AN OVERVIEW OF NUCLEAR ENERGY

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SET
تقنيات الطاقة المستدامة
Sustainable Energy Technologies

Outline of the Seminar

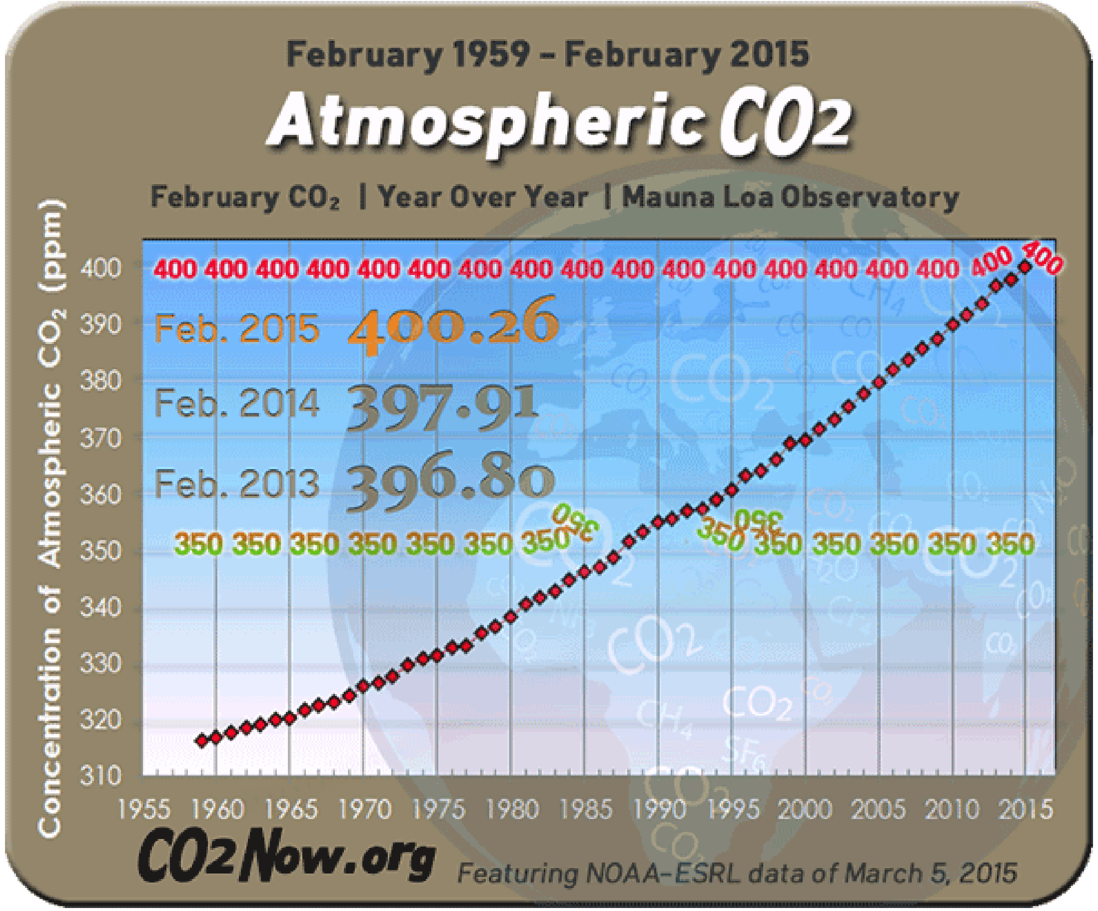
- Motivation and Importance of Nuclear Energy
- Future Energy Planning in the Kingdom
- Current Status of Nuclear Energy Worldwide
- Atomic Structure and Fission Process
- Nuclear Fuel Cycle
- Nuclear Power Plants
- Conclusions

Motivation

- Energy is the one of the most important challenge that the world is facing today.
- The consumption of fossil fuels cause environmental problems, so their use should be decreased.
- Fossil Fuel burning emit 34 billion tons of CO_2 per year
- Currently nuclear power generation avoids the emission of over two billion tons of carbon dioxide per year.
- Nuclear energy is mature, clean, safe and reliable technology therefore it is being considered in a number of countries for power generation.

Global Warming

Increase in the CO_2 concentration in the atmosphere is the main source of global warming. The rays of sun which are reflected back from earth are trapped by CO_2 in the atmosphere and they cannot return to space. This leads to global warming. The CO_2 content of the air has increased from a pre-industrial level of 280 ppm to a current value of around 400 ppm. [2 ^{0}C increase]



Effects of Higher CO_2 Concentration

- Global warming leads to severe weather conditions including droughts, storms, and floods
- Melting of glaciers and polar ice cause a rise in the ocean level leading to floods
- Air pollution contributes to health disorders from respiratory infections

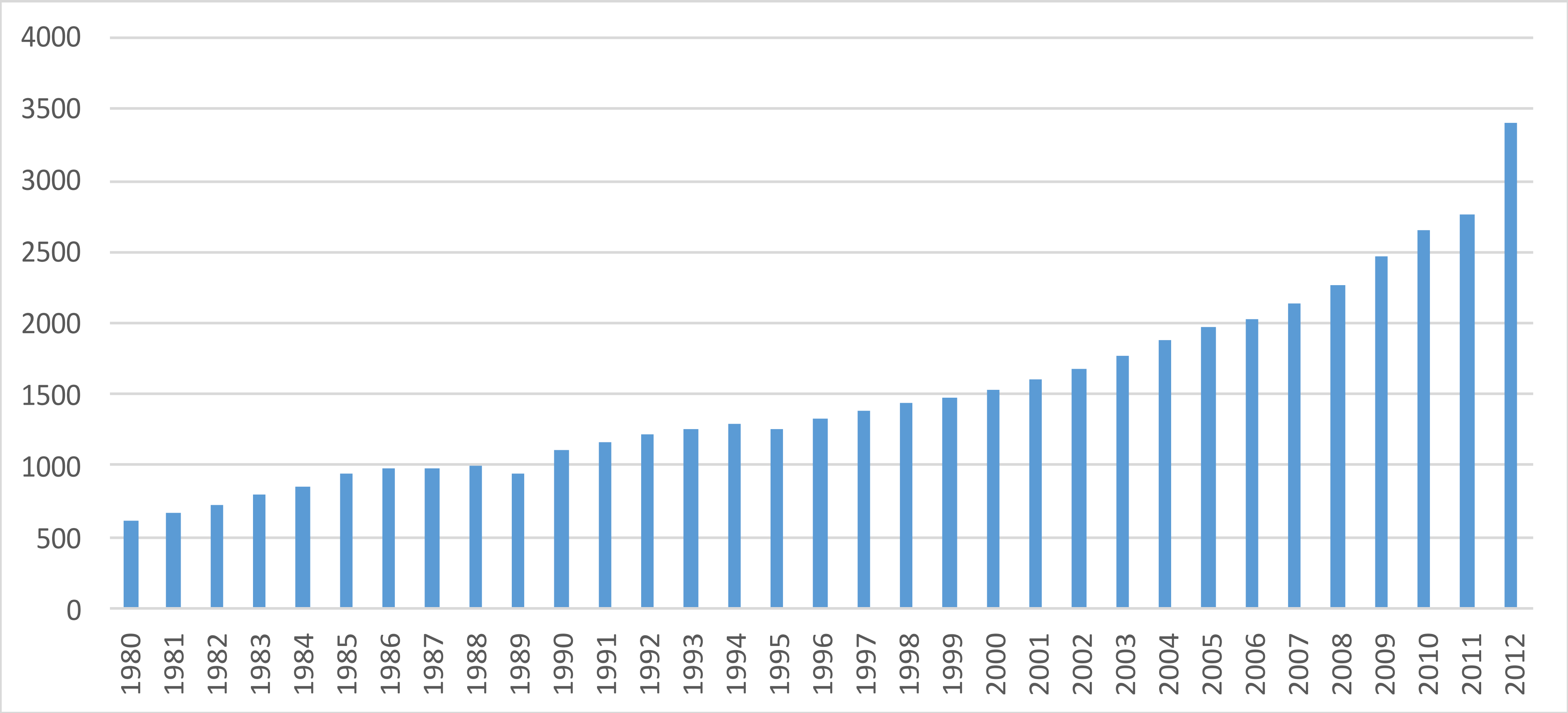
The World Health Organization (WHO) has estimated that air pollution causes over 1 million premature deaths worldwide each year.

Consumption of Oil VS Energy Demand

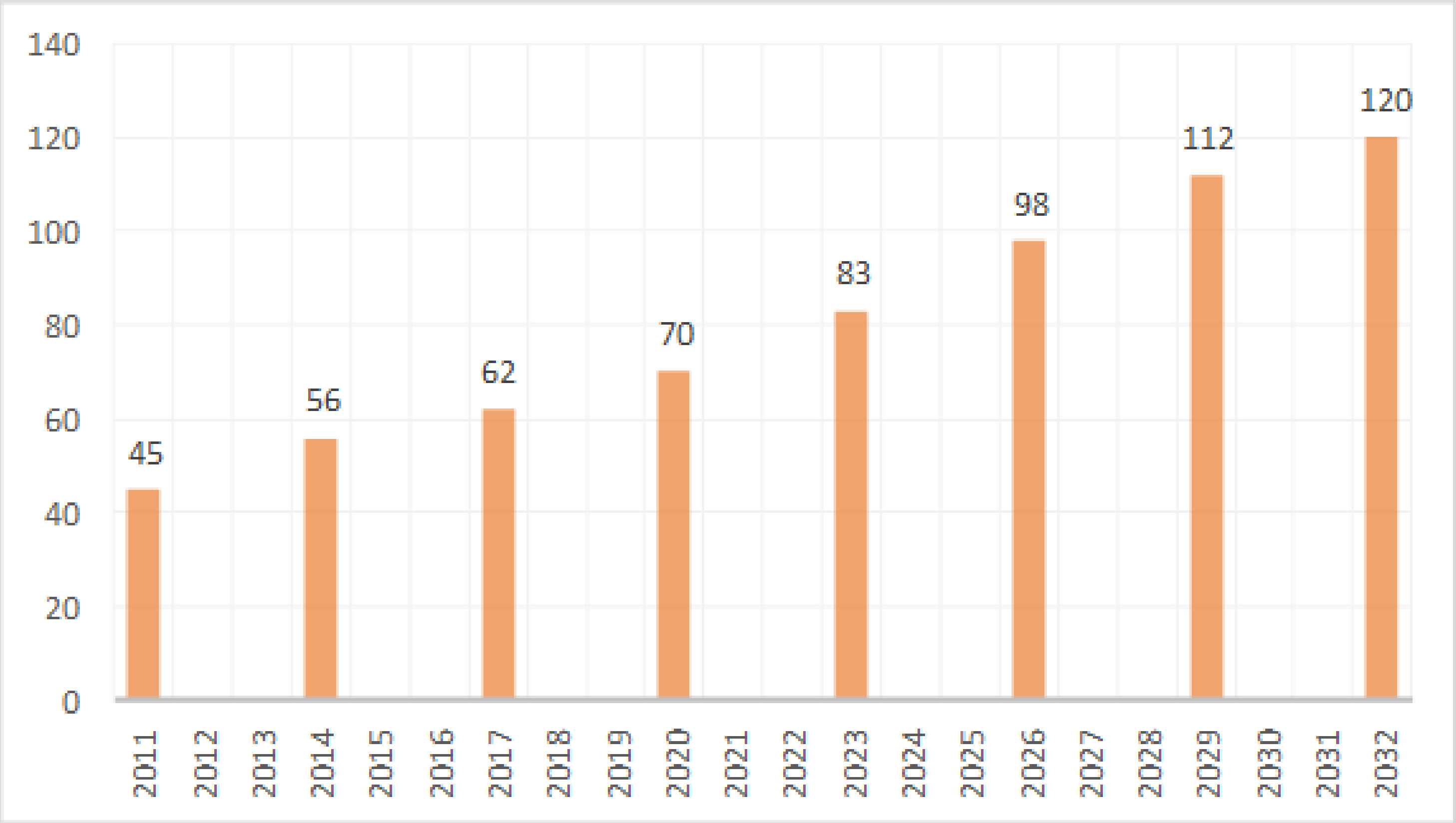
The current domestic oil consumption in the Kingdom is about one-fourth of the production. If this growth continues, it will have major impact on oil export. Saudi Arabia depends on oil export for 80 to 90% of its annual revenue. Current generating capacity of KSA is about 55 GW which, based on current projections, will increase to 120 GW by 2032, creating a demand for new sources of electricity to add about 65 GW of power generation capacity within next two decades.

Domestic Oil Consumption

ANNUAL CONSUMPTION OF CRUDE OIL IN SAUDI ARABIA (THOUSANDS BARRELS /DAY)



KSA PEAK DEMAND (GW)



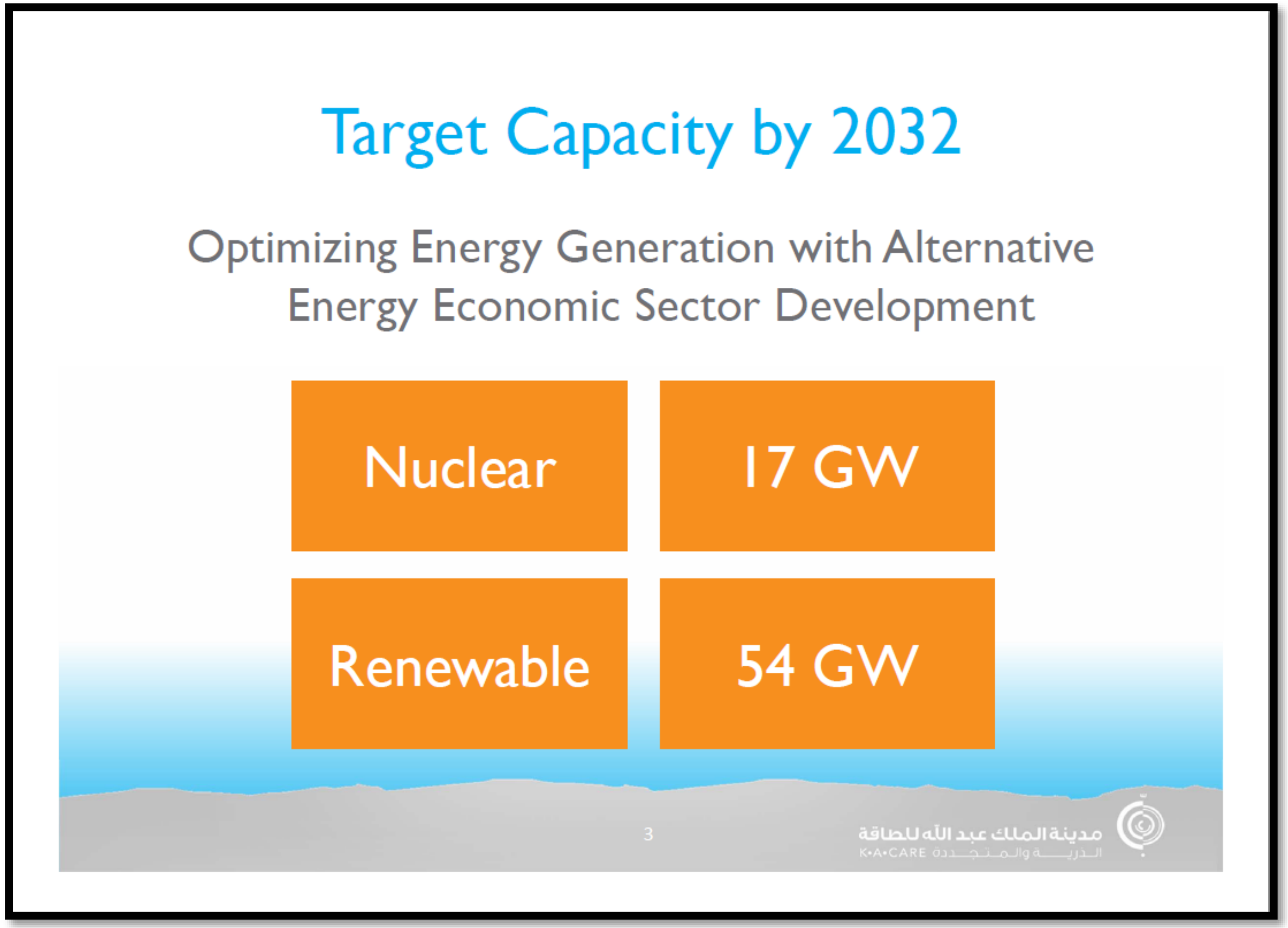
Future Plans of Kingdom

To meet the increasing energy demand, KSA has made a clear commitment to generate power from alternate energy sources.

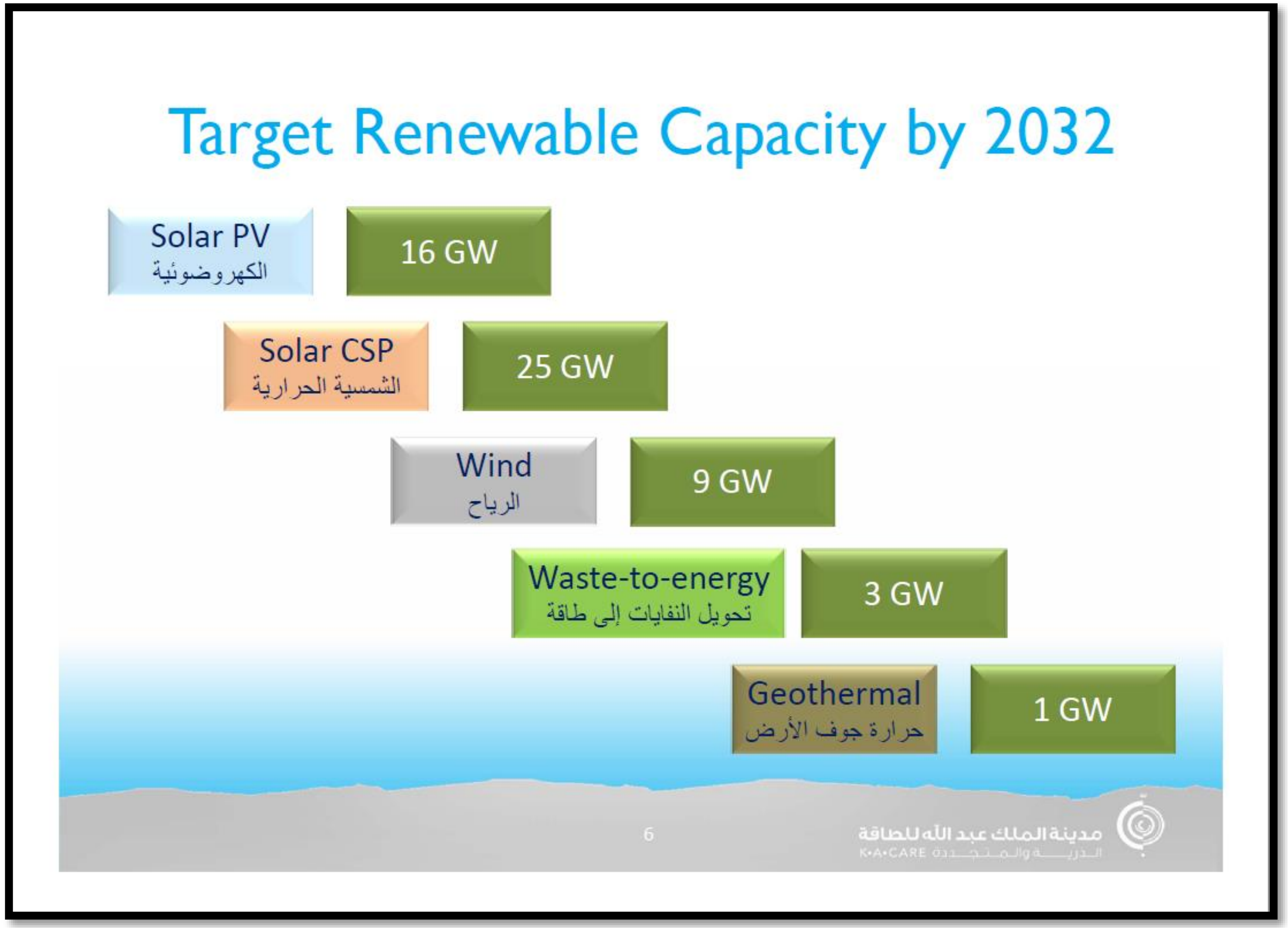
In April, 2010, a landmark decision was taken through a royal decree to establish King Abdullah City for Atomic and Renewable Energy (KACARE).

Its mandate is to make atomic and renewable energy an integral part of the energy mix in the kingdom.

KACARE Plans for Kingdom



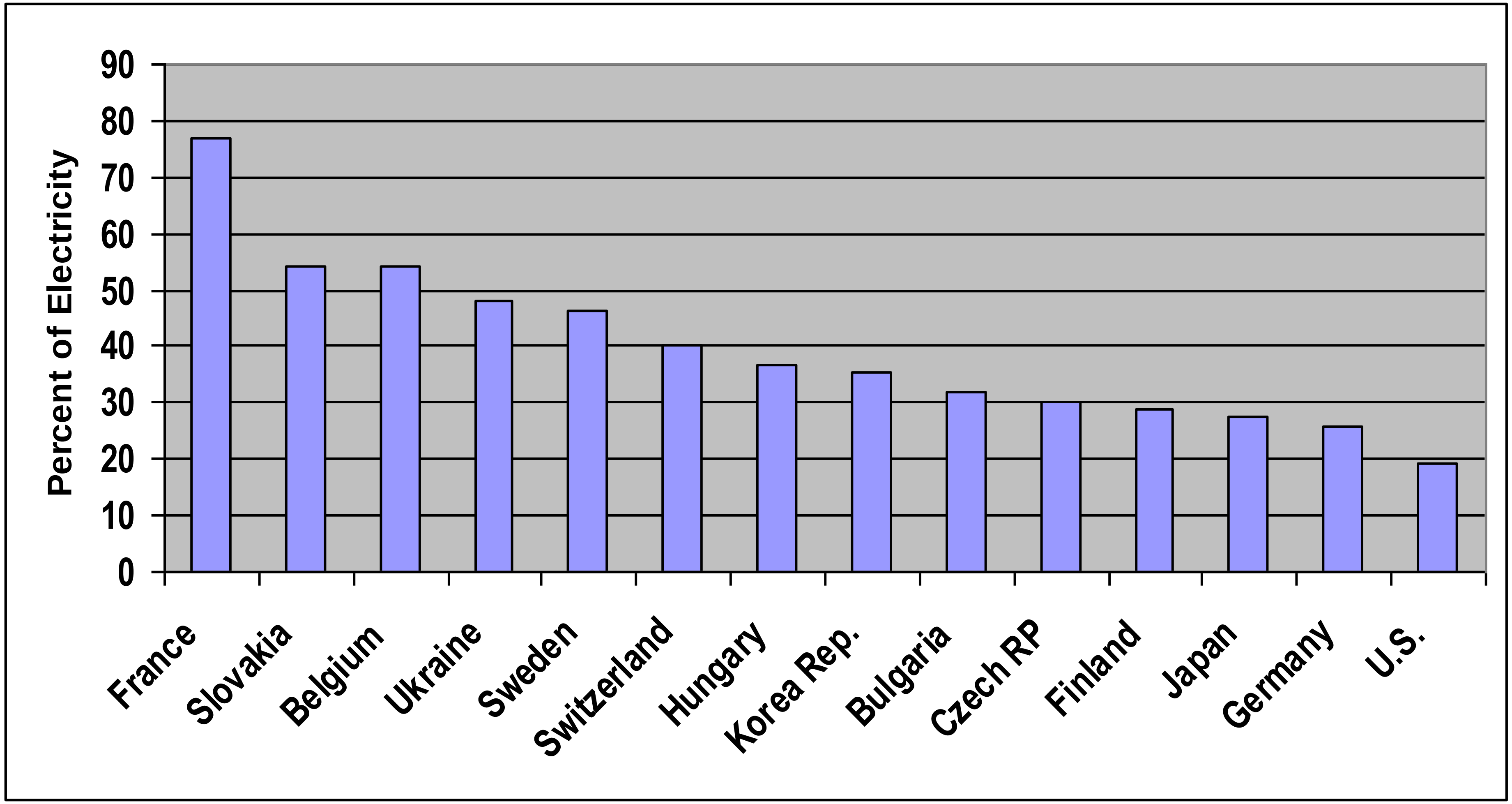
Renewable Energy Plans



The Number of Nuclear Reactors and Corresponding Electrical Capacity Worldwide

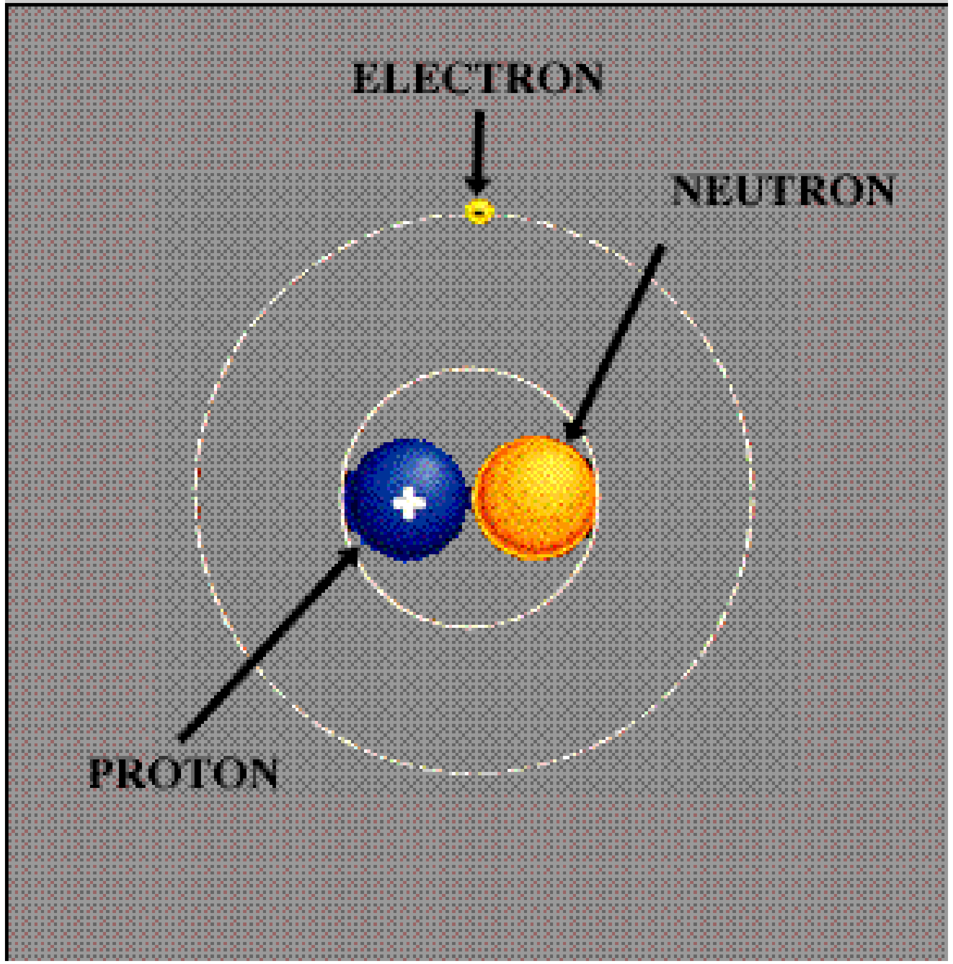
Country	In Operation	Total Net Electrical Capacity (MW)
Argentina	2	935
Armenia	1	375
Belgium	7	5927
Brazil	2	1884
Bulgaria	2	1906
Canada	19	13500
China	18	13860
Czech Republic	6	3804
Finland	4	2752
France	58	63130
Germany	9	12068
Hungary	4	1889
India	20	4391
Iran, Islamic Republic of	1	915
Japan	50	44215
Korea, Republic of	23	20739
Mexico	2	1530
Netherlands	1	482
Pakistan	3	725
Romania	2	1300
Russia	33	23643
Slovakia	4	1816
Slovenia	1	688
South Africa	2	1860
Spain	8	7560
Sweden	10	9395
Switzerland	5	3278
Ukraine	15	13107
United Kingdom	16	9231
United Arab Emirates		
United States of America	103	100680
Total	**437**	**372613**

% OF ELECTRICITY FROM NUCLEAR ENERGY

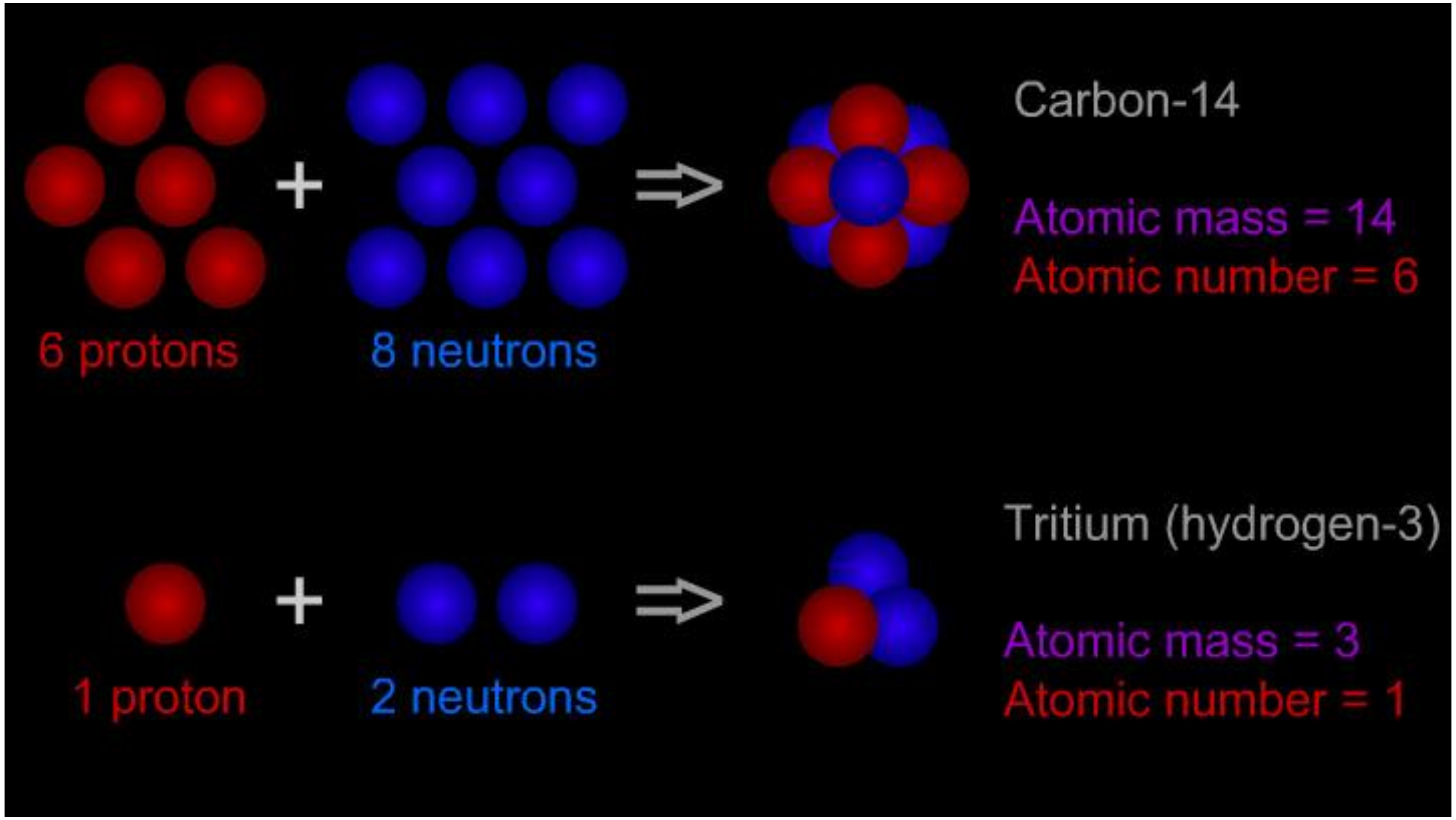


Atomic Structure

- Atom is the basic unit of matter.
- Nucleus is surrounded by orbital electrons.
- Nucleus consists of neutrons and protons.
- Atomic Number is number of protons in the nucleus.
- Atomic mass is sum of protons and neutrons.

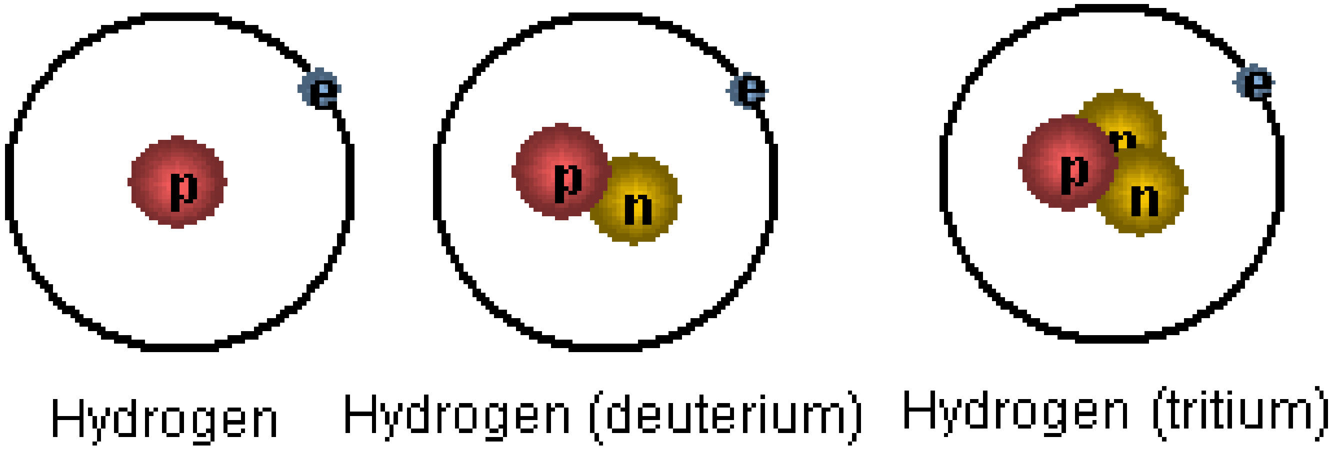


Atomic Number & Atomic Mass



Isotopes of Hydrogen

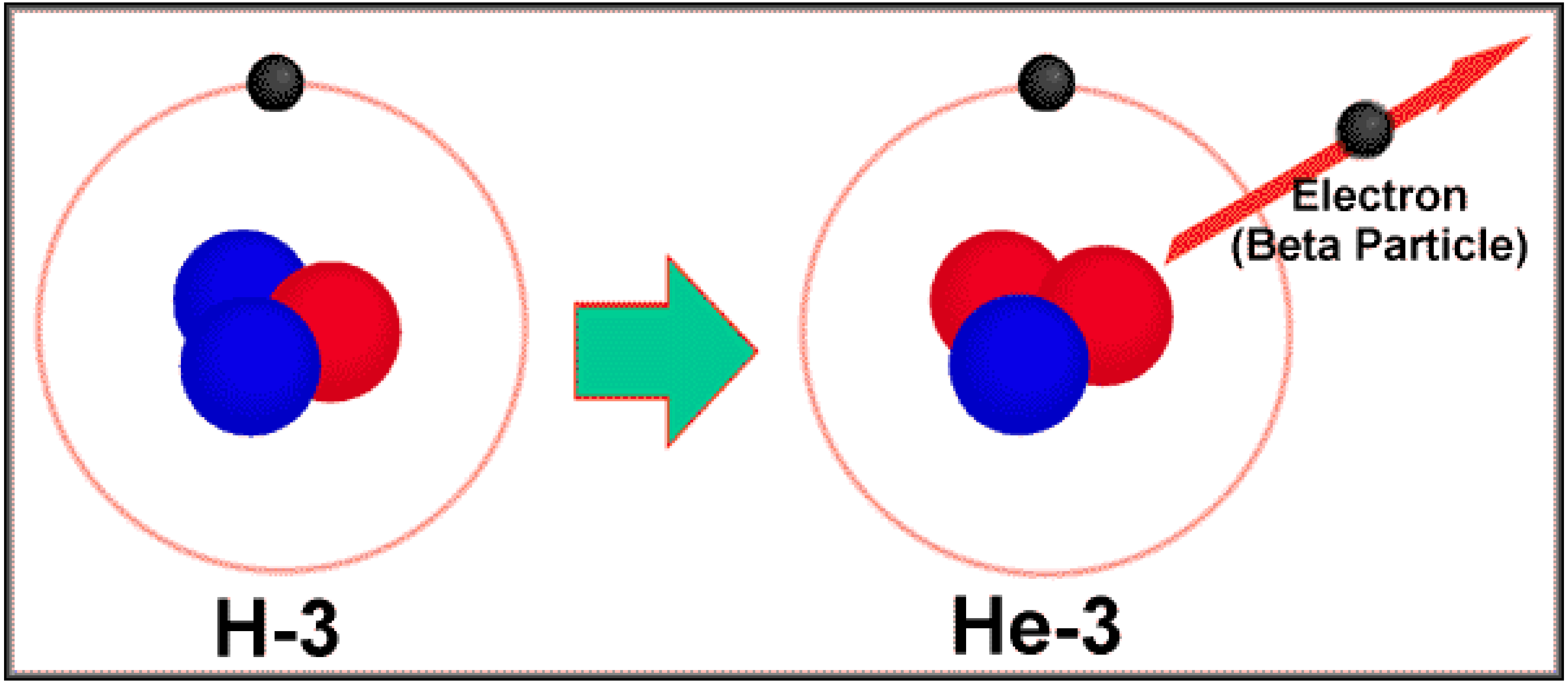
Different nuclides of a same elements are called Isotopes. For example, Hydrogen has three isotopes: Hydrogen, Deuterium and Tritium with zero, one and two neutrons respectively.



Carbon Isotopes

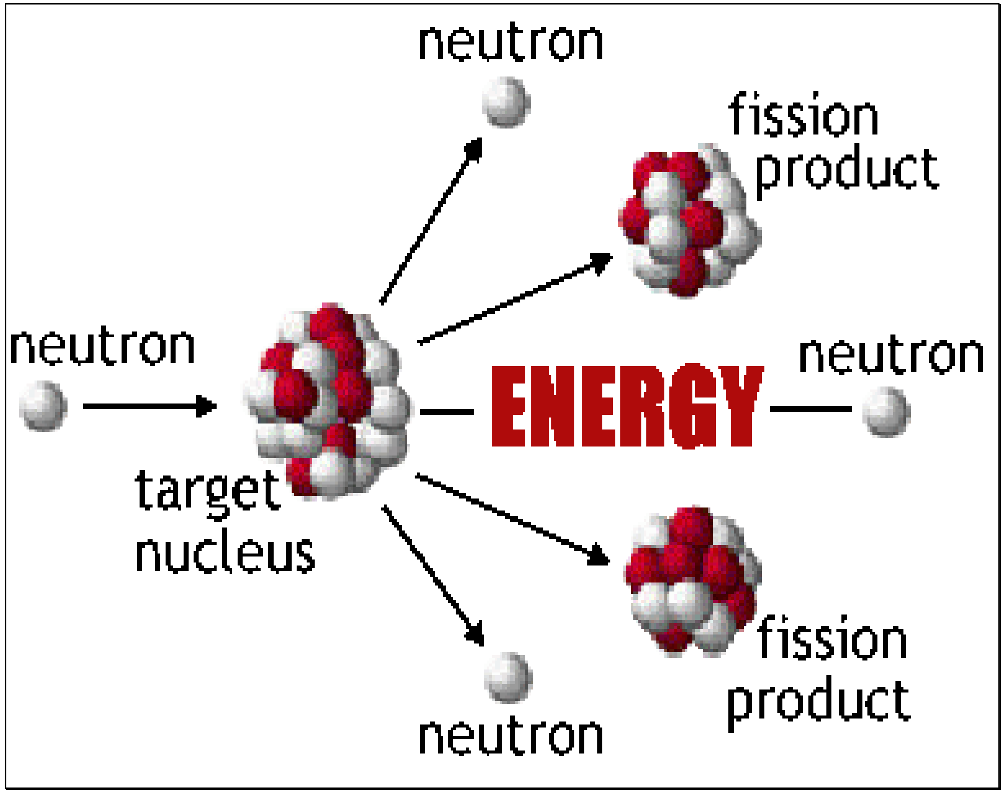
- The most common *isotope of carbon has 6* protons and 6 neutrons (98.9%) $Z = 6; N = 6; A = 12$
- Another stable *isotope of carbon has 6 protons and 7* neutrons (1.1%) $Z = 6; N = 7; A = 13$
- An unstable *isotope of carbon has 6 protons and 8* neutrons (half-life is *5730* years). It decays via beta decay to N-14.

Beta Decay of Hydrogen-3 to Helium-3.



Nuclear fission

In 1939, Otto Hahn and Fritz made the unexpected discovery. They had bombarded uranium with neutrons looking for heavier atoms. They found the splitting of uranium into two roughly equal pieces.



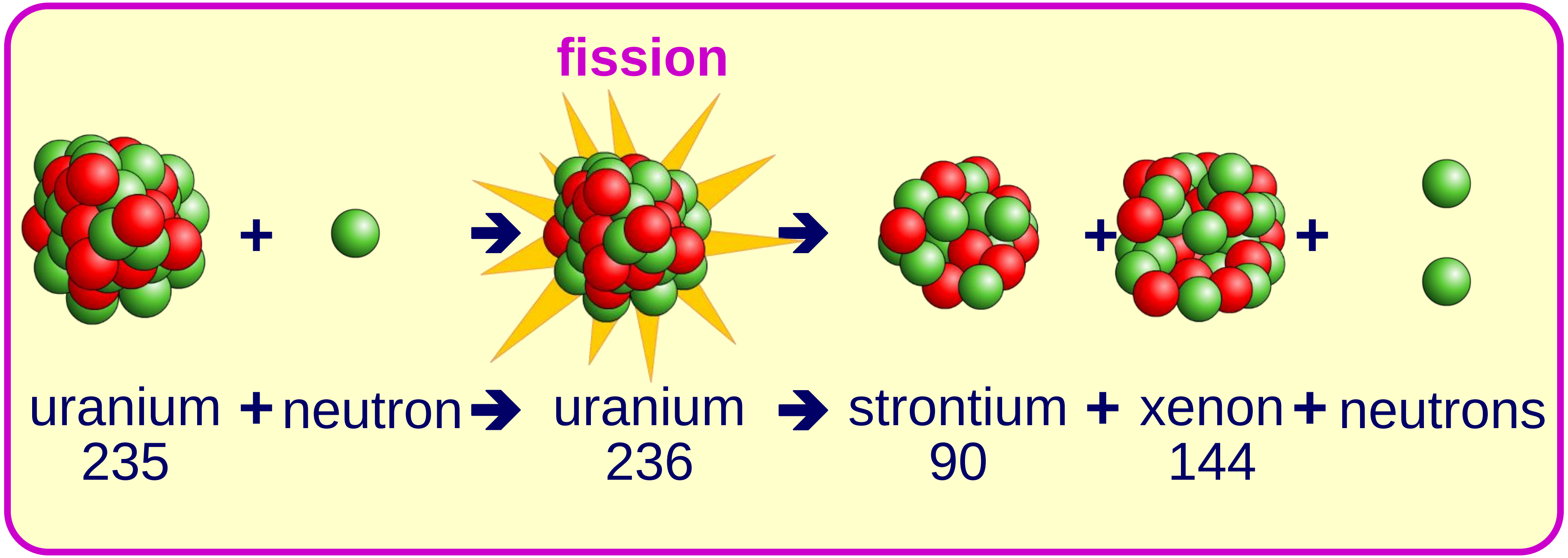
Fission Chain Reaction Apparatus

Binding Energy

One important observation in nuclear physics is that ***the mass of an atom is less than the sum of masses of individual constituent.*** This mass difference is converted to energy at the time nucleus is formed. This energy is called Binding energy.

Where does the energy come from?

Barium and krypton are often the daughter nuclei formed by the fission of uranium-235. Another decay equation is:

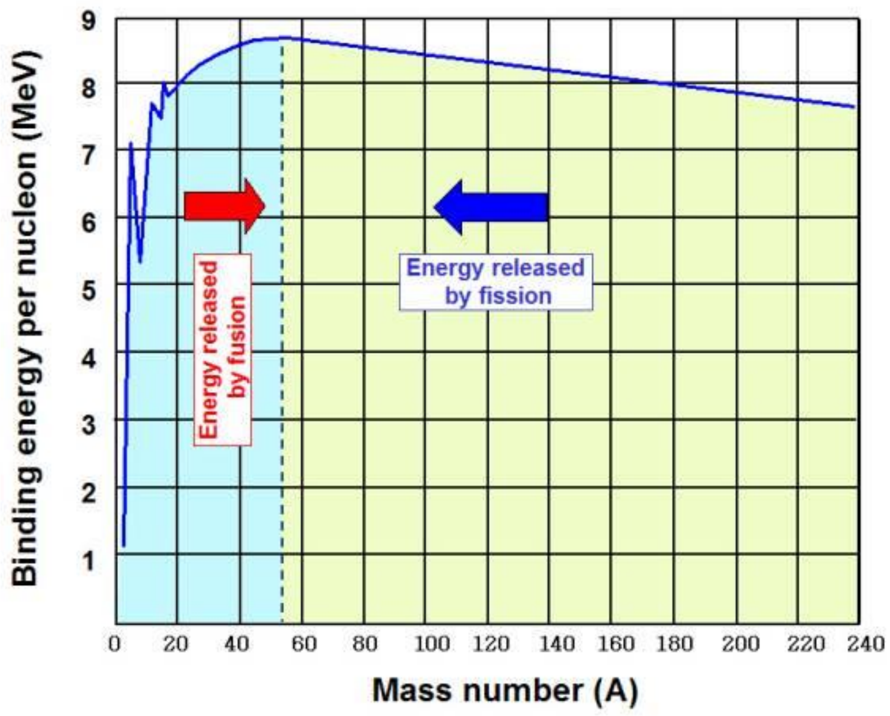


The particles after fission have slightly less mass than before fission. The mass difference has been converted into **energy**.

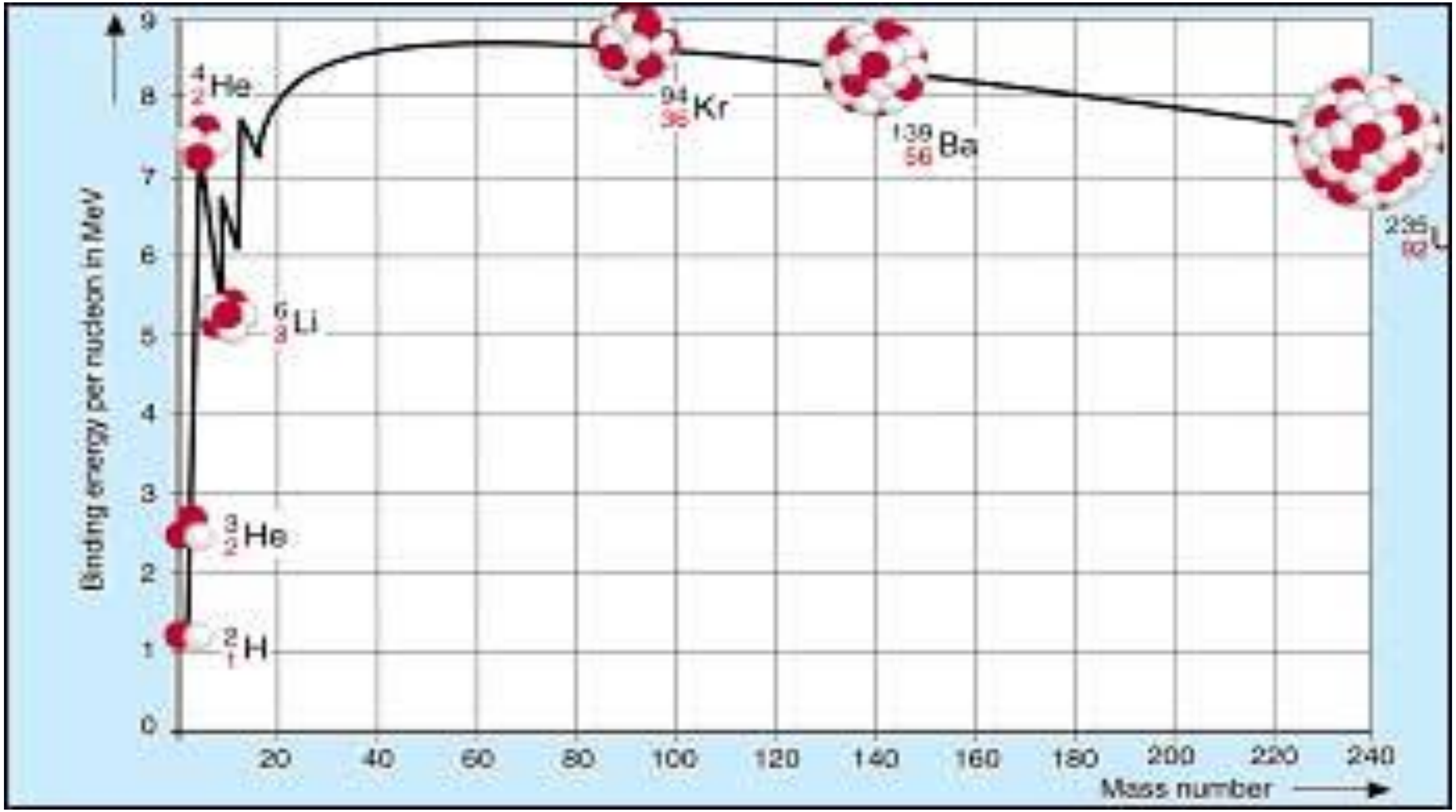
Nuclear Fission

When heavy atom breaks into two smaller atoms, there is a mass difference which is converted into energy.

Note the increase in binding energy per nucleon.

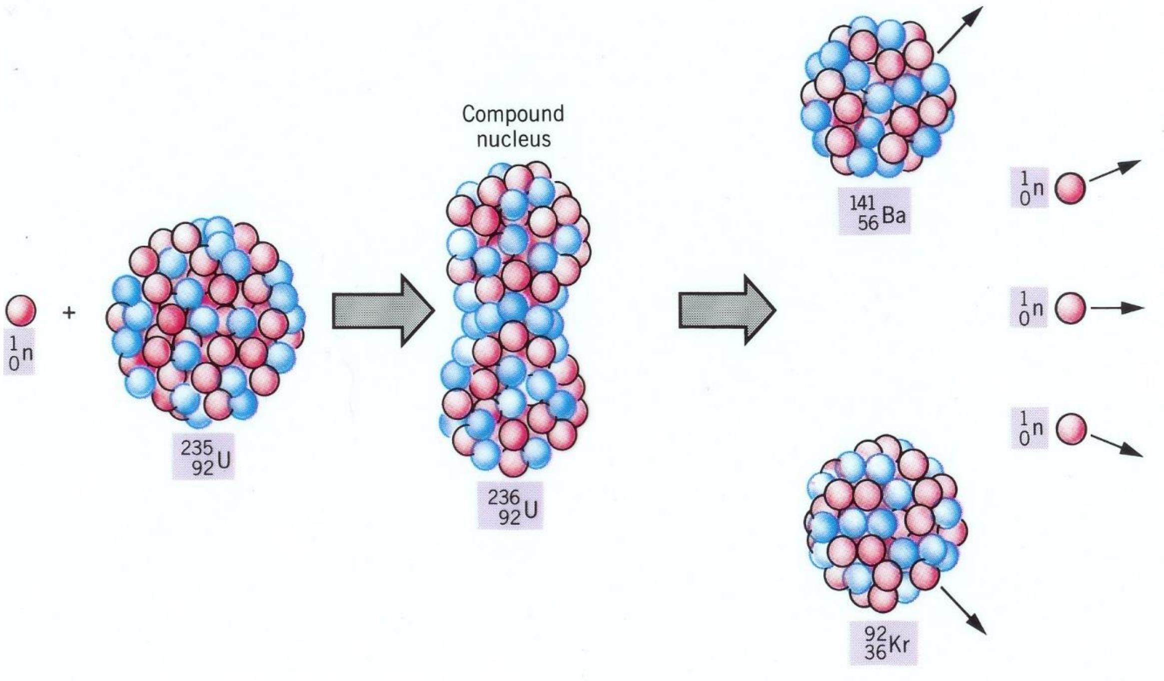


Nucleons more tightly bound in Fission Product

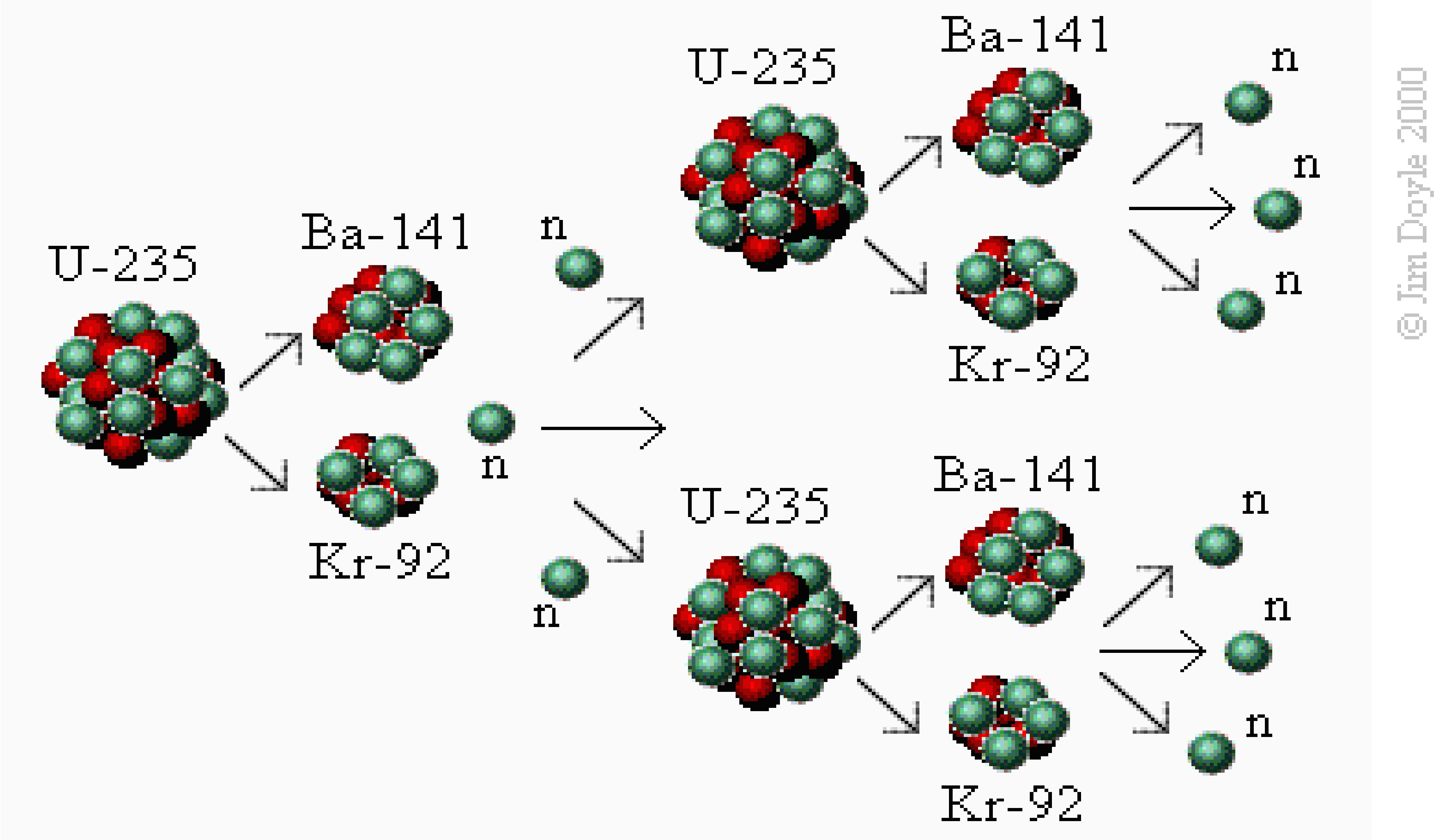


Fission Energy

The fission of an atom of uranium produces 50 million times the energy produced by the combustion of an atom of fossil fuel.



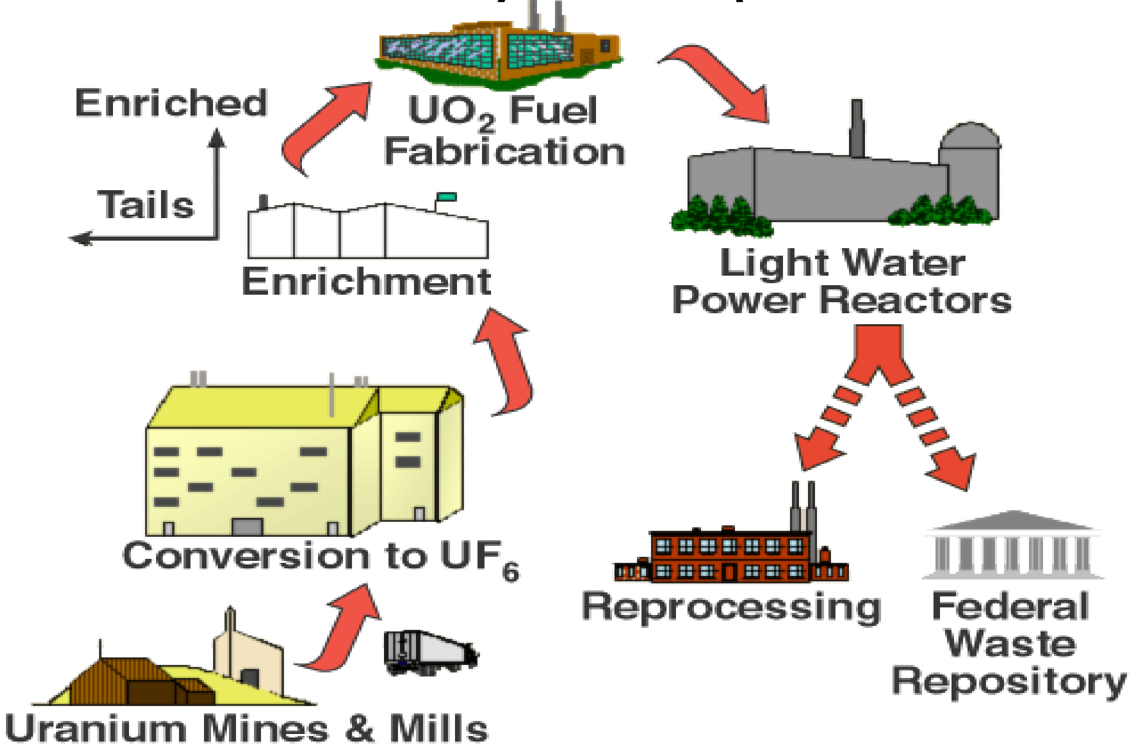
Fission Chain Reaction



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.

Fuel Cycle Steps



Mining

Uranium ore is usually located aerially; core samples are then drilled and analyzed by geologists. The uranium ore is extracted by means of drilling and blasting. Mines can be in either open pits or underground. Uranium concentrations in the ore is quite small (0.2-0.25%).

Milling

- Milling is carried out close to uranium ore.
- The mined ore is crushed and chemically treated to separate the uranium.
- The result is a yellow powder U_3O_8 with more than. 80% Uranium concentration.

Enrichment

Most nuclear reactors require fuel with a U-235 content of 3–5%. UF_6 gas can be enriched either by gaseous diffusion or by gas centrifuge. Both processes enrich UF_6 from 0.7% U-235 to the required level.

Enrichment (cont.)

Most reactors use fuel enriched in the U-235 isotope. The solid uranium oxide from the mine is converted into the gas UF_6, which is then enriched in the U-235 isotope.

Diffusion enrichment *works by exploiting the different speeds at which U-*235 and U-238 pass through a membrane. ***Centrifuge enrichment*** *works by passing the gas* through spinning cylinders, the centrifugal force moving the heavier U-238 to the outside of the cylinder, leaving a higher concentration of U-235 on the inside.

Conversion & Fuel Fabrication

- UF_6 gas is chemically processed to form uranium dioxide (UO_2) powder
- It is then pressed into pellets, sintered into ceramic form (fuel pellets)
- Pellets are then loaded into Zircaloy tubes (fuel rods)
- Rods are constructed into fuel assemblies
- Fuel assemblies are made with different dimensions and number of fuel rods, depending on the type of reactor

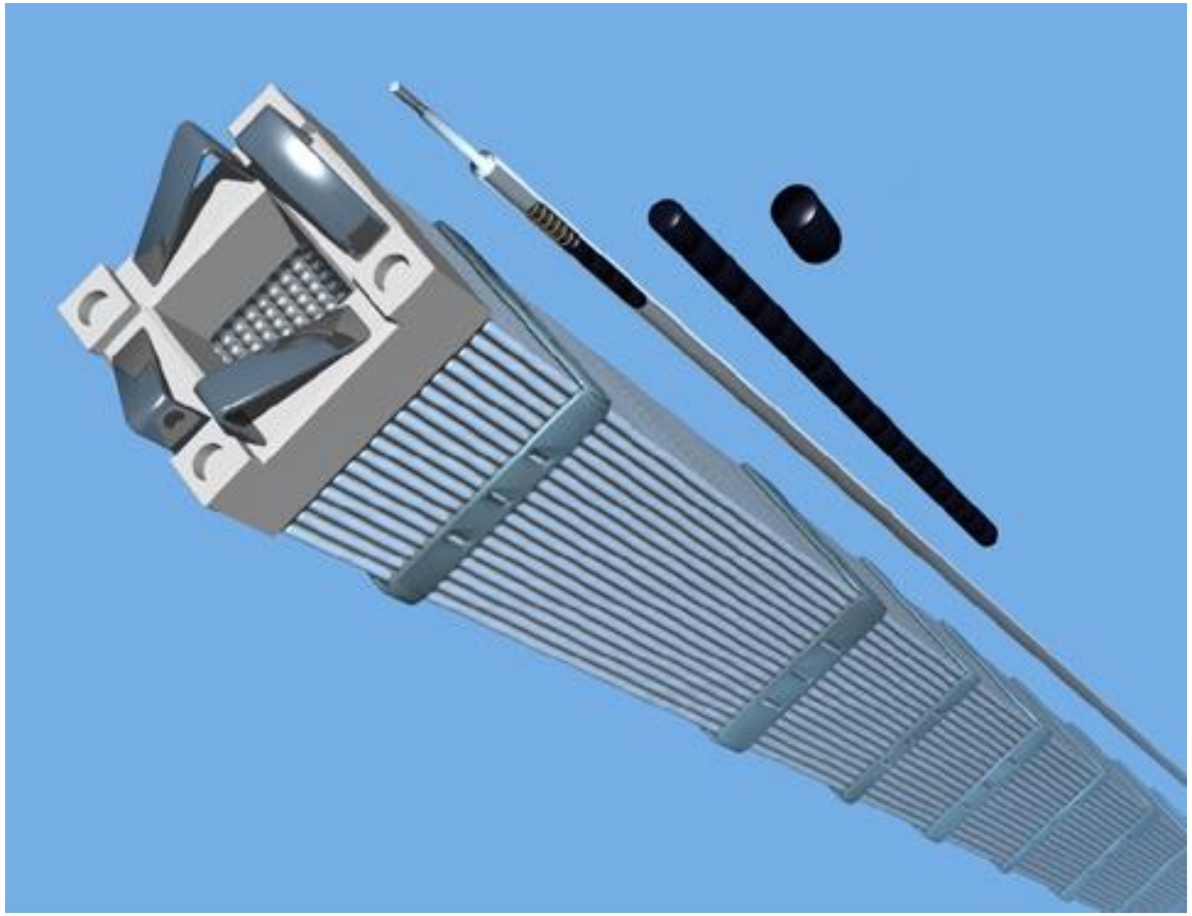
Uranium

Nuclear Fuel Pellet

The fuel pellets (usually about 1 cm diameter and 1.5 cm long) are typically arranged in a long zirconium alloy (zircaloy) tube to form a fuel rod.

Pellets Inserted into Rods

Pellets of uranium oxide (UO_2) are arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core.



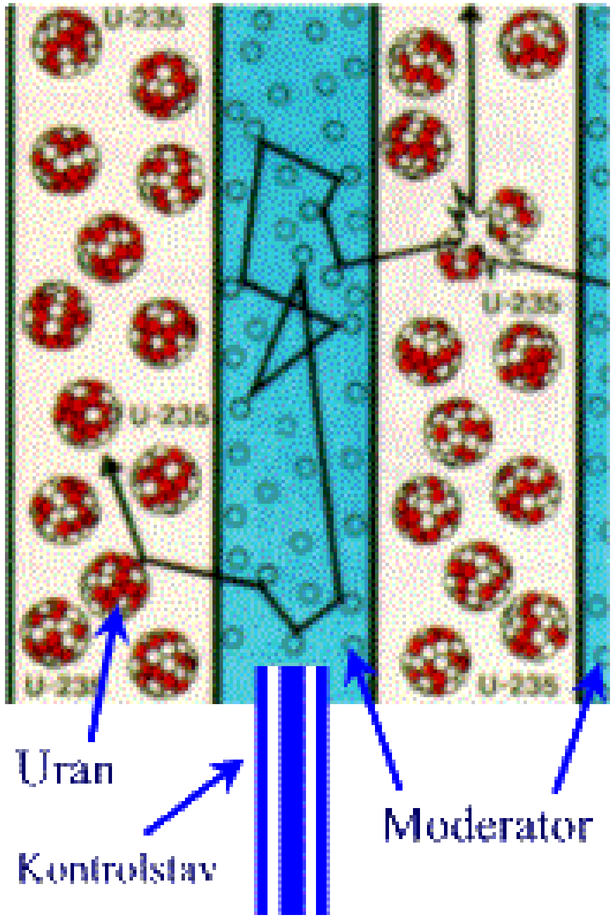
Tricks of the trade

- Slow moving (thermal) neutrons are more effective at inducing fission, but, fissions produce fast moving electron. We need to slow neutrons down.
- Fissions typically produce several neutrons but a linear chain reaction only needs one. We need to get rid of a good fraction of our neutrons.

Moderator

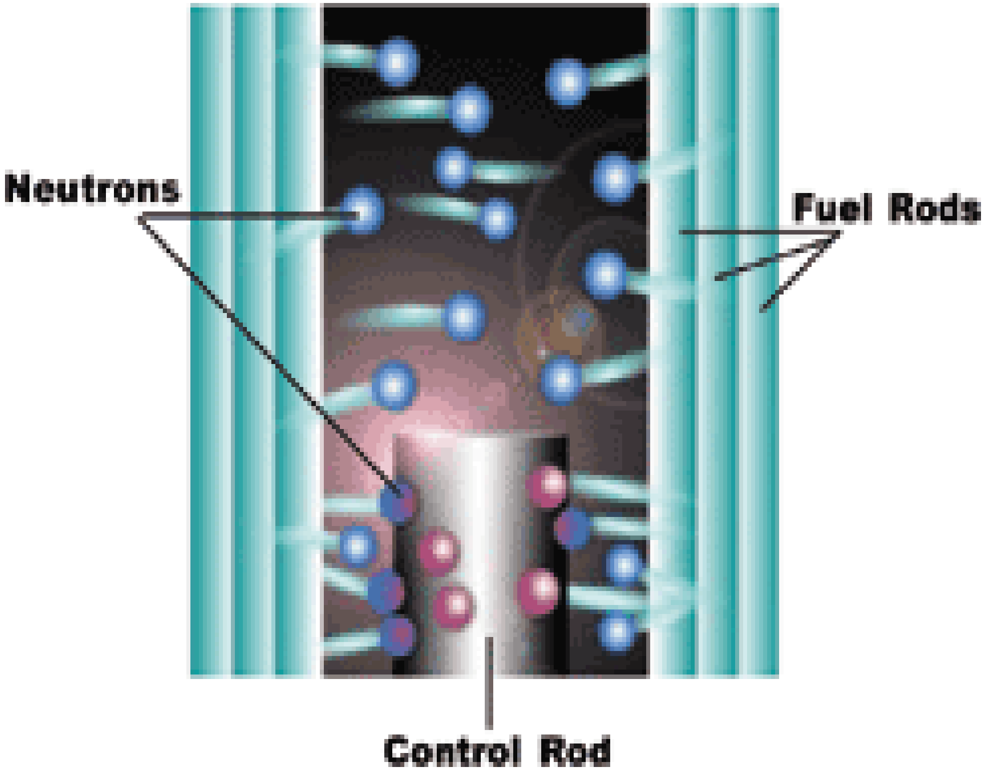
This is material which slows down the neutrons released from fission so that they cause more fission. It is usually water.

In light water reactors the moderator functions also as coolant.



Control Rods

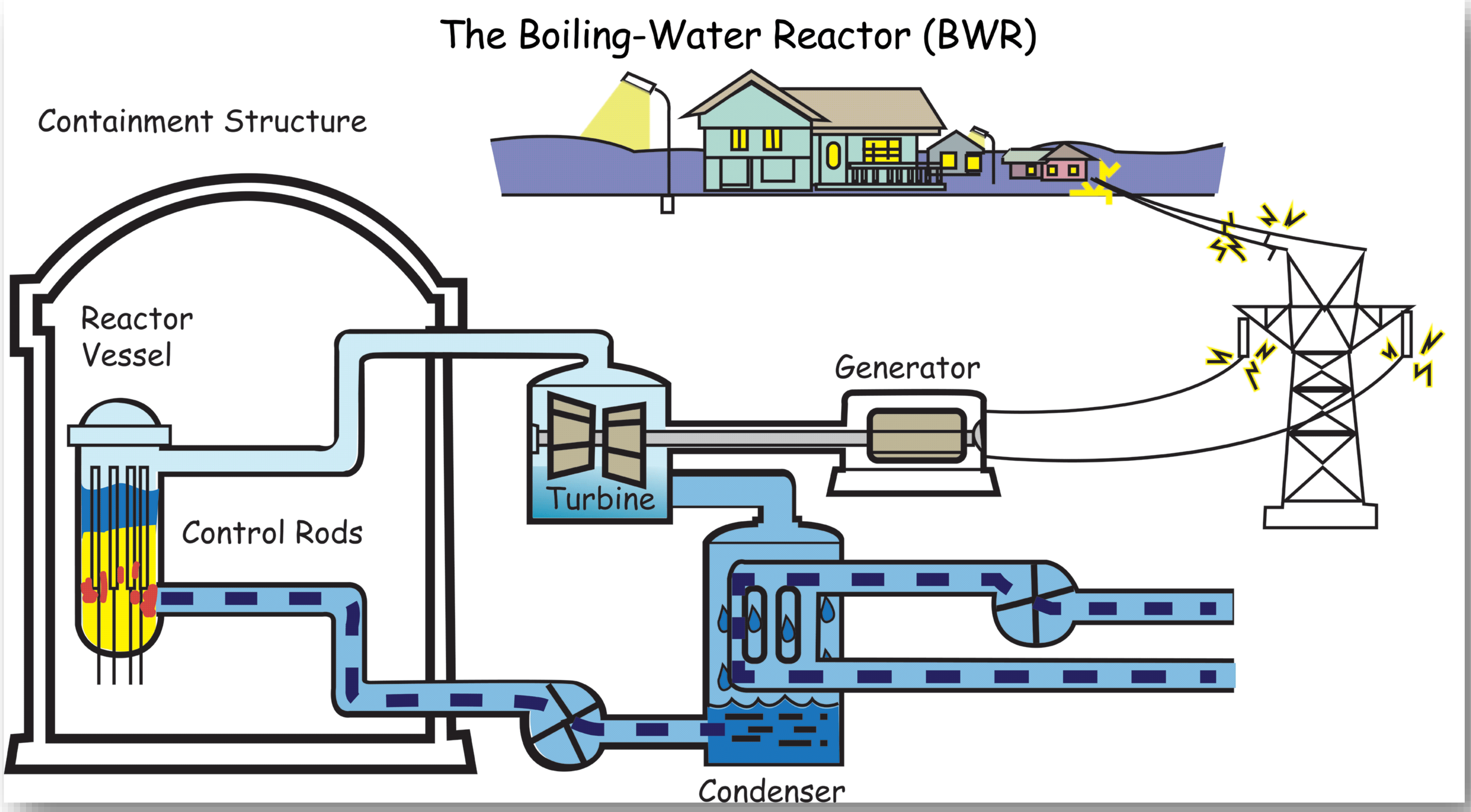
- Control rods are made of a material that absorbs excess neutrons (usually Boron or Cadmium).
- By controlling the number of neutrons, we can control the rate of fissions



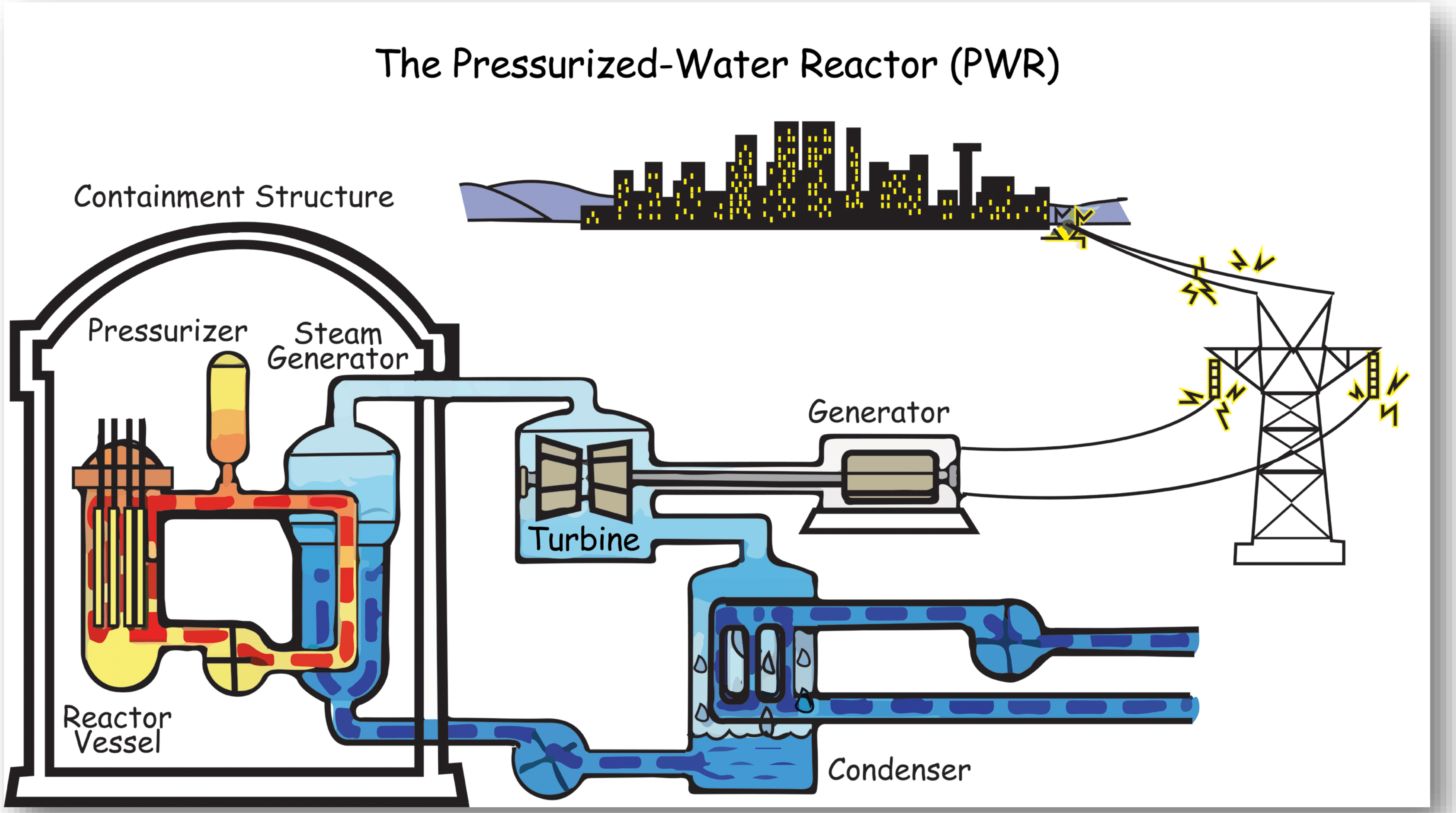
Nuclear Power Plants

- Nuclear reactors produce electricity by heating water to make steam. The steam is then used to drive turbines that generate electricity.
- In this sense, nuclear power plants are similar to other thermal power stations, where the heat from burning oil or gas is used to produce steam.
- A key difference of nuclear reactors is that they produce heat by releasing energy from fission without CO_2 .

Anatomy of a Boiling Water Reactor



Anatomy of a Pressurized Water Reactor



Conclusions

- Nuclear energy has an important role in the future energy mix since the world reserves of fossil fuels are limited.
- Fossil fuel-based electricity is projected to account for more than 40% of global greenhouse gas emissions by 2020. Nuclear power will reduce the emission gases.
- Modern nuclear power plant designs are more inherently safe and may be constructed with less capital cost.
- KSA should avail the opportunity of nuclear power option.

QUESTIONS