Lecture 14:Nuclear Power Plants

Course: MECH-422 – Power Plants

Instructor: Kashif Liaqat

Term: Fall 2021

BUITEMS – DEPARTMENT OF MECHANICAL ENGINEERING

Introduction to nuclear power

- Uranium was discovered in 1789 by Martin Klaproth, a German chemist, and named after the planet Uranus.
- The science of atomic radiation, atomic change and nuclear fission was developed from 1895 to 1945, much of it in the last six of those years
- Over 1939-45, most development was focused on the atomic bomb
- From 1945 attention was given to harnessing this energy in a controlled fashion for naval propulsion and for making electricity
- Since 1956 the prime focus has been on the technological evolution of reliable nuclear power plants.

Economic Advantages

- The energy in one pound of highly enriched Uranium is comparable to that of one million gallons of gasoline.
- One million times as much energy in one pound of Uranium as in one pound of coal.
- Nuclear energy annually prevents 5.1 million tons of sulfur 2.4 million tons of nitrogen oxide 164 metric tons of carbon
- First commercial power plant, England 1956
- 17% of world's electricity is from nuclear power

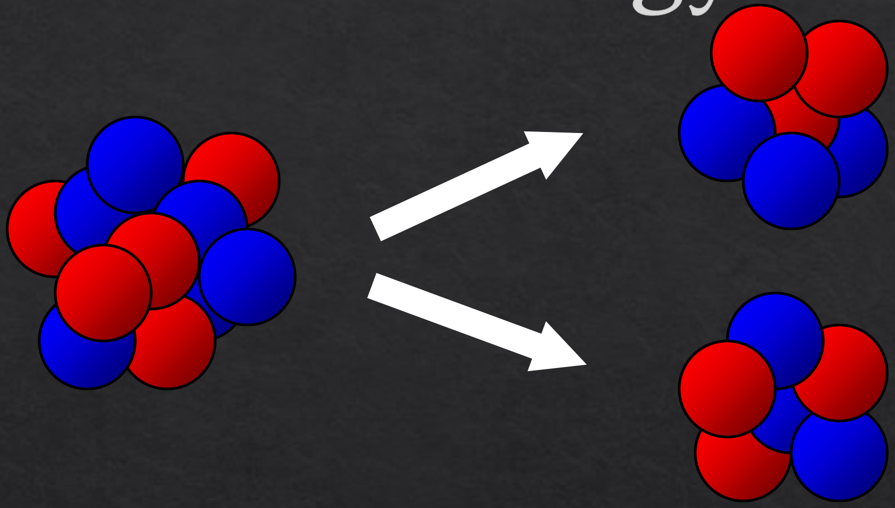
Why Are We Interested In Nuclear Power?

- There is a LOT of energy contained in atoms.
  - Fissioning **1 gram** of Uranium-235 produces 24,000 kW-hr of energy.
    - This is the same as burning **3 tons** of coal,
      or **12 barrels** of oil,
      or **50,000 ft^3** of natural gas
  - Your house uses ~20 kW-hr per day
- A *Nuclear* reaction, not a *Chemical* reaction

Nuclear Reactions

- Nuclear reactions deal with interactions between the nuclei of atoms including of nuclear fission and nuclear fusion
- Both fission and fusion processes deal with matter and energy
- Fission is the process of splitting of a nucleus into two "daughter" nuclei leading to energy being released
- Fusion is the process of two "parent" nuclei fuse into one daughter nucleus leading to energy being released

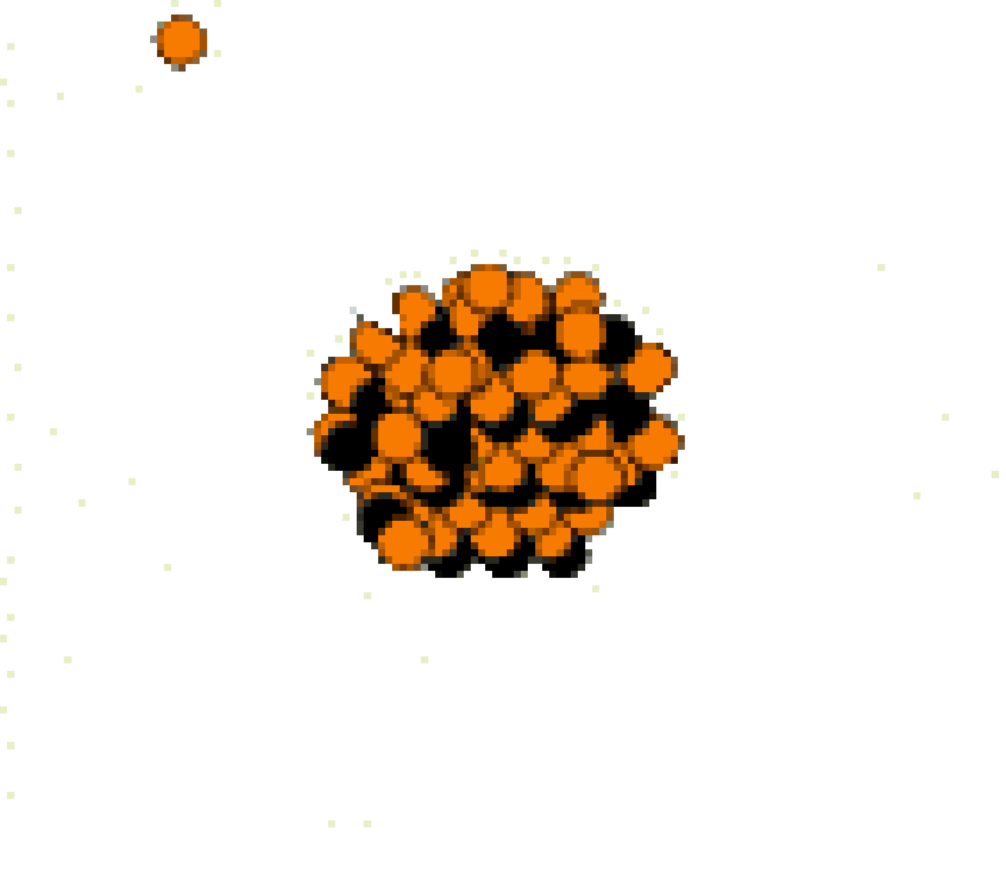
Where Does Nuclear Energy Come From?



Split 1 large atom into 2 smaller atoms…

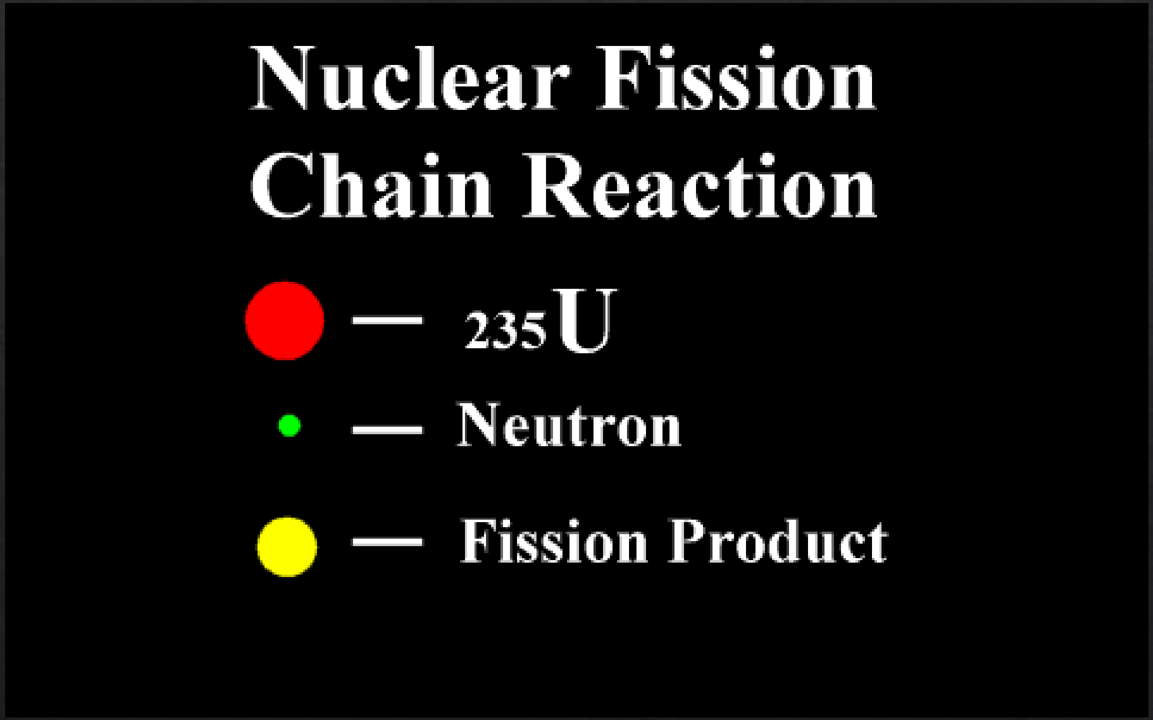
This is where all of the energy from nuclear power is produced.

Fission of Uranium-235



Fission Chain Reaction

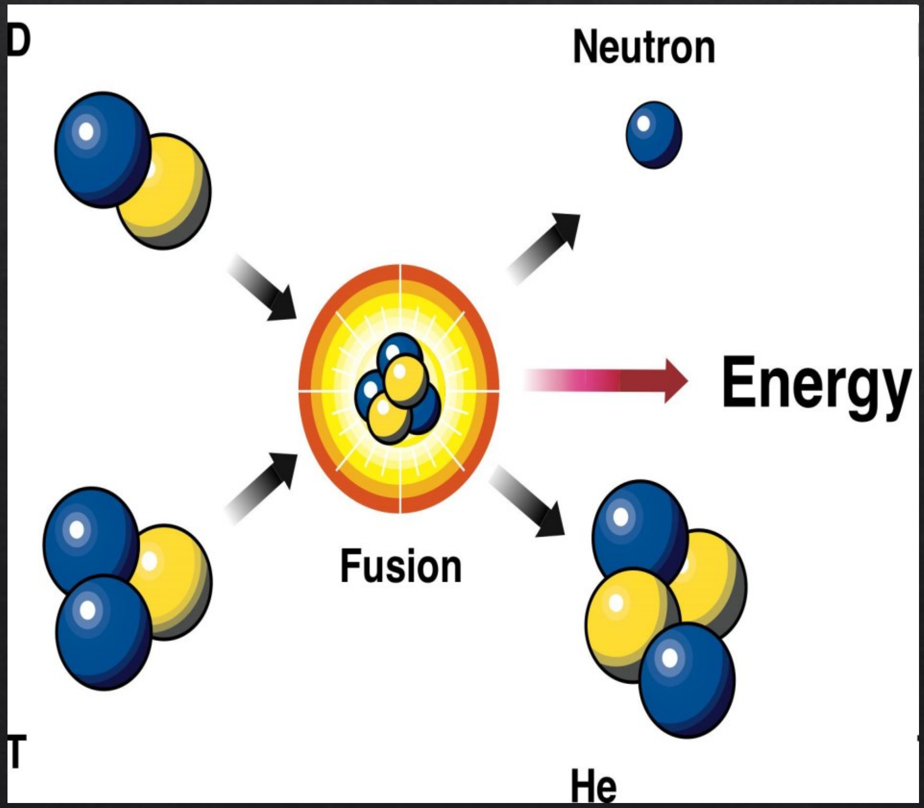
- This is the process that allows reactors to exist:
  - One free neutron causes one U-235 atom to fission
  - That fission produces 2 or 3 new free neutrons



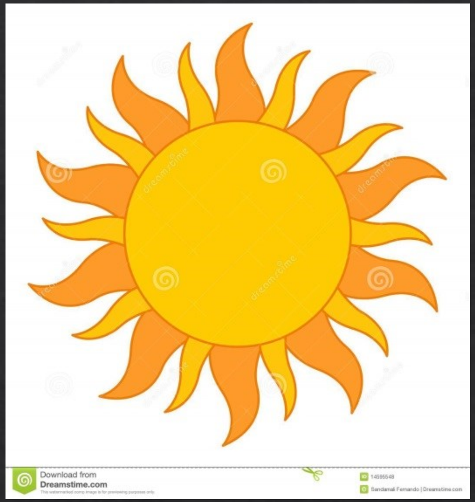
Fusion Reactions

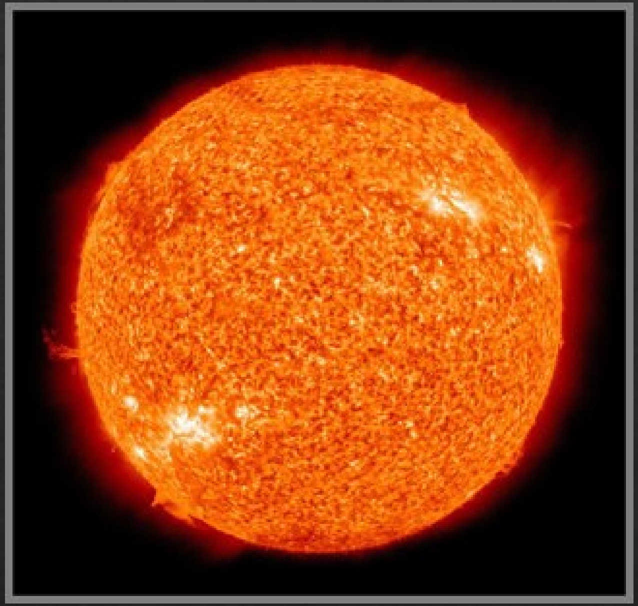
- A classic example of a fusion reaction is that of deuterium (heavy hydrogen) and tritium which is converted to Helium and release energy.

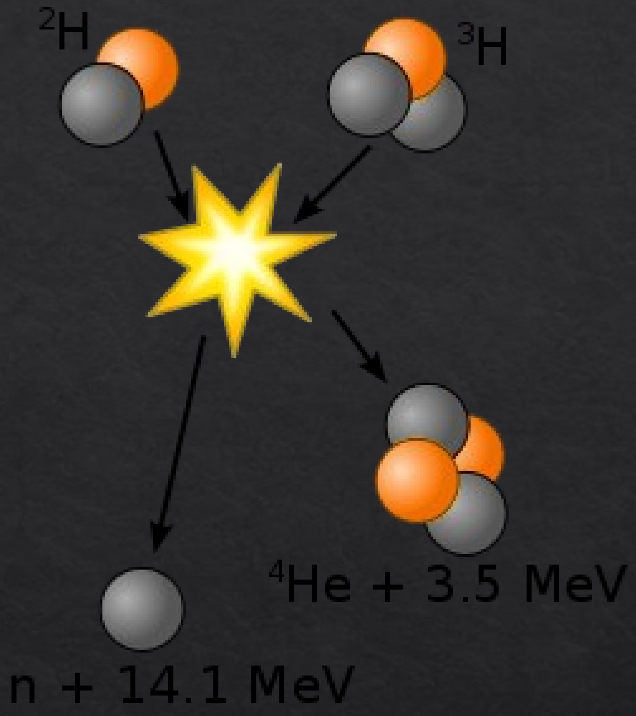
$$p + p \longrightarrow He + n + .42\ MeV$$



Deuterium – Tritium Fusion Reaction



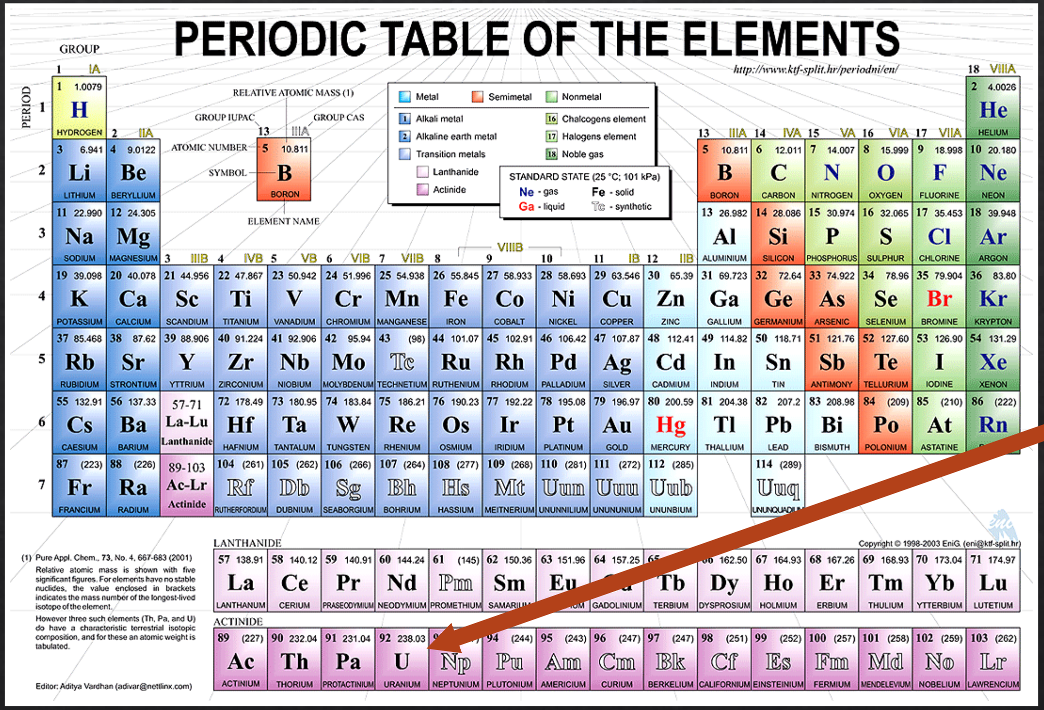




Fusion - Combining two light nuclei to form a heavier, more stable nucleus. The sun makes its energy by fusion.

Nuclear Fuel

- Nuclear (fission) reactors use Uranium as fuel



Wikimedia Commons

Uranium-235 has 92 protons and 143 neutrons

How Does a Nuclear Reactor Work?

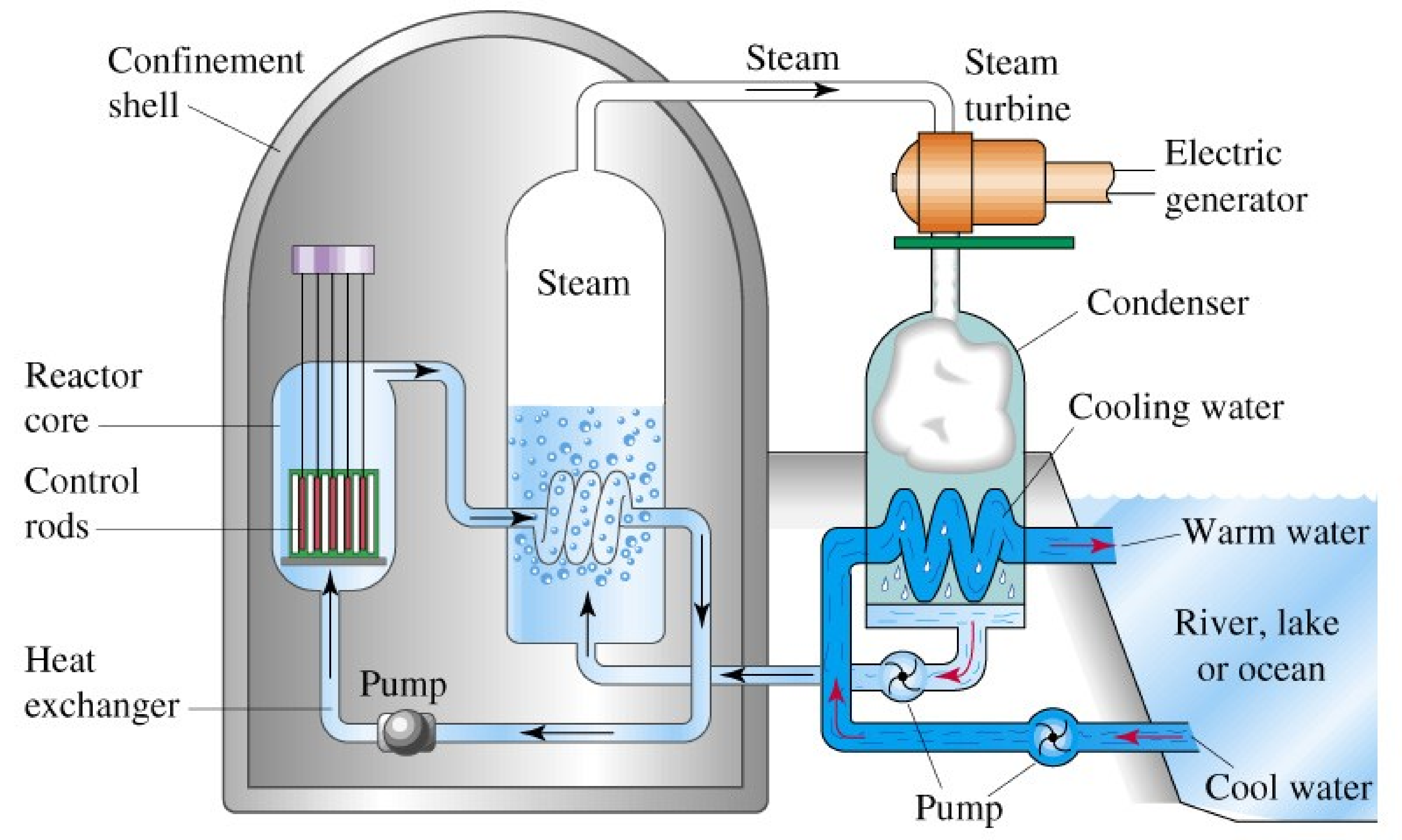
- Boil Water!

1. Produce heat
2. Boil water into steam
3. Use steam to turn a turbine-generator

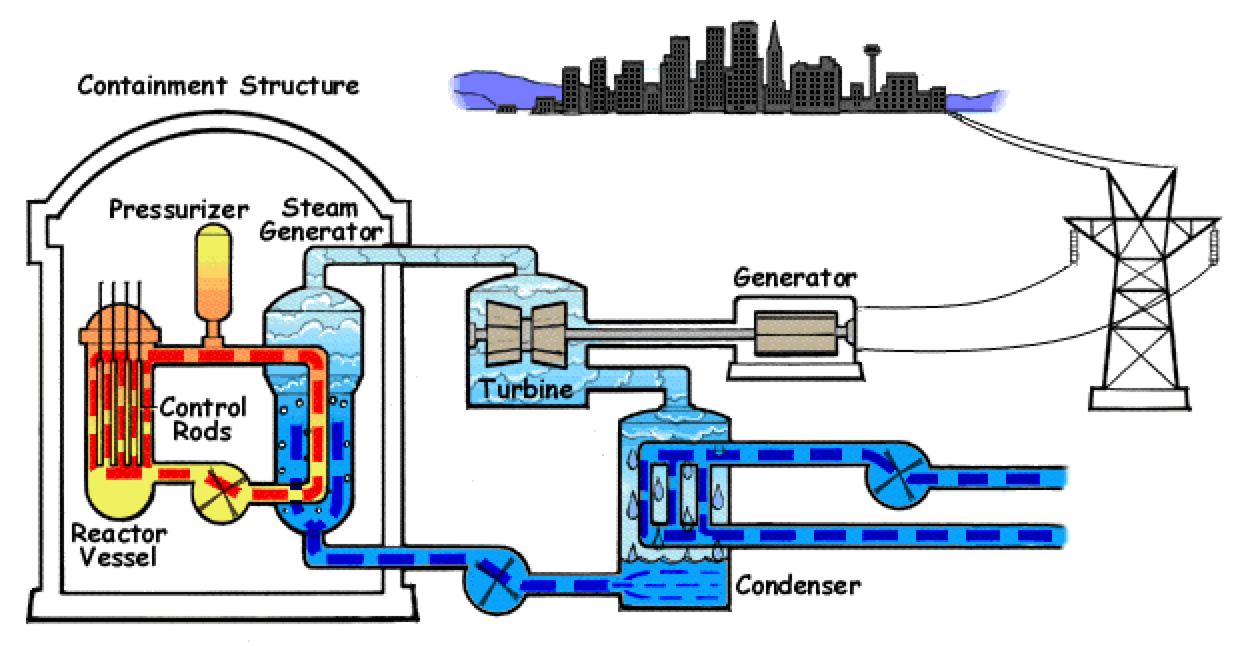
This is the same as a:

- Coal power plant
- Oil power plant
- Natural gas plant
- Solar thermal plant

A Fission Reactor

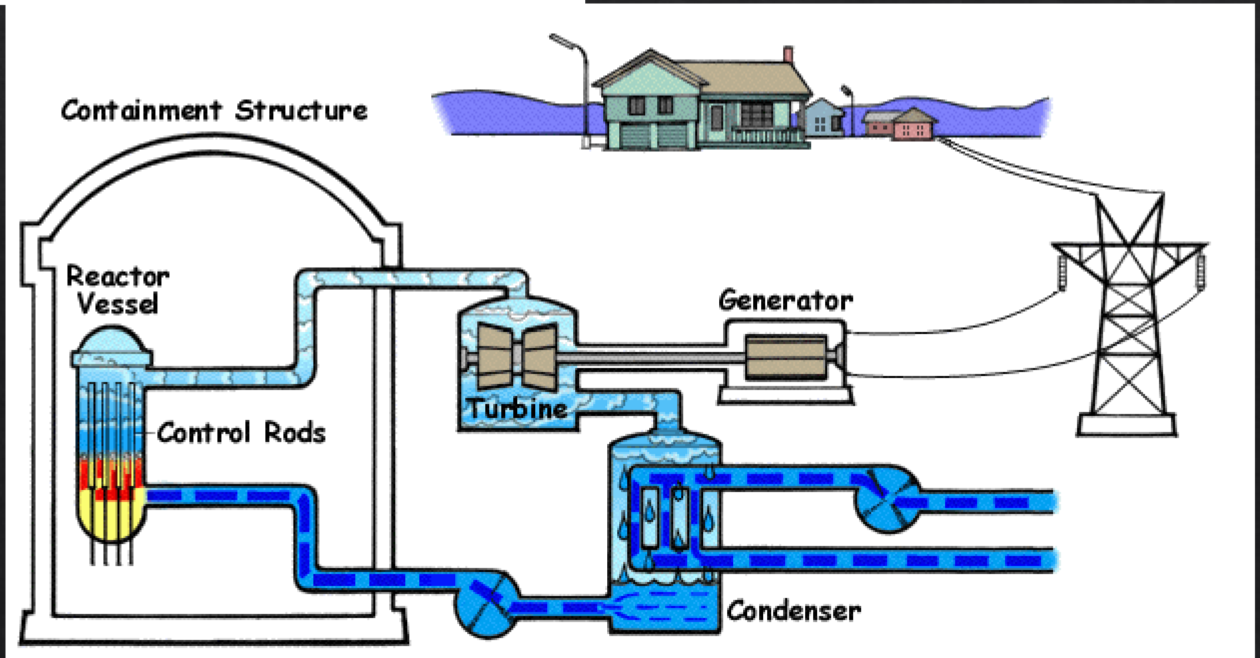


Nuclear Power Plant



The Pressurized Water Reactor (PWR)

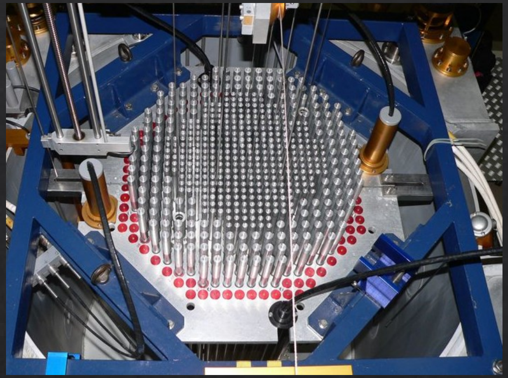
Boiling Water Reactor (BWR)



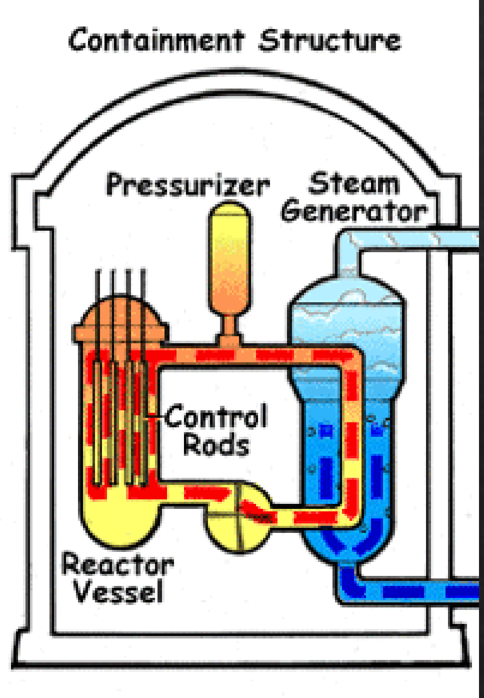
- https://www.youtube.com/watch?v=AMXxXoHtM-o

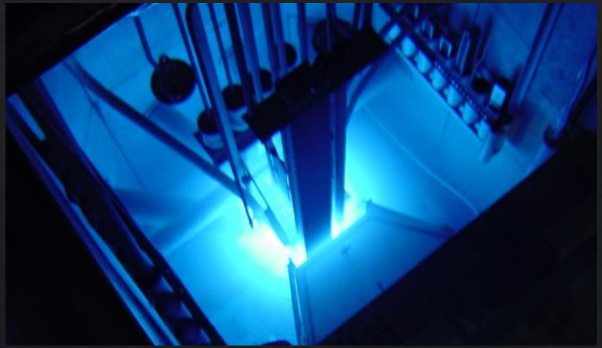
Nuclear Reactors

Nuclear Reactor → device built to sustain a controlled <u>nuclear fission chain reaction</u>



Main Components of Nuclear Reactor:
- reactor vessel
- tubes of uranium
- control rods
- containment structure





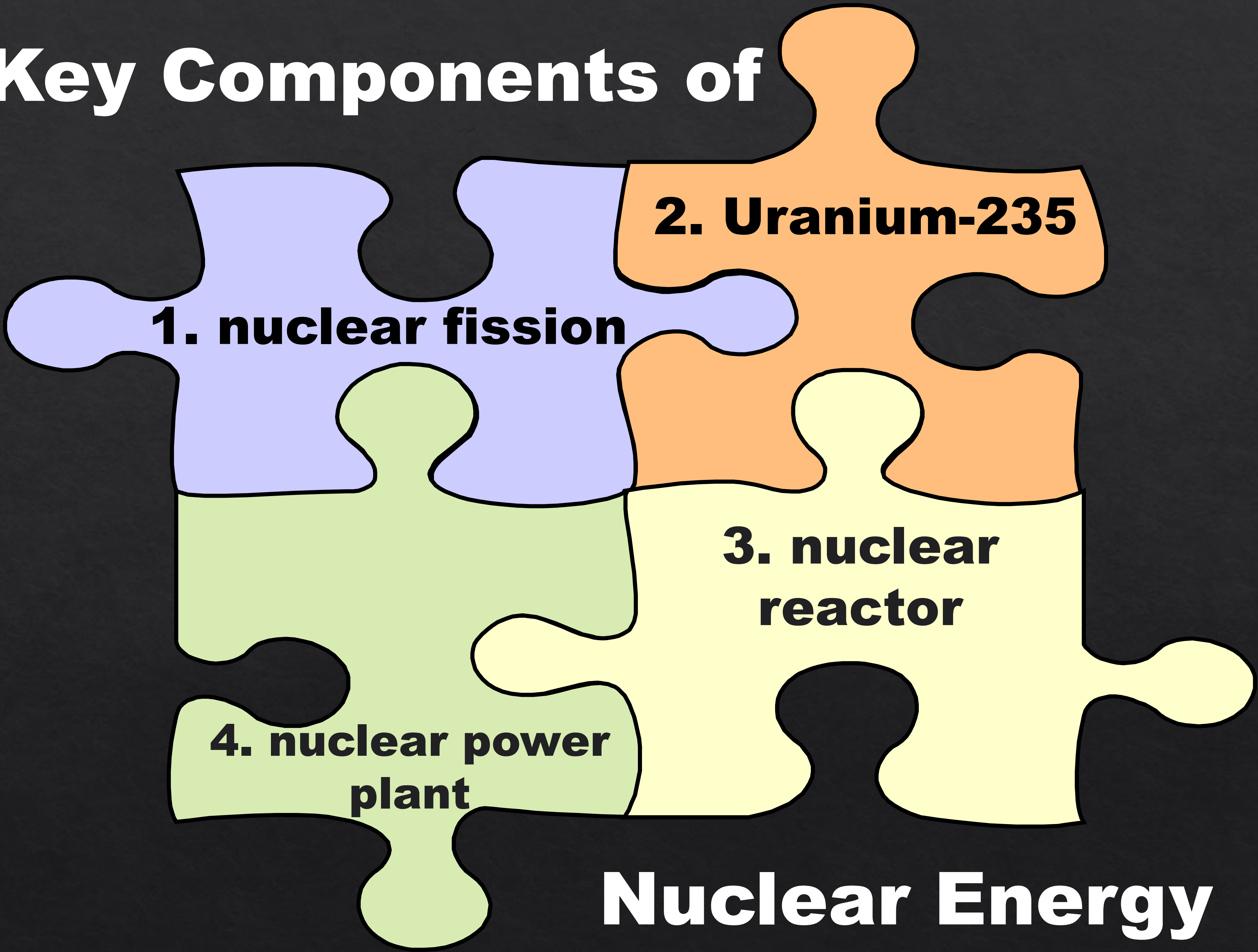
Containment structure contains the reaction in at least 3 feet of concrete!

control rods control radioactivity, absorbs neutrons

Controlling a Reactor

- We control the fission chain reaction by getting rid of neutrons
  - Insert control rods to absorb neutrons
- Fewer neutrons = fewer fissions = less heat
  - This can be very fast – full power to shutdown in <1 second!

Key Components of Nuclear Energy



Nuclear Safety

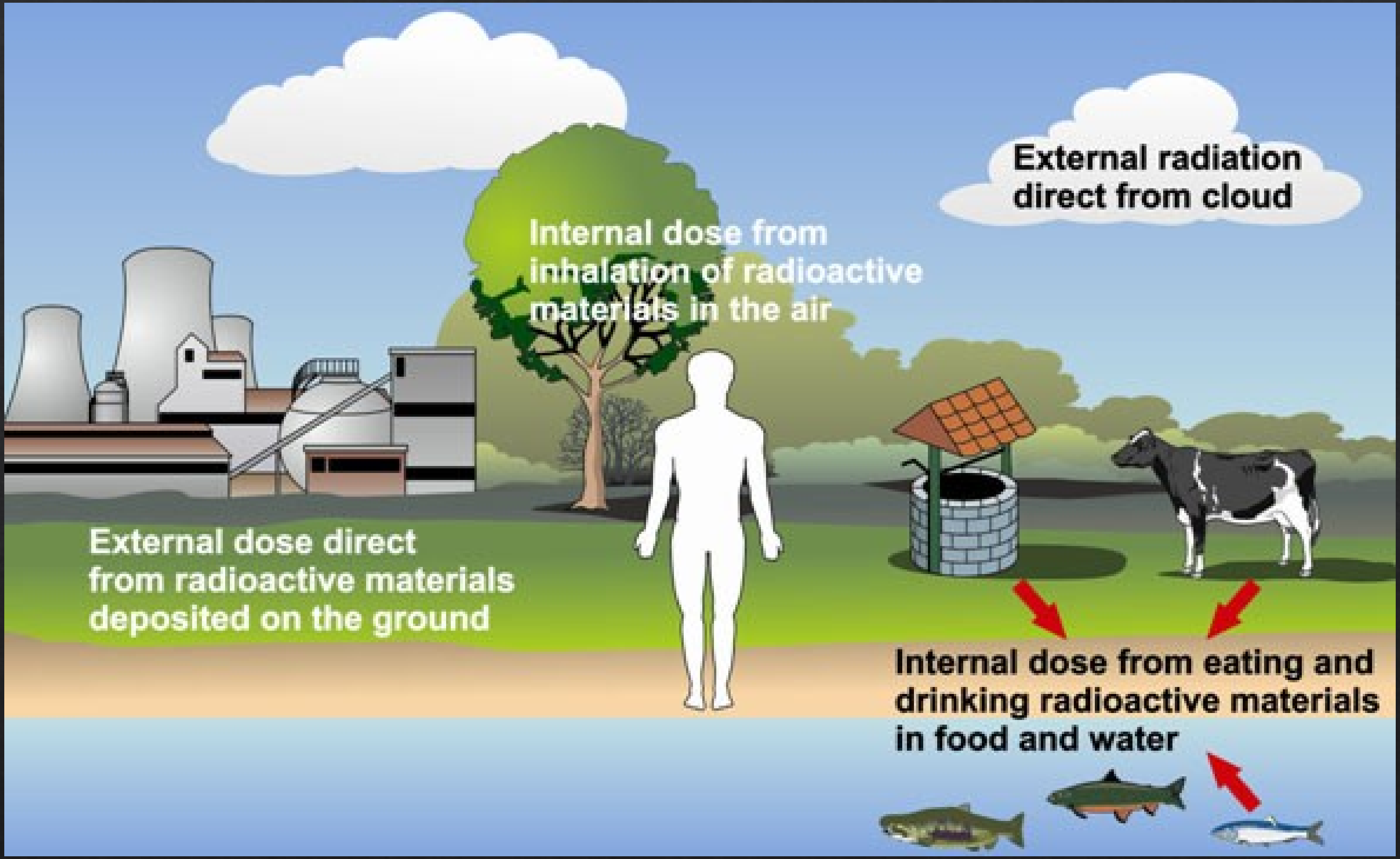
- Protect people from radiation
  - Rules on radiation exposure from man-made sources
- Keep radioactive material contained
  - Keep the fuel cool and shielded
  - Put waste somewhere safe

Handling Radioactive Material

- Reduce dose to people from **sources**
  - Shielding, distance, time
  - Dosimeters

- Prevent spread of **contamination**
  - Protective clothes
  - Monitors

Pathways Of Exposure To Man From Release of Radioactive Materials



Advantages of Nuclear Power

- Efficient – 91%!
- High energy production from a small amount of fuel
- Low greenhouse gas emissions so it doesn’t contribute to global warming or acid rain
- Low pollution
- Reliable 24/7
- Cheaper than other energy sources except Hydroelectric
- We don’t have to rely on other countries for our fuel

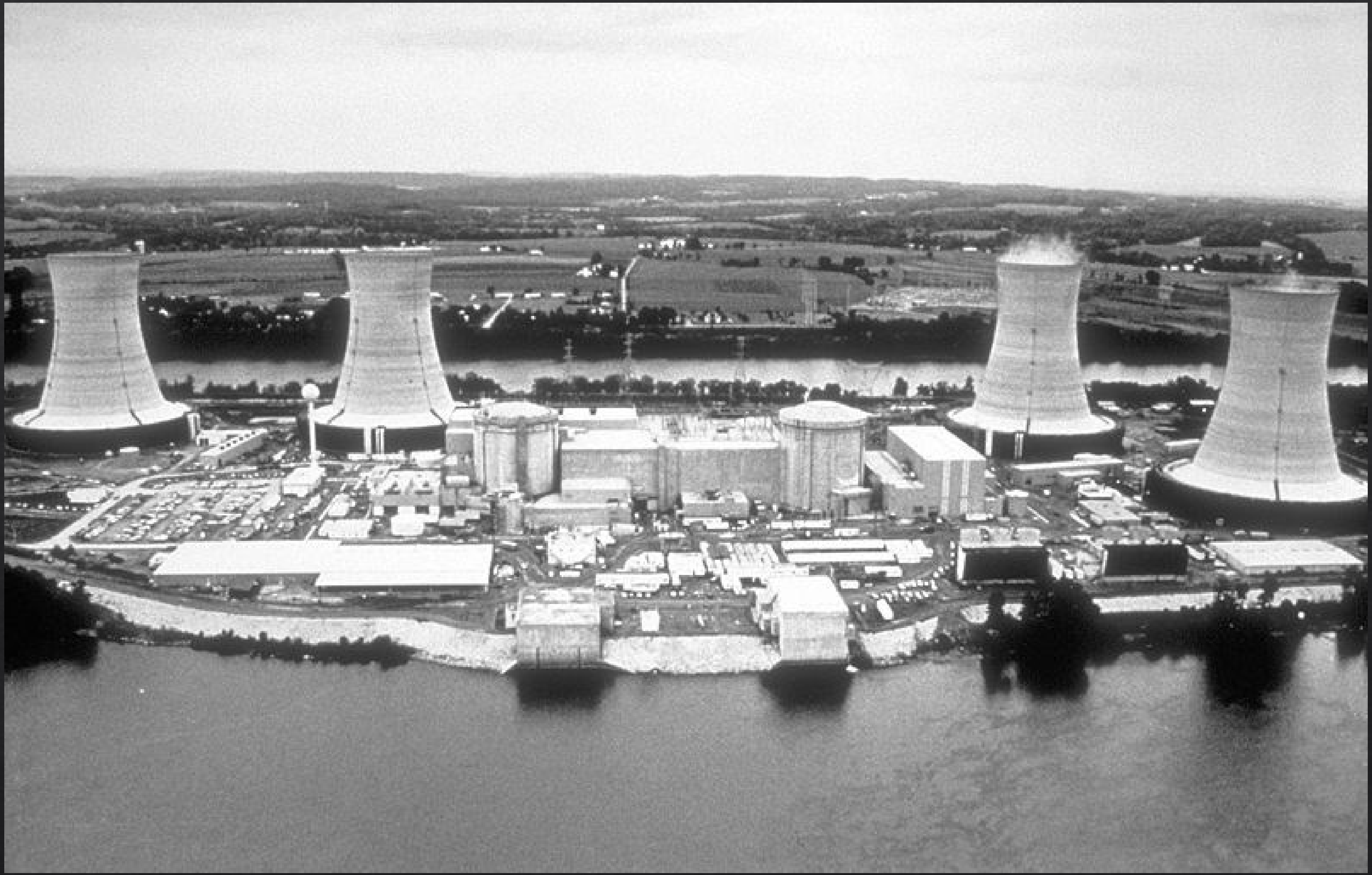
Disadvantages of Nuclear Power

- Storage and disposal of hazardous wastes. The half-life of 239 Pu (the radioactive waste from nuclear power plants is 24,000 years!)
- Proliferation (rapid growth) of nuclear materials
- Potential terrorist applications
- High startup costs and expenses to close down
- Danger of meltdown

Three Major Nuclear Disasters

- Three Mile Island- Harrisburg, PA
- Chernobyl – Russia
- Fukushima- Japan

Three Mile Island



Pennsylvania, USA

Chernobyl

Largest nuclear disaster in history.

Fukushima Nuclear Disaster

Nuclear disaster occurred as a result of an 8.0 earthquake and tsunami.

Nuclear Waste

- Challenges in the storage of spent reactor fuel

- **Waste**
  - Contains radioactive fission products
  - Can be hazardous for thousands of years
    - Half-life of Pu-239 is 24,110 years
  - Fission products, if released, can build up in the body and be fatal

Types of Nuclear Waste

- **High-level radioactive waste (HLW)**
  - Long half-lives of radioisotopes
  - Requires permanent isolation
  - “Mixed waste” because hazardous chemicals & radioactivity
  - National risk because the waste could be extracted and used to make nuclear weapons
  - From nuclear power plants
    - Spent Nuclear Fuel (SNF): radioactive material remaining in fuel rods after it’s used to generate power in nuclear reactor
      - Contains Pu-239

Types of Nuclear Waste

- **Low-level radioactive waste (LLW)**
  - Waste with smaller amounts of radioactive materials
  - Includes contaminated lab clothing, gloves, and tools (radioactivity levels are low)

- **90% of nuclear waste is LLW not HLW**

Options for Nuclear Waste

- **Almost all nuclear waste is stored where it was generated**
  - sites are not intended for long-term storage

Risks & Benefits of Nuclear Power

Table 7.6 Risks from Coal and Nuclear-Powered Electricity Generators

Hazard Type	Coal	Nuclear
Routine occupational hazards	Coal mining accidents and black lung disease constitute a uniquely high risk.	Risks from sources not involving radioactivity dominate.
Deaths*	2.7	0.3–0.6
Routine population hazards	Air pollution produces a relatively high, though uncertain, risk of respiratory injury.	Low-level radioactive emissions are more benign than the corresponding risks from coal.
Deaths*	1.2–50	0.03
Catastrophic hazards (excluding occupational)	Acute air pollution episodes with hundreds of deaths are not uncommon. Long-term climatic change, induced by CO_2, is conceivable.	Risks of reactor accidents are small compared with other quantified catastrophic risks.
Deaths*	0.5	0.04
General environmental degradation	Strip mining and acid runoff; acid rainfall with possible effect on nitrogen cycle.	Long-term contamination with radioactivity.

*Deaths are the number expected per year for a 1000-megawatt power plant. In all cases, 6000 person-days lost are assumed to equal one death.

Source: Modified from *Perilous Progress: Managing the Hazards of Technology*, by Robert W. Kates, Ed., 1985, Westview Press, Boulder, Colorado.

Risks associated with energy produced by nuclear power are less than from coal-burning plants.

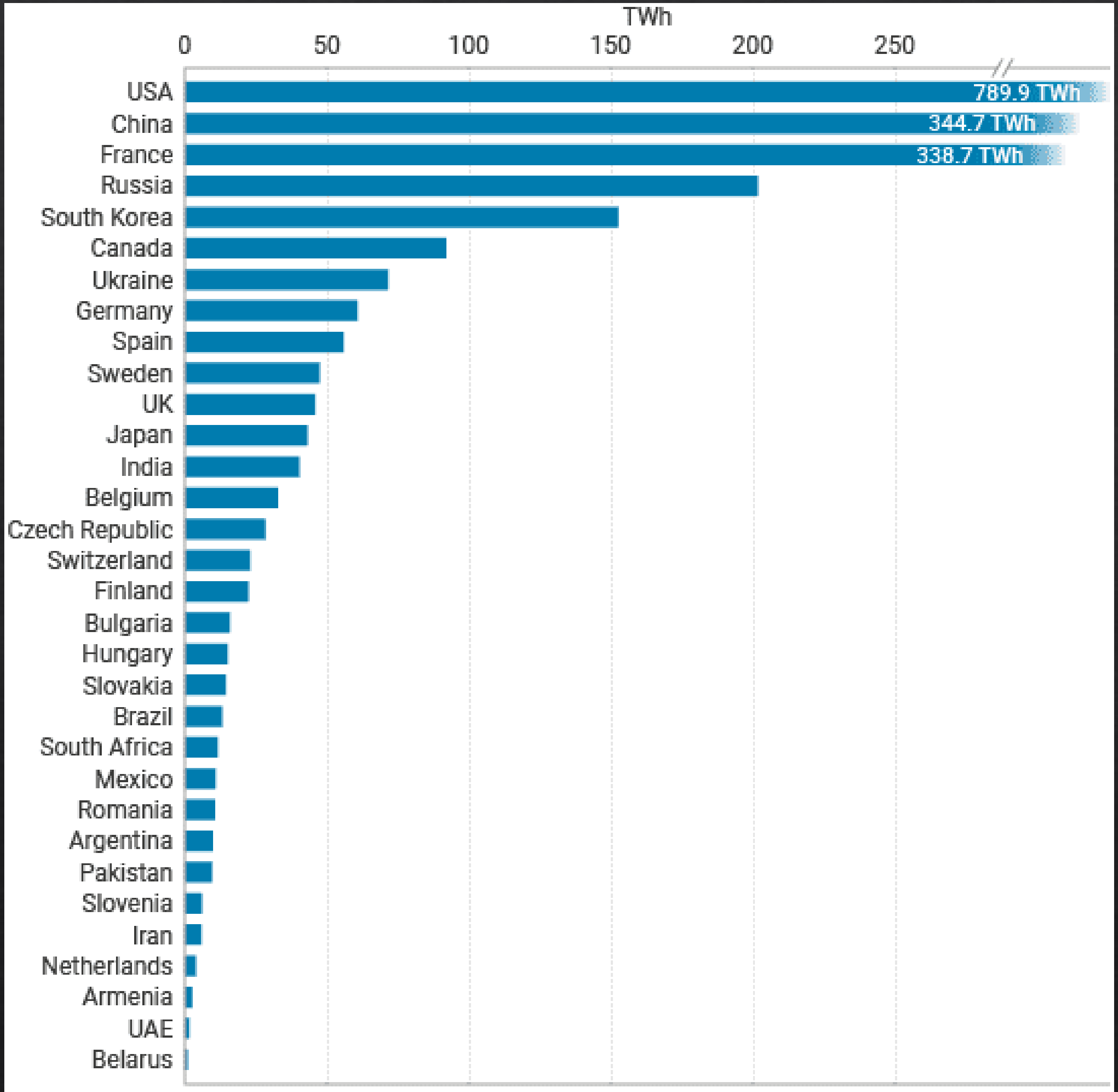
Risks & Benefits of Nuclear Power

Coal-fired electric plants (one 1000 MW plant)	Nuclear plants (one 1000 MW plant)
• releases 4.5 million tons of CO_2	• produces 70 ft^3 of HLW/year
• produces 3.5 million ft^3 of waste ash/year	• no CO_2 released
• releases 300 tons of SO_2 and ~100 tons NO_x/day	• no acidic oxides of sulfur and nitrogen released
• releases Uranium and Thorium from coal	

Future of Nuclear Power

- A new growth phase of nuclear power in near future
  - New reactor designs
  - Expansion in other countries

- Still a debate if risks of nuclear power outweigh those of global warming, acid rain, and nuclear terrorism.
  - Both our need for energy and the mass of radioactive waste are issues to balance.


TWh
0
50
100
150
200
250
USA
China
France
Russia
South Korea
Canada
Ukraine
Germany
Spain
Sweden
UK
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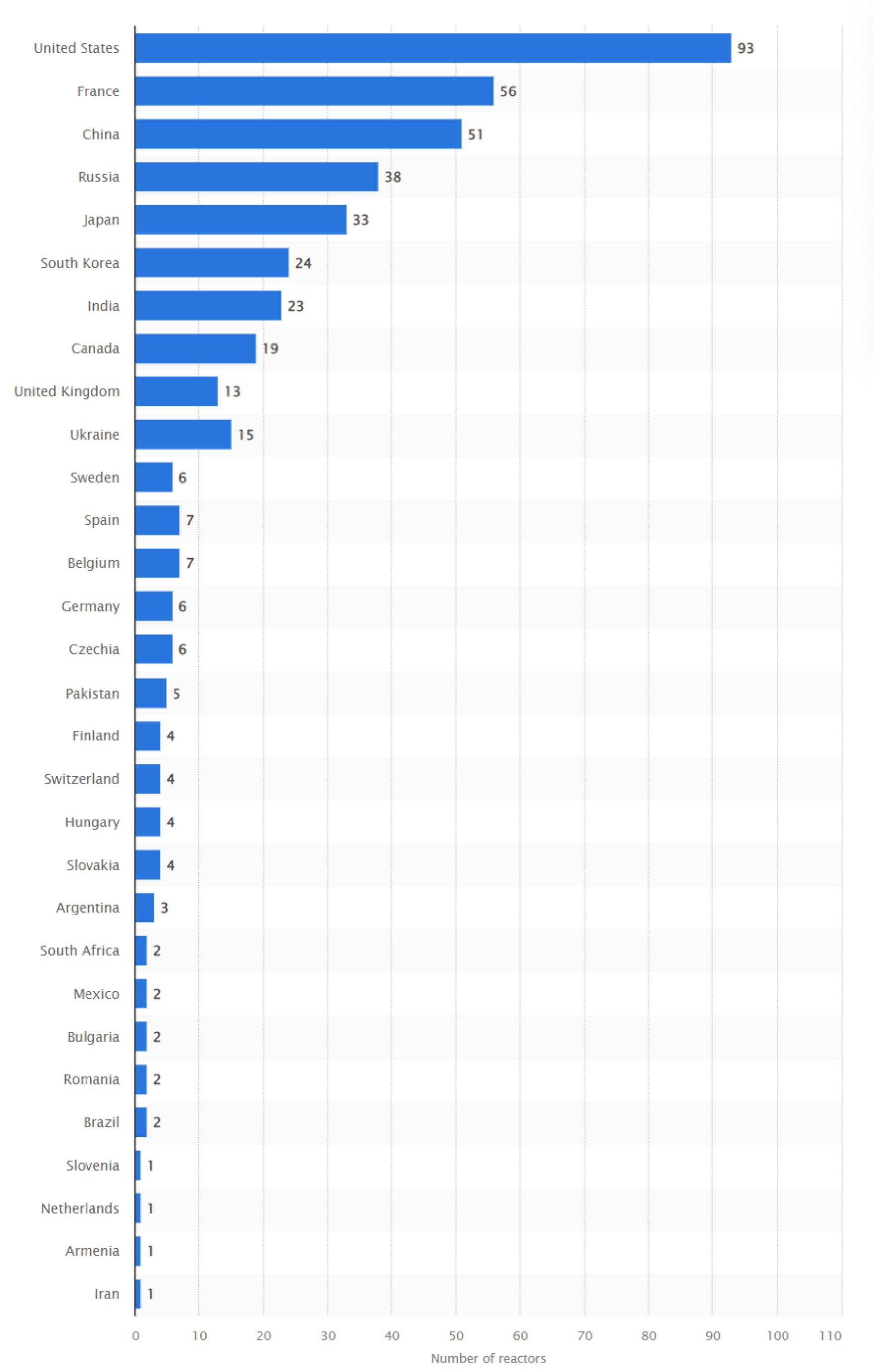
Belgium
Czech Republic
Switzerland
Finland
Bulgaria
Hungary
Slovakia
Brazil
South Africa
Mexico
Romania
Argentina
Pakistan
Slovenia
Iran
Netherlands
Armenia
UAE
Belarus
789.9 TWh
344.7 TWh
338.7 TWh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Pakistan 5
Finland 4
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South Africa 2
Mexico 2
Bulgaria 2
Romania 2
Brazil 2
Slovenia 1
Netherlands 1
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110
Number of reactors

End of Lecture!