7 Fission power

Fission is in Fashion

Fission energy

PWR nuclear power plants

ThorCon

Molten salt reactor

Cheaper than coal

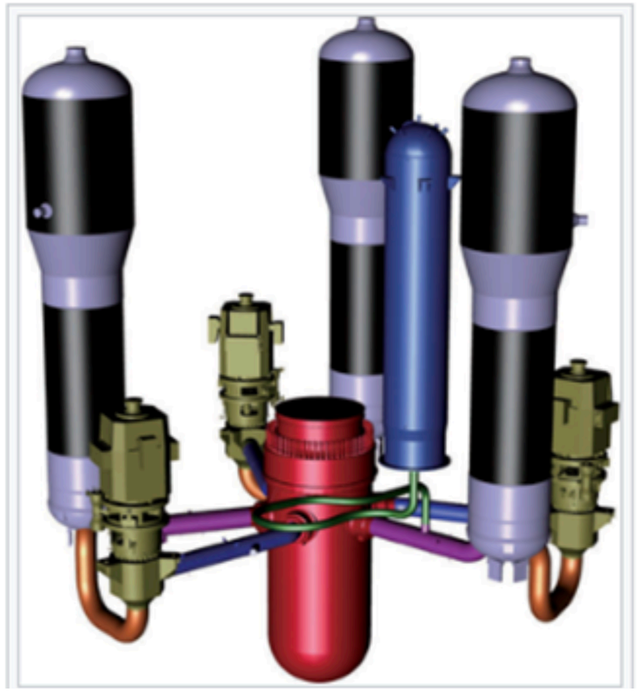
Market size, growth

Shipyard mass production

Fission is in Fashion

Argentina Signs $8B Deal for China's Hualong One PWR

(NucNet) State companies Nucleoeléctrica Argentina and China National Nuclear Corporation (CNNC) have signed an engineering, procurement and construction (EPC) contract for construction of a China-supplied HPR1000 nuclear power plant at what will become the Atucha III nuclear power station.



The cost of the project is estimated to be $8 billion with China providing 85% of the costs. A key remaining hurdle, and it's a big one, is financing Argentina's 15% share worth $1.2 billion.

Overwhelming support from college of commissioners for including nuclear in EU green taxonomy

France to build up to 14 new nuclear reactors by 2050, says Macron

French president says 'renaissance' of atomic energy industry will help end country's reliance on fossil fuels

WORLD NUCLEAR ASSOCIATION

Power reactors und

Start †				
2022	Belarus, BNPP			
2022	China, CGN			
2022	China, CGN	Fangchenggang 4	Hualong One	1180
2022	China, CGN	Hongyanhe 6	ACPR-1000	1119
2022	Finland, TVO	Olkiluoto 3	EPR	1720
2022	India, NPCIL	Kakrapar 4	PHWR-700	700
2022	India, NPCIL	Kalpakkam PFBR	FBR	500
2022	India, NPCIL	Rajasthan 7	PHWR-700	700
2022	Korea, KHNP	Shin Hanul 1	APR1400	1400
2022	Pakistan	Karachi/KANUPP 3	ACP1000	1161
2022	Russia, Rosenergoatom	Kursk II-1	VVER-TOI	1255
2022	Slovakia, SE	Mochovce 3	VVER-440	471
2022	USA, Southern	Vogtle 3	AP1000	1250
2023	Argentina, CNEA	Carem	Carem25	29
2023	Bangladesh	Rooppur 1	VVER-1200	1200

References

World Nuclear Association

tracks fission power plants in 42 countries.

Power	Status
392 GW	in operation
62 GW	under construction
96 GW	planned
354 GW	proposed

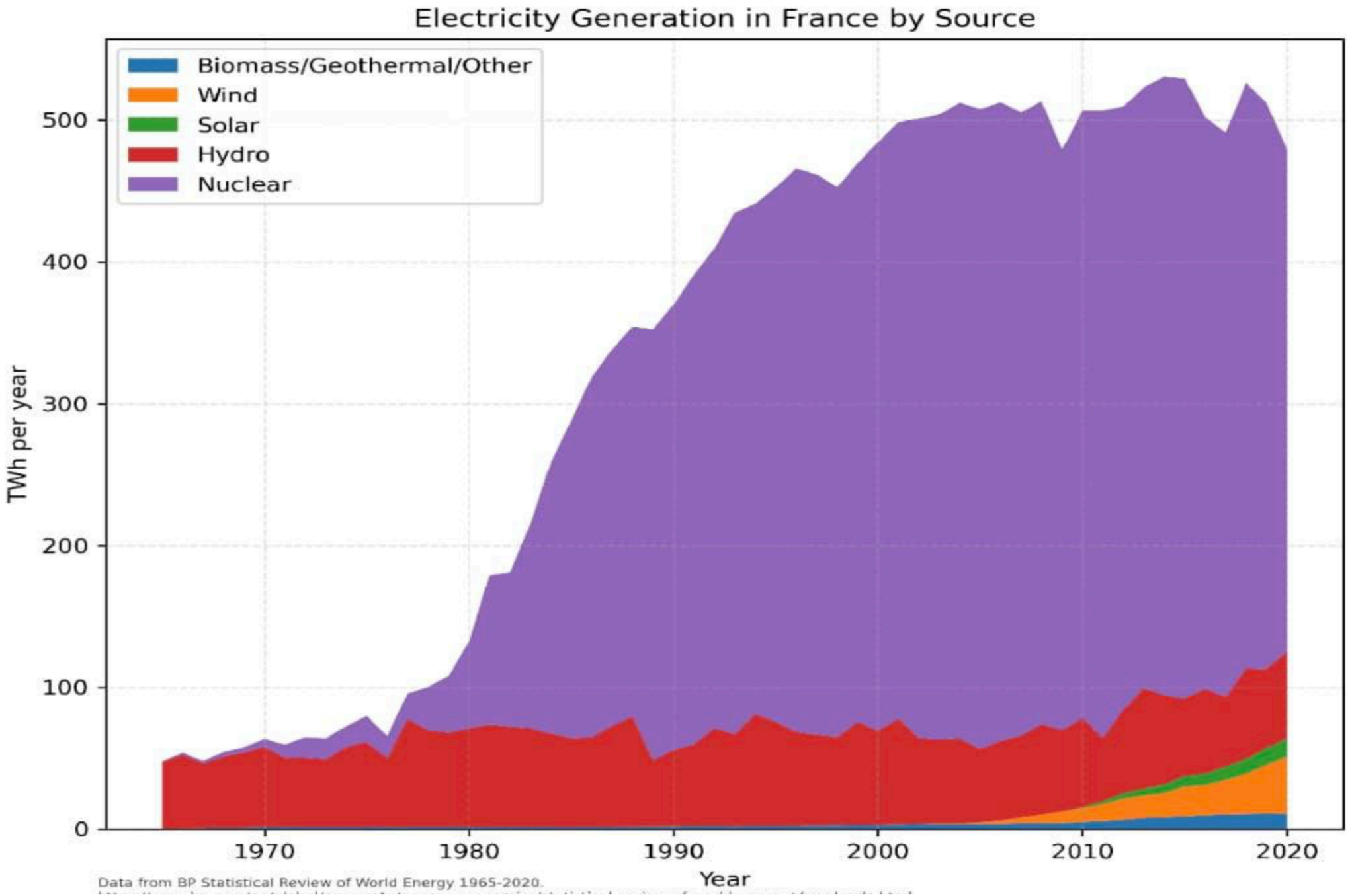
for Country Profile)	2020		March 2022		March 2022		March 2022		March 2022		2021
	TWh	% e	No.	MWe net	No.	MWe gross	No.	MWe gross	No.	MWe gross	tonnes U
Argentina	10.0	7.5	3	1641	1	29	1	1150	2	1350	167
Armenia	2.6	34.5	1	415	0	0	0	0	1	1060	50
Bangladesh	0	0	0	0	2	2400	0	0	2	2400	0
Belarus	0.3	1.0	1	1110	1	1194	0	0	2	2400	179
Belgium	32.8	39.1	7	5942	0	0	0	0	0	0	790
Brazil †	13.2	2.1	2	1884	1	1405	0	0	4	4000	340
Bulgaria	15.9	40.8	2	2006	0	0	1	1000	2	2000	322
Canada	92.2	14.6	19	13,624	0	0	0	0	2	1500	1492
China	344.7	4.9	53	50,769	19	20,930	34	38,110	168	196,860	9563
Czech Republic	28.4	37.3	6	3934	0	0	1	1200	3	3600	706
Egypt	0	0	0	0	0	0	4	4800	0	0	0
Finland	22.4	33.9	5	4394	0	0	1	1170	0	0	421
France	338.7	70.6	56	61,370	1	1650	0	0	0	0	8233
Germany	60.9	11.3	3	4055	0	0	0	0	0	0	521
Hungary	15.2	48.0	4	1902	0	0	2	2400	0	0	320
India	40.4	3.3	23	6885	8	6700	12	8400	28	32,000	977
Iran	5.8	1.7	1	915	1	1057	1	1057	5	2760	153
Japan †	43.0	5.1	33	31,679	2	2756	1	1385	8	11,562	1396
Jordan	0	0	0	0	0	0	0	0	1	1000	0
Kazakhstan	0	0	0	0	0	0	0	0	2	600	0
Korea RO (South)	152.6	29.6	24	23,136	4	5600	0	0	2	2800	4270
Lithuania	0	0	0	0	0	0	0	0	2	2700	0
Mexico	10.9	4.9	2	1552	0	0	0	0	3	3000	226
Netherlands	3.9	3.3	1	482	0	0	0	0	0	0	69
Pakistan	9.6	7.1	6	3256	0	0	1	1170	0	0	787
Poland	0	0	0	0	0	0	0	0	6	6000	0
Romania	10.6	19.9	2	1300	0	0	2	1440	1	720	185
Russia ‡	201.8	20.6	37	27,653	3	2810	27	23,725	21	20,100	5925
Saudi Arabia	0	0	0	0	0	0	0	0	16	17,000	0
Slovakia	14.4	53.1	4	1837	2	942	0	0	1	1200	359
Slovenia	6.0	37.8	1	688	0	0	0	0	1	1000	127
South Africa	11.6	5.9	2	1860	0	0	0	0	8	9600	277
Spain	55.8	22.2	7	7121	0	0	0	0	0	0	1221
Sweden	47.4	29.8	6	6882	0	0	0	0	0	0	914
Switzerland	23.0	32.9	4	2960	0	0	0	0	0	0	412
Thailand	0	0	0	0	0	0	0	0	2	2000	0
Turkey	0	0	0	0	3	3600	1	1200	8	9500	0
Ukraine †	71.5	51.2	15	13,107	2	1900	0	0	2	2,400	1876
UAE	1.6	1.1	2	2690	2	2800	0	0	0	0	907
United Kingdom	45.9	14.5	11	6848	2	3440	2	3340	2	2300	1259
USA	789.9	19.7	93	95,523	2	2500	3	2550	18	8000	17,587
Uzbekistan	0	0	0	0	0	0	2	2400	2	2400	0
WORLD*	**2553**	**c 10.3****	**439**	**392,279**	**56**	**61,713**	**96**	**96,497**	**325**	**353,812**	**62,496**
	TWh	% e	No.	MWe	No.	MWe	No.	MWe	No.	MWe	tonnes U

https://www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requireme.aspx

France electric power:

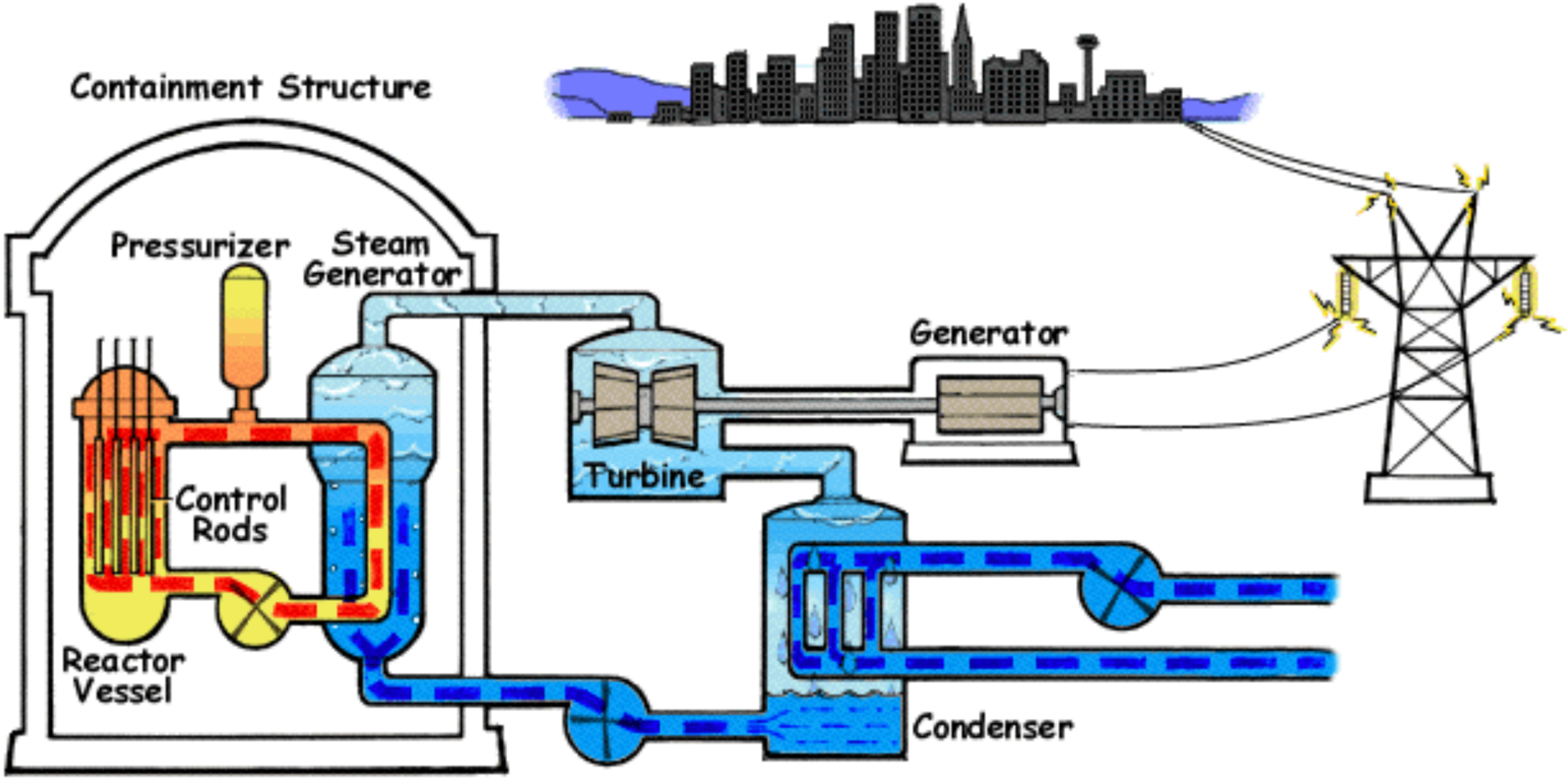
80% atomic fission:

39 GW



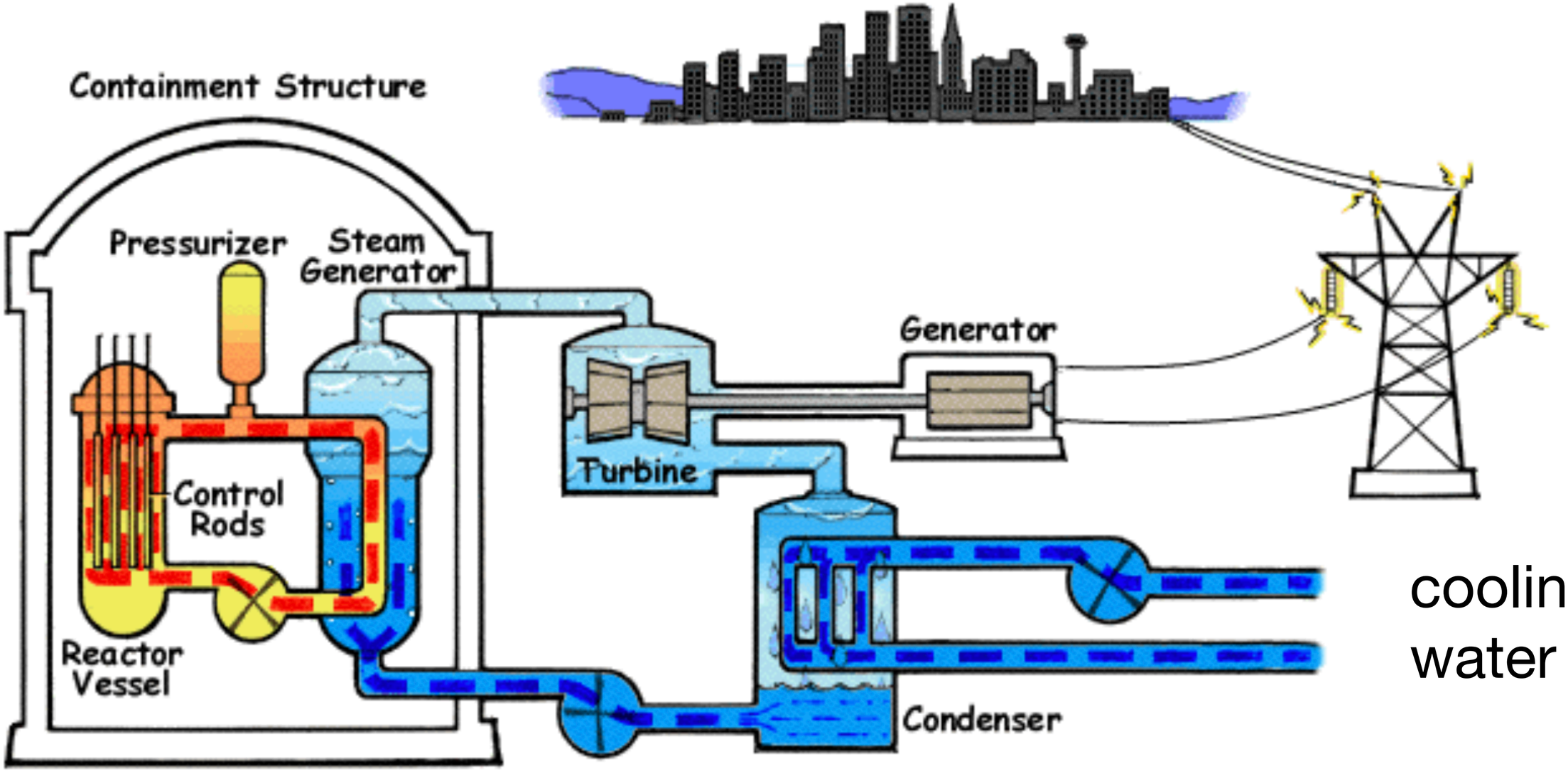
https://www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requireme.aspx

Pressurized water reactor (PWR) uses 155 bar 275C water to move heat to steam generator to turn turbine-generator.



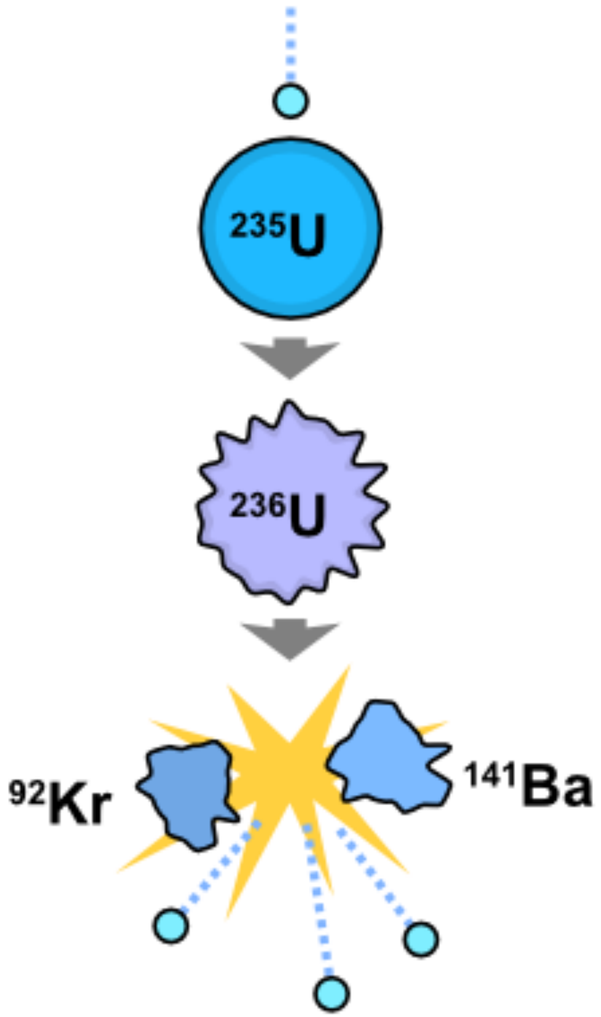
https://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html

Pressurized water slows neutrons so they split uranium atoms. Cooling water carries away rejected heat.



https://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html

Uranium-235 fissions to krypton and barium releasing energy.



http://en.wikipedia.org/wiki/Nuclear_fission

The total mass of the resulting

barium-141
krypton-92
neutrons (3)

is a bit less than the mass of the U-235 + neutron,

and by e = mc2

immediately releases 166 MeV of energy, totaling 200 MeV after Kr and Ba decay.

1 tonne-U235 fissioned -> 79,000 TJ
= 2.6 GW-years(t)

Oklo, Gabon
2 billion years ago

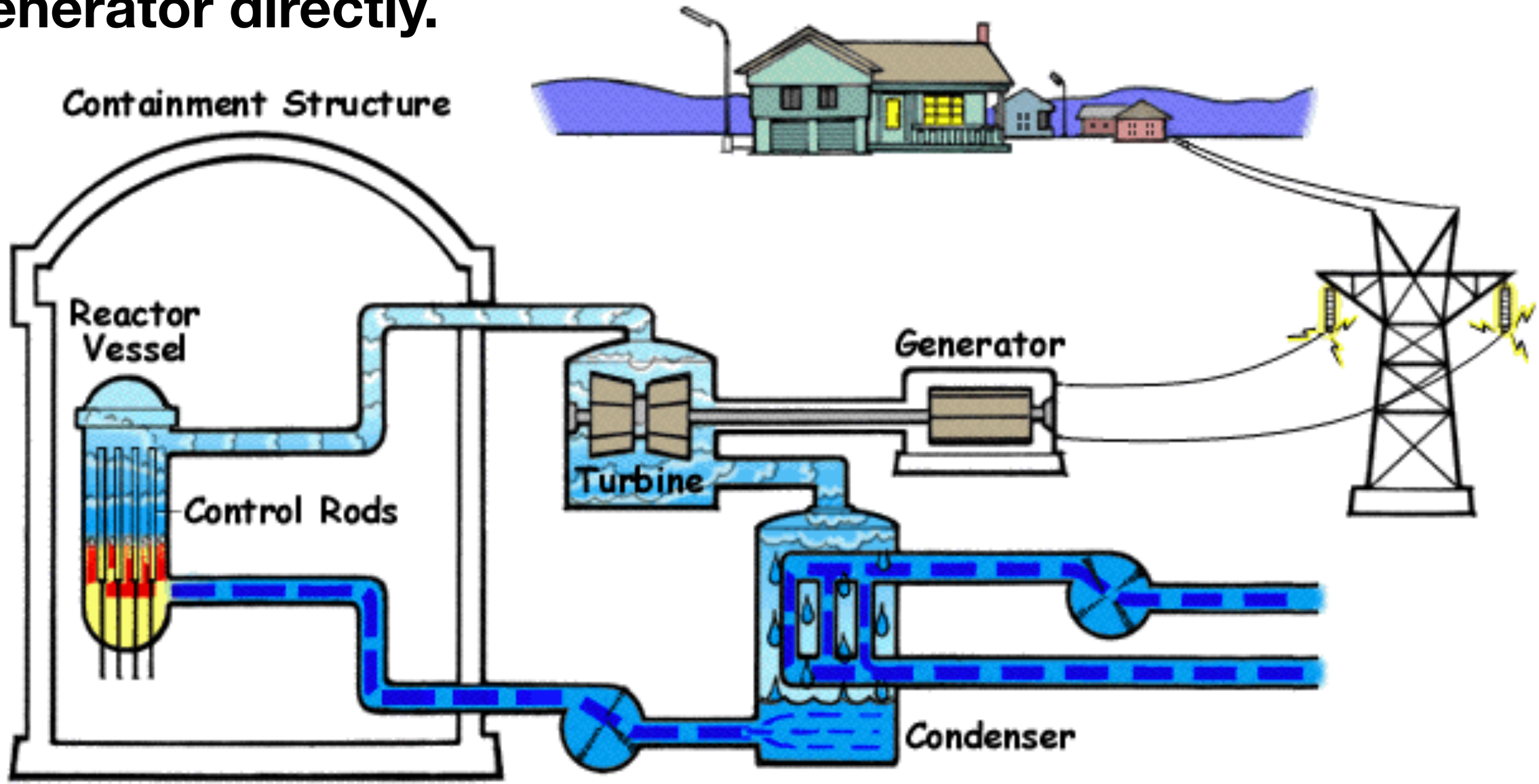
Fissile U-235 was
~ 3% of uranium.

Groundwater **H**2O
slowed neutrons to
fissioning speeds.

Fission heat
evaporated water.

Reactor cycled on/
off.

Boiling water reactor (BWR) 75 bar steam turns turbine-generator directly.

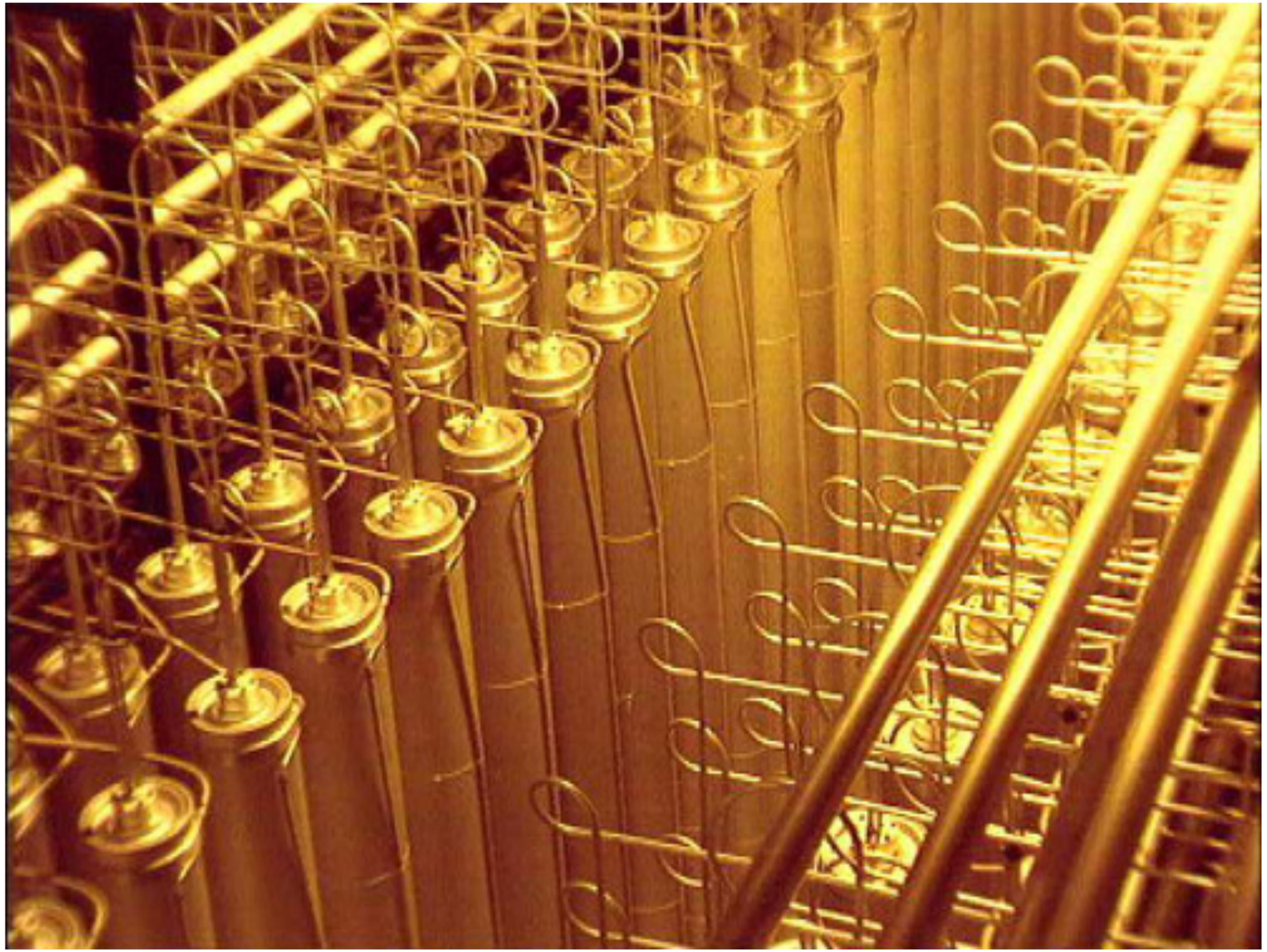


https://www.nrc.gov/reading-rm/basic-ref/students/animated-bwr.html

Uranium fuel is typically enriched from 0.7% U-235 to 3-5%.

Centrifuge enrichment capacity.

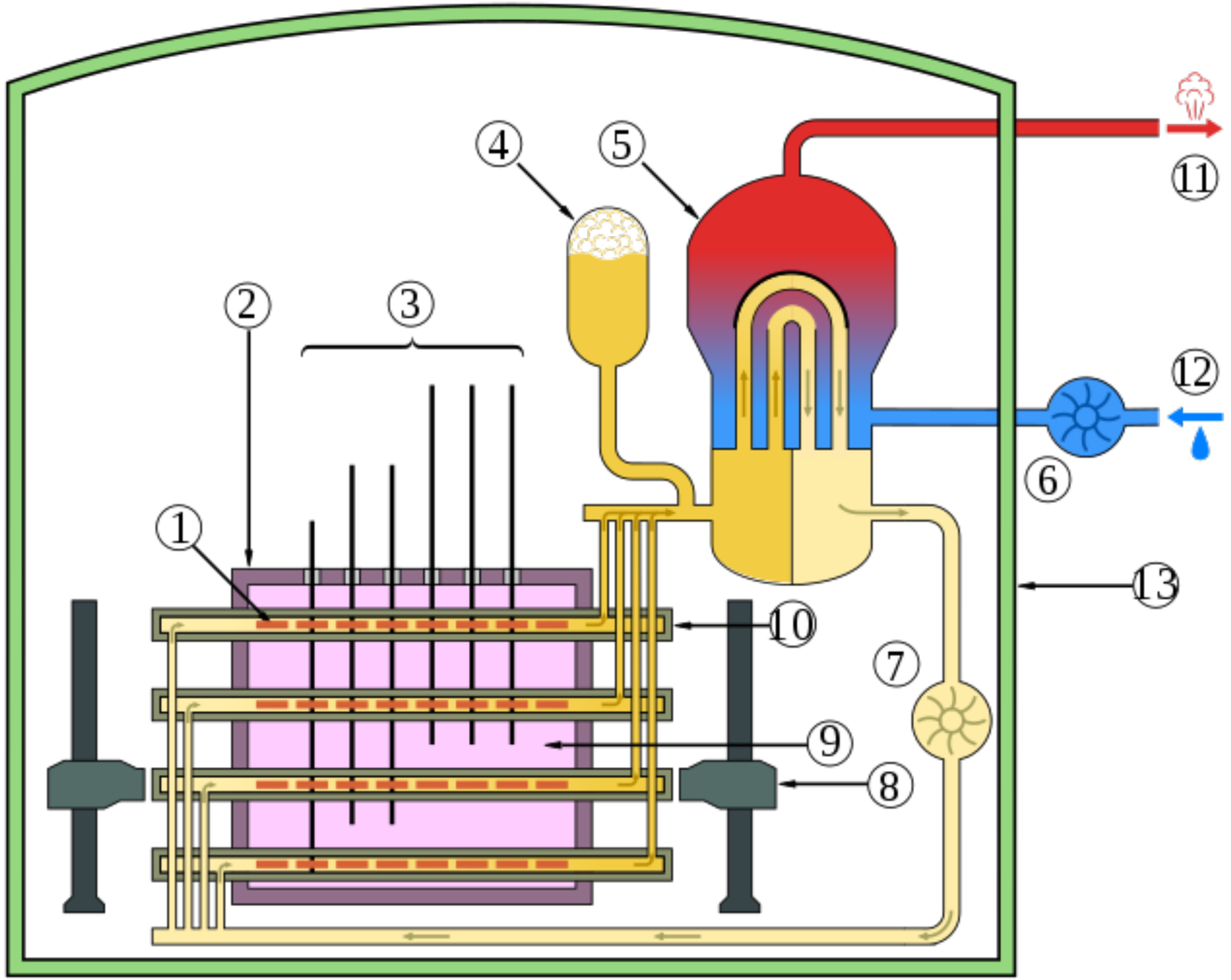
Operator	2018	2020	2030
CNNC	6750	6750	19,644
Orano	7500	7500	7500
Rosatom	28,215	27,654	25,000
Urenco	18,600	18,320	16,487
Other	46	66	450
Total	61,111	60,199	69,081



Cascade of centrifuges incrementally concentrating UF6 gas

https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx

CANDU reactor moderator is D2O, w/o large pressure vessel.



https://en.wikipedia.org/wiki/CANDU_reactor

D2O is heavy water, H2O where each H has 1 proton and 1 neutron, so does not absorb fission neutrons.

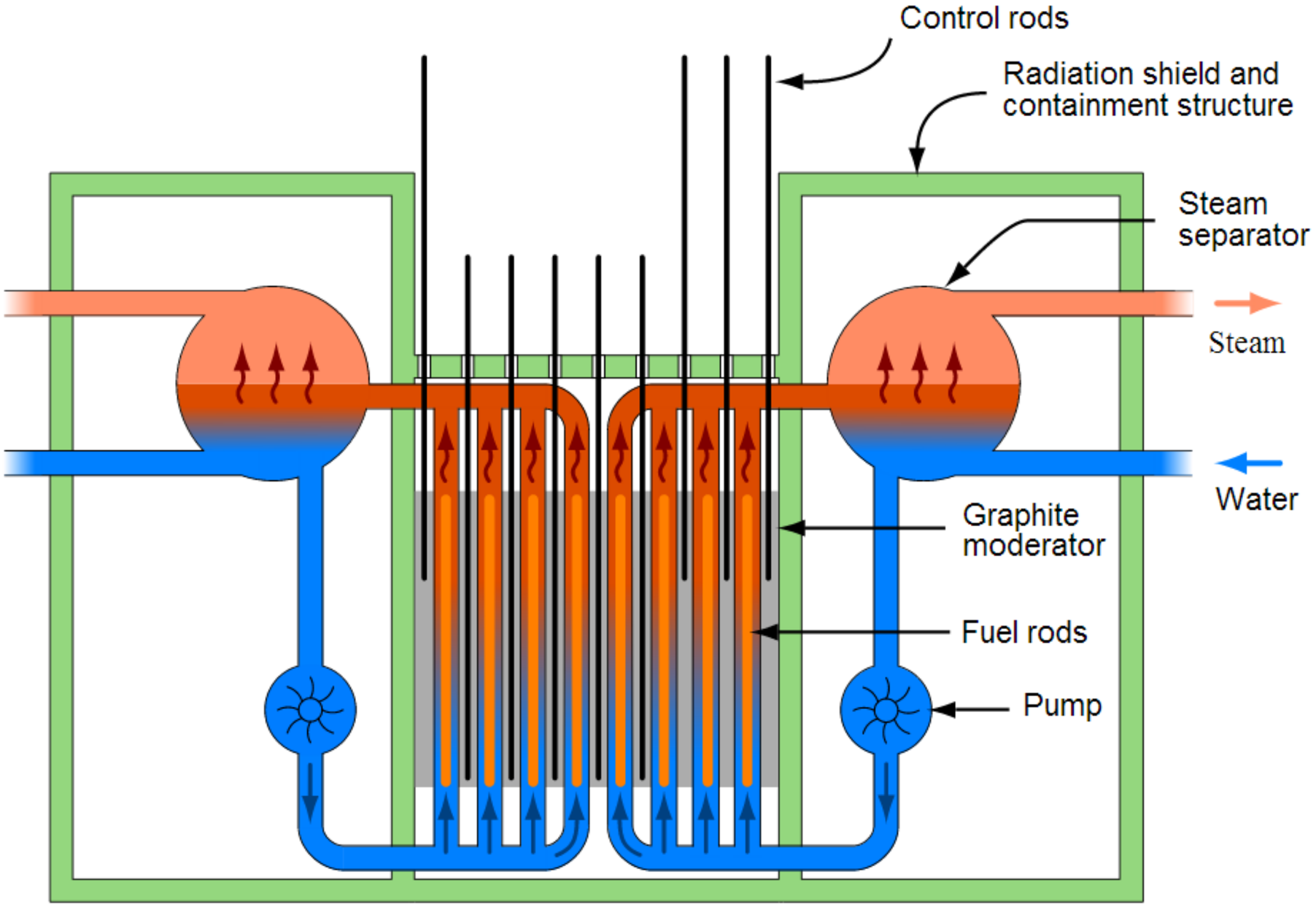
CANDU can use natural, unenriched uranium.

Hot and cold sides of the primary heavy-water loop

hot and cold sides of secondary light-water loop

cool heavy water moderator in the calandria

Russian RBMK is graphite moderated, water cooled



Chernobyl, 1986

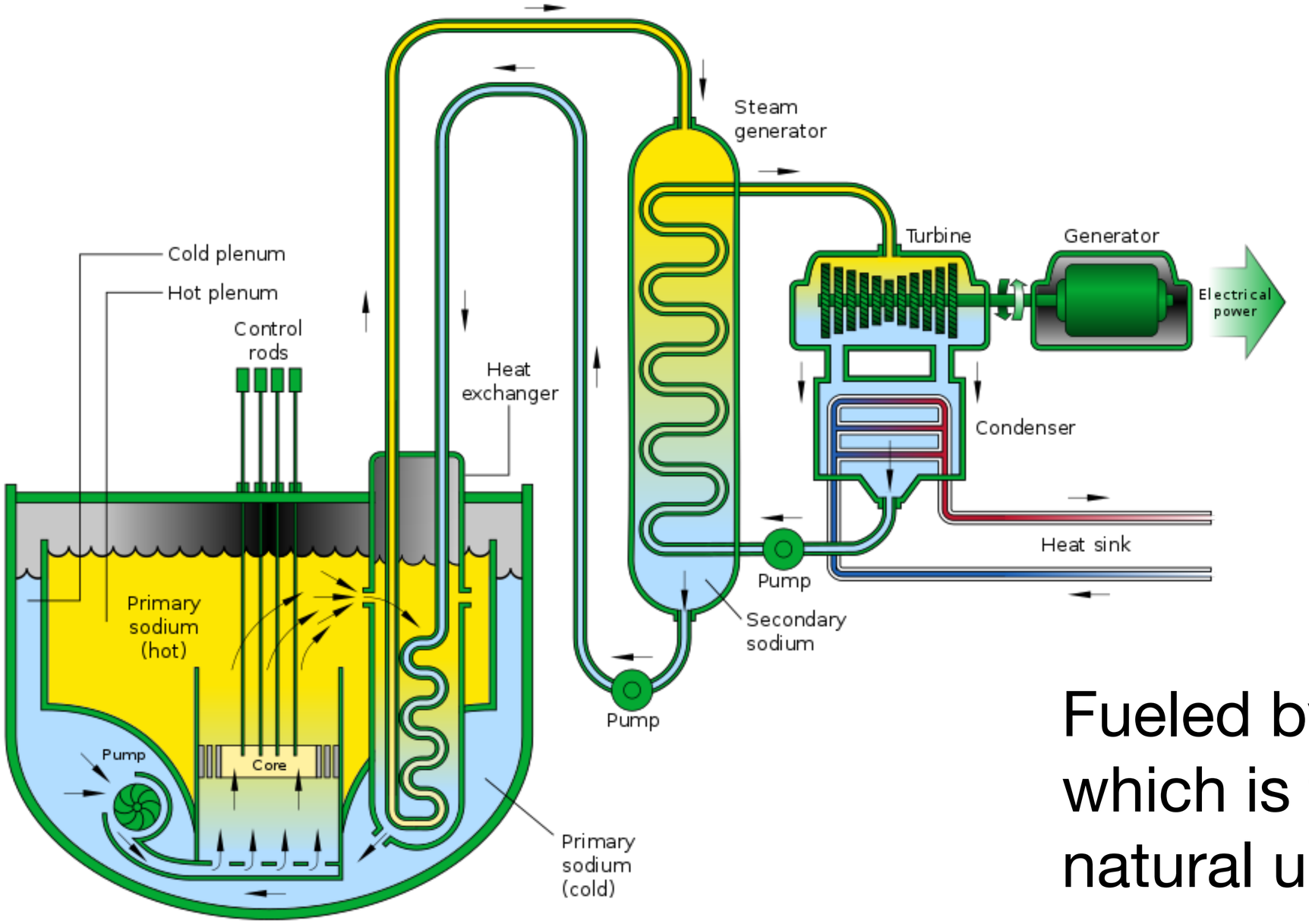
Positive void coefficient

Safety systems improved

8 RBMK plants still operating in Russia

https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/appendices/rbmk-reactors.aspx

Sodium cooled fast reactor has no neutron moderator.

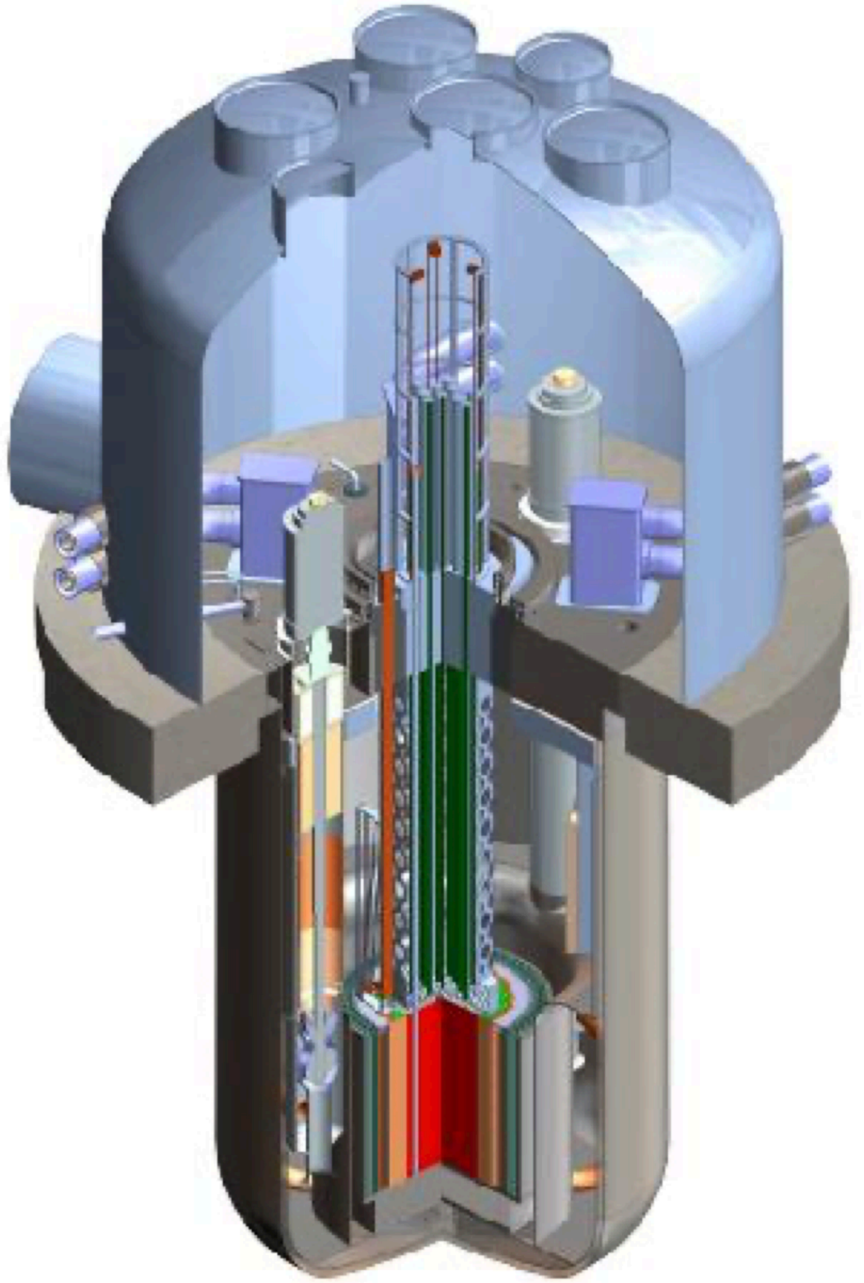


Fueled by U-238, which is 99% of natural uranium

https://en.wikipedia.org/wiki/Sodium-cooled_fast_reactor

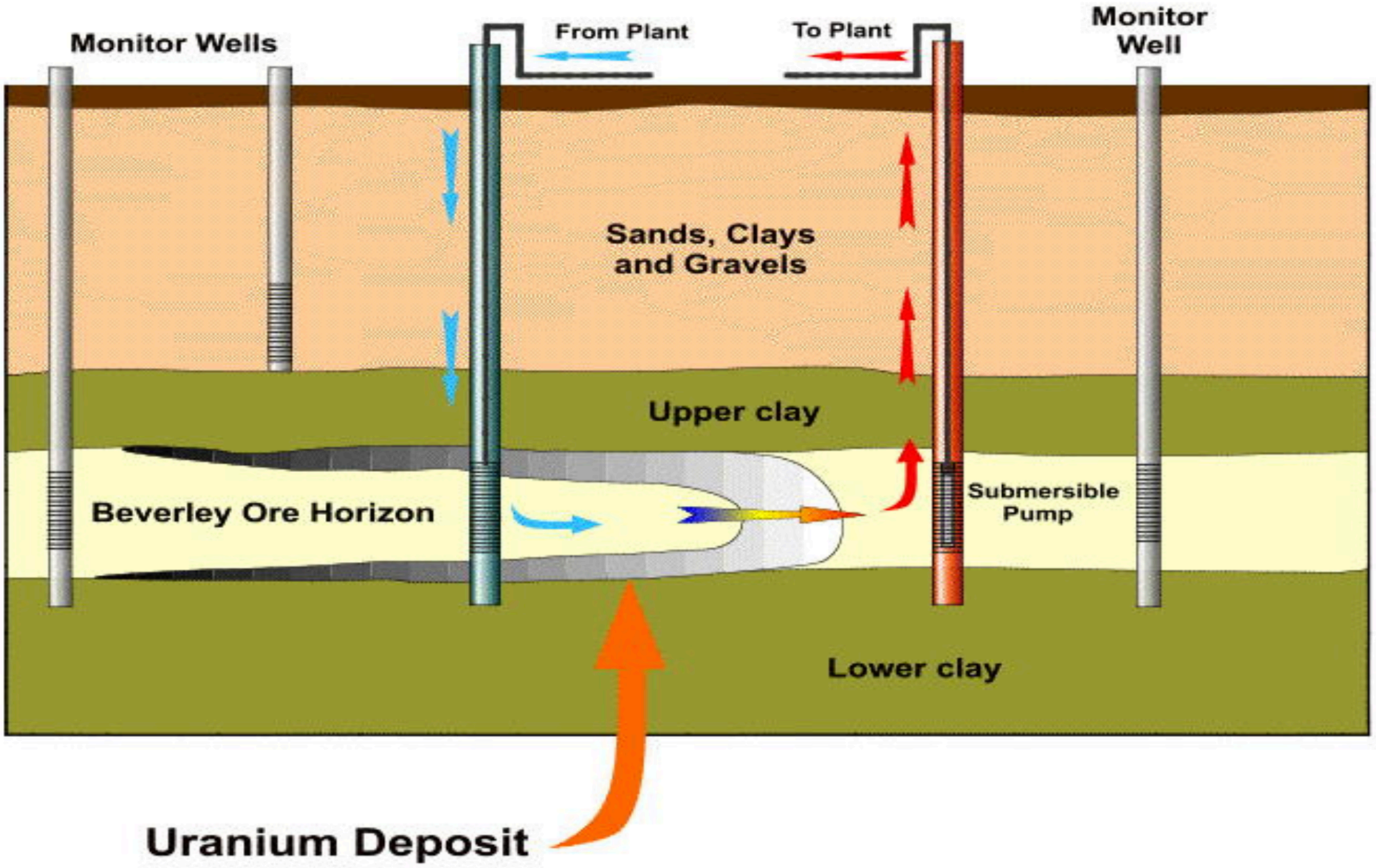
TWR-P (TerraPower)

1. Sodium cooled fast reactor
2. Funded by Bill Gates
3. US, then China, then US
4. 1475MWt, 600 MWe
5. U-238 fuel rods breed Pu-239 then moved internally
6. Ample U-238 fuel, tailings



https://aris.iaea.org/PDF/TWR-P.pdf

In situ leach mining of uranium



https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/in-situ-leach-mining-of-uranium.aspx

Many laboratories are developing seawater uranium extraction.

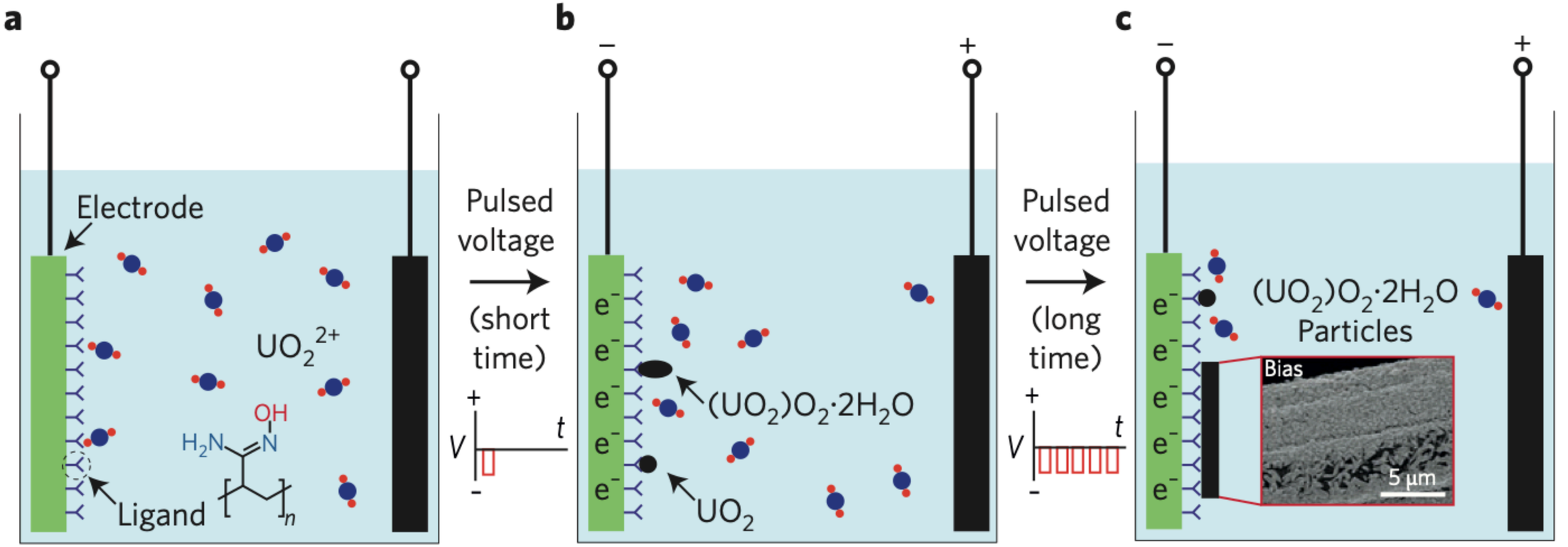
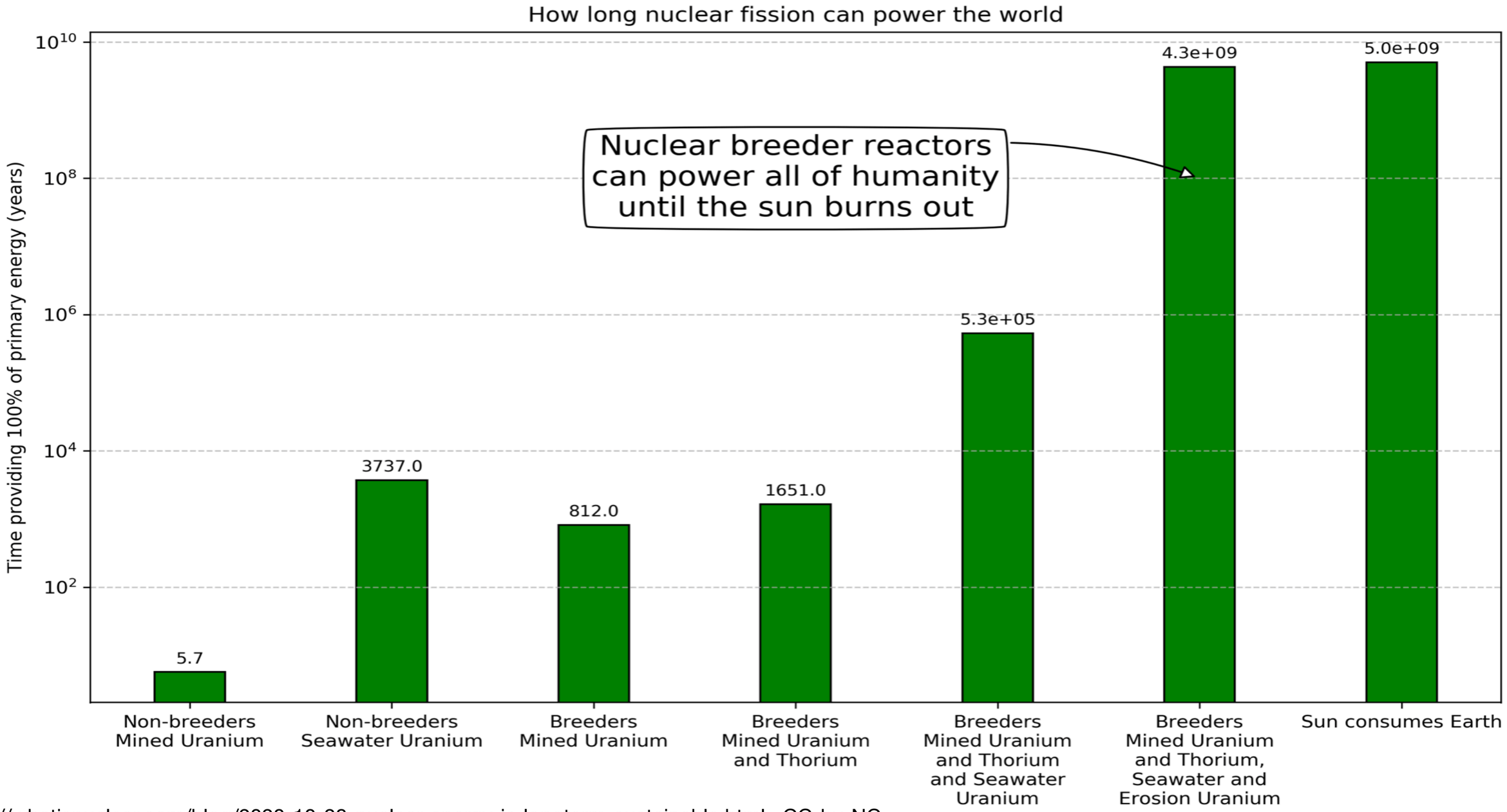


Figure 1 | Alternating-current method for electrochemical extraction of uranium. **a**, The amidoxime-functionalized electrode is submersed in uranium-spiked seawater. **b**, On application of a pulsed voltage, uranyl ions migrate towards the electrode leading to precipitation of uranium-rich particles. **c**, Continued pulsed voltage causes growth of the particles. The inset shows an SEM image of the amidoxime electrode covered by particles after 24 h of extraction with an initial uranium concentration of 1,000 ppm. Figure adapted from ref. 7, Macmillan Publishers Ltd.

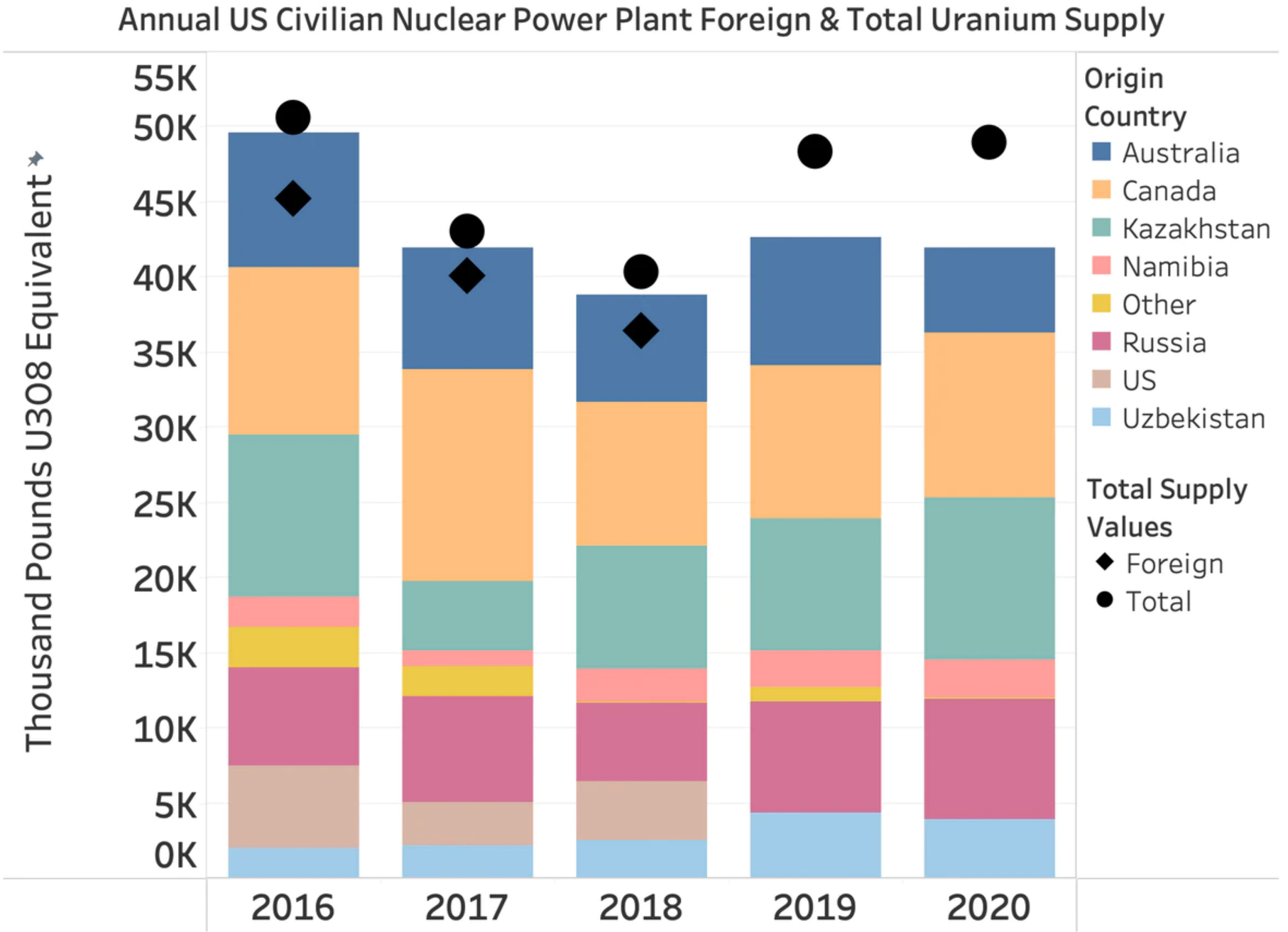
https://www.nature.com/articles/nenergy201722.pdf.

Nuclear fuel will last us for 4 billion years, writes Nick Touran.



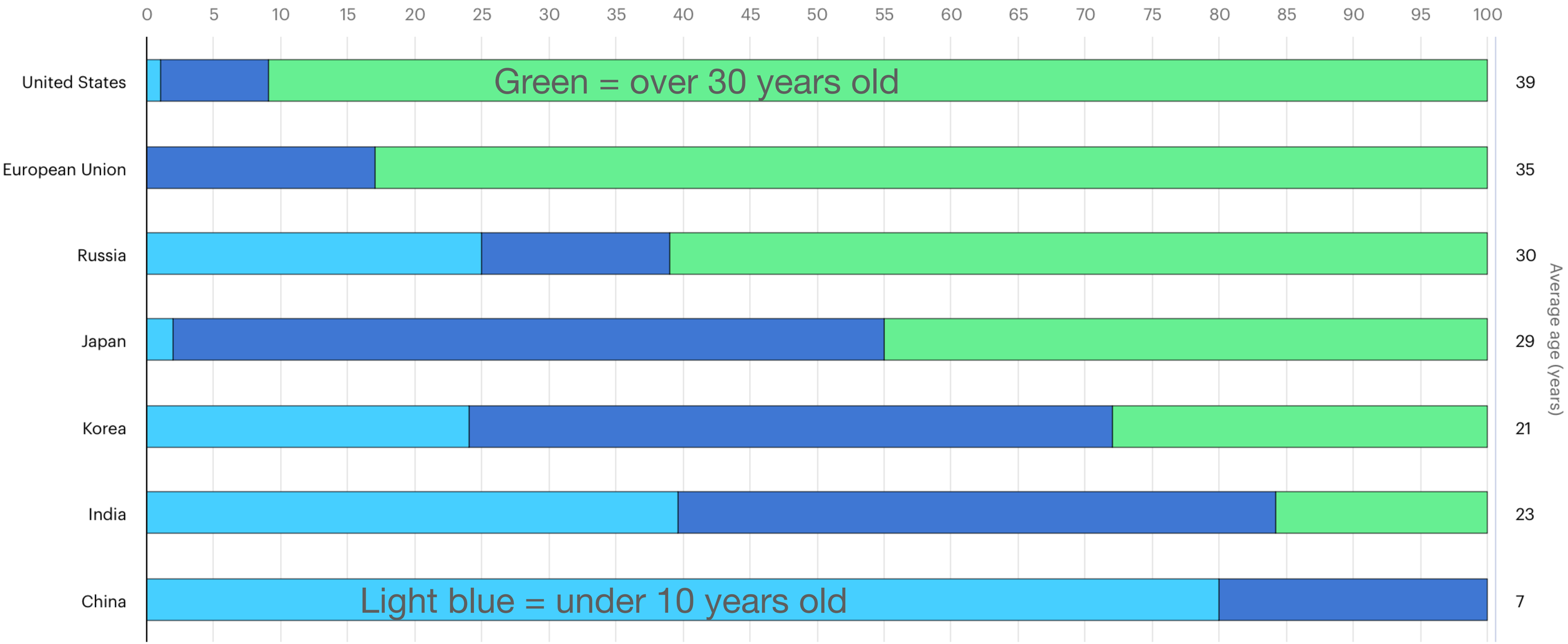
https://whatisnuclear.com/blog/2020-10-28-nuclear-energy-is-longterm-sustainable.html. CC-by-NC

The US supplies very little of its uranium fuel needs.



https://thebreakthrough.org/issues/energy/report-energy-security-and-decarbonization-in-response-to-russian-aggression?utm_source=Breakthrough+Newsletter&utm_campaign=78ed62e0df-BTI_Weekly_3_16_2022&utm_medium=email&utm_term=0_49b872540e-78ed62e0df-44367585

Age profile of nuclear power capacity in selected nations, 2019



https://www.iea.org/data-and-statistics/charts/age-profile-of-nuclear-power-capacity-in-selected-regions-2019

ThorCon

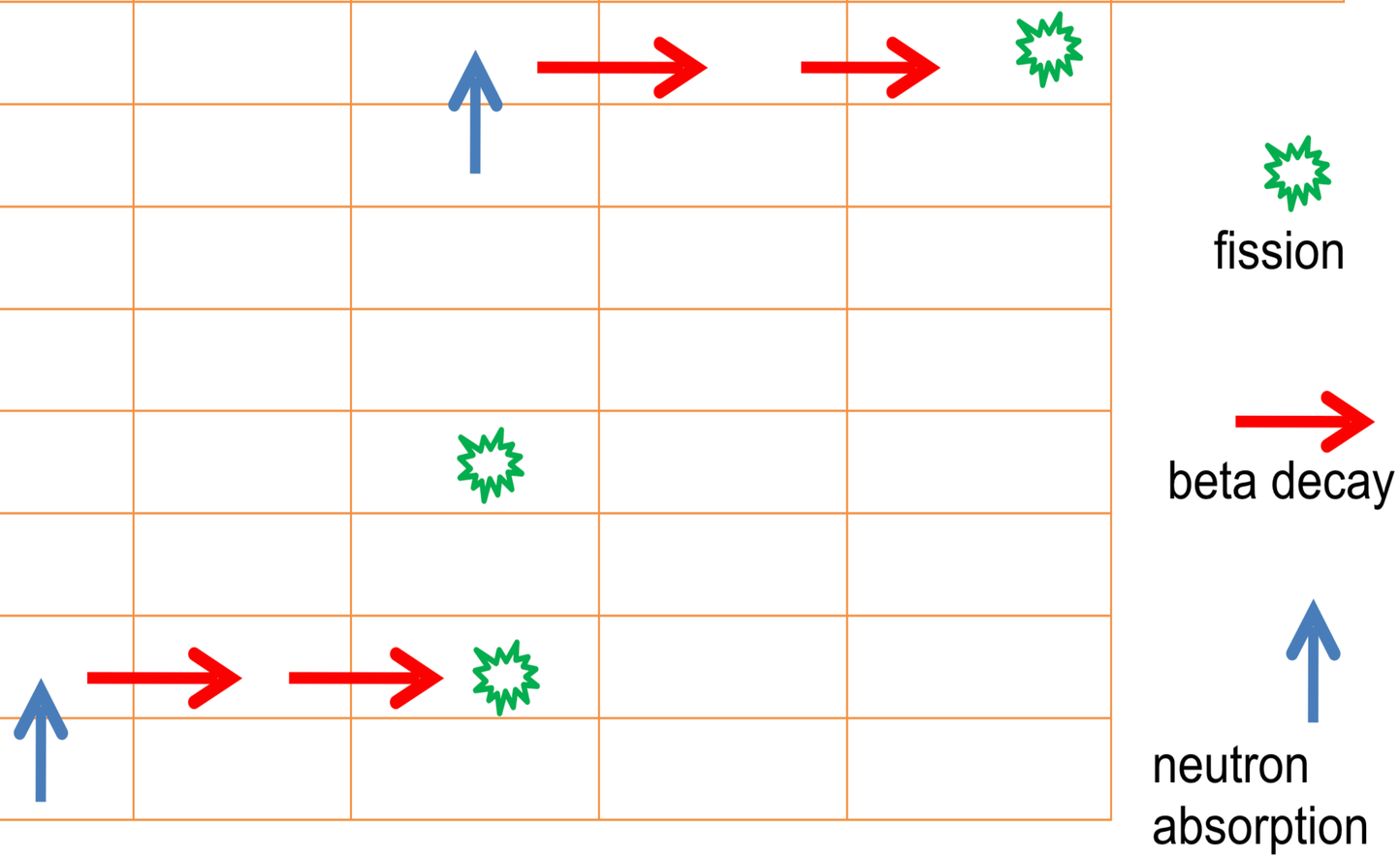
ThorCon
Powering Up Our World

- to mass-produce fission power plants
- to generate CO2-free, 24x7 electricity
- cheaper than from coal or LNG
- at shipyard scale — 10 GW per year
- helping people achieve prosperity.

Robert Hargraves is a cofounder of ThorCon.

ThorCon is a Thorium Converter

nucleons	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95
241						
240						
239						
238						
237						
236						
235						
234						
233						
232						



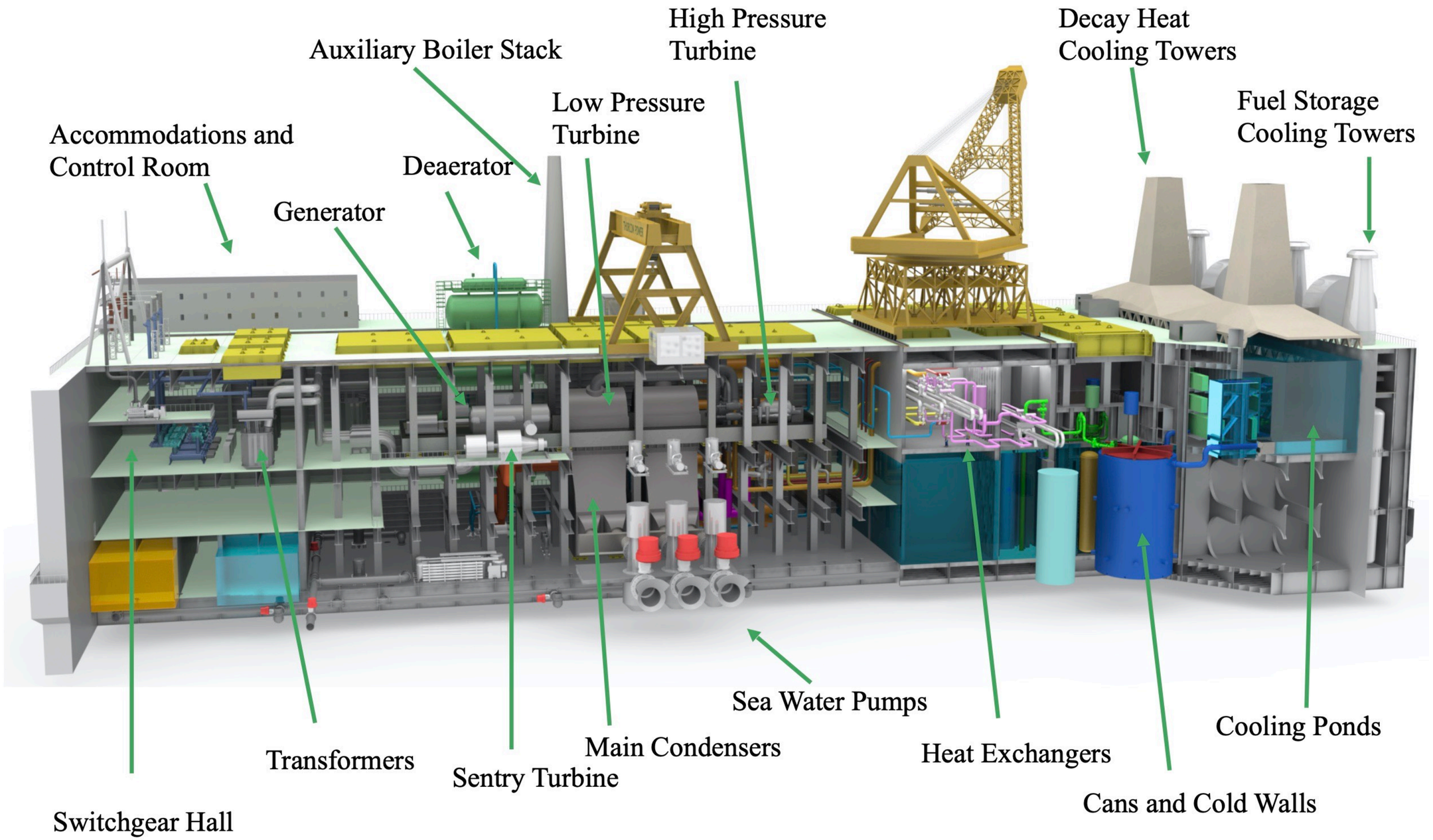
Fission power

Uranium
- 19.75% U-235
- 50%

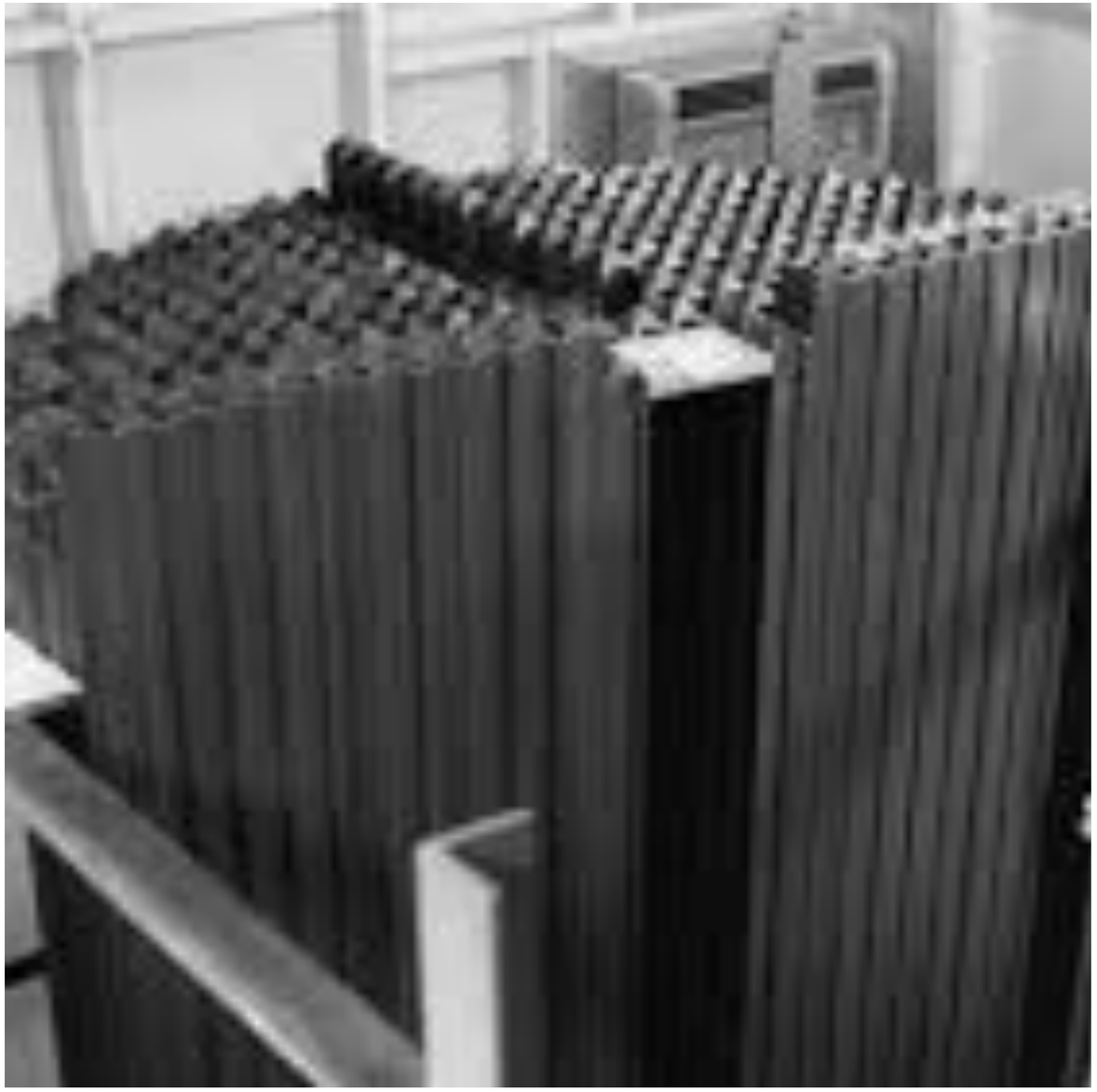
Thorium
Th-232 —> U-233
- 25%

Plutonium
U-238 —> Pu-239
- 25%

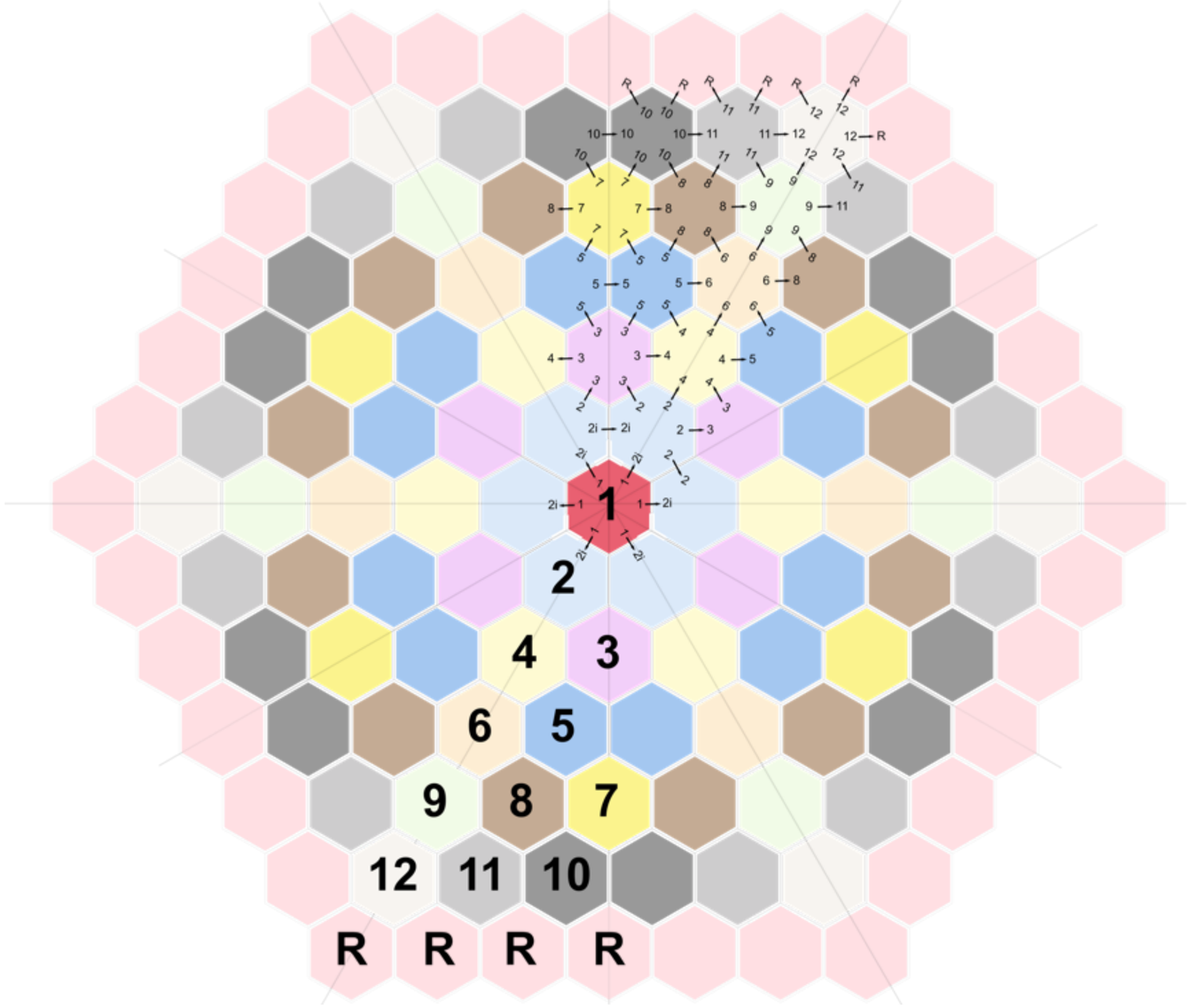
ThorCon 500 MW liquid fuel fission power plant



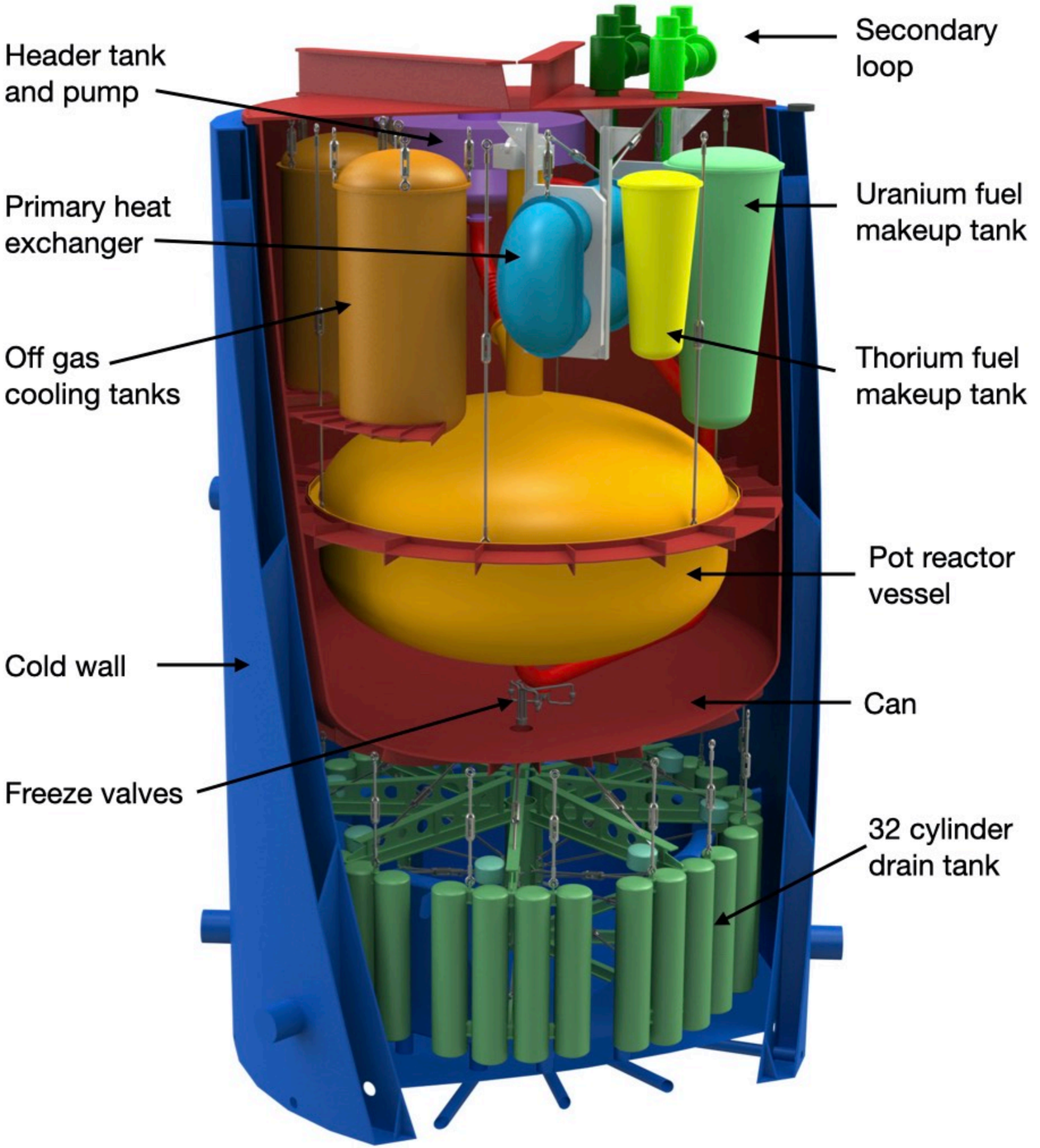
Molten salt with dissolved fuel flows up in channels in graphite moderator core.



In the reactor Pot the molten fuelsalt flows up in channels of graphite moderator logs.



- Fission energy heats molten salt as it is pumped up.
- Stable power: fission slows as temperature rises.
- Heat exchangers isolate radioactivity and transfer heat to make steam.
- High 700°C temperature gives high 46% efficiency.



Replaceable Can, in Silo Cold Wall

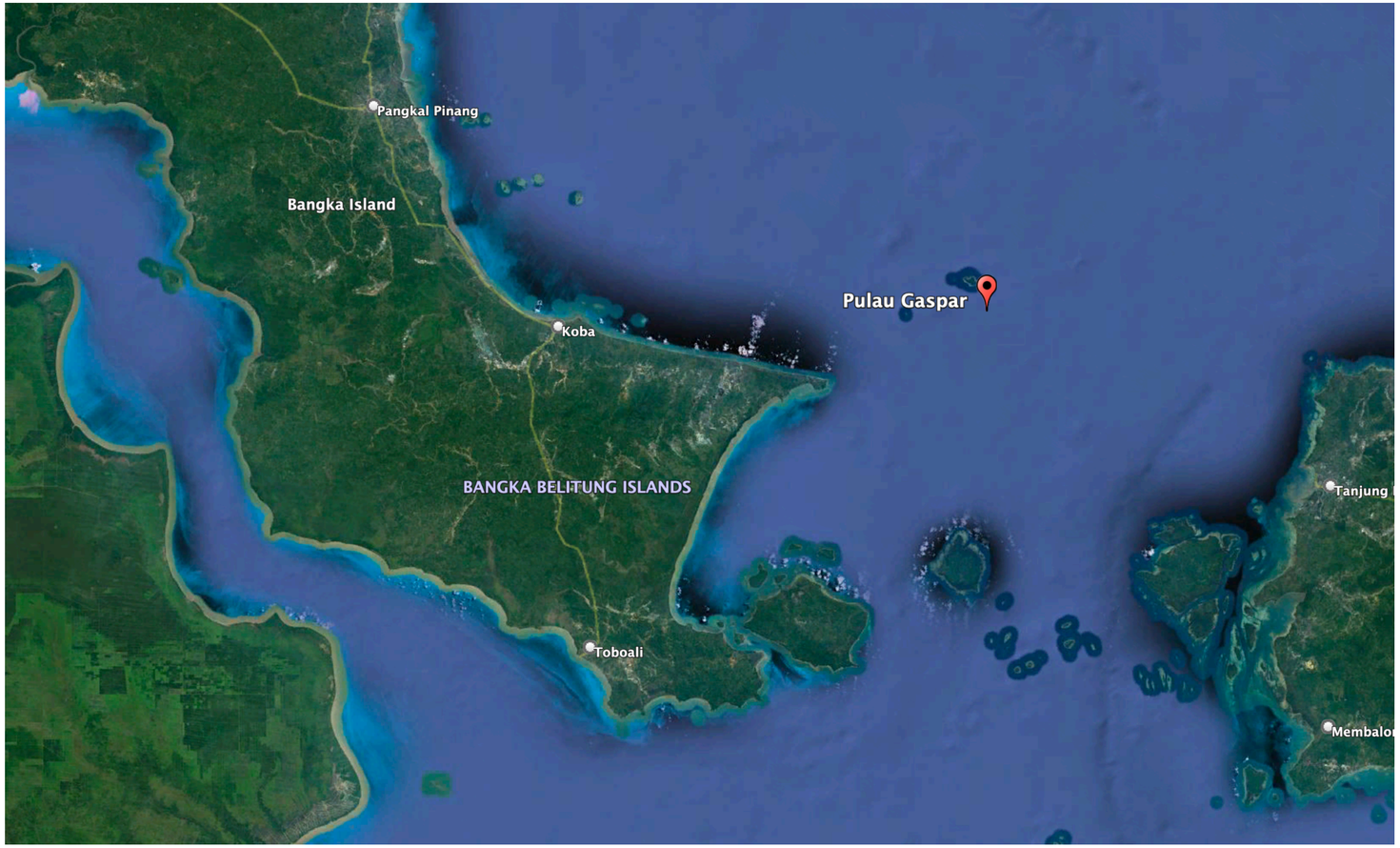
- The reactor Pot contains the graphite moderator with channels for molten salt flow.
- Freeze valve melt drains salt to drain tank.
- Cold wall absorbs heat radiated from drain tank.
- Cold wall is cooled by natural water circulation.

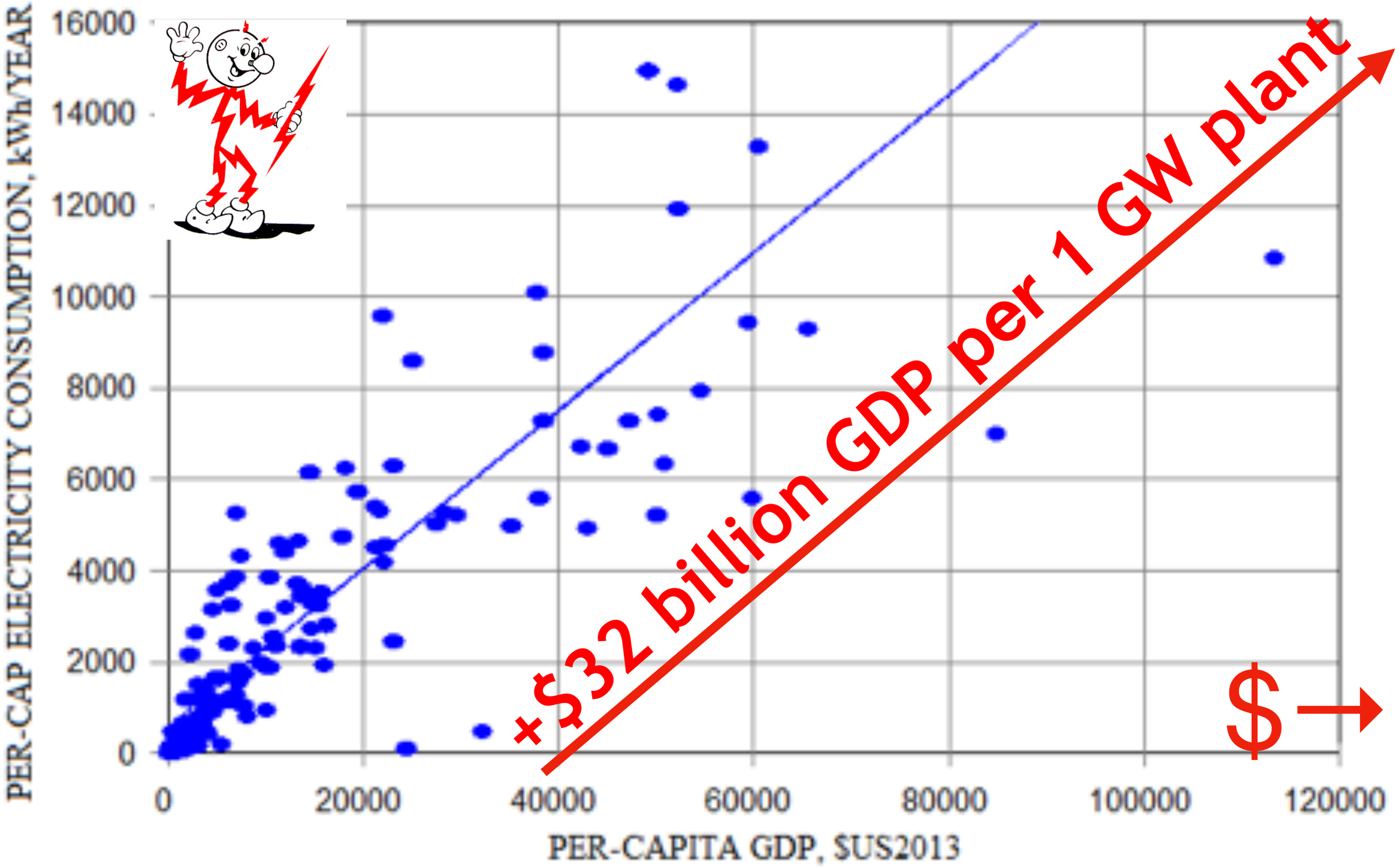
Daewoo Shipbuilding and Marine Engineering will be ThorCon's EPC.

Prototype will be towed to Indonesia.

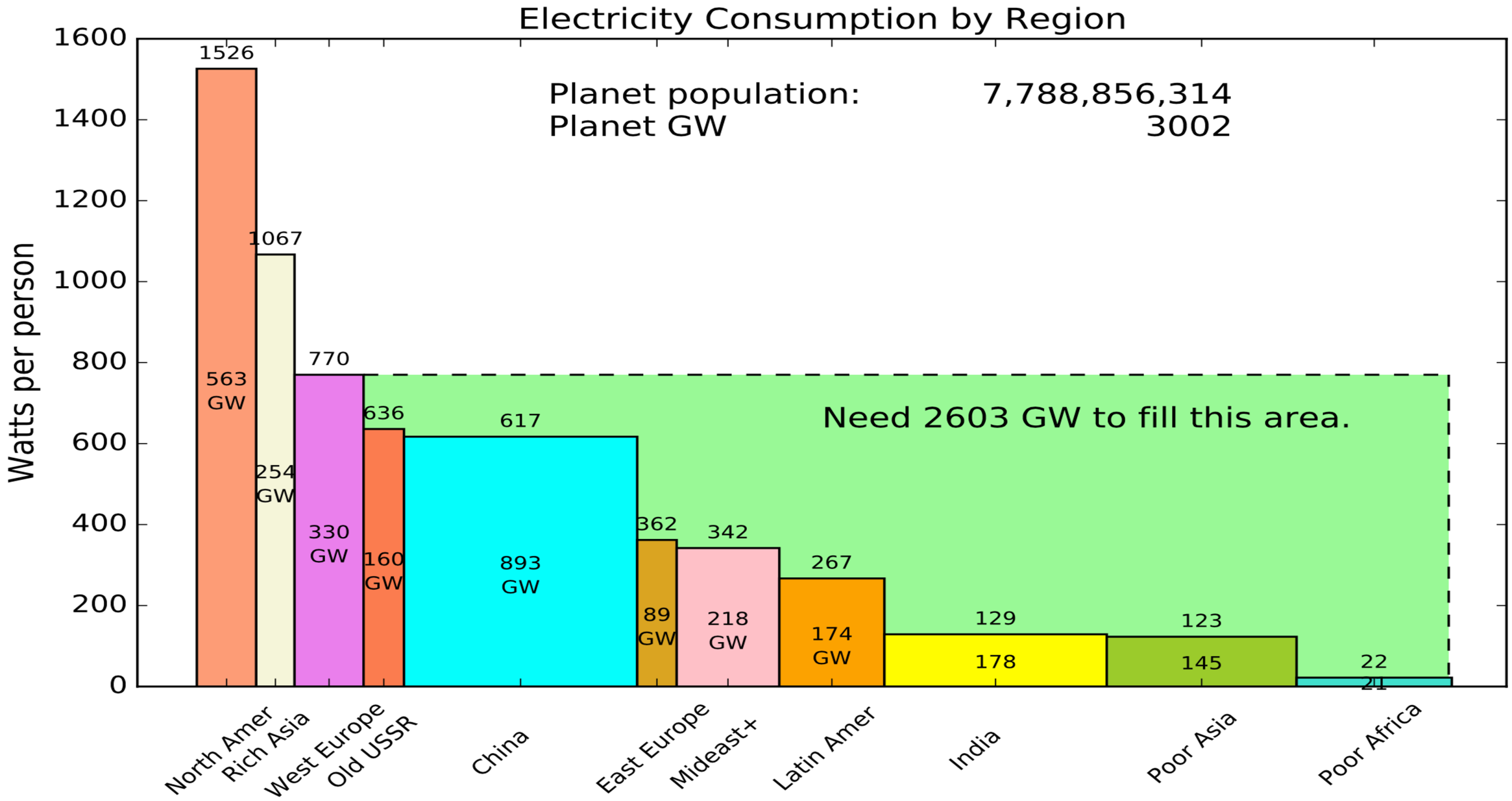

Sea
THAILAND
South China
Sea
Strait of
Malacca
MALAYSIA
BRUNEI
MALAYSIA
Pulau Ligitan
Celebes
Sea
Pulau
Sipadan
Borneo
Medan
Sungaipakning
SINGAPORE
Pekanbaru
Pontianak
Equator
Padang
Kalimantan
Sumatra
Sulawesi
(Celebes)
Palembang
Banjarmasin
Java Sea
Makassar
Ciwandan
JAKARTA
Semarang
Madura
Banda Sea
Bandung
Java
Surabaya
INDIAN
OCEAN
Denpasar
Kupang
TIMOR-L

Bangka-Belitung governor approved island site.




PER-CAP ELECTRICITY CONSUMPTION, kWh/YEAR
16000
14000
12000
10000
8000
6000
4000
2000
0
0
20000
40000
60000
80000
100000
120000
PER-CAPITA GDP, $US2013
+$32 billion GDP per 1 GW plant
$

3,000 GW global electricity use may grow by 2,600 GW.




Developing nations now build coal-fired power plants.
Reliable, 24x7, affordable

ThorCon capital, fuel, and electricity: cheaper than coal.

Costs	units	Coal	ThorCon
Capital	$/kW	1000-2000	800-1000
Fuel	cents/kWh	2.5	0.5
Electricity	cents/kWh	5	3

- Nations **will choose** 24x7 fission, if it's **cheaper.**

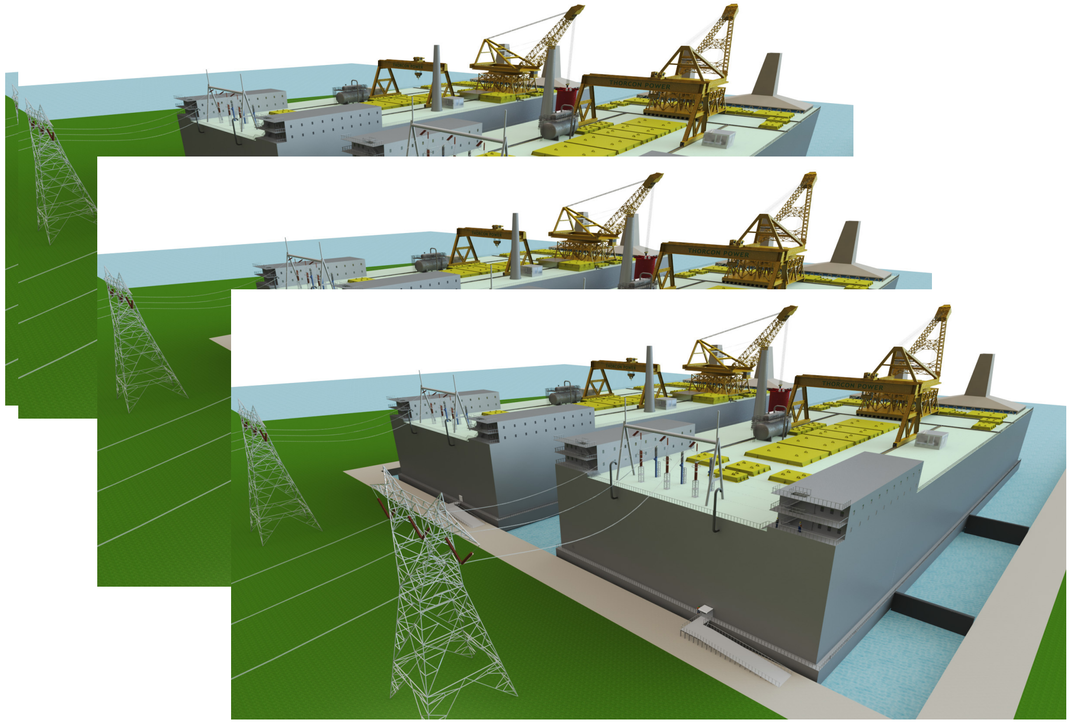
Economics	**Fission**	**Coal**
Capital cost, $/Watt	1.2	2.0
Fuel cost, cents/kWh	0.53	2.27
Electricity, cents/kWh	**3**	**5**

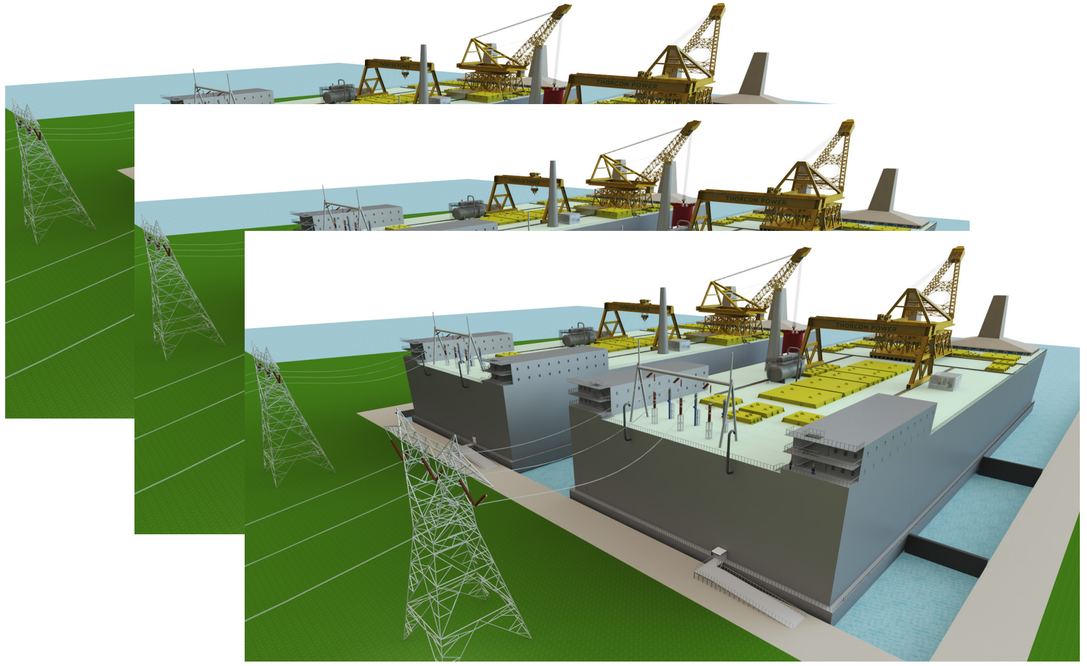
One large shipyard can build 10 GW of liquid fission power plants a year.

Cheaper than coal, 24x7, zero CO_2, 3¢/kWh


MOLTEN SALT
THORIUM CONVERTERS

The shipbuilding industry has capacity to build 12,000 GW of liquid fission plants in 30 years.





Powering Up Our World with 12,000 GW

@ $1.2/watt = $14.4 trillion, $30 per person per year

7 Fission power

Fission is in Fashion

Fission energy

PWR nuclear power plants

ThorCon

Molten salt reactor

Cheaper than coal

Market size, growth

Shipyard mass production