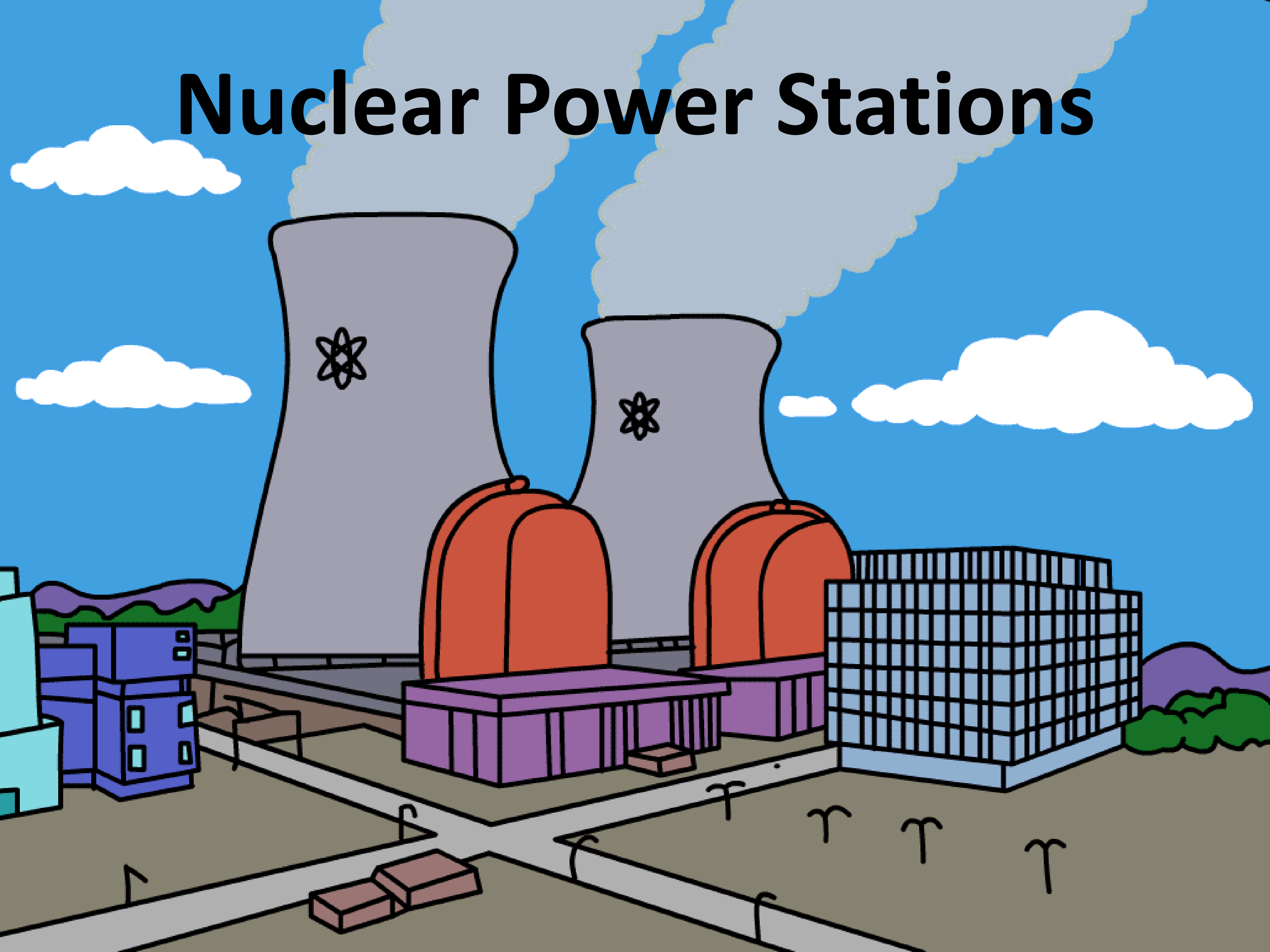
Nuclear Power Stations



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Nuclear Power Stations

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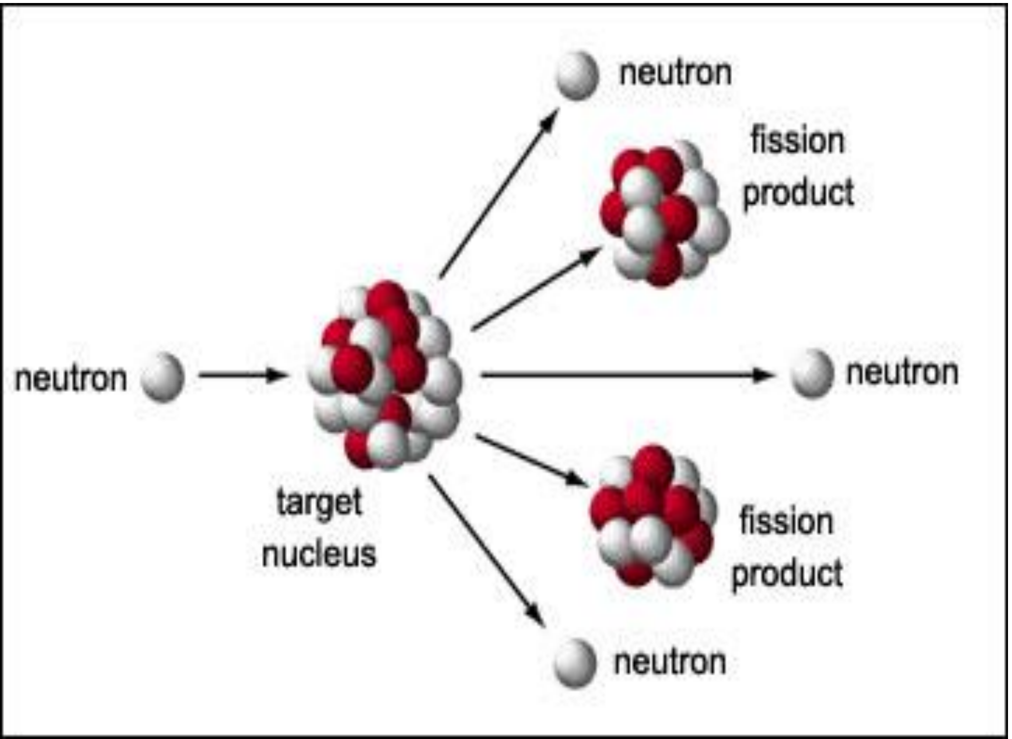
What is nuclear energy?

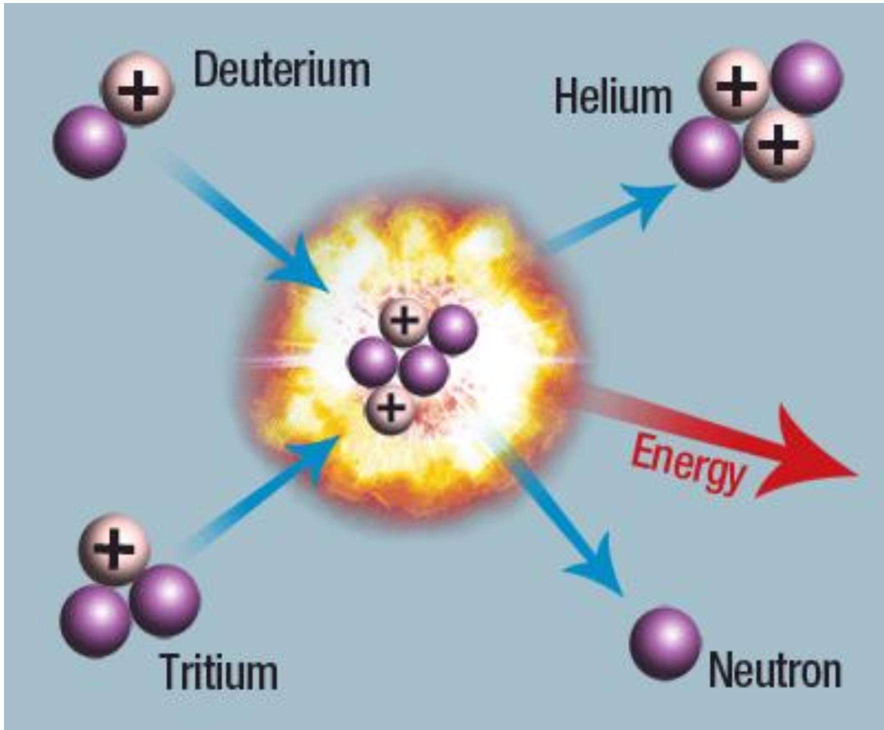
Nuclear energy is a powerful source of energy, generated during a nuclear reaction, by change in the nucleus of an atom. The source of nuclear energy is the mass of the nucleus and energy generated during a nuclear reaction is due to conversion of mass into energy (Einstein's Theory).

TWO WAYS TO OBTAIN NUCLEAR ENERGY:

1. Nuclear fission

2. Nuclear fusion





NUCLEAR FISSION

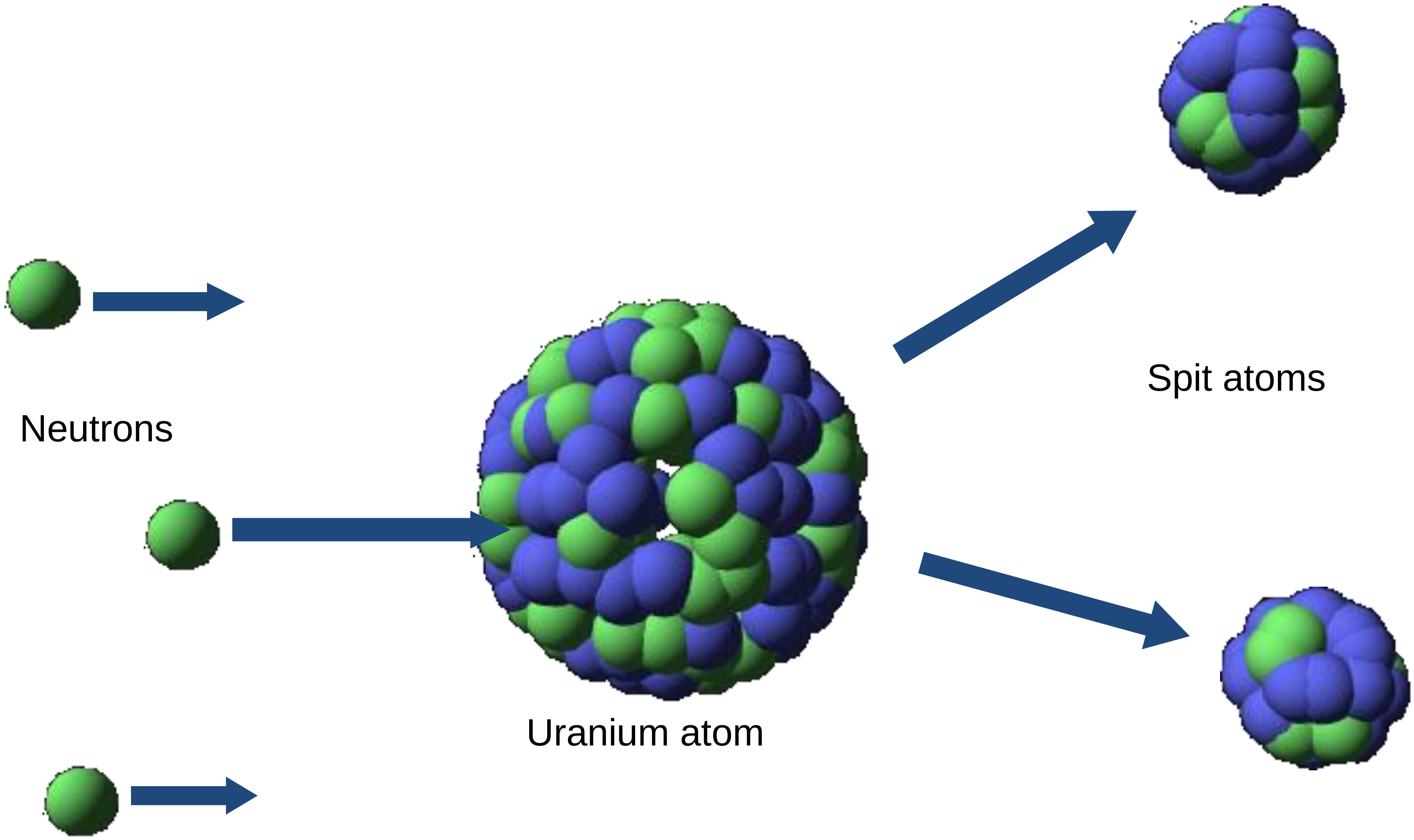
Nuclear fission reaction, *the nucleus of a heavy radioactive element like uranium or plutonium splits up into smaller nuclei, when bombarded by low energy neutrons. A huge amount of heat is generated in this process, which is used in nuclear power plants to generate electricity.*

NUCLEAR FUSION

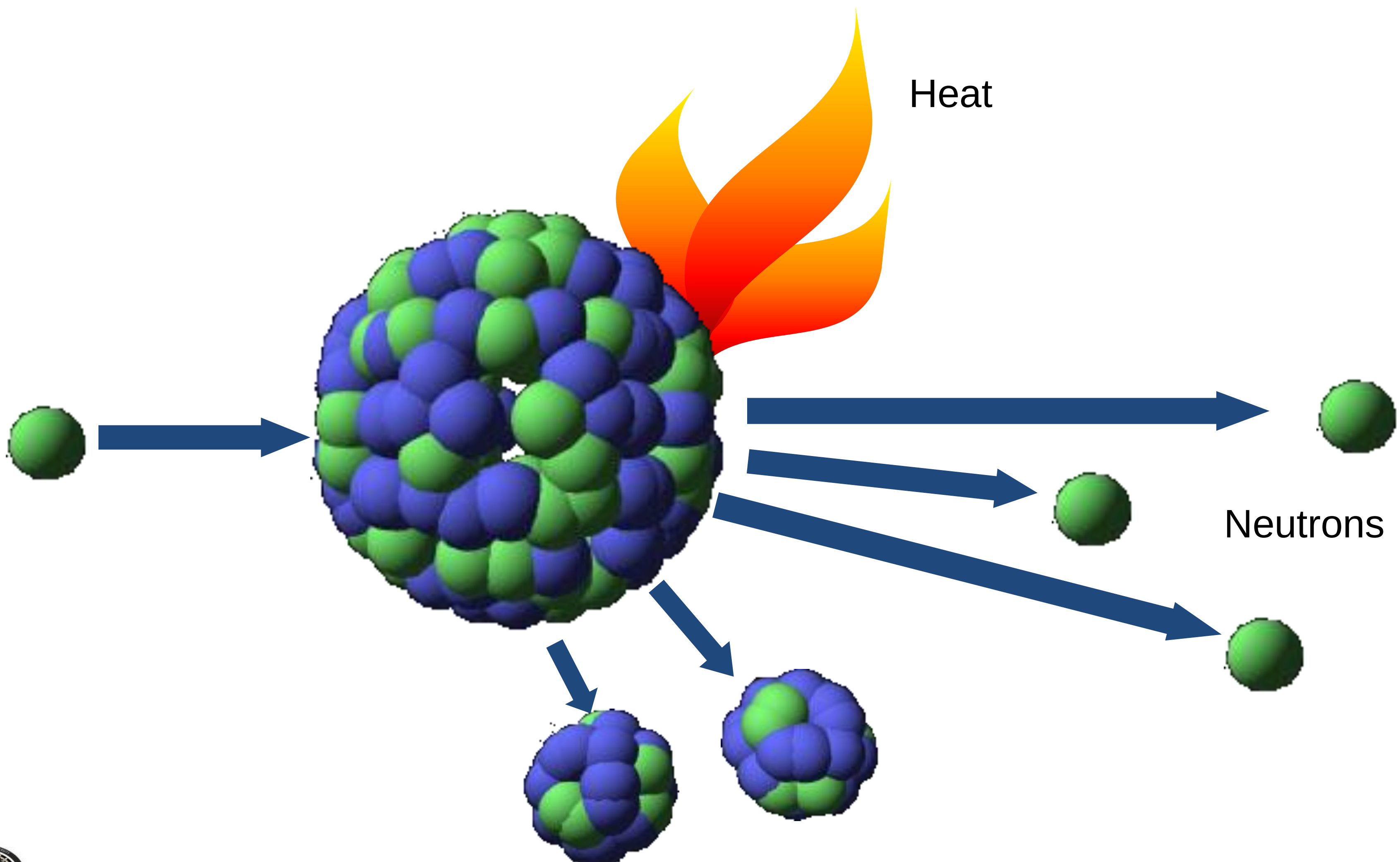
Nuclear fusion reaction *involves the combination of two light elements to form a heavier element and release uncontrollable energy. Thus it cannot be used to generate electricity, unlike fission reaction.*

The sun's energy is generated by nuclear fusion reaction. The heat and light that we get from Sun, is all due to the continuous reactions going on inside it. We can now imagine how much energy would be released in the nuclear fusion reaction, that it is the source of sun's energy

Nuclear Fission



Splitting Atoms Releases Neutrons, Making Heat

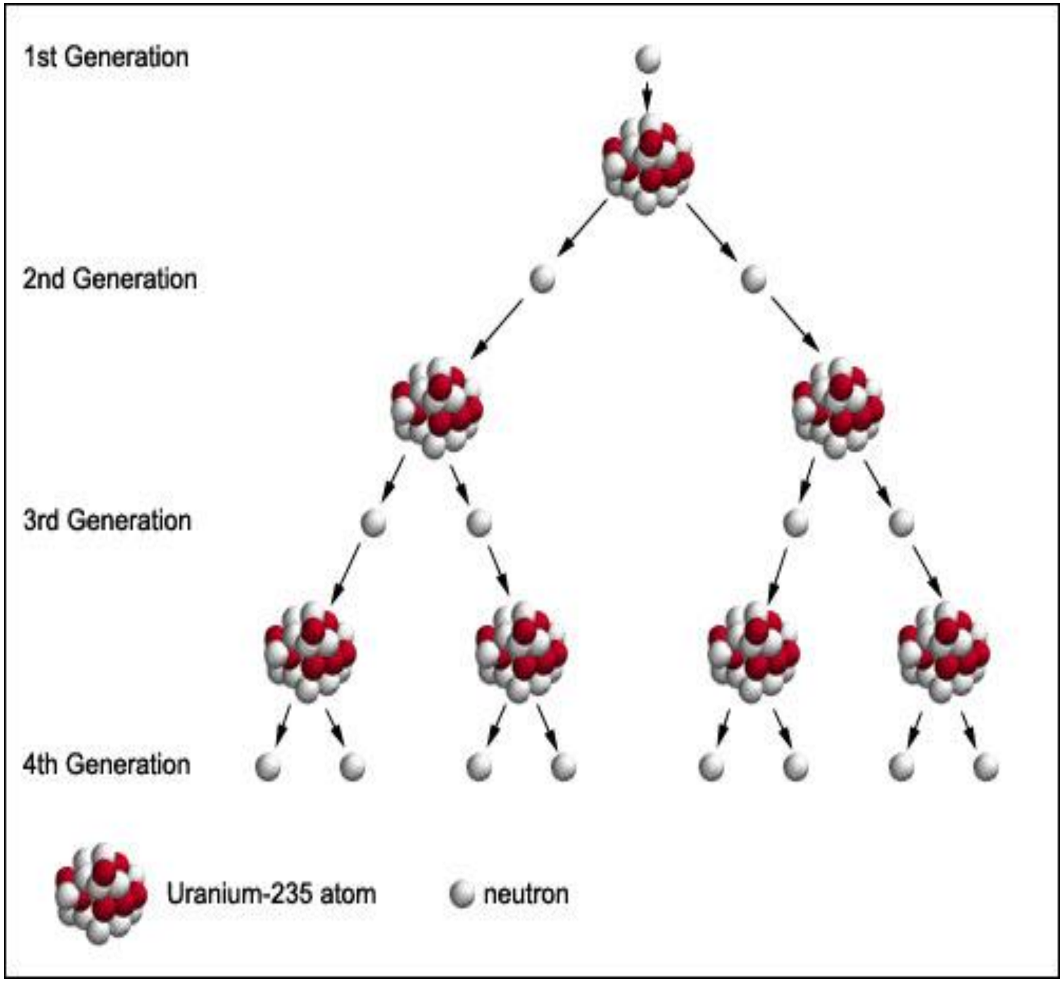


Fission and Fusion

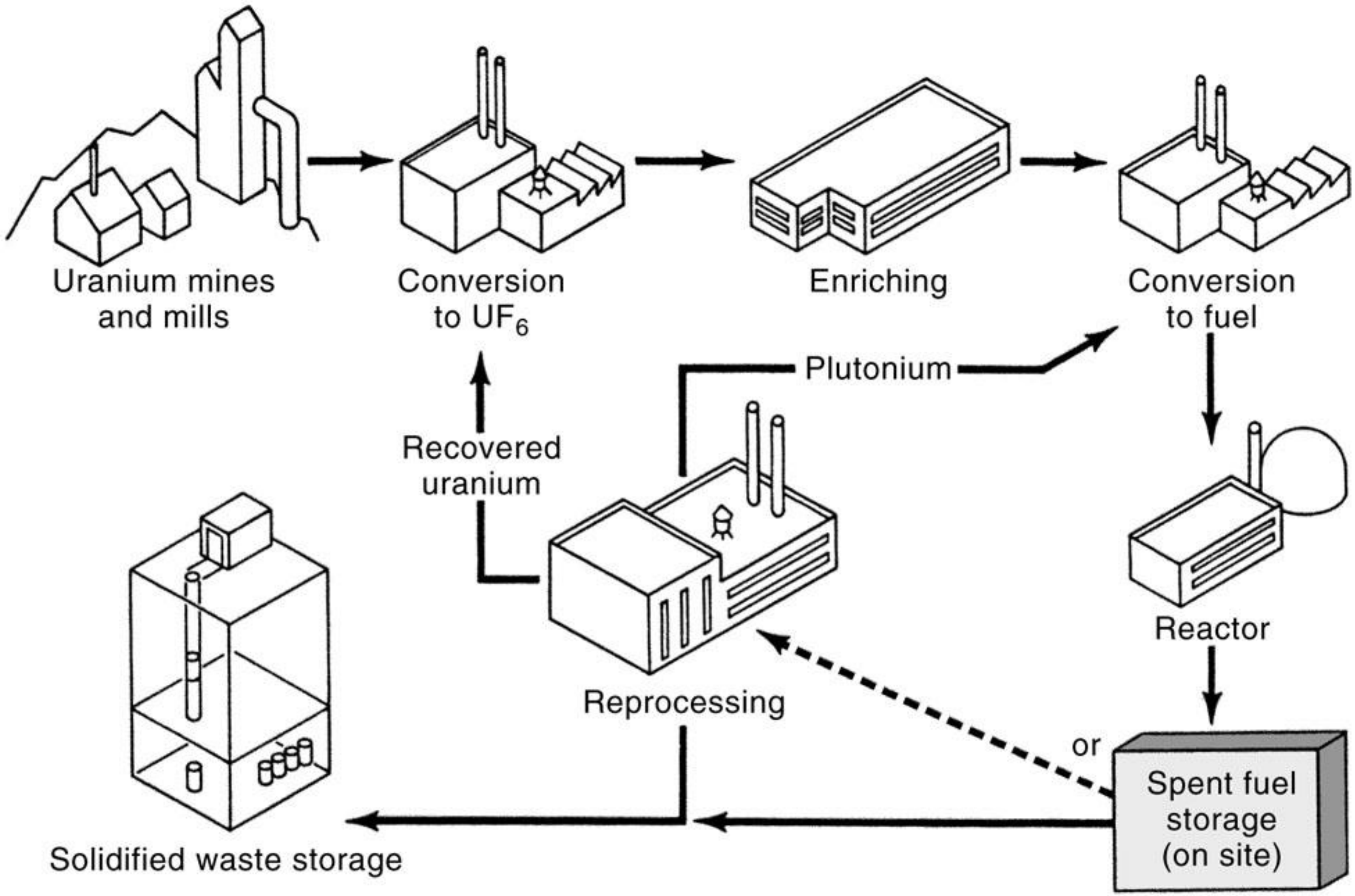
- Fission: A heavy nucleus is split into smaller nuclei, releasing energy
- Fusion: Two light nuclei fuse into a heavy nucleus, releasing energy
  - ***Fusion generates much more energy than fission***
  - **Fusion of hydrogen into helium is what provides power to the sun (and thus to the Earth)**

Chain Reactions

- A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus.
- This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons).

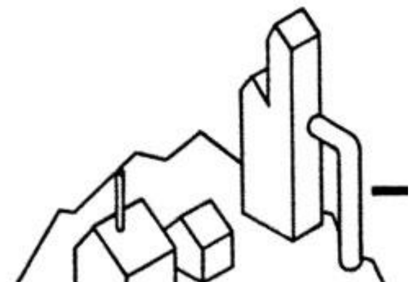


Nuclear Fuel Cycle



Mining and Milling

- Uranium is usually mined by either surface (open cut) or underground mining techniques, depending on the depth at which the ore body is found.
- From these, the mined uranium ore is sent to a mill which is usually located close to the mine.



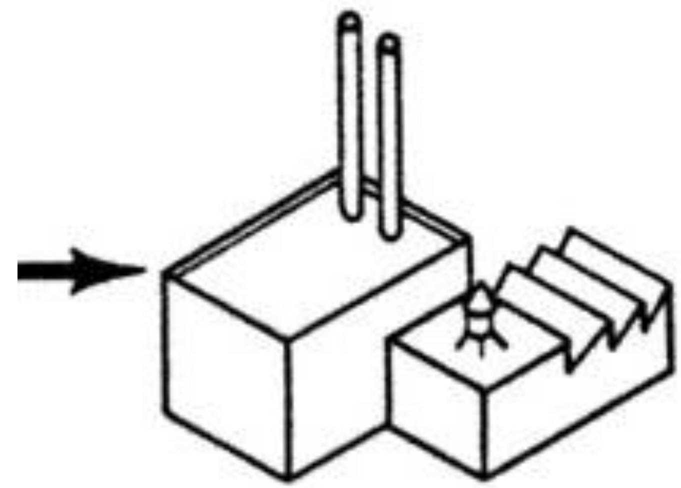
Uranium mines and mills

Mining and Milling

- At the mill the ore is crushed and ground to a fine slurry which is leached in sulfuric acid to allow the separation of uranium from the waste rock.
- It is then recovered from solution as uranium oxide (U_30_8) concentrate.
  - Sometimes this is known as "yellowcake"

Conversion

- Because uranium **needs** to be in the form of a **gas** before it can be enriched, the $U_3 0_8$ is converted into the **gas uranium hexafluoride** (UF_6) at a conversion plant.



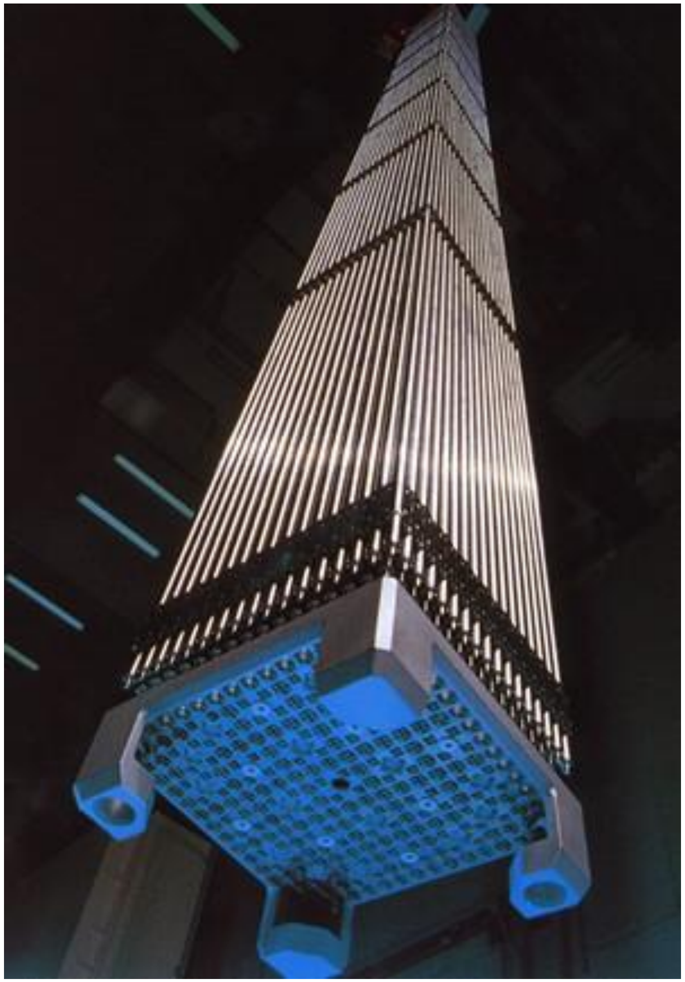
Enriching

- Need to enrich uranium to at least 3% for a power plant
- **Two** Methods of Enriching
- **Gaseous Diffusion Method**
  – UF_6 (hexafluoride) gas heated
  – U-238 is heavier than U-235
  – Hexafluoride Gas can be separated into two streams
    - Low velocity U-238
    - High Velocity U-235
- **Centrifuge Method**
  – Gas spun in centrifuge
  – Lighter U-235 will separate from heavier U-238

Fuel Conversion

- Enriched Uranium transported to a fuel fabrication plant where it is converted to **uranium dioxide (UO_2)** powder and pressed into small pellets.
- These pellets are inserted into thin tubes, usually of a zirconium alloy or stainless steel, to form **fuel rods**.
- The rods are then sealed and assembled in clusters to form fuel assemblies for use in the core of the nuclear reactor.

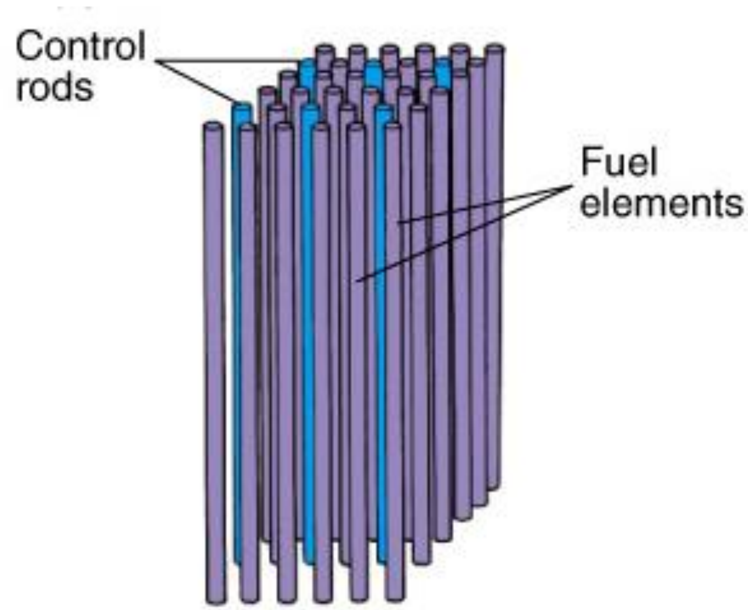
Fuel Packaging in the Core



- Rods contain uranium enriched
- Need roughly 100 tons **per year** for a 1000MW plant

The Reactor Core

- The reactor *core* consists of *fuel rods* and *control rods*
  - Fuel rods contain enriched uranium
  - Control rods are inserted between the fuel rods to absorb neutrons and slow the chain reaction
- Control rods are made of cadmium, which absorb neutrons effectively



Moderators

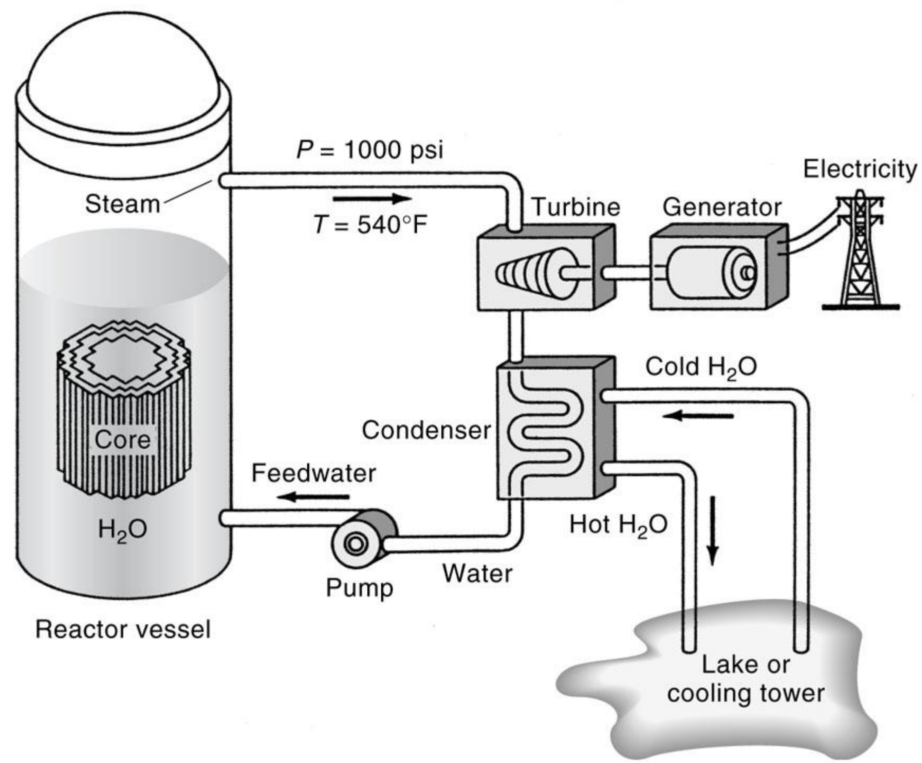
- Neutrons produced during fission in the core are moving too fast to cause a chain reaction
  - Note: This is not an issue with a bomb, where fissile uranium is so tightly packed that fast moving neutrons can still do the job.
- A *moderator* is required to slow down the neutrons
- In Nuclear Power Plants **water or graphite acts as the moderator**

Light vs. Heavy Water

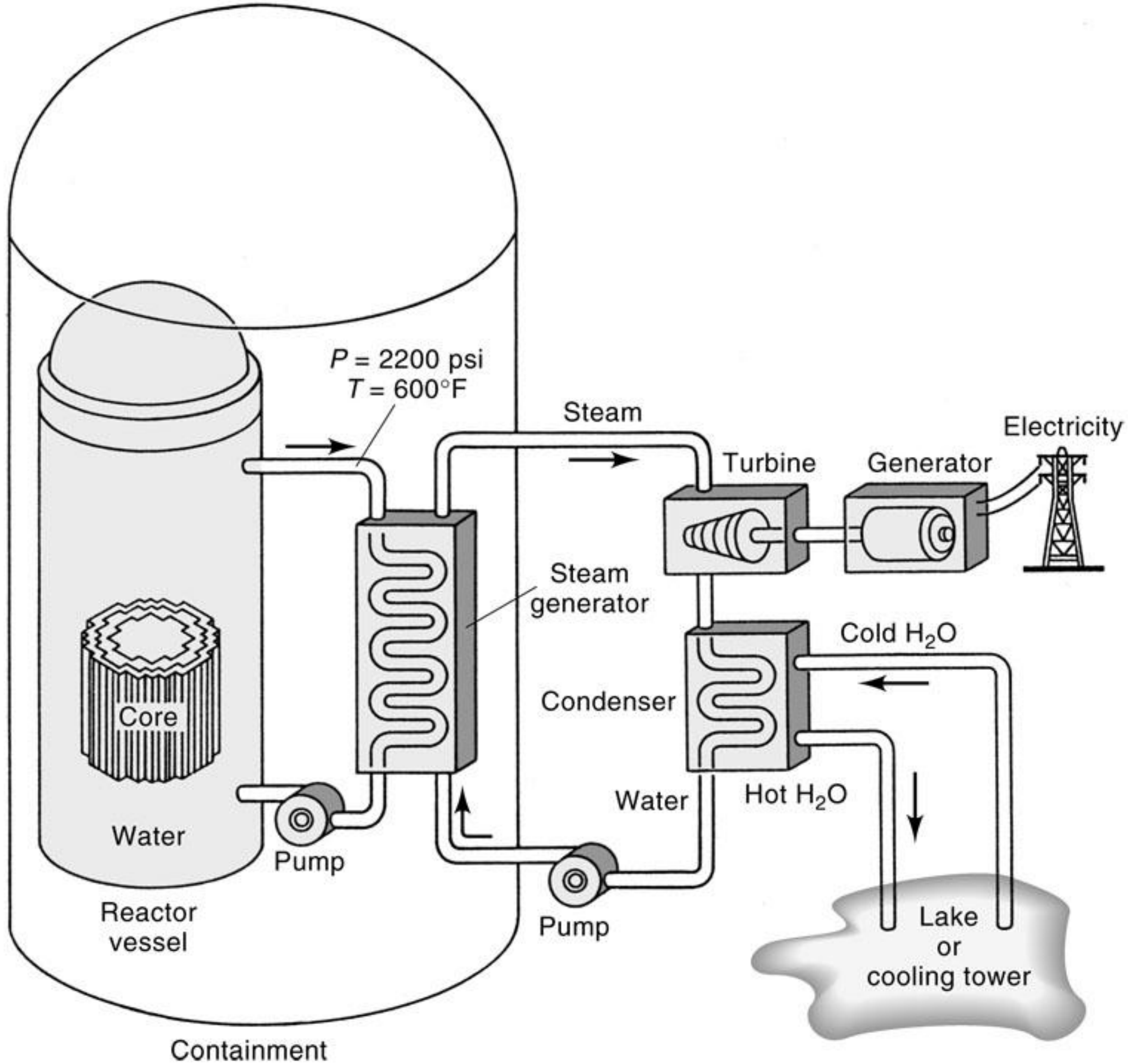
- 99.99% of water molecules contain normal hydrogen (i.e. with a single proton in the nucleus)
- Water can be specially prepared so that the molecules contain deuterium (i.e. hydrogen with a proton *and* a neutron in the nucleus)
- Normal water is called *light water* while water containing deuterium is called *heavy water*
- *Heavy water is a much better moderator but is very expensive to make*

Boiling Water Reactor (BWR)

- Heat generated in the core is used to generated steam through a heat exchanger
- The steam runs a turbine just like a normal power plant



Pressurized Water Reactor (PWR)



Pressurized Water Reactor (PWR)

- Water in the core heated top 315°C but is not turned into steam due to high pressure in the primary loop.
- Heat exchanger used to transfer heat into secondary loop where water is turned to steam to power turbine.
- Steam used to power turbine never comes directly in contact with radioactive materials.

PWR vs. BWR

Table 14.2 LIGHT WATER REACTOR FUEL DATA

	BWR	PWR
Electrical output (MWe)	1000	1000
Initial load (tons of uranium oxide)	135	80
Fuel rods per assembly	50	200
Fuel assemblies per core	750	180
Number of control rods	180	45

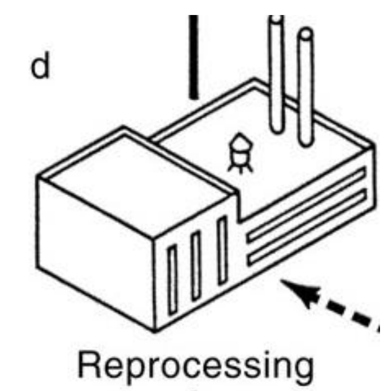
Source: WASH-1250, U.S. Department of Energy.

Uranium Reprocessing

- Spent fuel still contains approximately 96% of its original uranium, of which the fissionable U-235 content has been reduced to less than 1%.
- Spent fuel comprises waste products and the remaining 1% is plutonium produced while the fuel was in the reactor
- Reprocessing extracts useable fissile U-238

Uranium Reprocessing

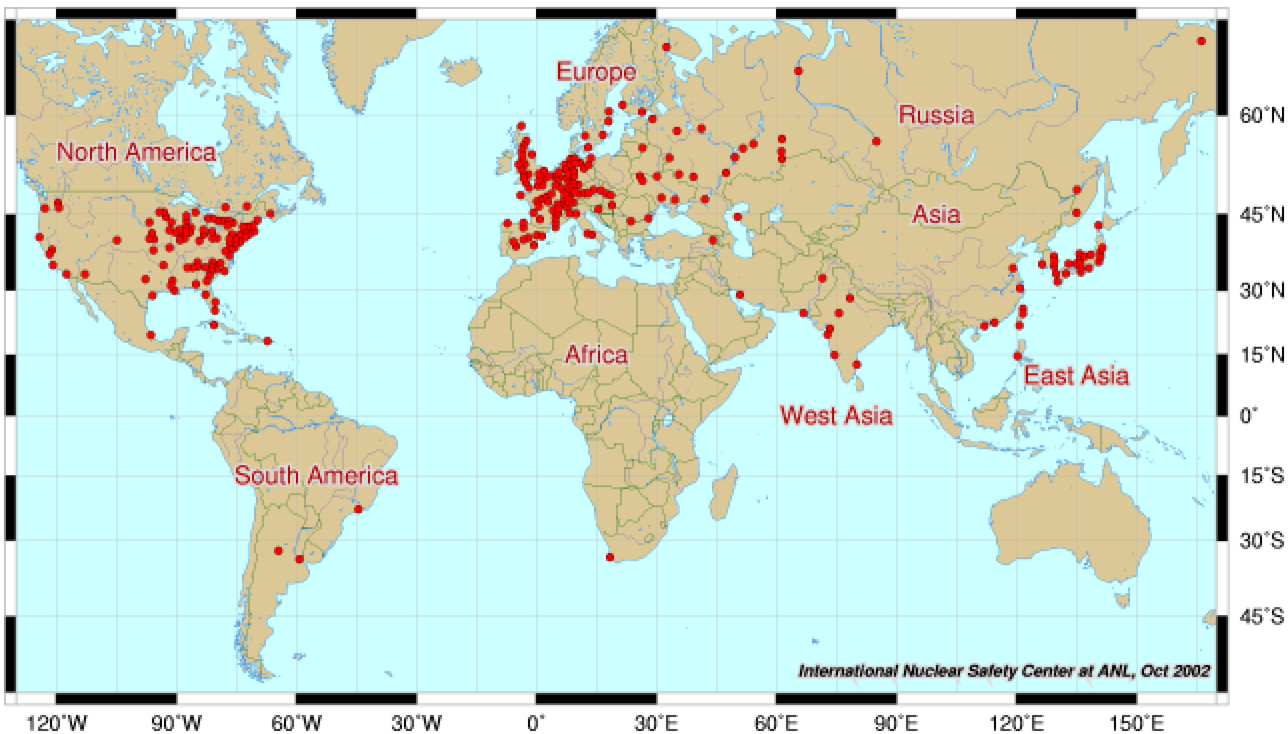
- Most of the spent fuel can be reprocessed.
- Federal law prohibits commercial reprocessing because it will produce plutonium (which can be used both as a fuel *and* in constructing bombs)



Nuclear Waste Disposal

- In the U.S., *no high-level nuclear waste is ever disposed of*--it sits in specially designed pools resembling large swimming pools (water cools the fuel and acts as a radiation shield) or in specially designed dry storage containers.
- Spent nuclear fuel must be isolated for thousands of years
- After 10,000 years of radioactive decay, according to EPA standards, the spent nuclear fuel will no longer pose a threat to public health and

World Nuclear Power Plants



Advantages of Nuclear Power

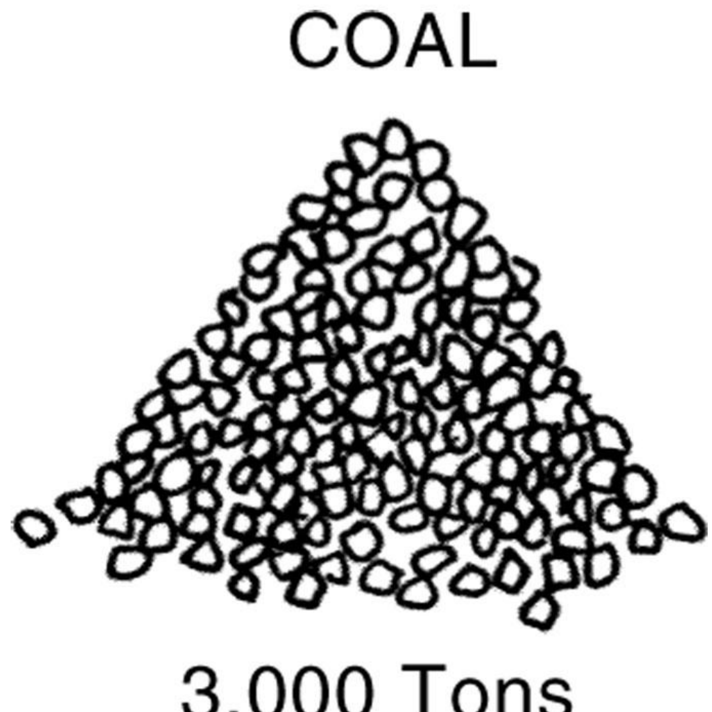
- Nuclear electricity is reliable and relatively cheap (with an average generating cost of 2.9 cents per kW/h) once the reactor is in place and operating.
- Large reserves of Uranium - Fuel for nuclear power plants will not run out for tens of thousands of years
- Nuclear power plants contribute no greenhouse gasses and few atmospheric pollutants

Disadvantages of Nuclear Power

- Uranium is ultimately a nonrenewable resource.
- Nuclear power plants are extremely costly to build.
- The slight possibility that nuclear power plants can have catastrophic failures.(JAPAN)
- Large environmental impact during the mining and processing stages of uranium are numerous.
- Nuclear waste (Spent nuclear fuel) is extremely hazardous and must be stored safely for thousands of years.

Comparing Uranium to Coal

*1 kg of uranium-235 will generate as much energy as 3,000 tons of coal without CO_2 emissions



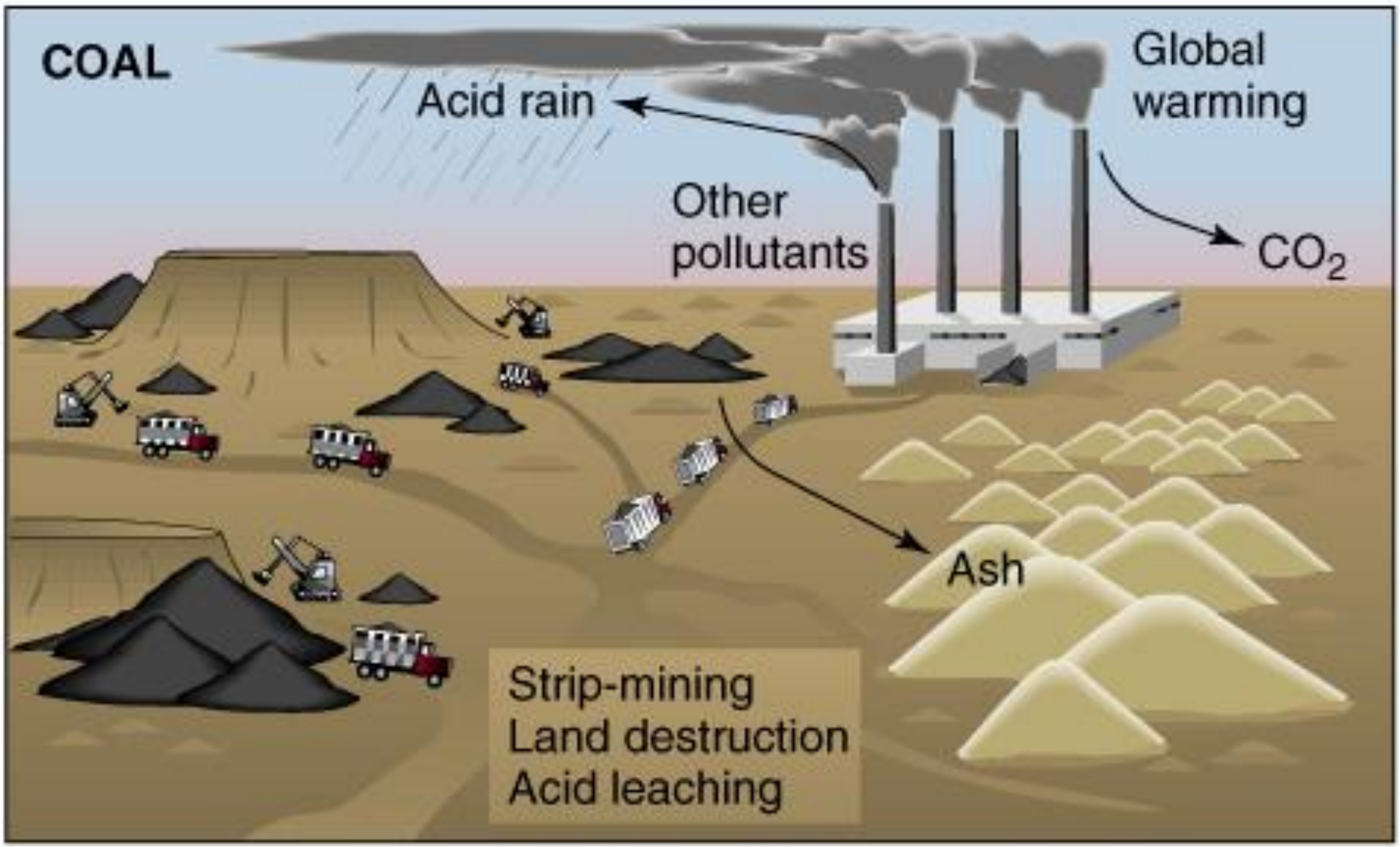
Comparing Uranium to Coal

Table 14.6 ANNUAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH A 1000-MWe POWER PLANT*

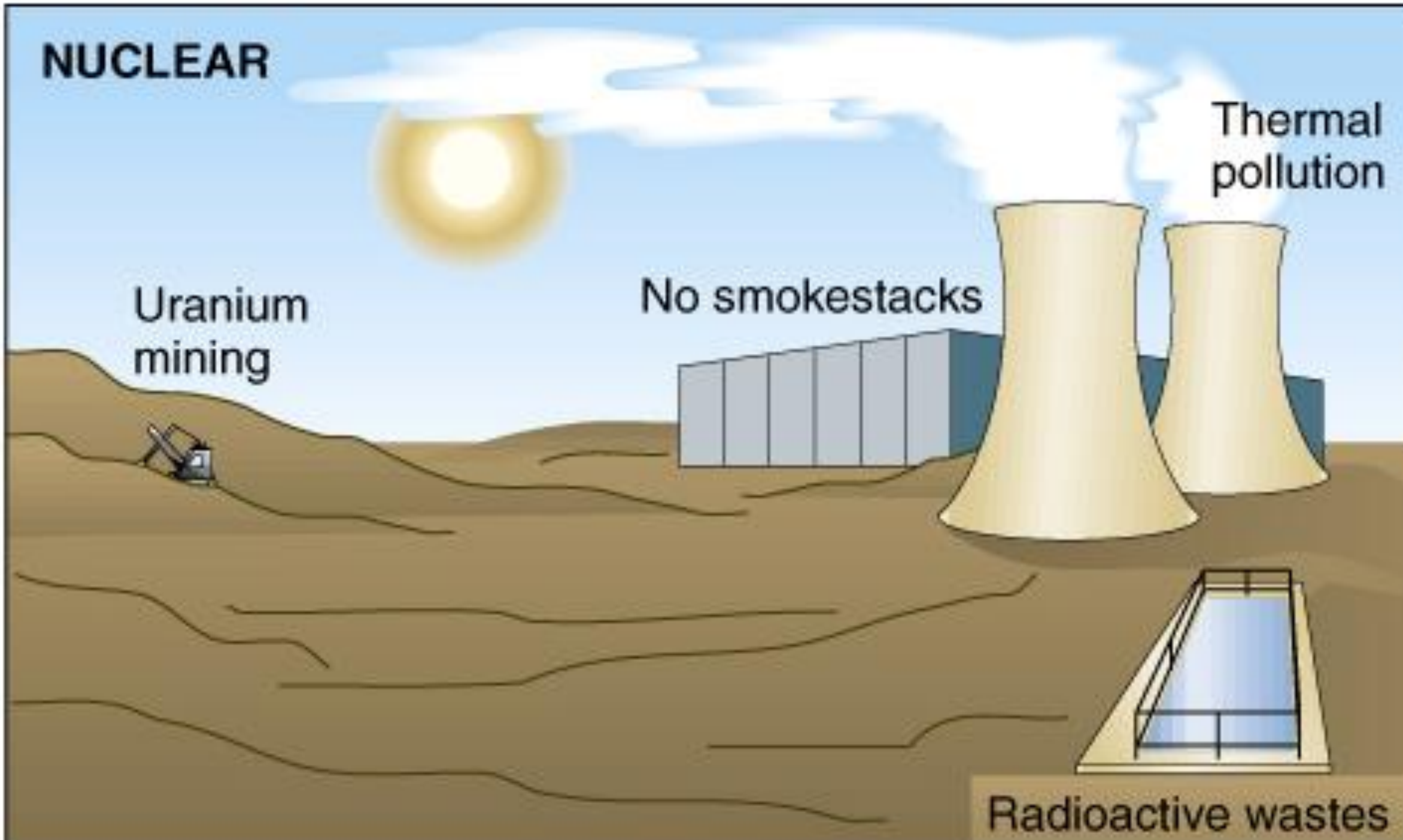
Impact	Coal	Nuclear (LWR)
Land use (acres)	17,000	1900
Water discharges (tons)	40,000	21,000
CO_2 emissions (tons)	6×10^6	0
Air emissions (tons)	380,000	6200
Radioactive emissions (curies)	1	28,000
Occupational health:		
deaths	0.5–5	0.1–1
injuries	50	9
Total fatalities (public and worker)	2–100	0.1–1

*Includes extraction, processing, transportation, and conversion. Strip-mined coal.
Source: WASH-1250 and *Ann. Nuclear Energy,* 13, 173 (1986).

Coal Power Plant Environmental Concerns



Nuclear Power Plant Environmental Concerns



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