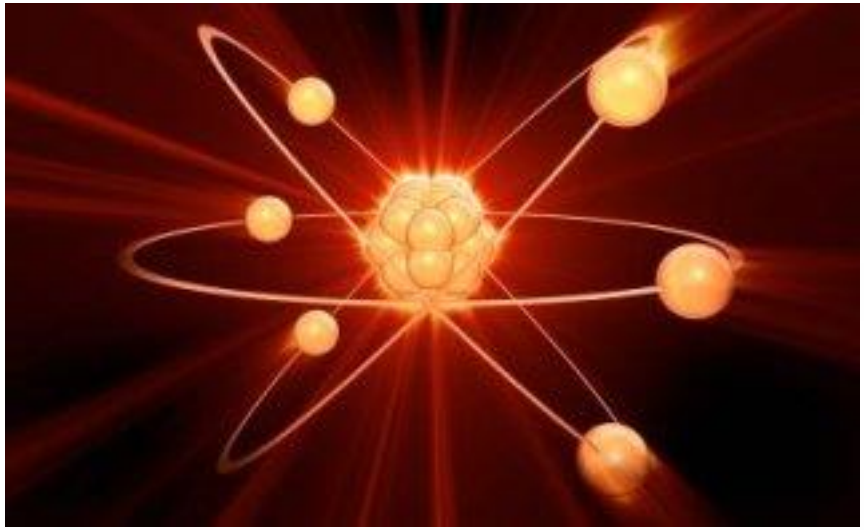
Nuclear Power Reactors



Kaleem Ahmad

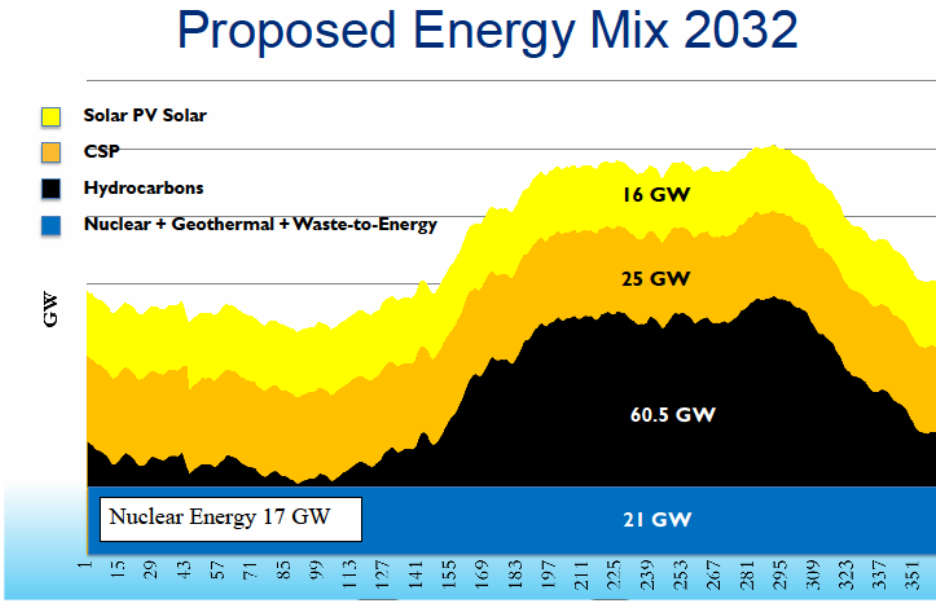
Outline

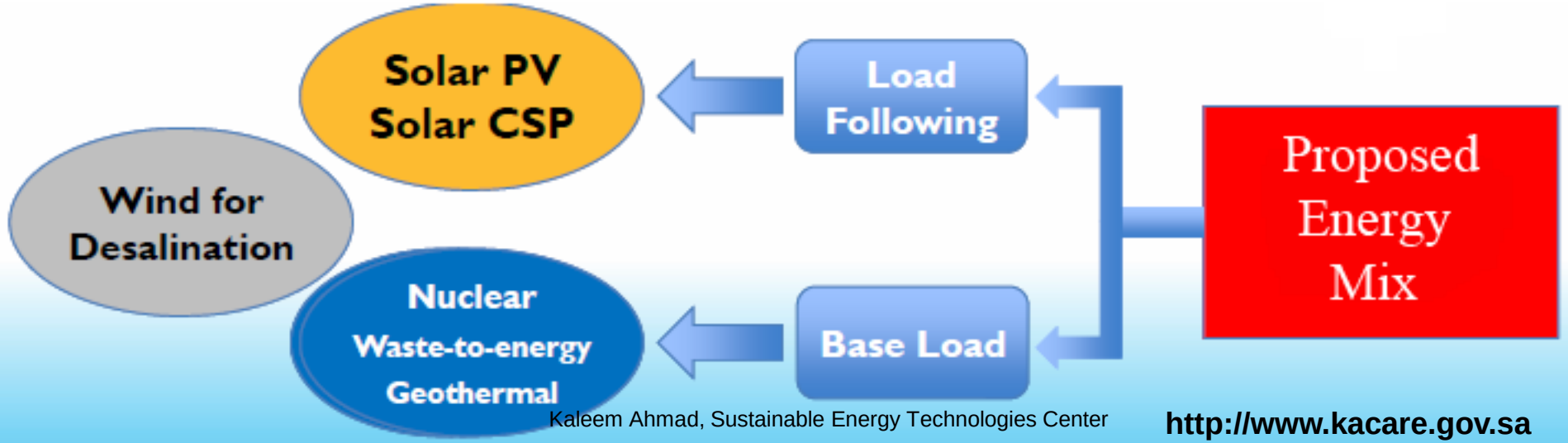
- Significance of Nuclear Energy
- Nuclear Fission
- Nuclear Fuel Cycle
- Nuclear Power Reactors
- Conclusions

Key Role of Nuclear Energy in the Proposed Energy Mix of KSA

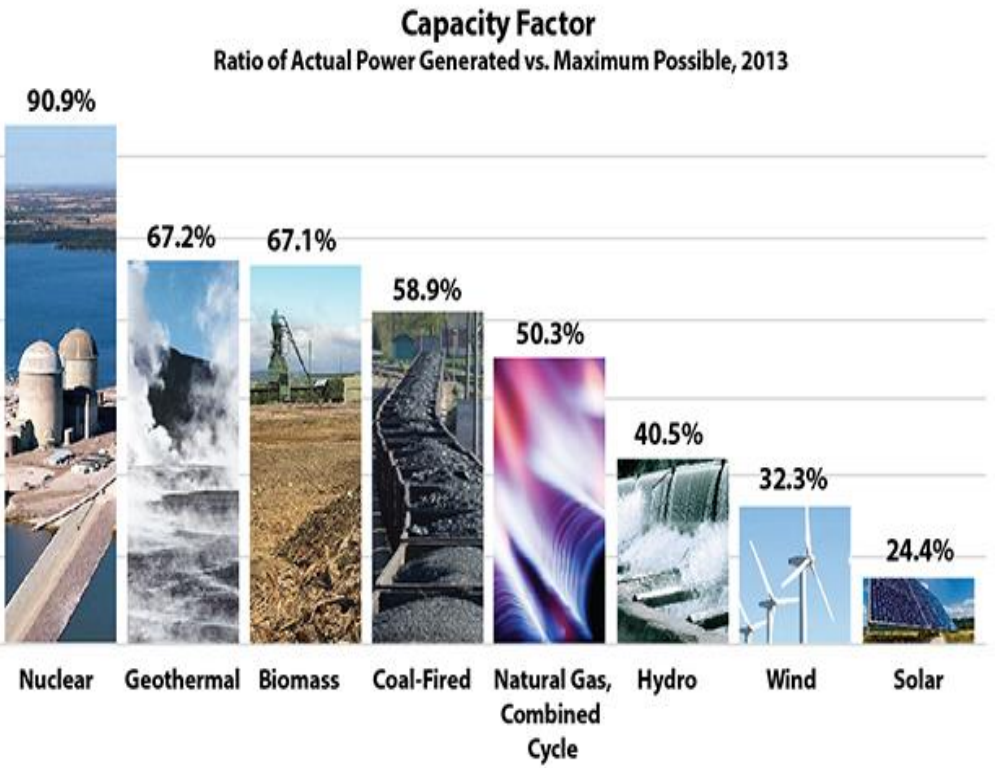
- Introduction of ~50% sustainable energy to Saudi Arabia's energy mix
- Nuclear energy is an integral part of Kingdom energy plan

It projects 17 GWe of nuclear capacity by 2032





Why Nuclear Energy



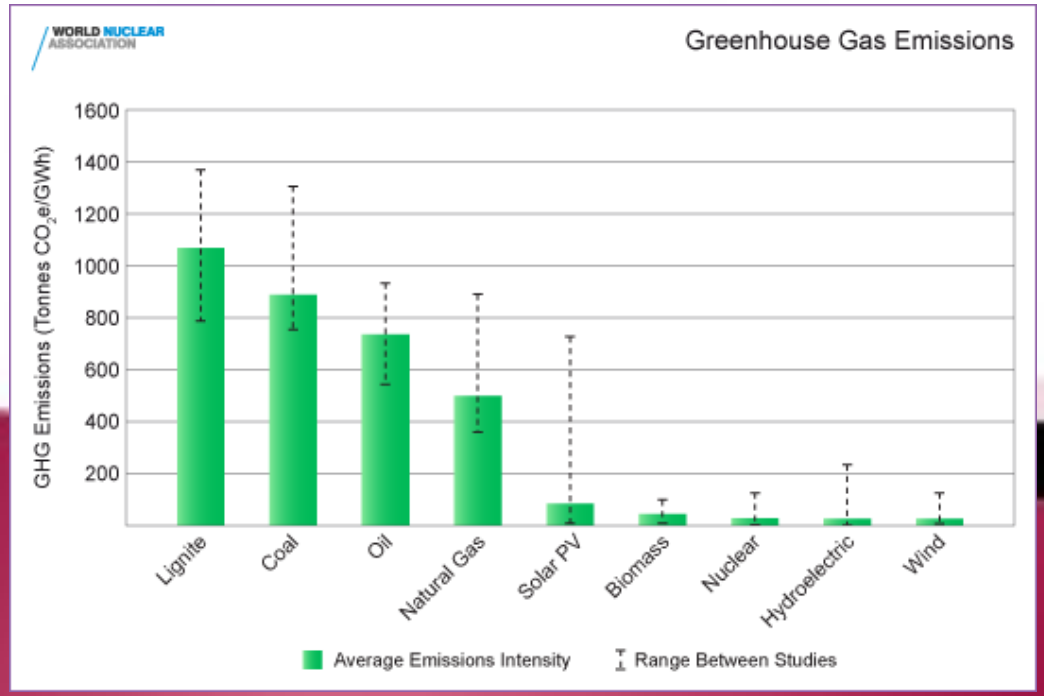
- Nuclear energy is a base load energy source that generates power more than 90 percent of the time, 24 hours a day, 365 days a year on average.
- Essential part of Kingdom energy mix strategy according to a Royal Decree

•Readily available, reliable proven technology without contributing to climate change

•Cost for nuclear is competitive with oil and gas as well as with renewable energy

Greenhouse Gas Mitigation

- Nuclear energy is a vital component of a clean energy strategy.
- Currently nuclear generation avoids the emission of over two billion tonnes of carbon dioxide each year.
- Nuclear power has already prevented the release of around 56 gigatonnes of carbon dioxide since 1971 equivalent to two years of global emissions at current rates.

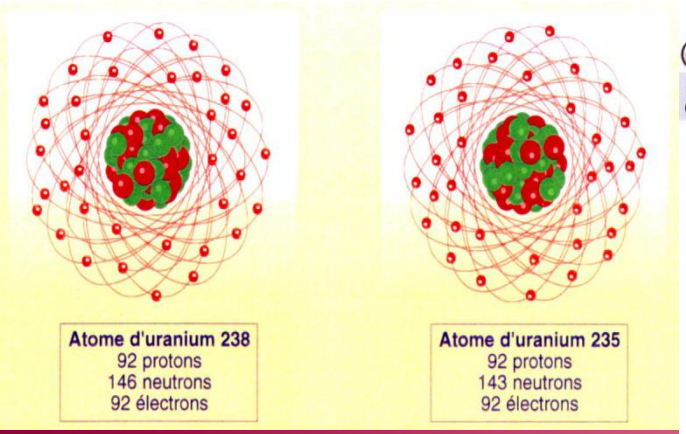


Nuclear Fission

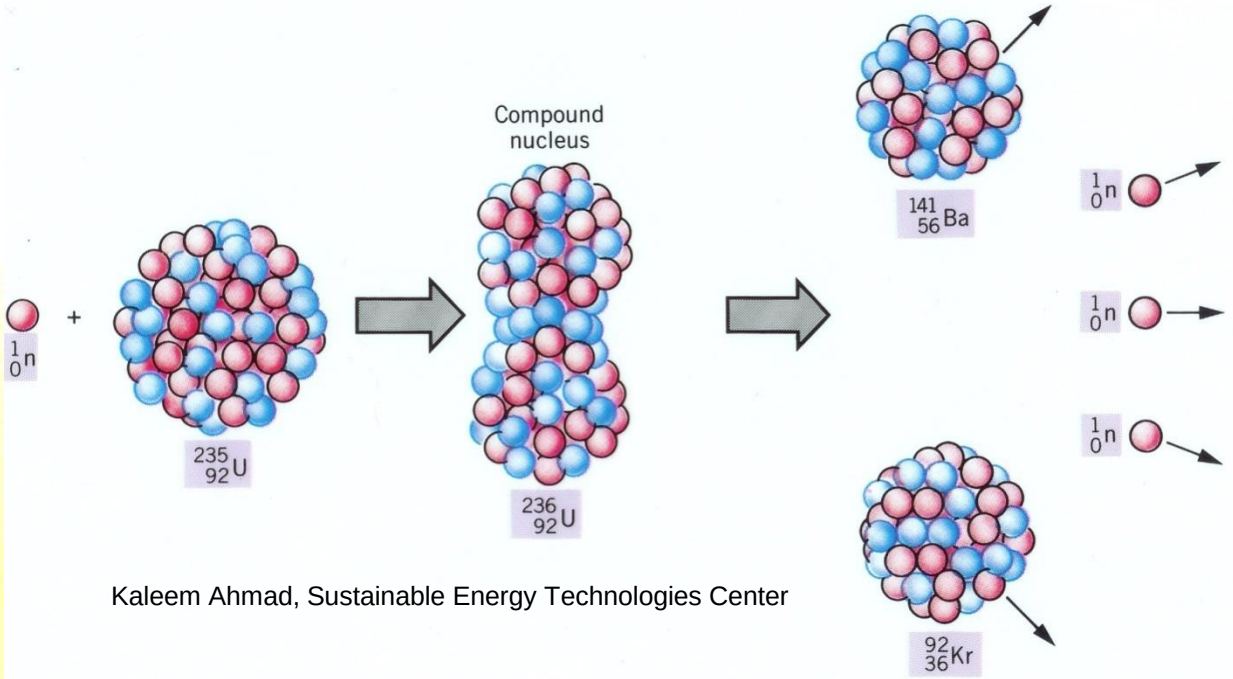
Nuclear Fission

A reaction in which an atomic nucleus of heavy elements notably uranium and plutonium splits by bombardment of a neutron, with simultaneous release of large amounts of energy is called fission

U238
99.3 %



U235
0.7 %



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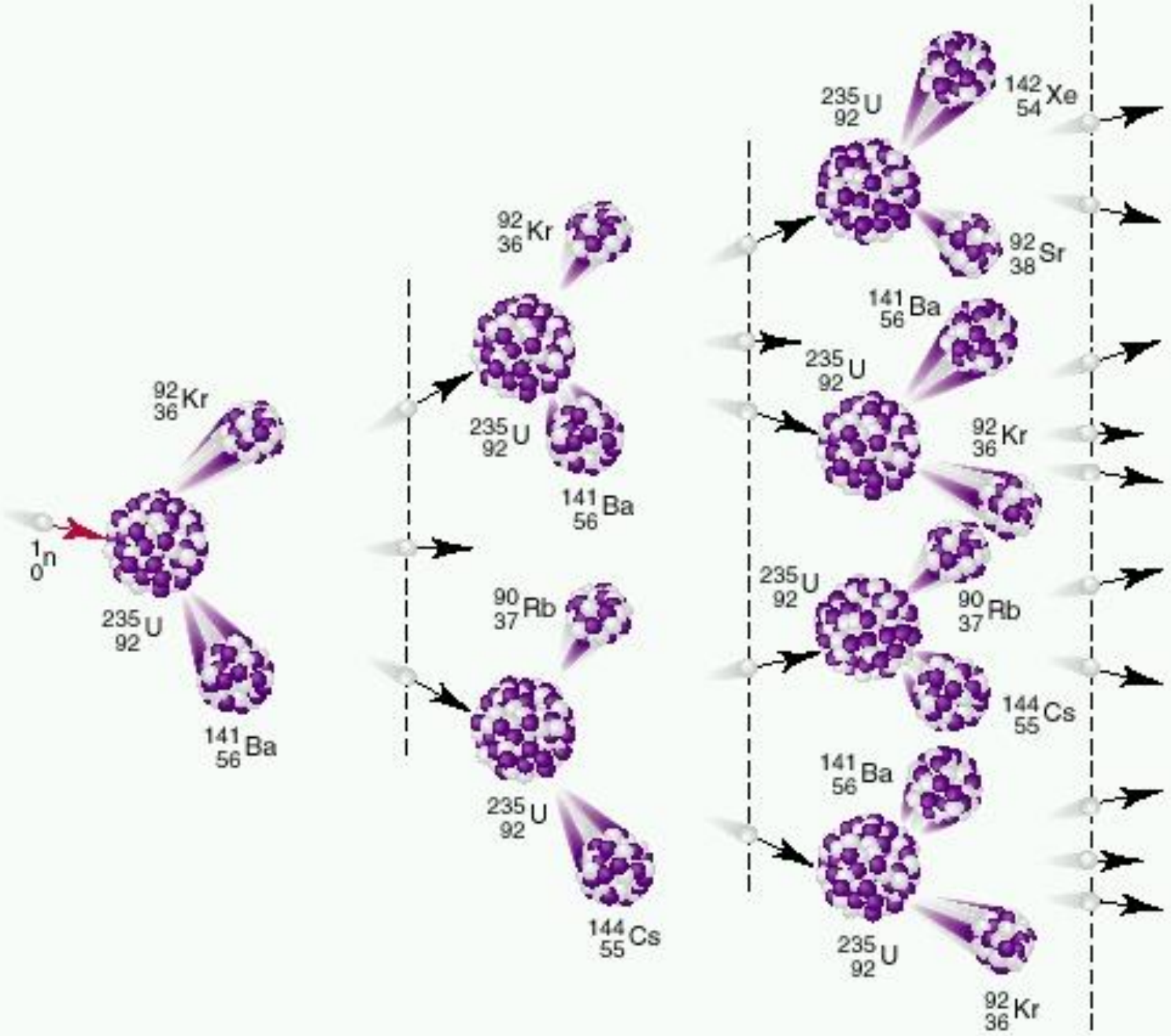
Fission Chain Reaction



Nuclear Fuel Cycle

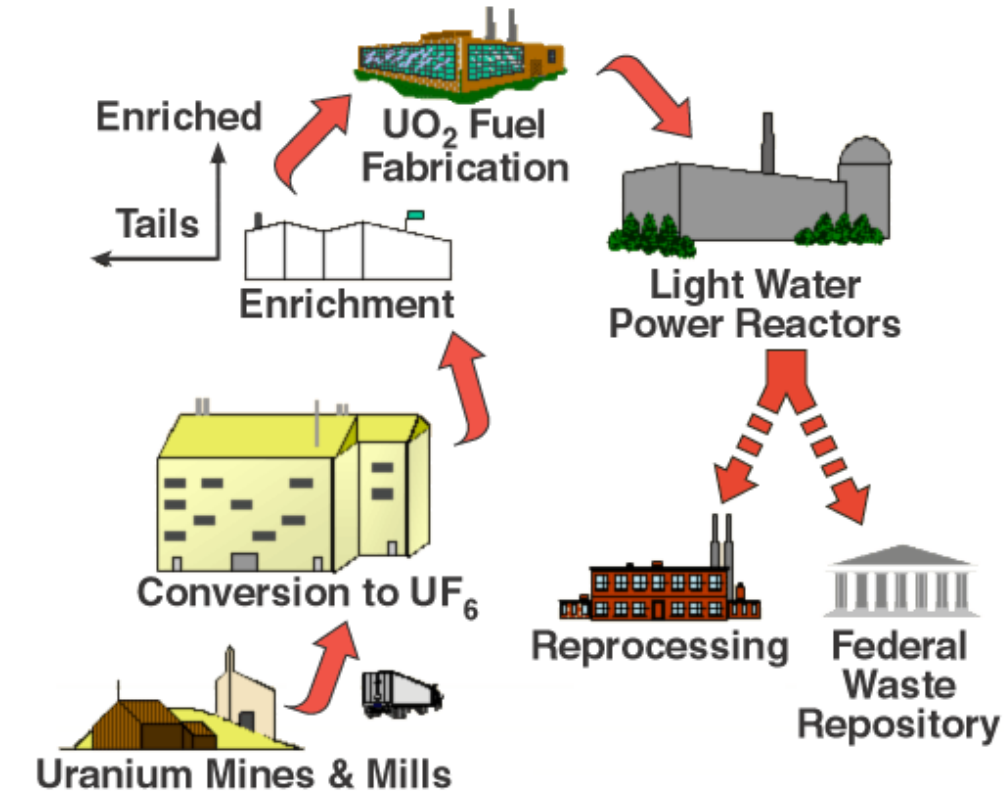
The Nuclear Fuel Cycle

- The Nuclear Fuel Cycle consists of sequence of steps in which uranium ore is mined, milled, enriched, and fabricated into nuclear fuel and then irradiated in a reactor for several years

- Nuclear Fuel is highly engineered manufactured product. Materials comprising the core are more pure than the medicine we swallow and the machined precision of fuel assemblies is comparable to that of fine wrist watch.

Nuclear Fuel Cycle

- Uranium Mining and Milling
- Conversion to UF_6
- Enrichment
- Fuel Fabrication
- Power Reactors
- Waste repository



Uranium Mining and Milling

Uranium deposits are found in rocks around the world

- Open pit mining
- Underground mining
- In-situ recovery

Mined rock is crushed and then leached to dissolve out the uranium, which is then precipitated out of solution as the uranium oxide U_3O_8, sometimes known as 'yellowcake'

Refining and Conversion

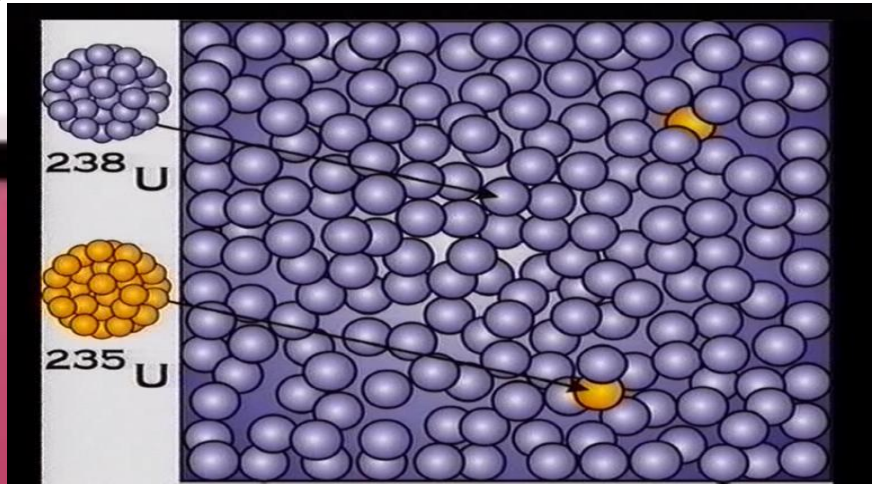
Refining – A series of chemical processes separate the uranium from impurities, producing high-purity uranium trioxide (UO3).

Conversion – UO3 is converted to uranium dioxide (UO2) for use in heavy water reactors, or to uranium hexafluoride (UF6) for enrichment, before it can be used in light water reactors.

Enrichment

- Uranium-235 is the uranium isotope that can be used in fission, but it makes up only 0.7% of naturally occurring uranium
- Enrichment processes increase the concentration of U-235 to about 3% – 5%.
- After undergoing enrichment, the UF6 is chemically transformed back into UO2 powder.

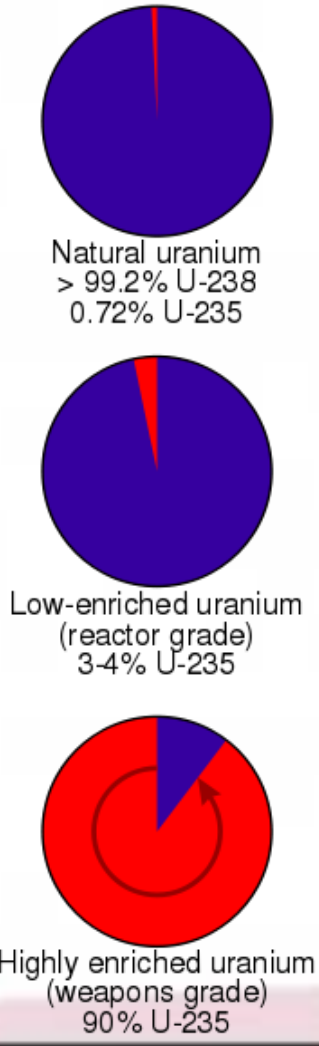
Natural Uranium



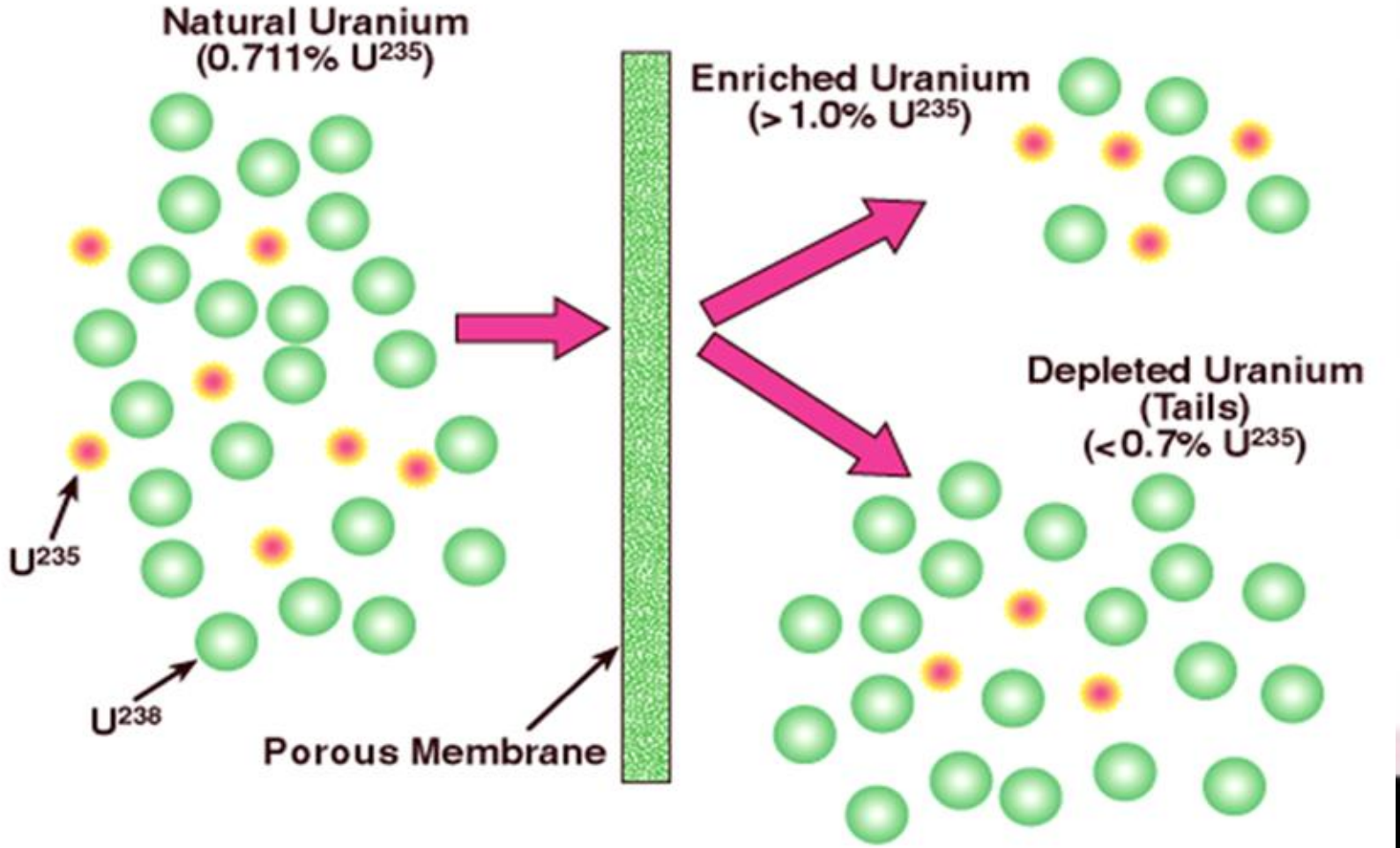
Enrichment

The two method of uranium enrichment are:

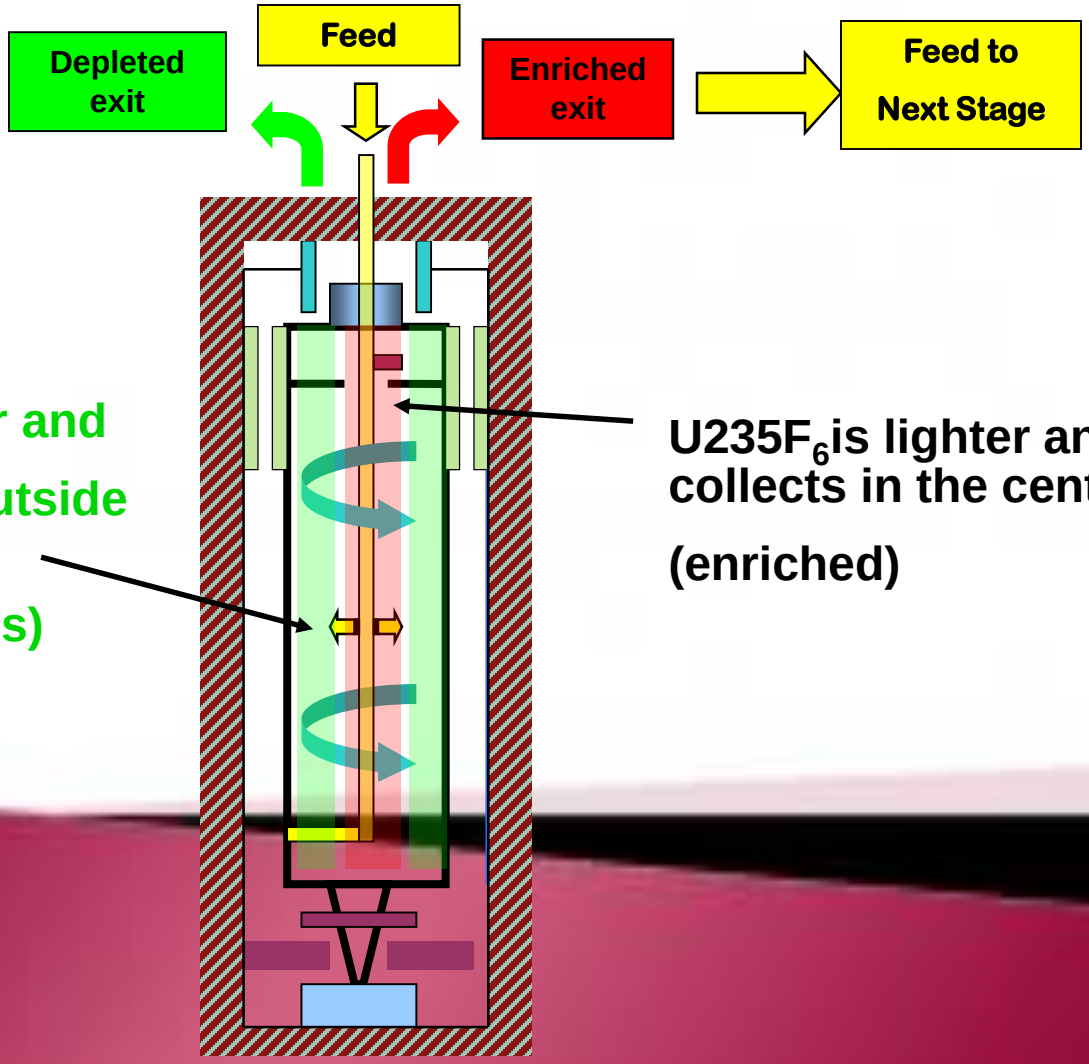
- Gaseous diffusion
- Centrifugation



Gaseous Diffusion Enrichment

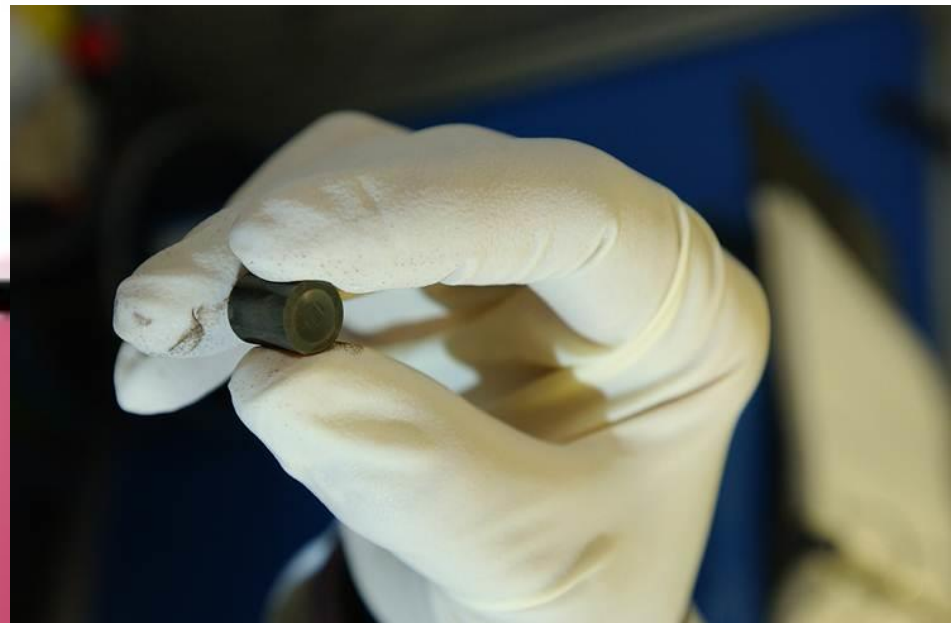


Centrifuge Enrichment

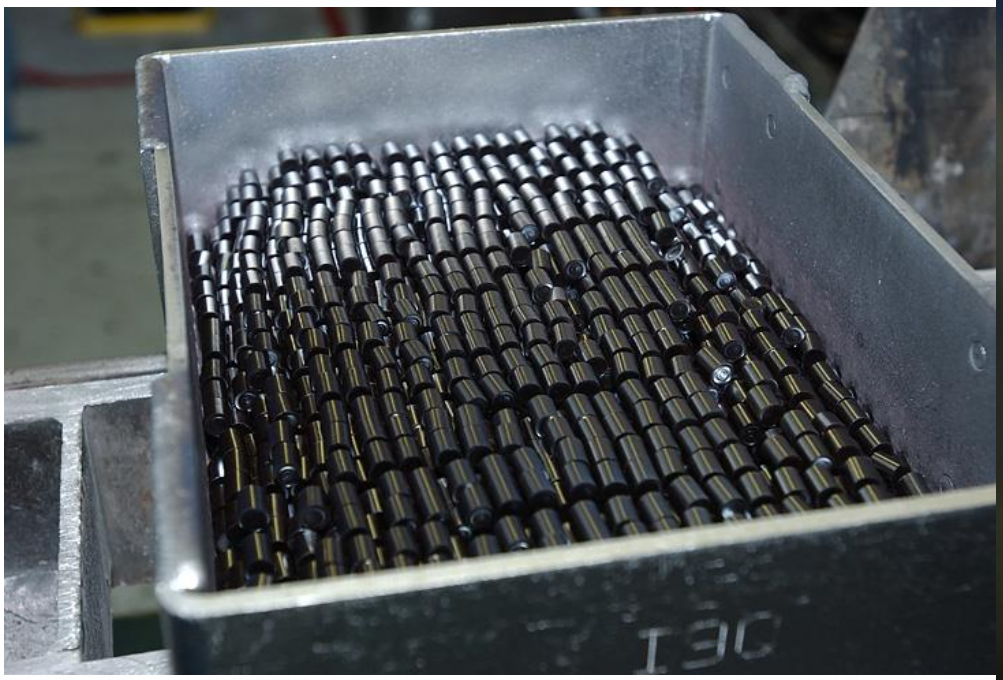


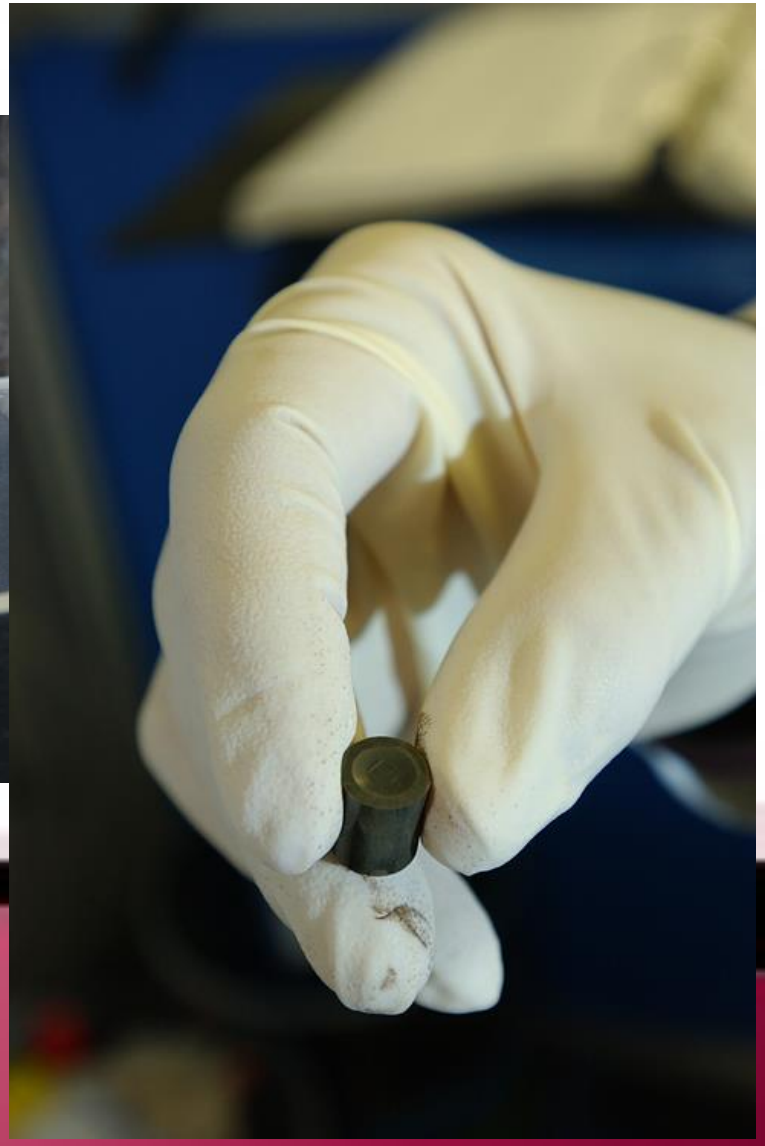
Fuel Fabrication

- Reactor fuel is generally in the form of ceramic pellets.
- These are formed from pressed uranium oxide which is sintered (baked) at a high temperature (over 1400°C).
- The pellets are then encased in metal tubes to form fuel rods, which are arranged into a fuel assembly ready for introduction into a reactor.



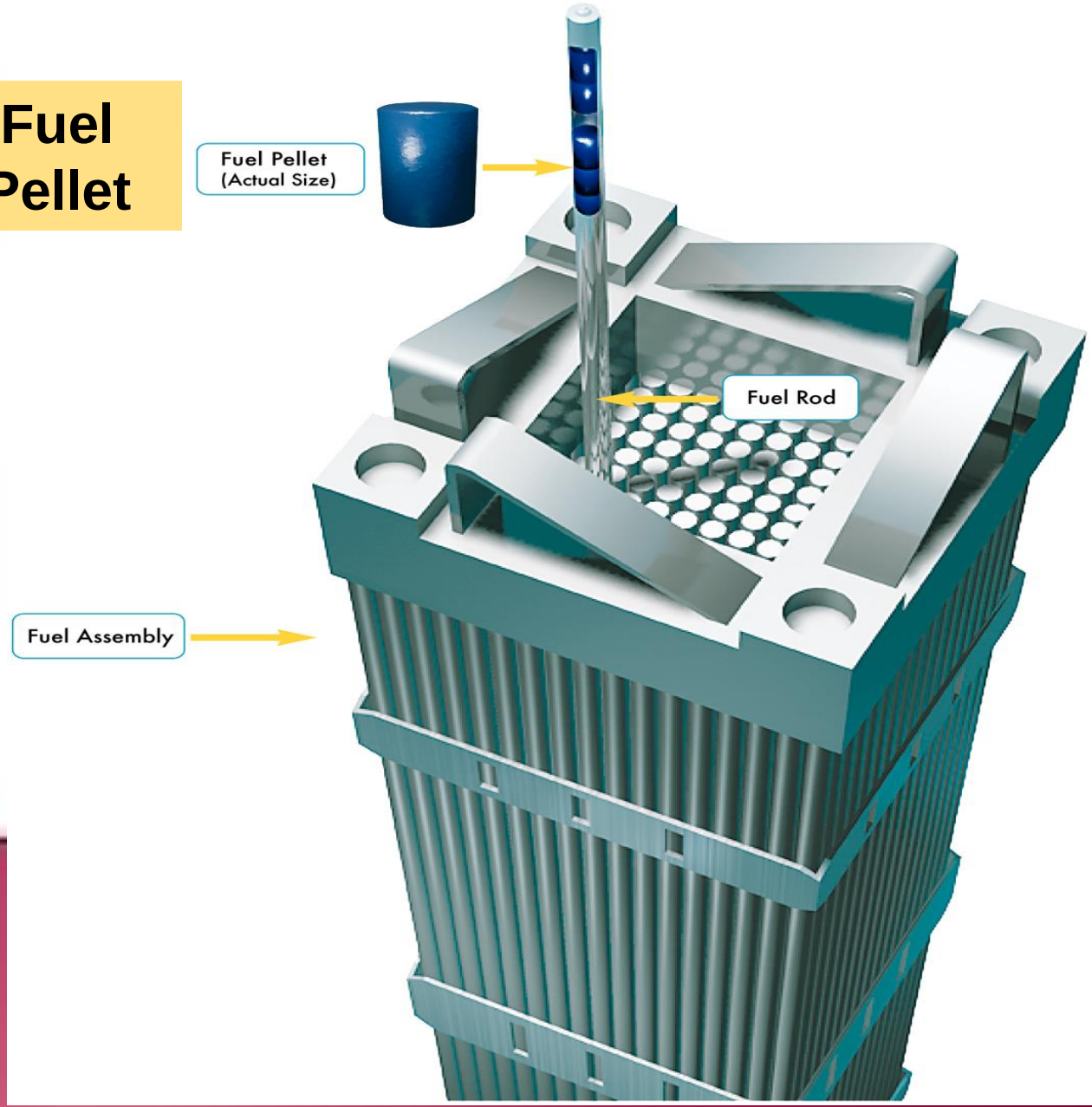
Fuel Pellets



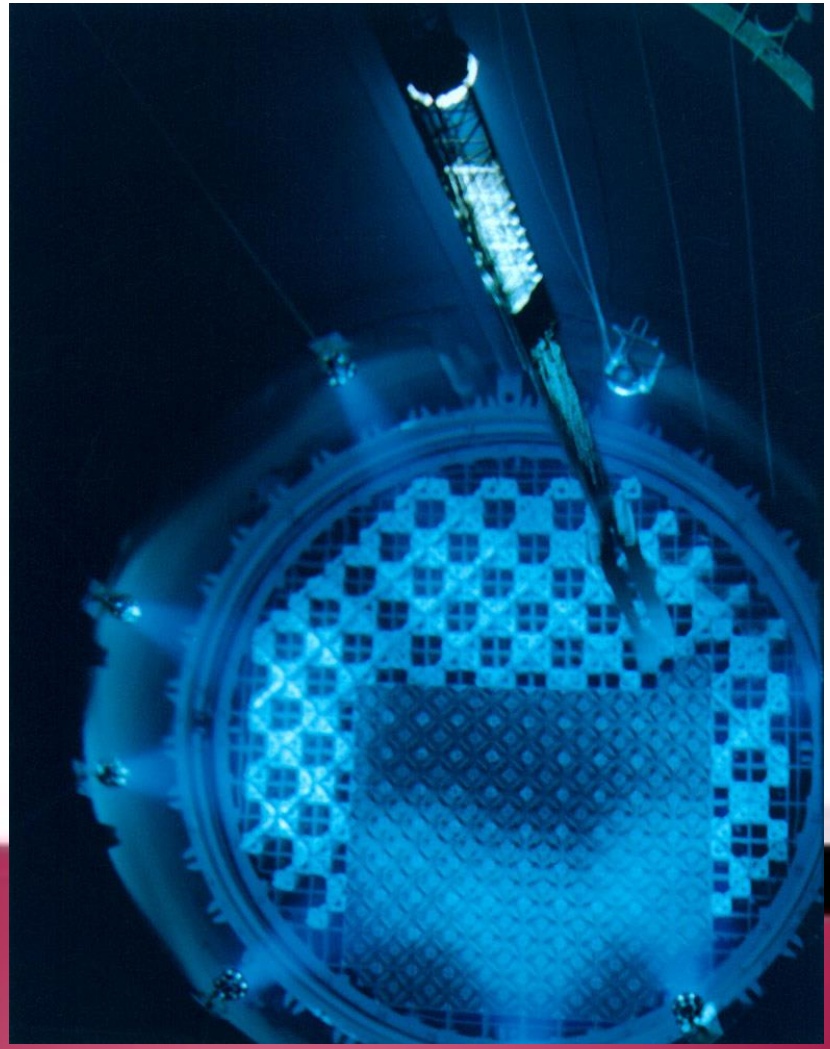


Nuclear Fuel Assembly

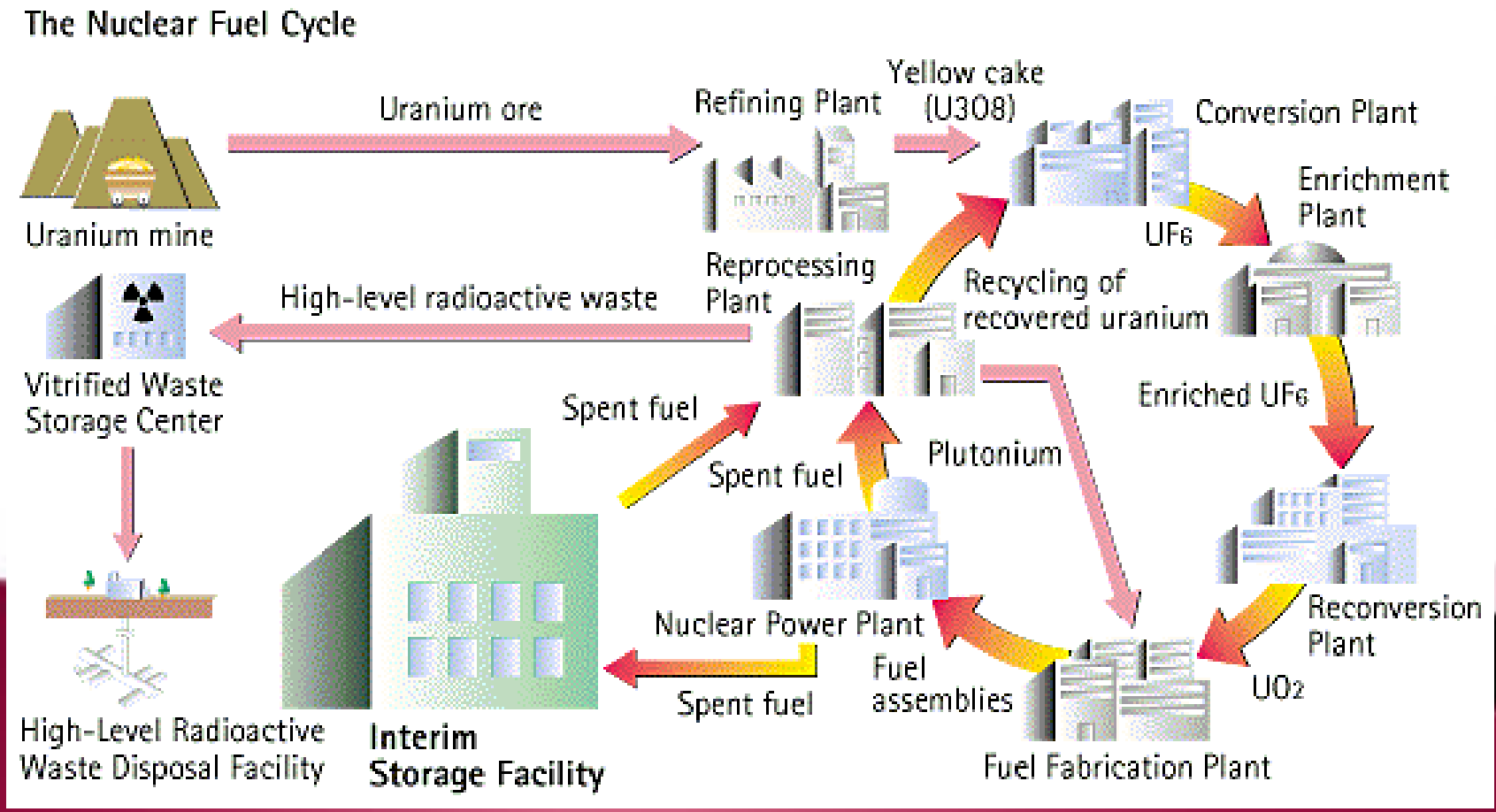
Fuel Pellet



Fuel Assemblies are Inserted in Reactor Vessel



Nuclear Fuel Cycle with Reprocessing



Nuclear Power Plants

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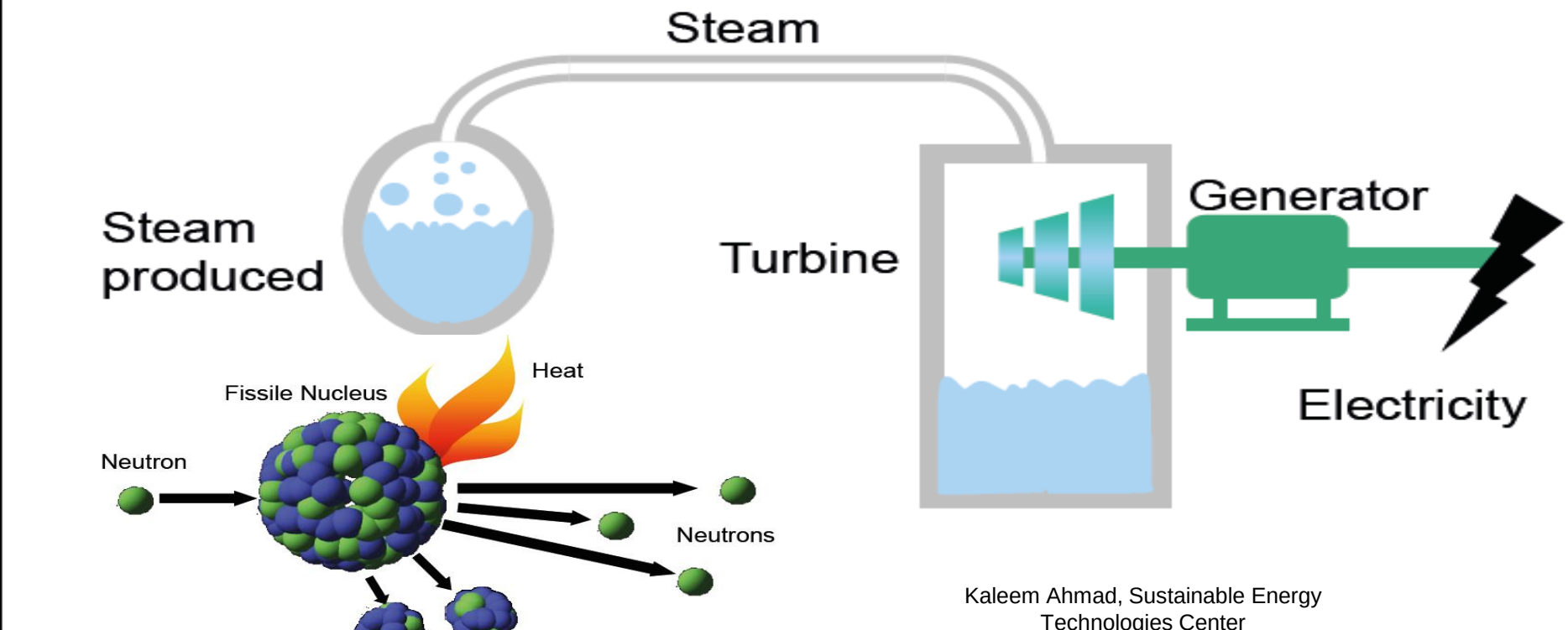
Nuclear Reactor

A nuclear reactor is a system that contains and controls sustained nuclear chain reactions.

Commercial reactors are used for generating electricity,

- Propulsion power for submarines/ships
- Producing medical isotopes for imaging and cancer treatment
- Conducting research, training and material testing.



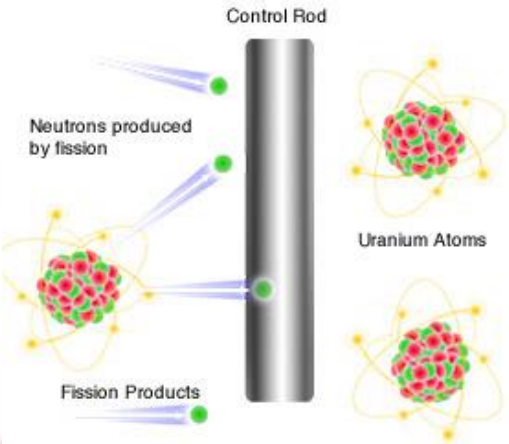
Nuclear Reactor Components

1. **Fuel rods**

These contain U235 or Pu239. They become very hot due to nuclear fission.

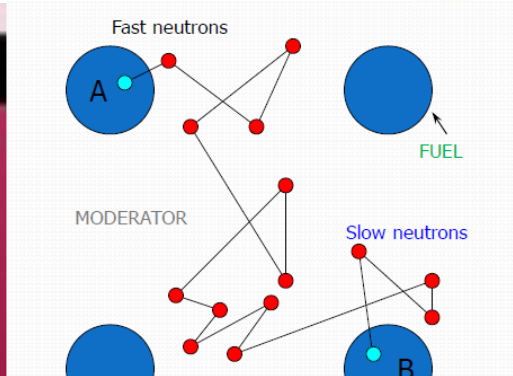
2. **Control rods**

Made of boron, when placed in-between the fuel rods these absorb neutrons and so reduce the rate of fission to control the reactor power.



3. **Moderator**

This surrounds the fuel rods and slows neutrons down to make further fission more likely.



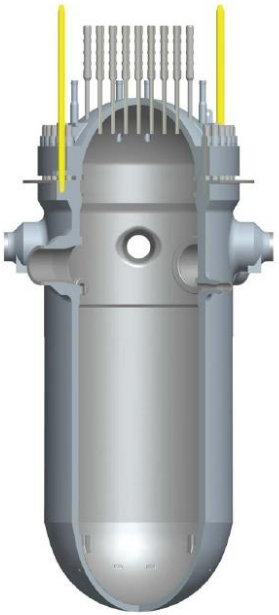
Nuclear Reactor Components (cont.)

4. **Coolant**

This transfers the heat energy of the fuel rods to the heat exchanger. Coolant be water, carbon dioxide gas or liquid sodium.

5. **Steam Generator**

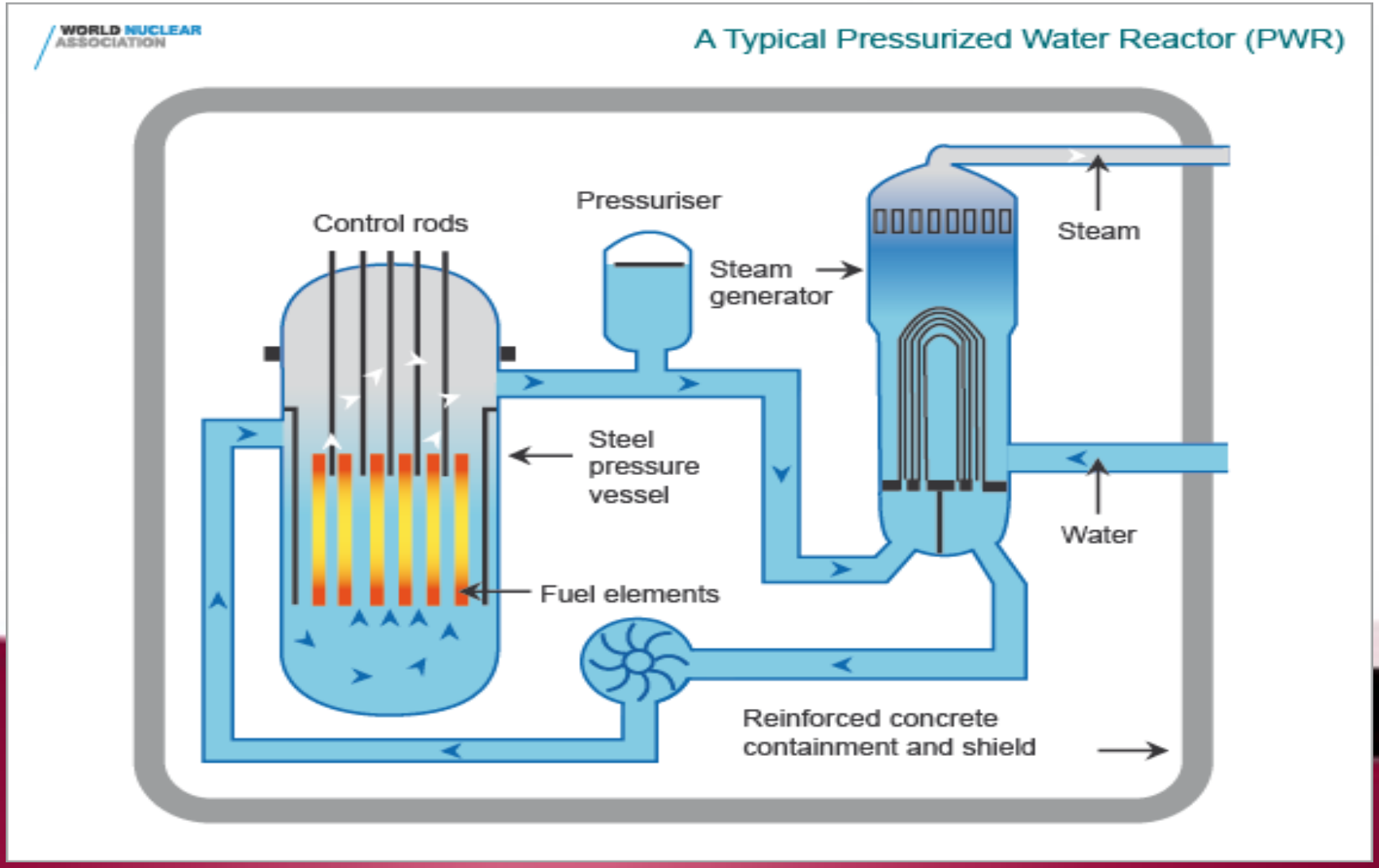
Feed water is converted into high pressure steam using the heat energy of the coolant.



6. **Reactor pressure vessel**

This is a thick steal vessel designed to withstand the very high pressure and temperature.

Nuclear Reactor Components (cont.)



Types of Nuclear Reactors

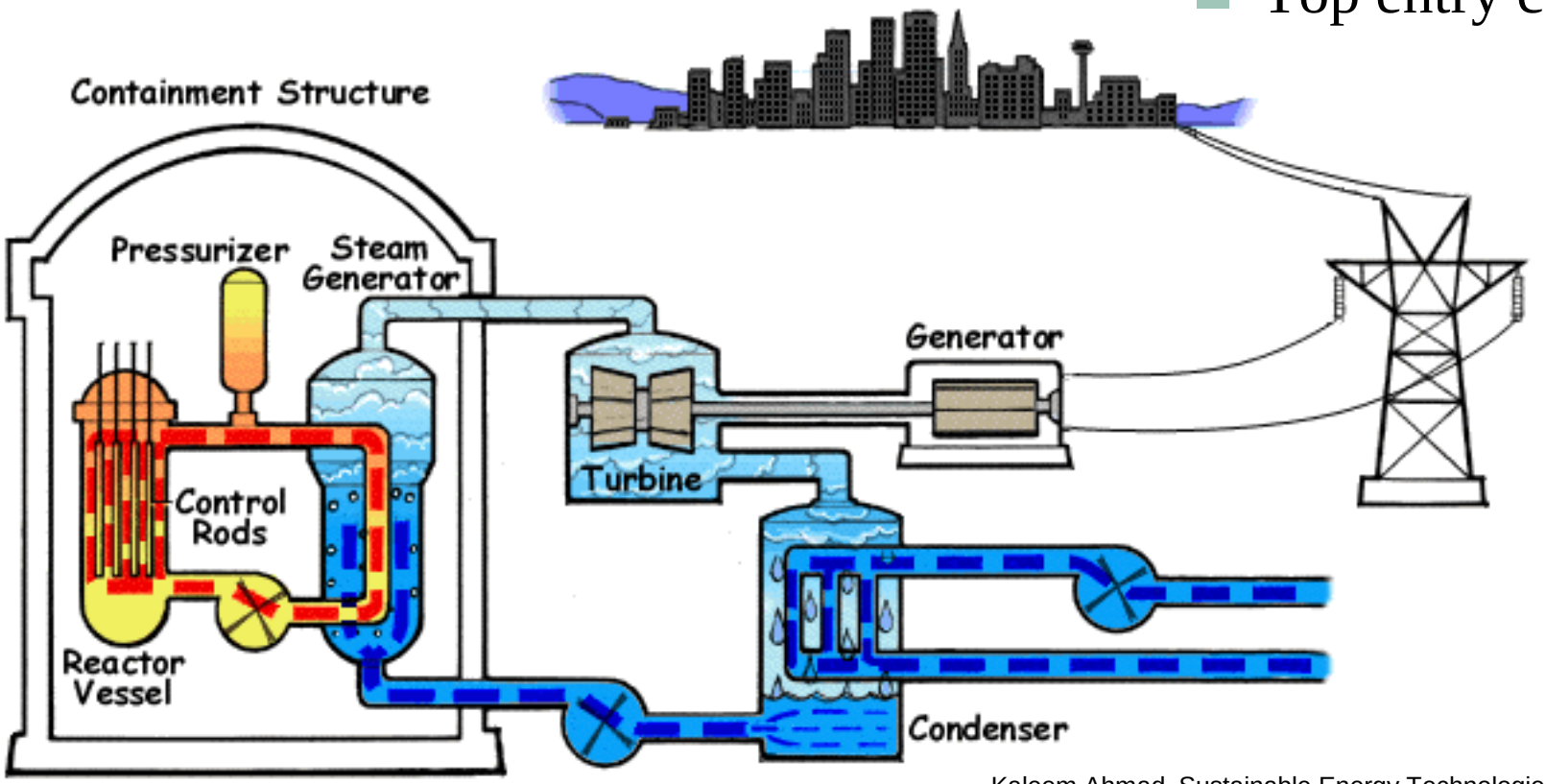
1. Light Water Reactors
   - Pressurized Water Reactor (PWR)
   - Boiling Water Reactor (BWR)

2. Heavy Water Reactors
   - Pressurized Heavy Water Reactor (PHWR-CANDU)

3. Fast Breeder Reactor (FBR)

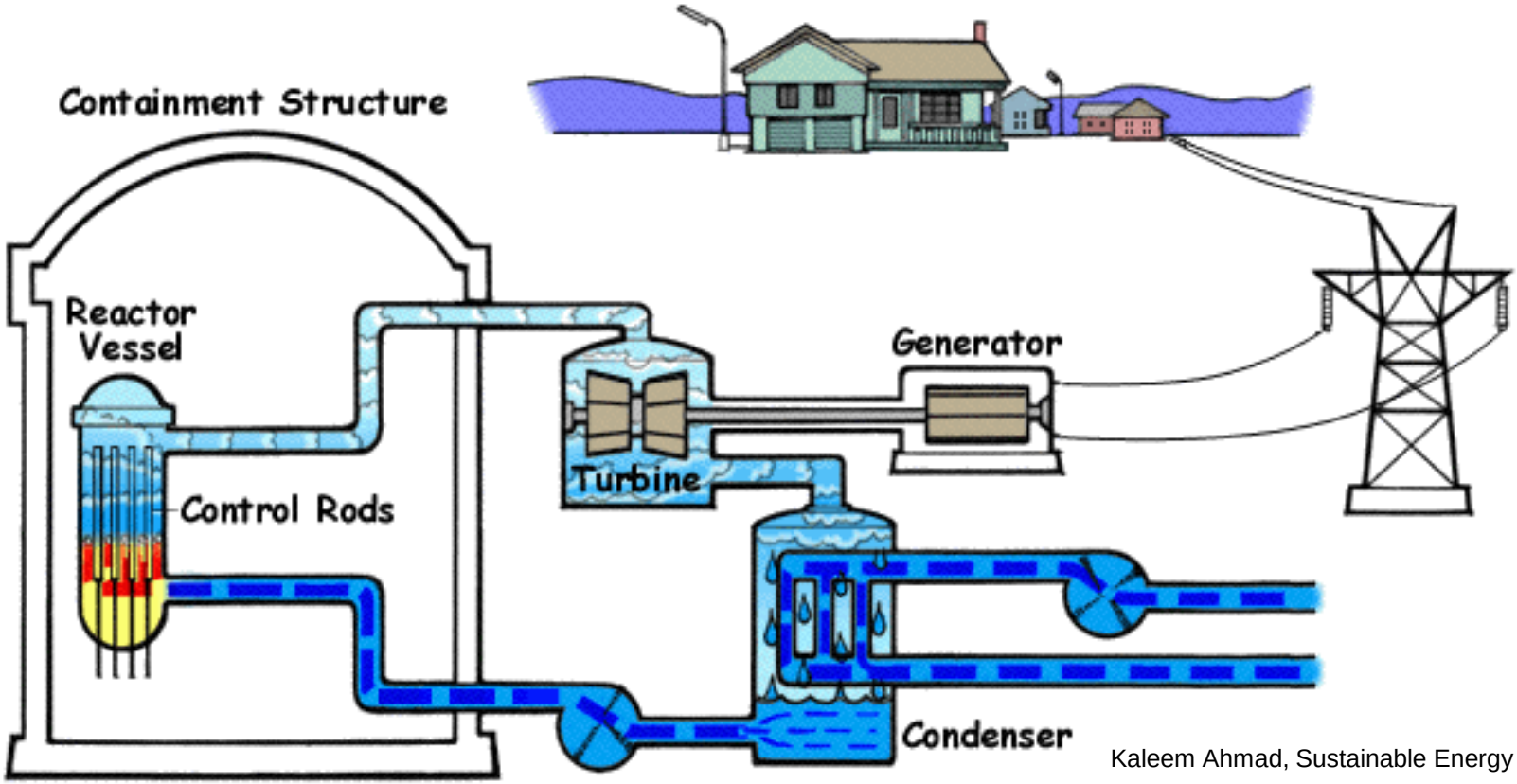
Pressurized Water Reactor (PWR)

- 3.2% U-235 Fuel
- 2-4 Loops => Steam
- UO_2 Pellets in Zircalo
- ~32% Efficiency
- Pressurizer
- Steam Generator
- Top entry control rod



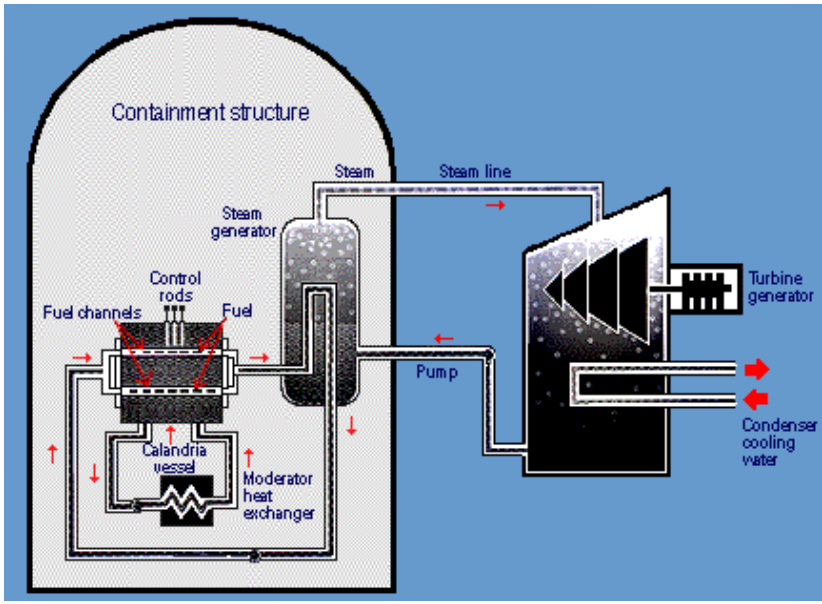
Boiling Water Reactor (BWR)

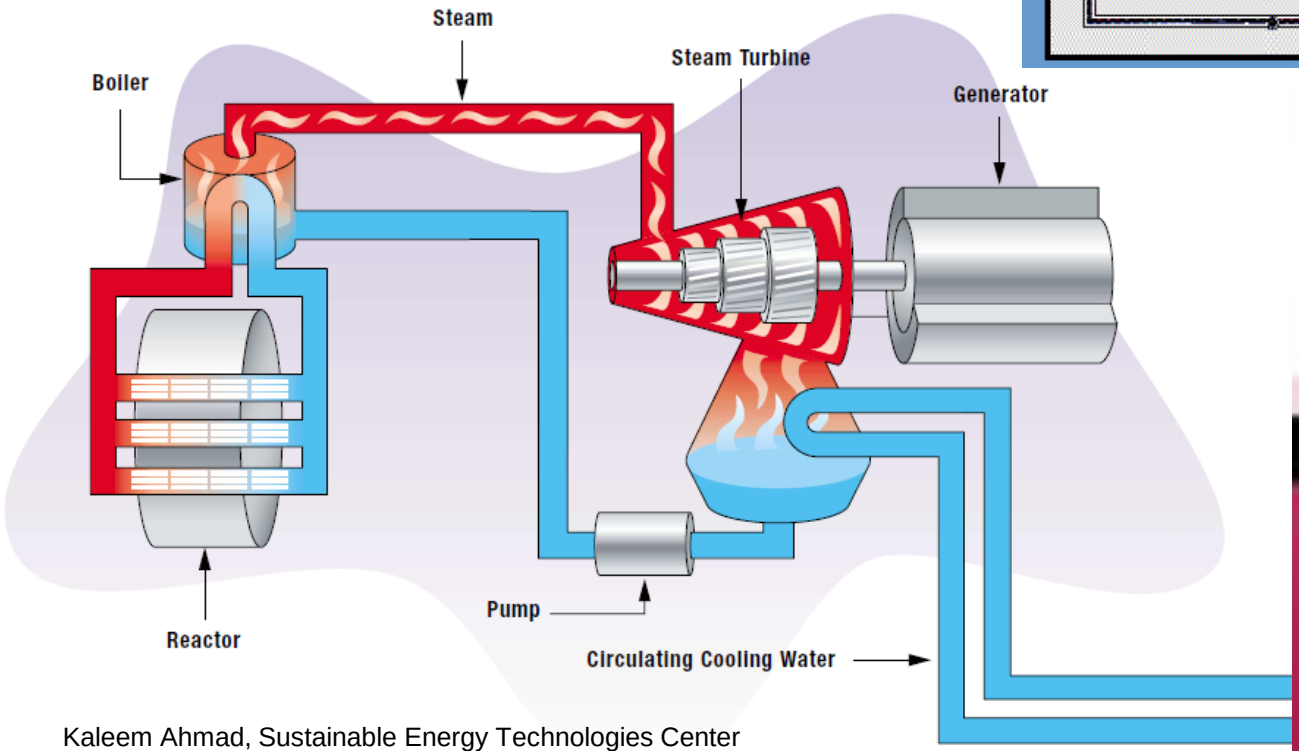
- 3.2% U-235 Fuel
- UO_2 Pellets in Zircaloy
- ~32% Efficiency
- Bottom entry control rod
- Direct cycle cooling



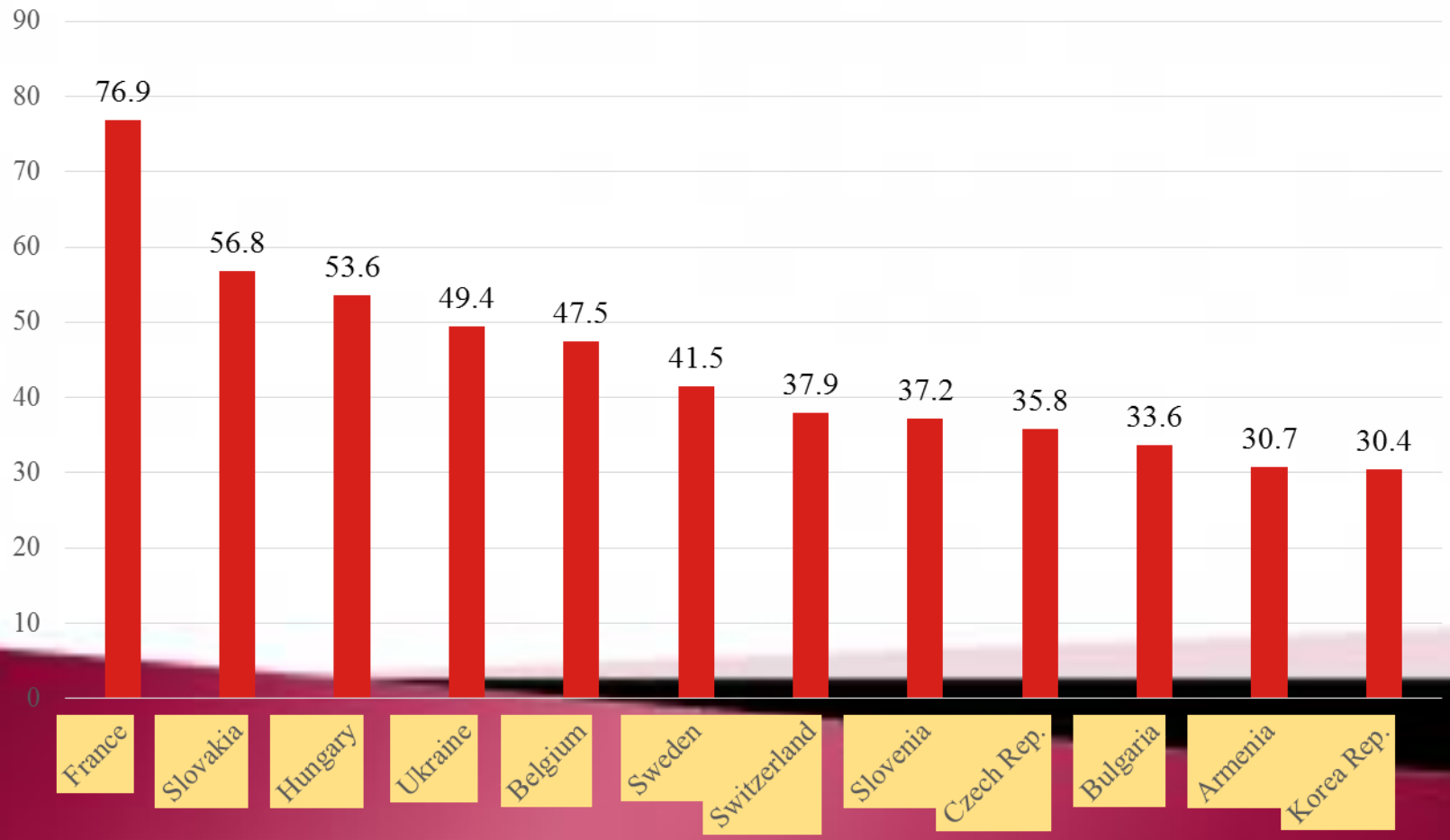
CANDU-Pressurized Heavy Water Reactor (PHWR)

- Natural UO_2 Pellets (fuel)
- Heavy water (coolant + moderator)
- Online refueling

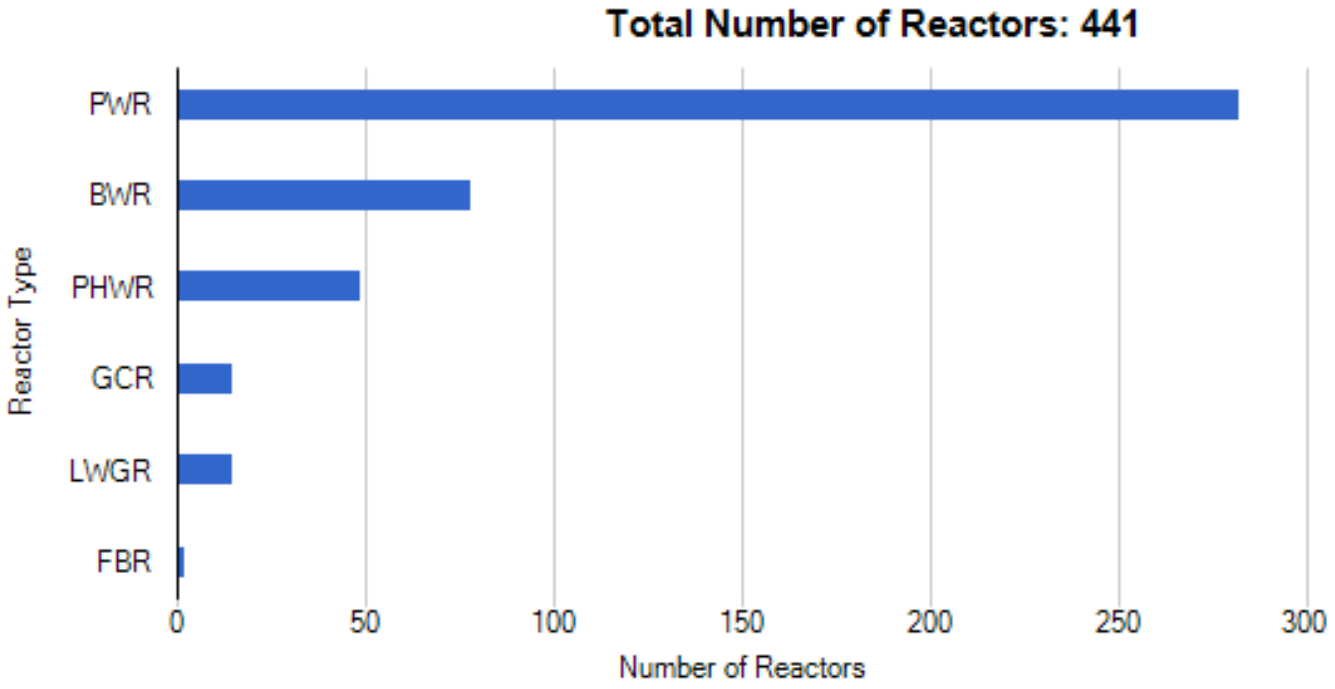


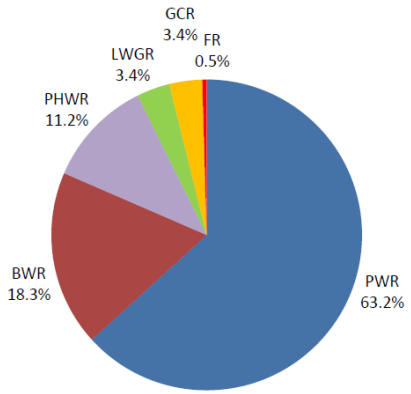


Nuclear Electricity Generation of Top Countries



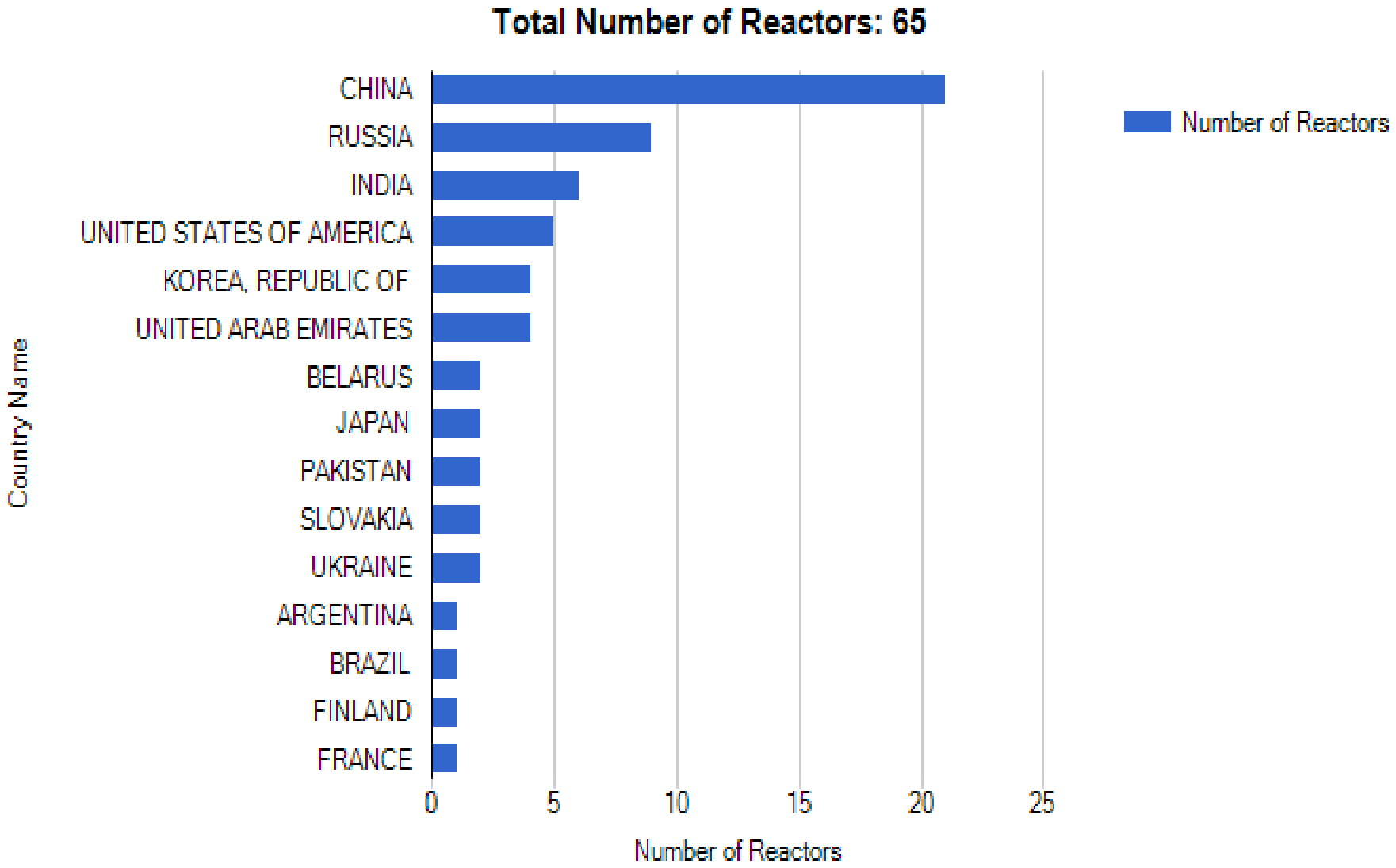
Nuclear power plants provided 12.3 percent of the world's electricity production





Reactor Type	Reactor Type Descriptive Name	Number of Reactors	Total Net Electrical Capacity [MW]
PWR	Pressurized Light-Water-Moderated and Cooled Reactor	282	263387
BWR	Boiling Light-Water-Cooled and Moderated Reactor	78	74755
PHWR	Pressurized Heavy-Water-Moderated and Cooled Reactor	49	24549
GCR	Gas-Cooled, Graphite-Moderated Reactor	15	8175
LWGR	Light-Water-Cooled, Graphite-Moderated Reactor	15	10219
FBR	Fast Breeder Reactor	2	580
Total		441	381665

Reactors under construction



Nuclear Energy Research

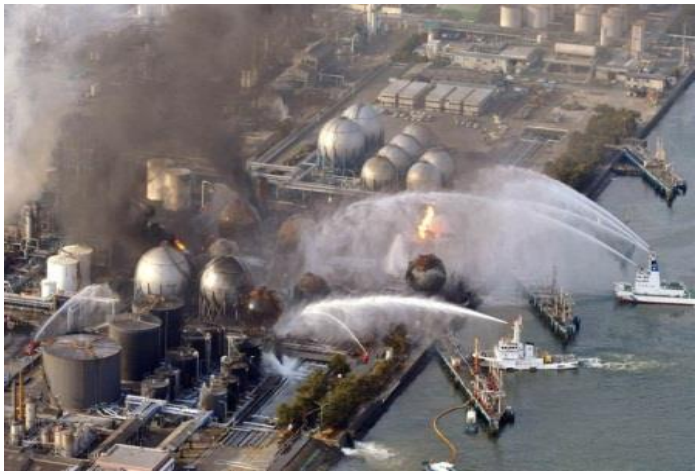
To carry out research and development in important areas of nuclear science and technology to complement the Kingdom's Nuclear Energy Program

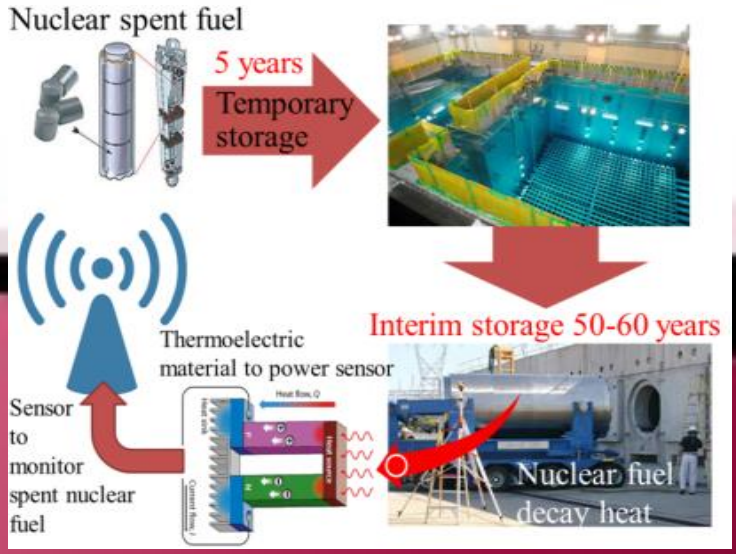
Current Research Activities

- **Development of high performance thermoelectric energy harvester for nuclear safety applications**
- **Laser spectroscopic studies for nuclear fuel, safety, and safeguard applications**
- **Developing simulation models and techniques for nuclear safety and water desalination**

Development of high performance thermoelectric energy harvester for nuclear safety applications

- Power safety sensors and communication devices for reactor safety
- Spent fuel monitoring in nuclear industry
- Automobile Industry
  - Provide 30% of car's electrical requirement
  - M… …uel c…





Education and Training

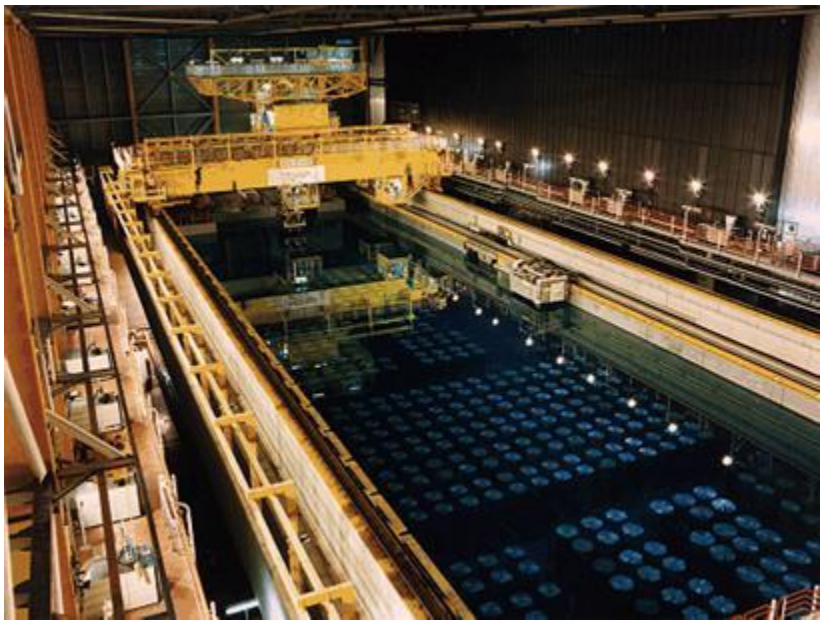
- Master Program in Nuclear Engineering
- Post Diploma Training Program for Technicians
- Post Graduate Training program for Engineers/Scientists

Technology[3]	Jobs/MWe	Average Size (MWe)	Direct Local Jobs
Nuclear	0.50	1,000	504
Coal	0.19	1,000	187
Concentrating Solar Power	0.47	100	47
Gas Combined Cycle	0.05	630	34
Solar Photovoltaic	1.06	10	11
Wind	0.05	75	4

Conclusions

- Nuclear energy is a crucial component of Kingdom's energy mix strategy.
- Nuclear power is one of the major low-carbon energy source and could play a significant role in ensuring sustainable and reliable energy supplies while curbing GHG emissions in the Kingdom.
- Modern nuclear power plant designs are more inherently safe and are less capital intensive, thereby making them attractive as compared to other energy sources.
- SET can play a vital role in assisting and promoting Kingdom's program for development of nuclear energy.

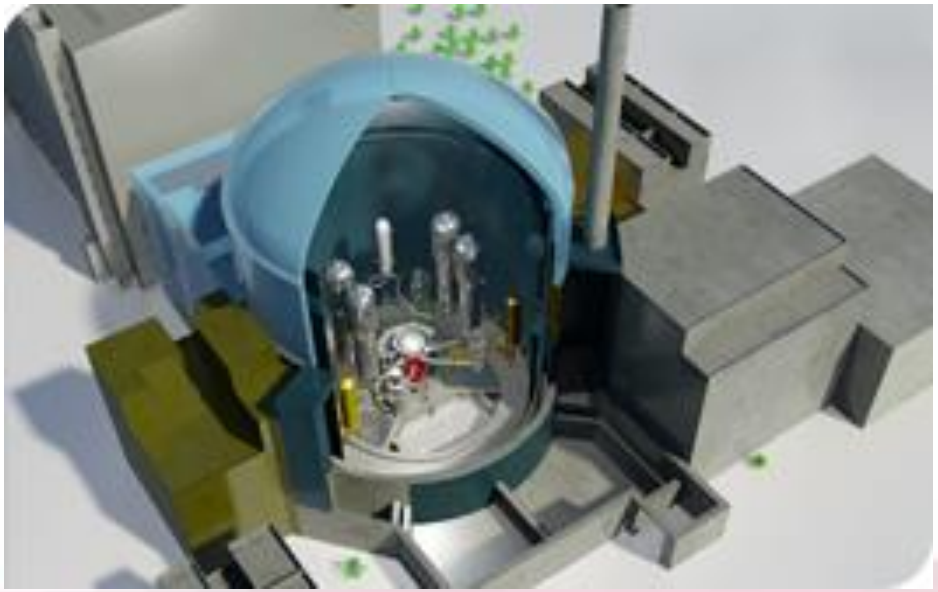
Composition of Spent fuel Rods of LWR



Material	Initial Fuel	Spent Fuel
Transuranic elements	0.000	0.065%
U-236	0.000	0.46%
Pu isotopes	0.000	0.89%
Fission products	0.000	0.35%
U-235	3.3%	0.08%
U-238	96.7%	94.3%

AREVA EPR (European Pressurized Water Reactor)

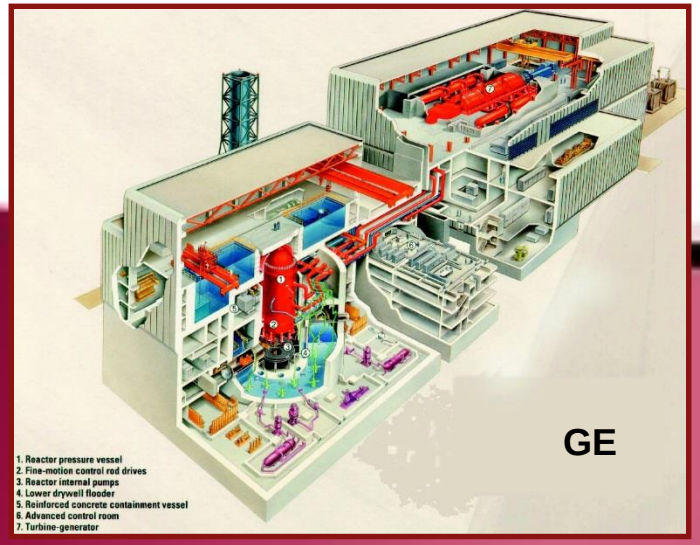
- 1650 MWe
- 36 – 37% Efficiency
- Mixed Oxide (MOX) Fuel
- 60 – yr Service Life
- 3 – 4 yr Construction
- Multiple Barriers and Simple Safety Systems

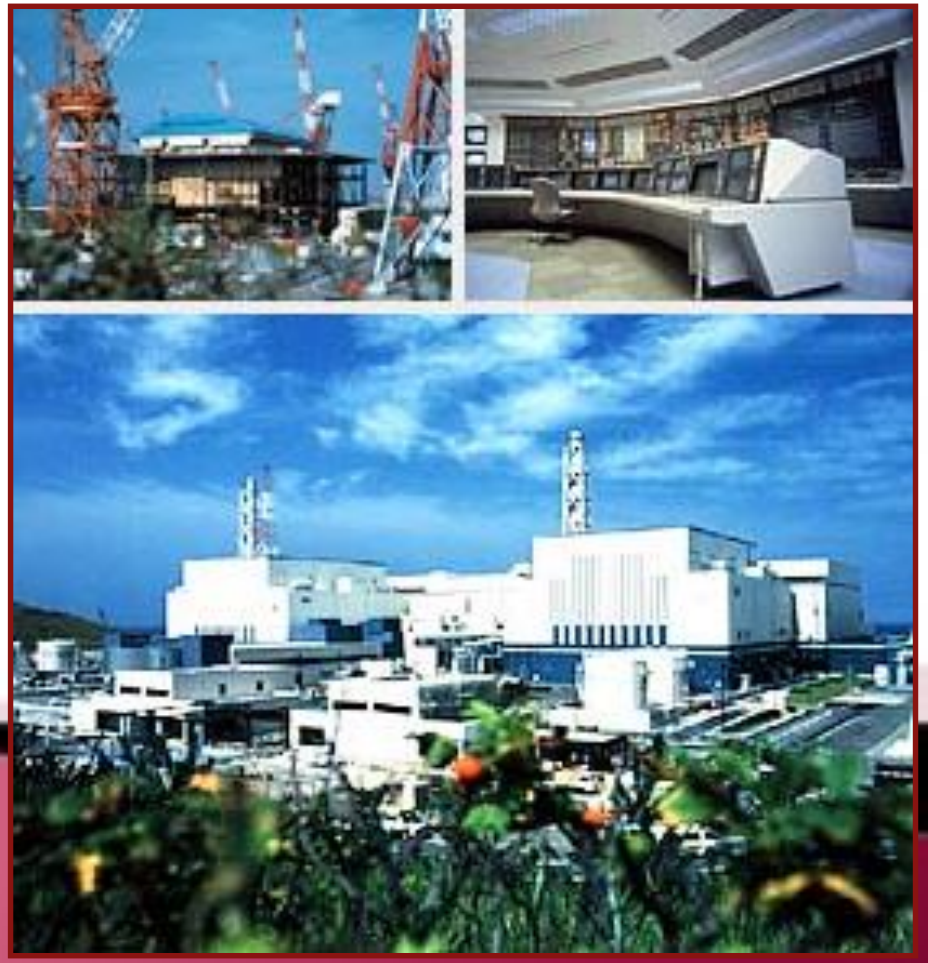


http://www.areva.com/EN/global-offer-419/epr-reactor-one-of-the-most-powerful-in-the-world.html

Advanced Boiling Water Reactor (ABWR)

- 1350 MWe
- 77% more compact than BWR design
- 39 month construction period





TOSHIBA, Kashiwazaki-Kariwa Unit 6, Japan