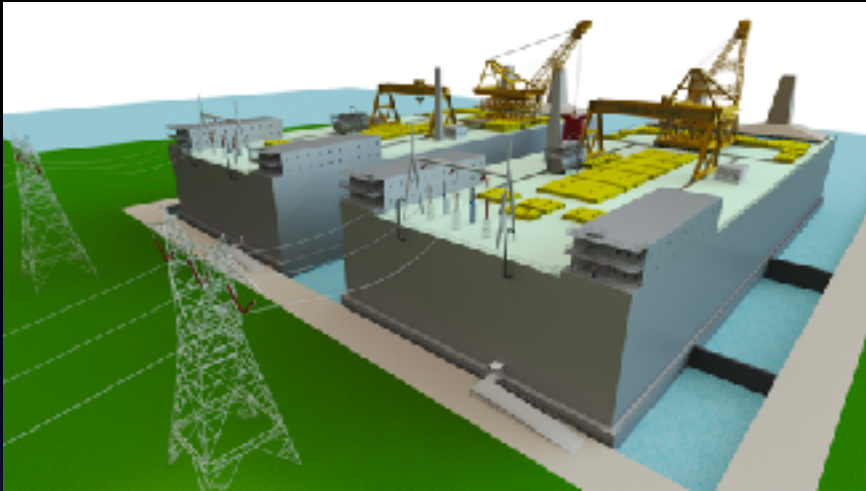
\$5.32 billion for 462 MWe =>  
\$11,515/kW = 80 percent more than Vogtle when construction started

# Molten Salt Reactors





# Thorcon



Source: <https://thorconpower.com/fuel/>

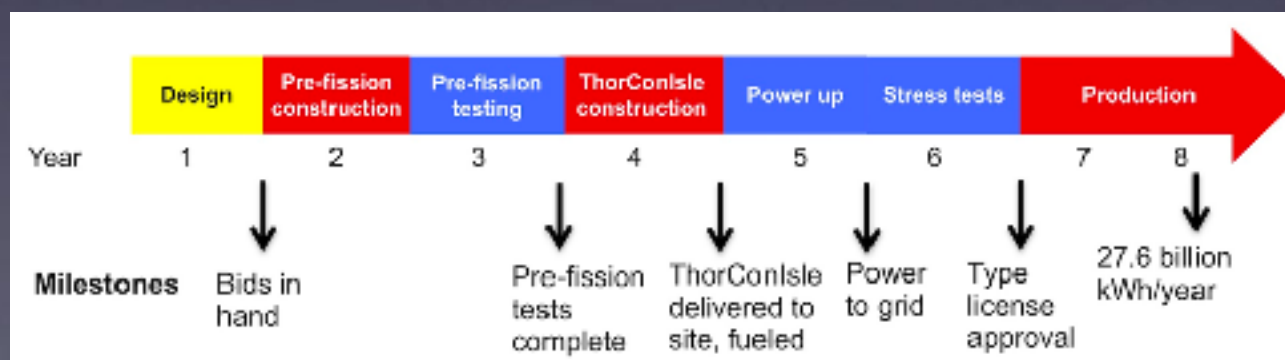
## Thorcon, Defense Ministry to cooperate on thorium nuclear reactor

**JP** [thejakartapost.com/news/2020/07/28/thorcon-defense-ministry-to-cooperate-on-thorium-nuclear-reactor.html](https://thejakartapost.com/news/2020/07/28/thorcon-defense-ministry-to-cooperate-on-thorium-nuclear-reactor.html)

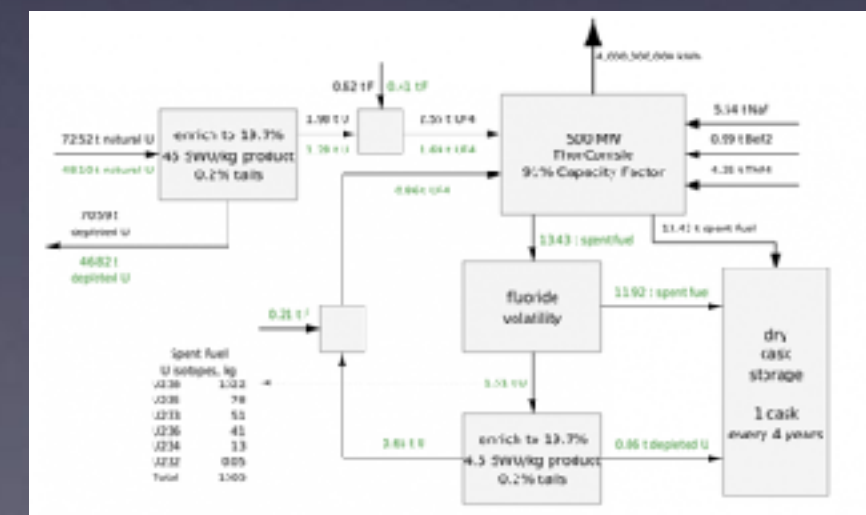
Jakarta / Tue, July 28, 2020 / 10:05 am

# Variant of molten salt reactor design

No experience with such a “reactor” anywhere



Source: <https://thorconpower.com/project/>



Source: <https://thorconpower.com/fuel/>

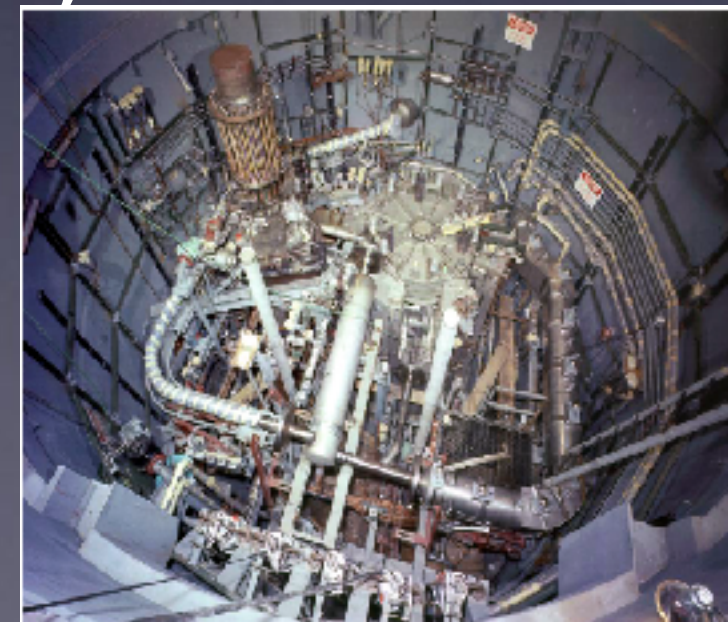


# MSRE Experience

Operated intermittently from 1965 to 1969

Interrupted 225 times (scrams and fuel draining through the so-called freeze valve)

Fluoride salt wastes have been difficult to manage (\$10 million/year for 8 MW)



# Radioactive Waste

Multiple types of waste

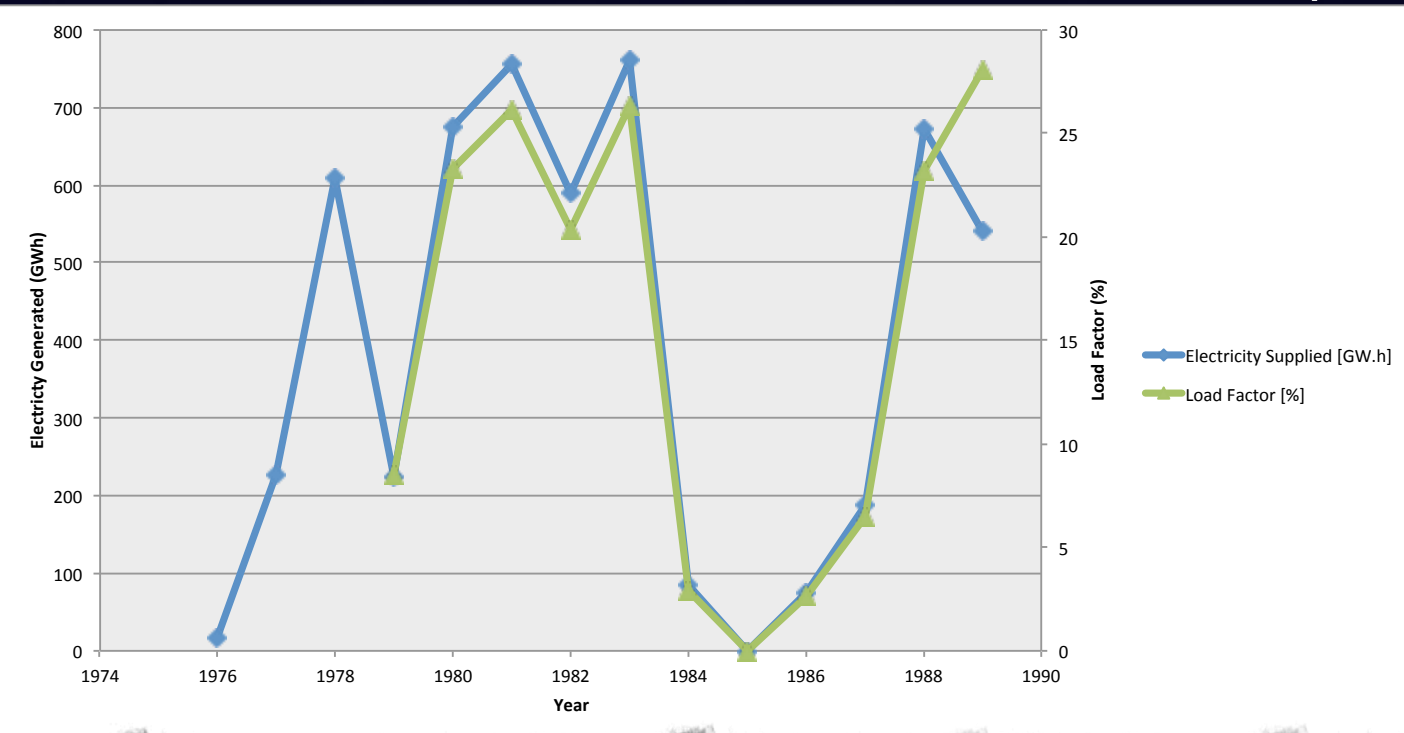
High fissile content => implications for repository (concerns about criticality)

Chemical forms that are difficult to deal with: Uranium tetrafluoride unsuitable for geological disposal (DOE 1999)

Source: Krall, Lindsay. "A Critical Analysis Of The Nuclear Waste Management Consequences For Small Modular Reactors." Presented at the Center for International Security and Cooperation Seminar, Stanford University, Palo Alto, CA, June 4, 2020. <https://cisac.fsi.stanford.edu/events/critical-analysis-nuclear-waste-management-consequences-small-modular-reactors>. Also see Krall, Lindsay, and Allison MacFarlane. "Burning Waste or Playing with Fire? Waste Management Considerations for Non-Traditional Reactors." Bulletin of the Atomic Scientists, August 31, 2018. <https://thebulletin.org/2018/08/burning-waste-or-playing-with-fire-waste-management-considerations-for-non-traditional-reactors/>.

# What looks good on paper might not be so good in practice

Fort St. Vrain (1974-1988)



## Safest Reactor Is Closing Because It Rarely Runs

By MATTHEW L. WALD

New York Times, December 8, 1988

BULLETIN OF THE ATOMIC SCIENTISTS, 33:4  
VOL. 33, NO. 4, 133-139  
<http://bulletin.org/DOI/10.1080/00964022.1985.1170389>

Routledge  
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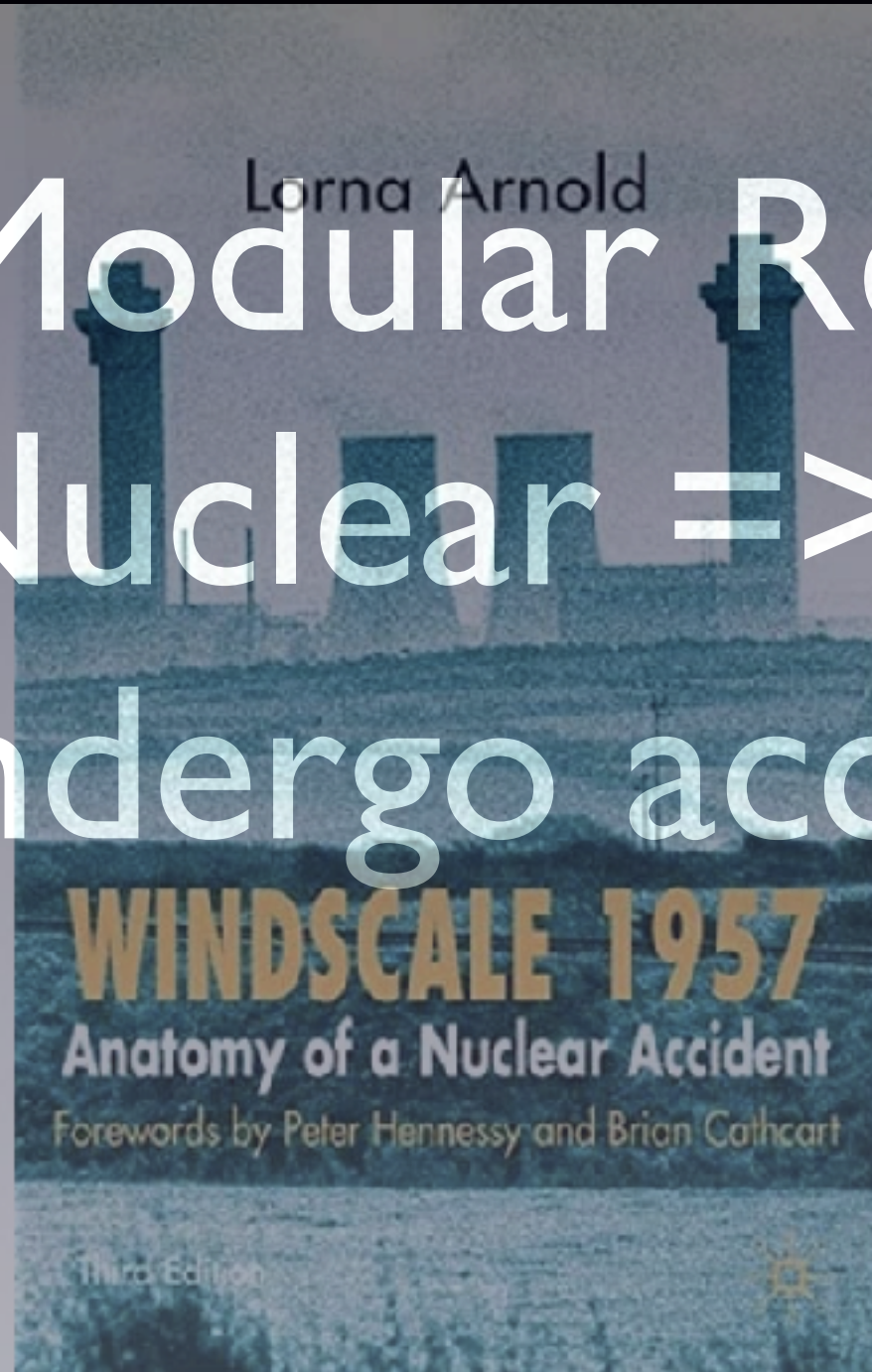
FEATURES

The checkered operational history of high-temperature gas-cooled reactors

M. V. Ramana



Small Modular Reactors  
are Nuclear => they  
can undergo accidents





# Theoretical Concerns

Nuclear reactors are complex - lots of things that can go wrong

Contain large quantities of radioactive materials

Operate at high temperatures and/or pressures

Large energy releases possible

Events occur at a very rapid pace





Conventional methods used to estimate frequencies of serious accidents and compare safety levels are misleading

Redundancy can sometimes make things worse

**Bulletin  
of the  
Atomic  
Scientists**

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**Beyond our imagination: Fukushima and the problem of assessing risk**

BY M. V. RAMANA | 19 APRIL 2011



**‘One in infinity’: failing to learn from accidents and implications for nuclear safety in India**

M.V. Ramana<sup>a\*</sup> and Ashwin Kumar<sup>b</sup>

<sup>a</sup>*Program on Science and Global Security, Princeton University, Princeton, NJ, USA;*

<sup>b</sup>*Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA*

# Overconfidence by nuclear authorities

## Regulatory failures

*Journal of Risk Research*, 2015

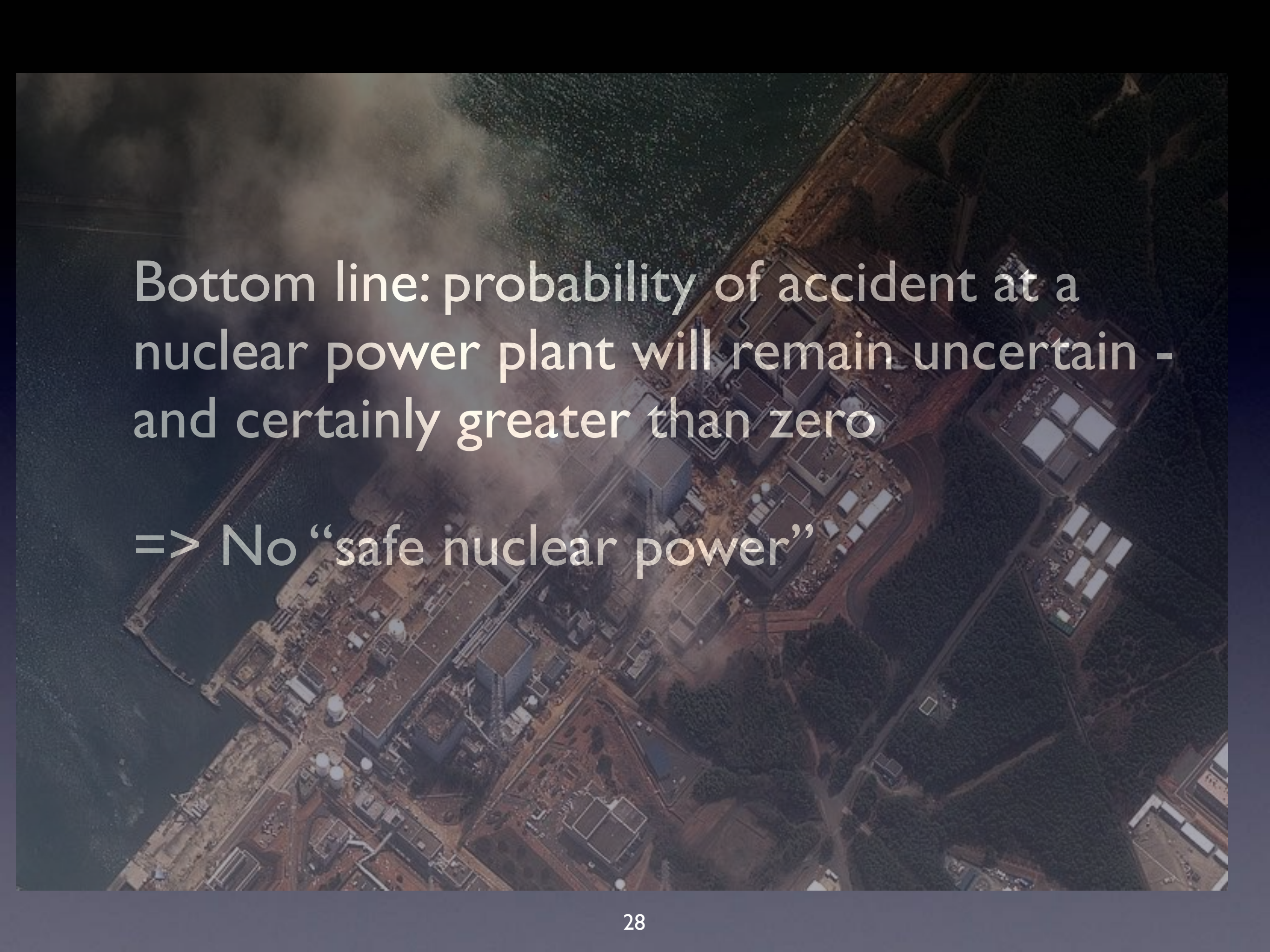
<http://dx.doi.org/10.1080/13669877.2014.1003958>

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**Negligence, capture, and dependence: safety regulation of the design of India’s Prototype Fast Breeder Reactor**

M.V. Ramana<sup>a\*</sup> and Ashwin K. Seshadri<sup>b</sup>



An aerial photograph of a nuclear power plant. Several large, white, cylindrical cooling towers are visible, with thick white plumes of steam or smoke rising from them. The plant itself is a complex of various buildings, pipes, and structures situated near a body of water. The surrounding area includes some greenery and other industrial or residential structures.

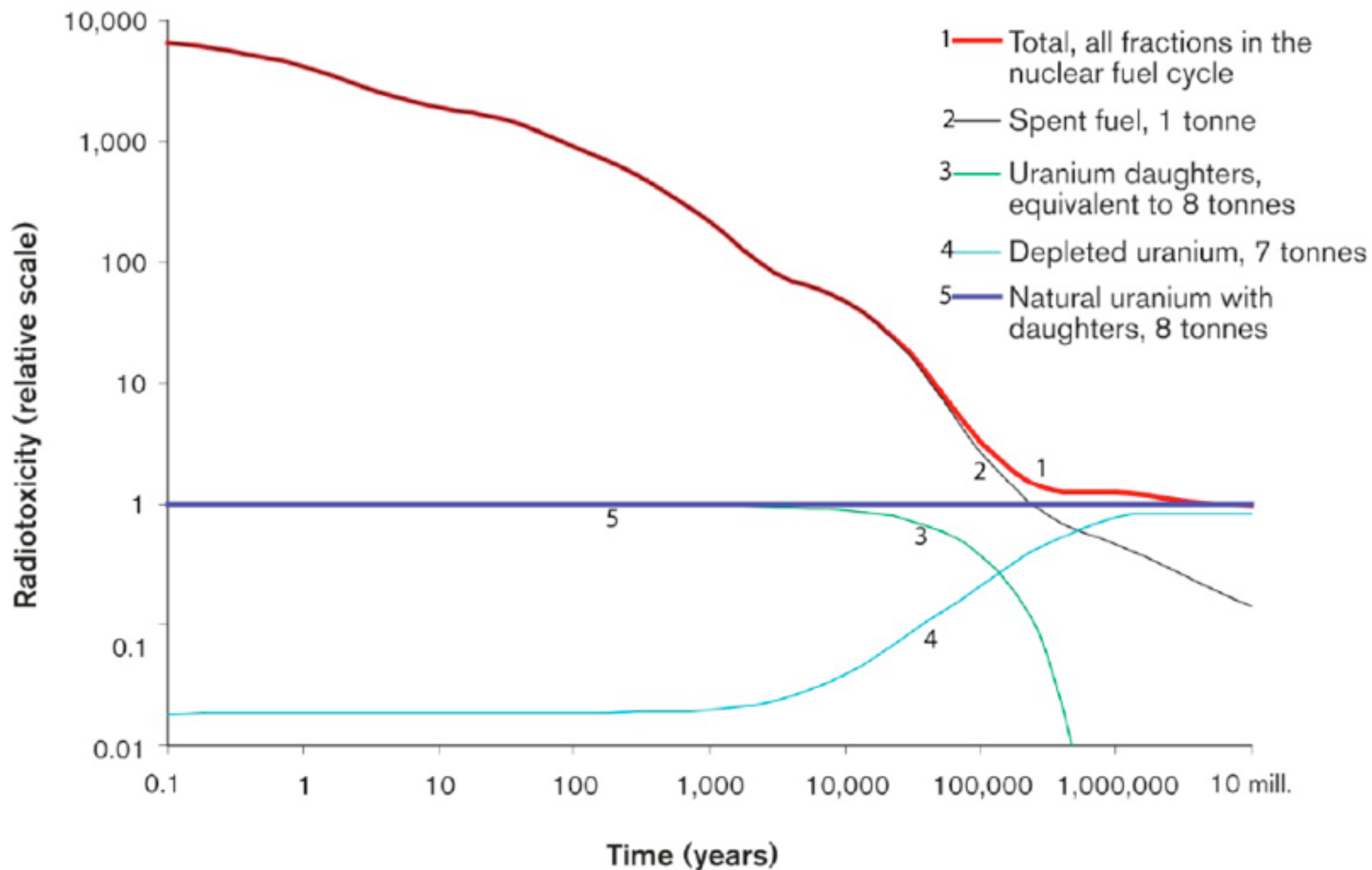
Bottom line: probability of accident at a nuclear power plant will remain uncertain - and certainly greater than zero

=> No “safe nuclear power”





Nuclear power produces radioactive wastes that remain hazardous for millennia



Source: Feiveson, Harold, Zia Mian, M.V. Ramana, and Frank Von Hippel. 2011. "Managing Spent Fuel from Nuclear Power Reactors: Experience and Lessons from Around the World." Princeton: International Panel on Fissile Materials.

# Technical challenges coupled with social concerns => no operating nuclear waste repositories

## No demonstrated solution

## An Enduring Problem: Radioactive Waste From Nuclear Energy

BY M. V. RAMANA

Program on Science and Global Security, Princeton University, Princeton, NJ, USA



Photograph of a waste container at the Waste Isolation Pilot Plant, USA, with its lid removed and apparent heat dissipation taken by the U.S. Department of Energy on May 28, 2015. Source: <https://www.eia.doe.gov/images/stories/photos/wipp/wipp01.jpg>

### 1. GEOLOGICAL DISPOSAL: THE PROMISE AND THE REALITY

Some of the radioactive elements produced during the operation of nuclear reactors have extremely long half-lives, and have to be isolated from human contact for hundreds of thousands of years (see Fig. 1). This requirement for stewardship is unprecedented in human history. Since the 1950s, nuclear establishments have advocated dealing with these radioactive wastes by constructing an underground repository in a suitable geological medium and placing the waste there, within special containers. Much attention from the technical community has been focused on finding a suitable location because the choice of geological media (e.g., granite, volcanic tuff, or clay) will influence the behavior of radionuclides when they escape from the containers [2]. The question is one of “when,” not “if,” because of our status; radionuclides will migrate into the biosphere over the long periods of time it would take for them to decay. As Allison Macfarlane, former Chair of the U.S. Nuclear Regulatory Commission put it, no “site will...contain nuclear waste indefinitely. The goal is to select a site and engineered features, such as the waste container, which maximize the amount of time the waste is isolated” [3, p. 24].

Nevertheless, confidence in the idea of a repository remains high. The U.S. National Academy of Sciences’

Decades after the idea was first proposed, it appears that underground repositories to manage radioactive spent fuel from commercial reactors are finally going to be constructed. In November 2015, the ruling center-right party in Finland became the first government to grant a construction license for such a repository [1]. The U.S. Department of Energy is pursuing a consent-based process to set up a similar repository. Do these developments mean that a long-sought solution to the problem of nuclear waste is imminent?

As this article will argue, there are many fundamental reasons why dealing with radioactive waste is a special and enduring challenge. Even if a repository is constructed in one or two countries, those examples are by no means generalizable. The confusing problem of radioactive waste disposal, in turn, is another reason to be wary of a large scale expansion of nuclear power.

Digital Object Identifier 10.1002/wene.289

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DOI: 10.1002/wene.289

### ADVANCED REVIEW

## Technical and social problems of nuclear waste

M. V. Ramana

WILEY







原子力明るい未来のエネルギー

Should we expand  
nuclear power to solve  
climate change?

3 of 16

An empty shopping street, under a sign reading "Nuclear Power - The Energy for a Better Future", is seen at the entrance of Futaba town, inside the exclusion zone around the crippled Fukushima Daiichi nuclear power plant January 15, 2012. REUTERS/Stringer [less](#)



# Not Desirable



Source: [https://www.youtube.com/watch?v=B3\\_ZRO5oATk](https://www.youtube.com/watch?v=B3_ZRO5oATk)

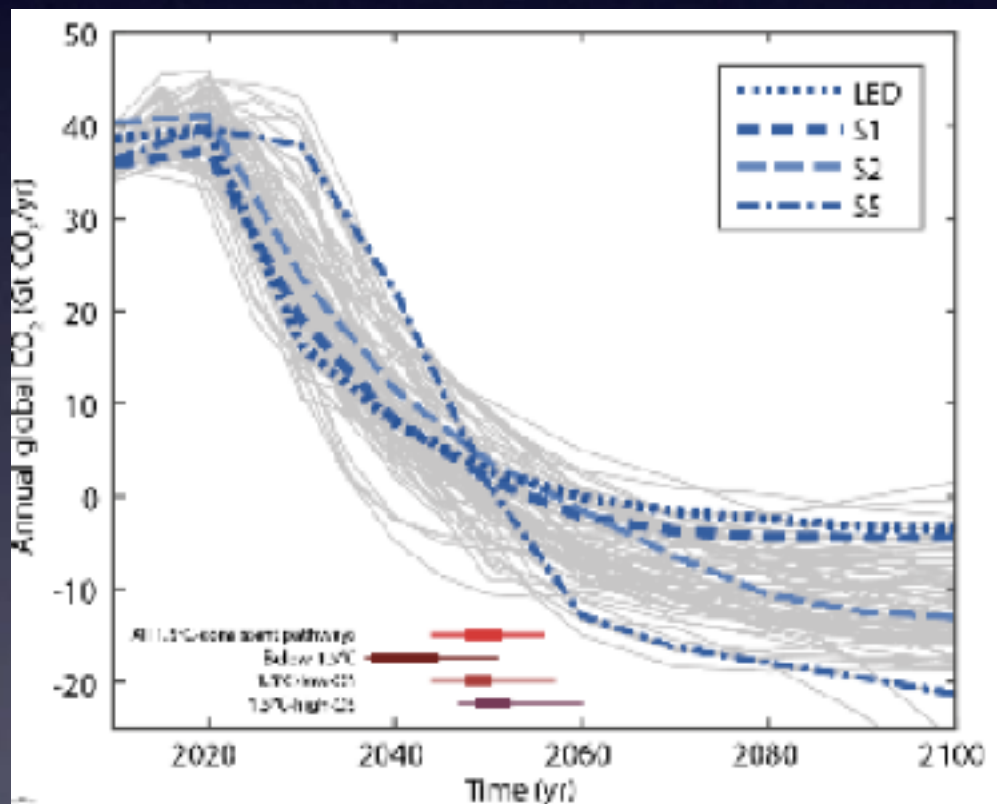


Source: <https://antinuclearinfo.files.wordpress.com/2017/11/joined-at-hip-weapons.gif?w=300>

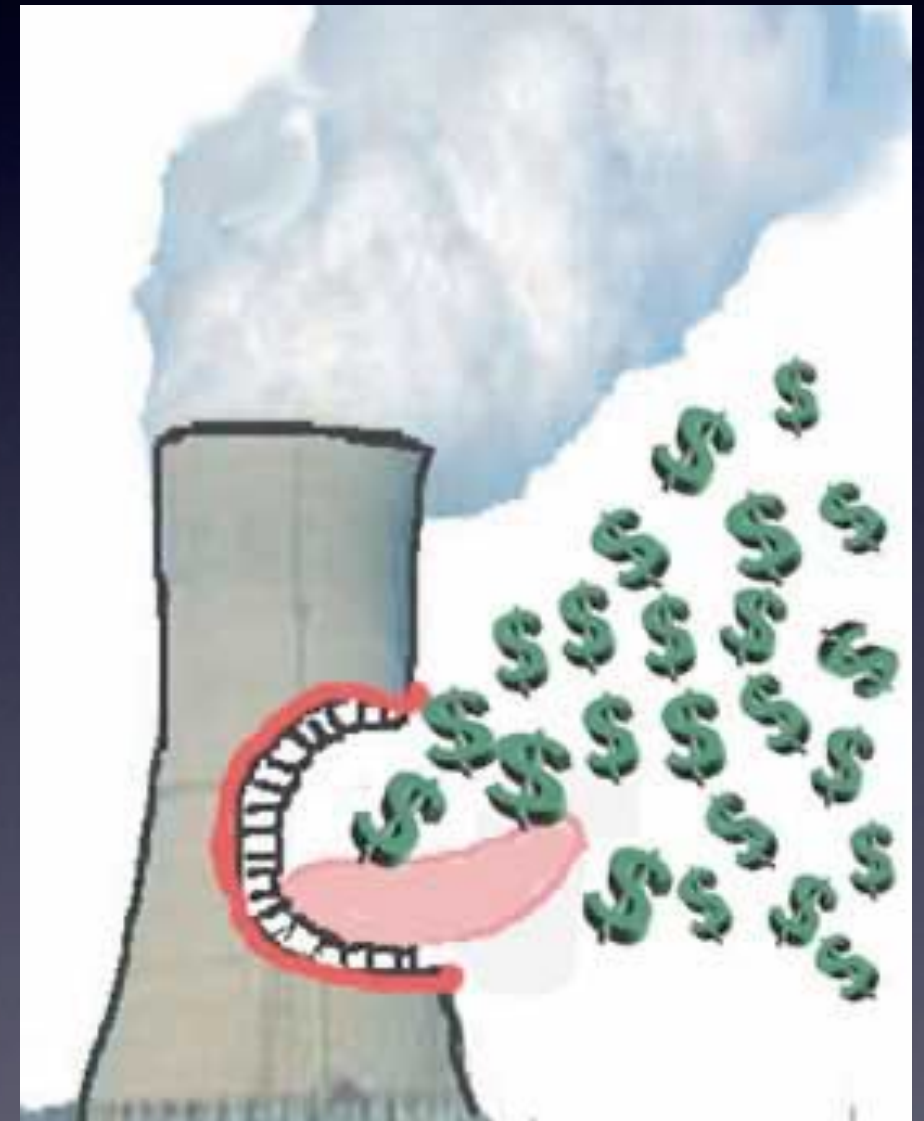


Source: <https://liber.post-gazette.com/image/2017/06/15/hanford-nuclear-waste.jpg>

# Infeasible



Source: IPCC SR1.5 report, 2018



<http://antinuclearinfo.files.wordpress.com/2009/04/nuclear-costs.jpg>