Nuclear Energy

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Introduction

- Nuclear energy Definition

  ✓ Changes can occur in the structure of the nuclei of atoms

  ✓ These changes are called **nuclear reactions**. Energy created in a nuclear reaction is called **Nuclear Energy**, or **Atomic Energy.**

- Nuclear power is released, in huge quantities, by reactions that determine transmutations of given elements.
- The quantity of energy derived from these reactions can be calculated through the well-known Einstein relation that links mass and energy.
- The calculation is based on the mass defect that the products of the reaction show compared to the elements involved in the reaction itself.

[39] This is the famous equation $E = mc^2$, where e is, by definition, the value of nuclear power owned by a mass, m is the so-called *mass defect* and c is the speed of light ($c \cong 3\times 10^8$ m/s). The mass value of a nucleus, theoretically calculated by adding up the masses of neutrons and protons that compose it, is higher than the one experimentally calculated, and the difference between the two quantities is precisely the mass defect.

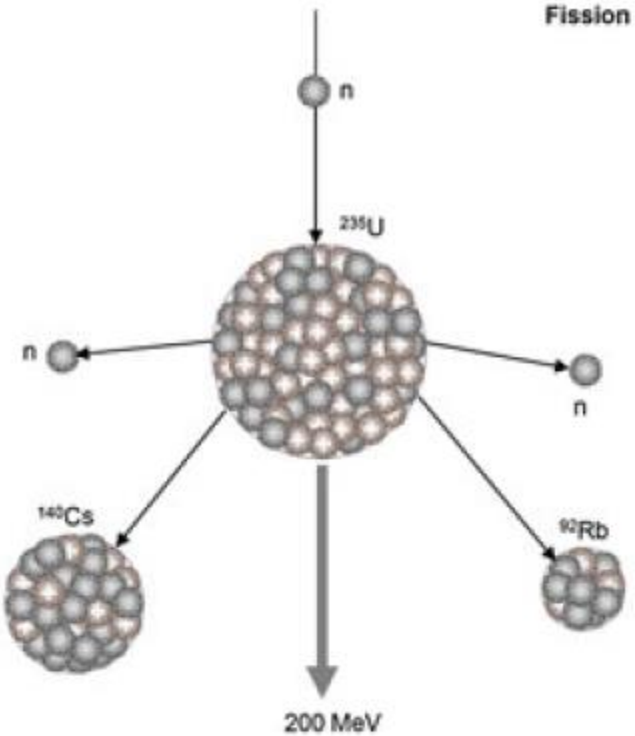
Nuclear power can be exploited in two ways:

1. Through the *fission* of the *uranium* atom
2. Through the *fusion* of two *hydrogen* atoms.

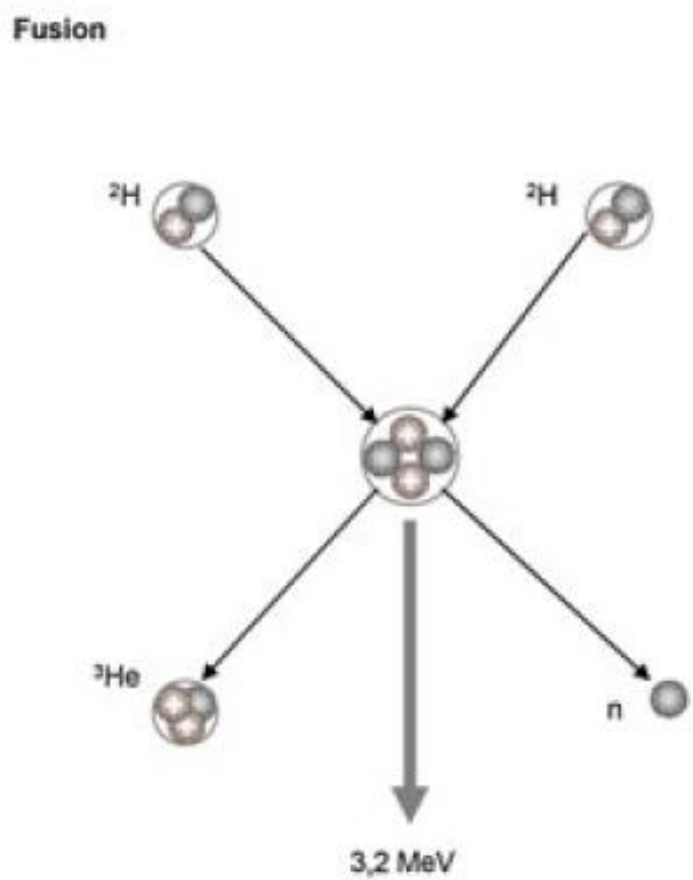
- The fission technology has been available for a few decades,
- Fusion, on the other hand, is still undergoing a pre-commercial development phase.
- https://www.youtube.com/watch?v=fNMowCojiOU
- https://www.youtube.com/watch?v=Cqlj4_4hcgU
- https://www.youtube.com/watch?v=WLMjEJ_EGUs

Fission انشطار

The uranium used for fission purposes is contained in its minerals in quantities ranging between 0.1 and 0.5%, and is 0.71% made up of isotope ^{235}U, 99.28% of isotope ^{238}U and the remaining 0.01% by isotope ^{234}U; the "fissile" one that is, to say useful for nuclear fission, is ^{235}U, present in a much lower percentage. For this reason, uranium generally undergoes "enrichment" to obtain higher percentages of the fissile isotope.



Fusion اندماج



From the fusion of two hydrogen atoms, it is possible to obtain one helium atom and a quantity of energy amounting to 3.2 MeV.

In consideration of molecular weights and by comparing the energy released given the same mass, it is possible to derive that from the fission of 1 kg of ^{235}U 18.6 GWh are obtained, whereas from the fusion of 1 kg of hydrogen, 5,262 GWh are obtained.

[42] MeV: MegaelectronVolt. 1 MeV = $1{,}60217646 \times 10^{-13}$ J.

(MeV)) means the energy equal to that acquired by a particle with one electron charge in passing through a potential difference of one million volts in a vacuum.

In the International units (SI units) 1eV corresponds to $1.6*10^{-19}$ Joules.

Combustion Vs. fission

- The energy generated through fission by 1 g of Uranium is equivalent to nearly **$8.4 * 10^{10}$ J**, whereas the one released through combustion by 1 g of gasoline is equal to nearly $4.84 * 10^4$ J;
- Given the same masses, then the ratio between the two energy capacities amounts to nearly $24 * 10^{6}$ [F.Naso].

Introduction

- Nuclear energy is produced naturally and in man-made operations under human control

  - ✓ **Naturally:** Some nuclear energy is produced naturally. For example, the Sun and other stars make heat and light by nuclear reactions.

  - ✓ **Man-Made:** Nuclear energy can be man-made too. Machines called nuclear reactors, parts of nuclear power plants, provide electricity for many cities. Man-made nuclear reactions also occur in the explosion of atomic and hydrogen bombs.

Nuclear Fuel (Uranium)

- **Uranium is a relatively common metal, found in rocks and seawater**

- **Naturally occurring Uranium is composed of three major Isotopes, Uranium-238, Uranium-235, & Uranium-234.**
- **All three isotopes are radioactive, creating radioisotopes, with the most abundant and stable being Uranium-238**

- **The world's power reactors, require about 68,000 tonnes of Uranium each year.**

tonnes U	percentage of world	
Australia	1,661,000	31%
Kazakhstan	629,000	12%
Russia	487,200	9%
Canada	468,700	9%
Niger	421,000	8%
South Africa	279,100	5%
Brazil	276,700	5%
Namibia	261,000	5%
USA	207,400	4%
China	166,100	3%
Ukraine	119,600	2%
Uzbekistan	96,200	2%
Mongolia	55,700	1%
Jordan	33,800	1%
other	164,000	3%
World total	**5,327,200**	

How Nuclear energy produced?

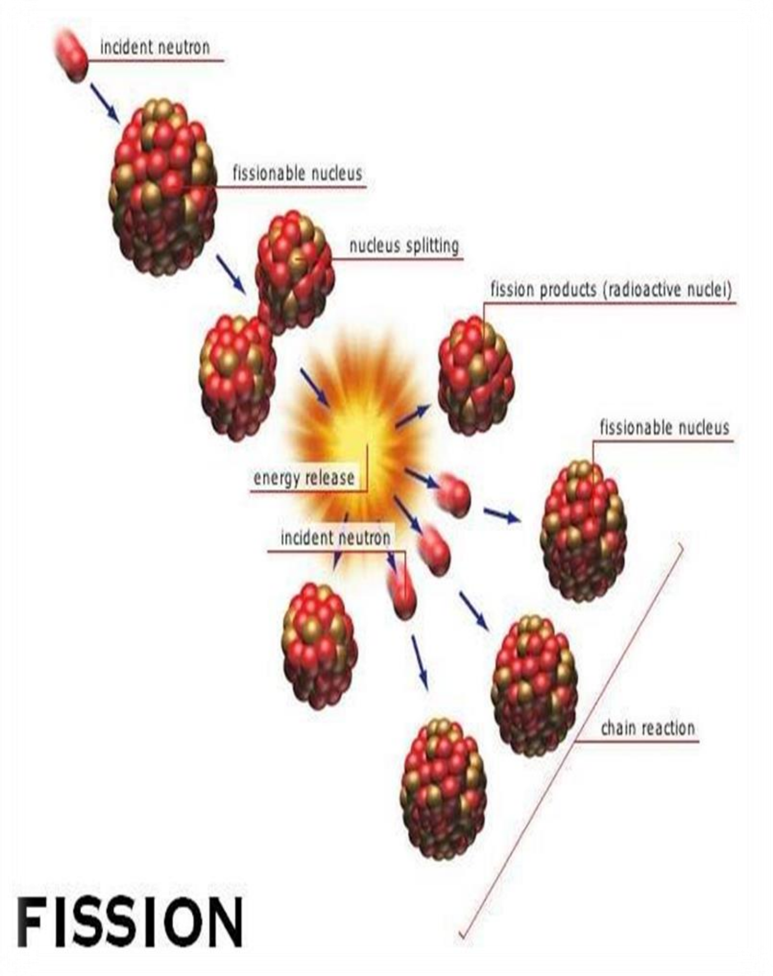
- Nuclear energy is produced in two different ways;
  - ✓ Large nuclei are split to release energy (Fission).
  - ✓ In the other method, small nuclei are combined to release energy (Fusion).

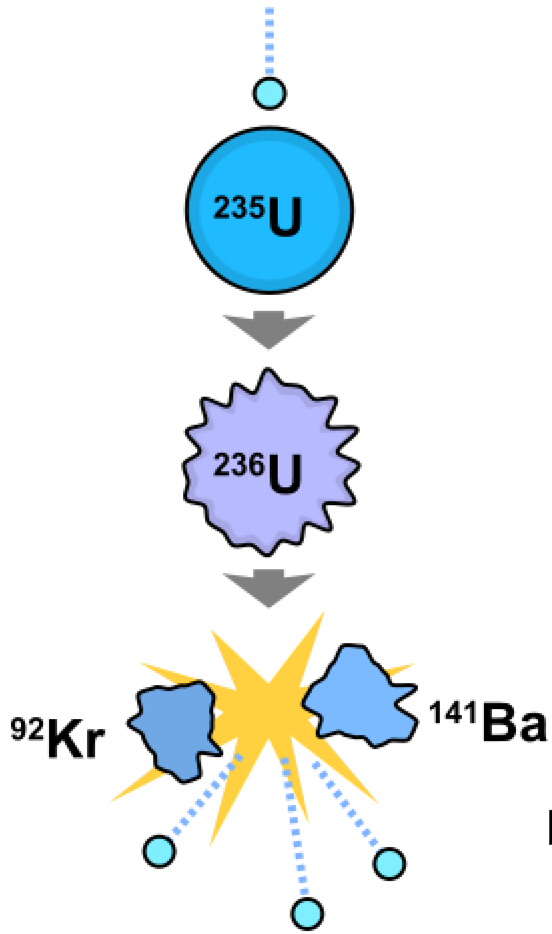
Nuclear Fission

- **In nuclear fission, the nuclei of atoms are split, causing energy to be released. The atomic bomb and nuclear reactors work by fission.**

- **The element Uranium is the main fuel used to undergo nuclear fission to produce energy since it has many favorable properties.**

- **Uranium nuclei can be easily split by shooting neutrons at them. Also, once a Uranium nucleus is split, multiple neutrons are released which are used to split other Uranium nuclei.**
- **This phenomenon is known as a chain reaction.**





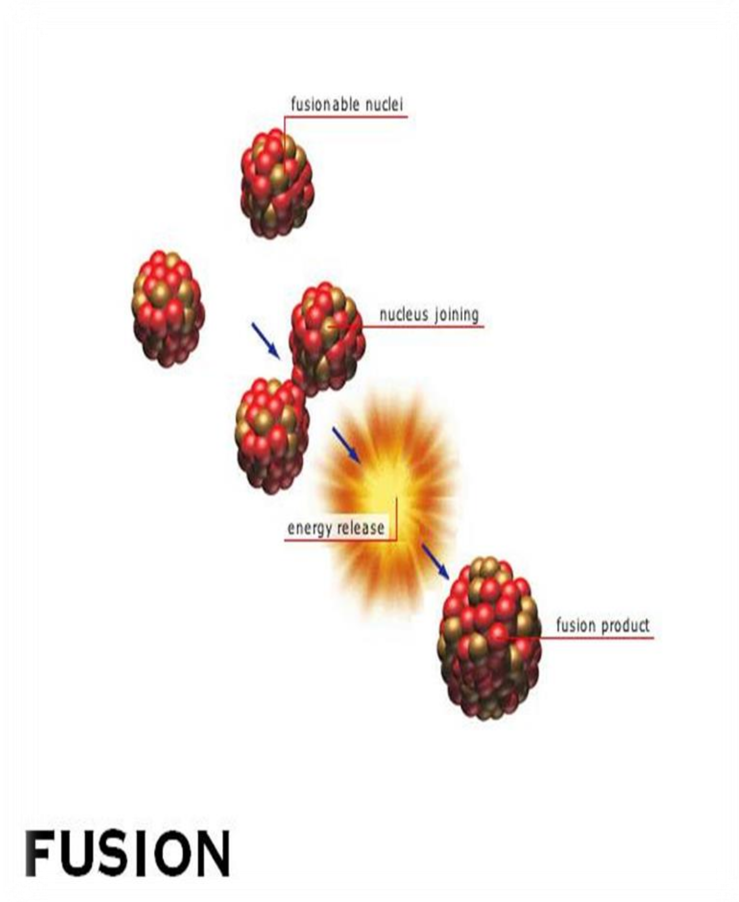
krypton (Kr) **barium (Ba)**

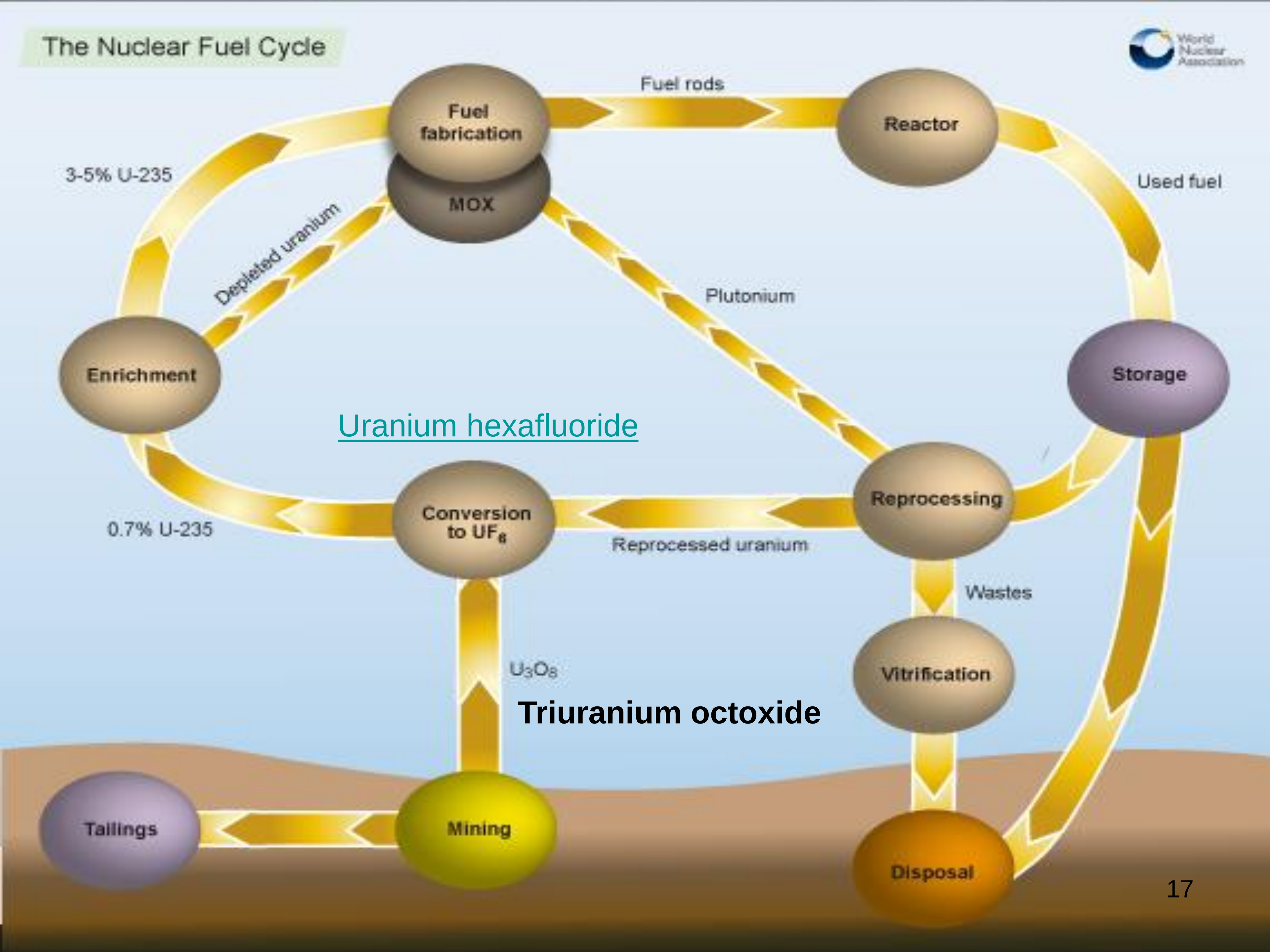
Nuclear Fusion

- **In nuclear fusion, the nuclei of atoms are joined together, or fused. This happens only under very hot conditions. The Sun, like all other stars, creates heat and light through nuclear fusion.**

- **In the Sun, hydrogen nuclei fuse to make helium. The hydrogen bomb, humanity's most powerful and destructive weapon, also works by fusion.**

- **The heat required to start the fusion reaction is so great that an atomic bomb is used to provide it. Hydrogen nuclei fuse to form helium and in the process release huge amounts of energy thus producing a huge explosion.**





[Uranium hexafluoride]

Triuranium octoxide

Nuclear Fuel Cycle

- The nuclear fuel cycle is the series of industrial processes which involve the production of electricity from Uranium in nuclear power reactors.

- To prepare Uranium for use in a nuclear reactor, it undergoes the steps of mining and milling, conversion, enrichment and fuel fabrication. These steps make up the '*front end*' of the nuclear fuel cycle.

- **Mining and Milling:** Both excavation and in situ techniques are used to recover Uranium Ore. Most mining facilities include a mill, one mill may process the ore from several mines.
- Milling produces a Uranium Oxide (U_3O_8) sometimes referred as "***Yellowcake***"

Nuclear Fuel Cycle

- **Conversion:** The Uranium Oxide product of a uranium mill is not directly usable as a fuel for a nuclear reactor and additional processing is required. The enrichment process requires the Uranium to be in a gaseous form. The ***Uranium Oxide*** concentrate is therefore first converted to ***Uranium Hexafluoride***

- **Enrichment:** The enrichment process separates gaseous Uranium Hexafluoride into two streams, one being enriched to the required level (3.0~5.0%) and known as low-enriched Uranium; the other stream is progressively ***depleted*** Uranium.

نسب وجود النظائر في اليورانيوم الطبيعي واليورانيوم المنضب (%)			
نوع اليورانيوم	يورانيوم 234	يورانيوم 235	يورانيوم 238
اليورانيوم الطبيعي	0.0055	0.720	99.274
اليورانيوم المنضب	0.0008	0.202	99.797

Nuclear Fuel Cycle

- **Fuel Fabrication:** The fuel is encased in metal tubes to form fuel rods, which are arranged into a fuel assembly ready for introduction into a reactor. The dimensions of the fuel pellets and other components of the fuel assembly are precisely controlled to ensure consistency in the characteristics of the fuel.

- After Uranium has spent about three years in a reactor to produce electricity, the used fuel may undergo a further series of steps including temporary storage, reprocessing, and recycling before wastes are disposed. Collectively these steps are known as the 'back end' of the fuel cycle.

Nuclear Fuel Cycle

- **Storage and Reprocessing:** When the fuel is removed from a reactor it is unloaded into a storage pond immediately adjacent to the reactor to allow the radiation levels to decrease. Reprocessing separates Uranium and **Plutonium** from waste products. The Uranium recovered from reprocessing can be reused as fuel after conversion and enrichment. The Plutonium can be directly made into mixed oxide (MOX) fuel, in which Uranium and Plutonium Oxides are combined.

- **Wastes Disposal:** Wastes from the nuclear fuel cycle are categorized as: **high, medium or low -level wastes** by the amount of ***radiation that they emit.*** At the present time, there are no disposal facilities in operation in which used fuel can be placed. In either case the material is in a solid, stable waste form.

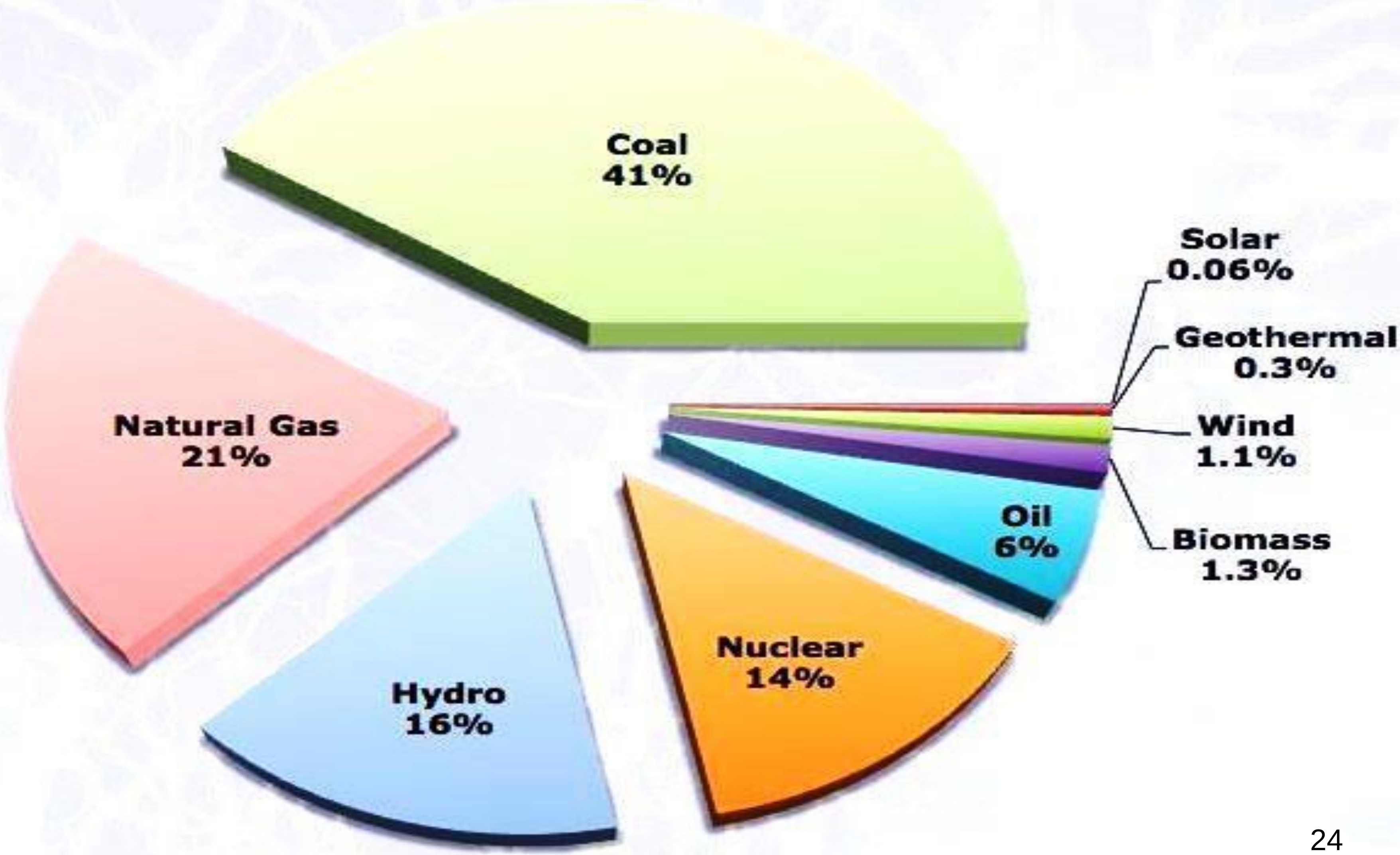
Nuclear Energy Application

- Electricity Generation

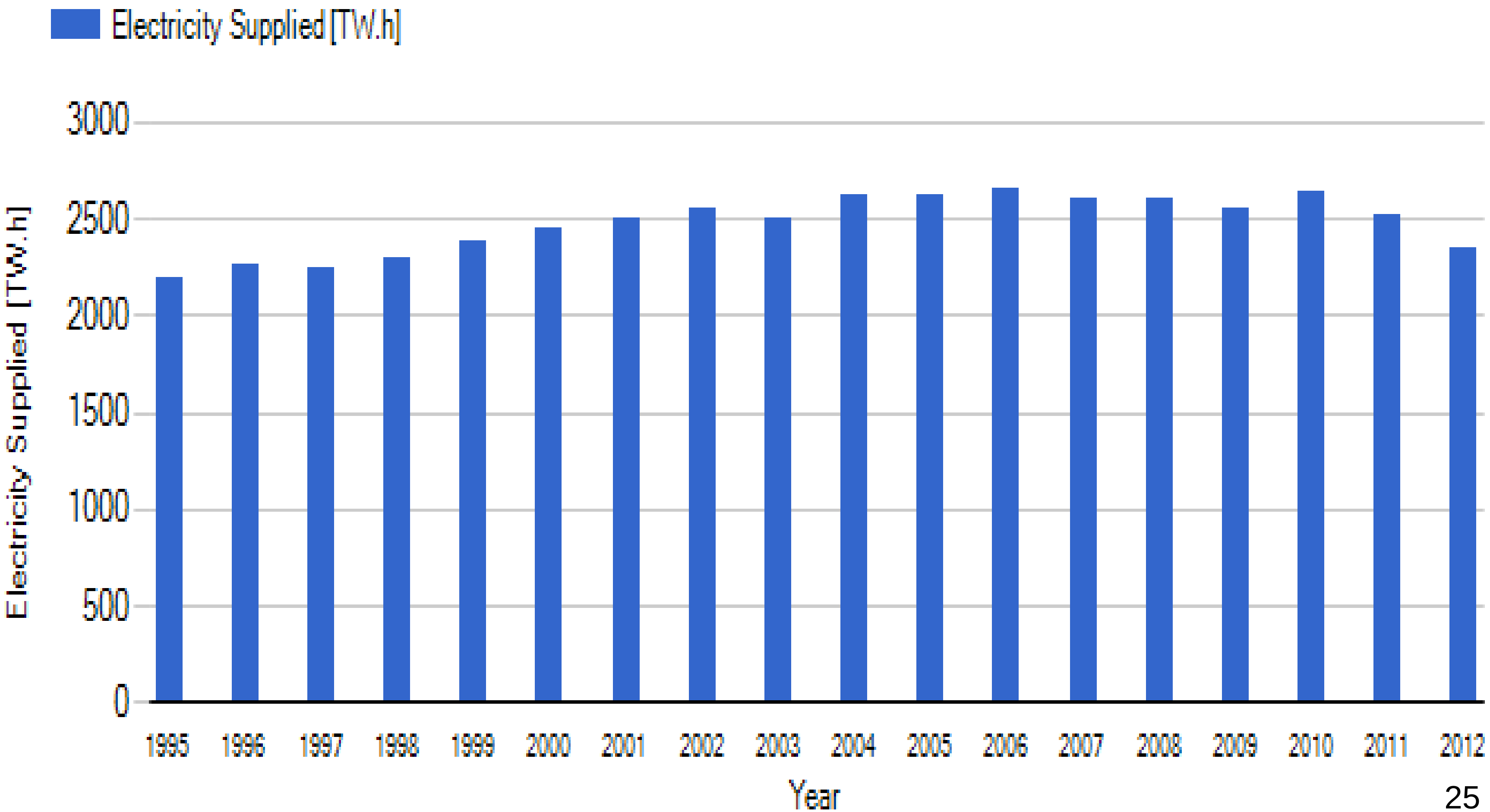
- Non-Electrical application
  - ✓ Nuclear Medicine
  - ✓ Industrial (Gauging)
  - ✓ Nuclear propulsion: Fuel for aircraft carriers and submarines
  - ✓ Nuclear Bomb

Electricity Generation

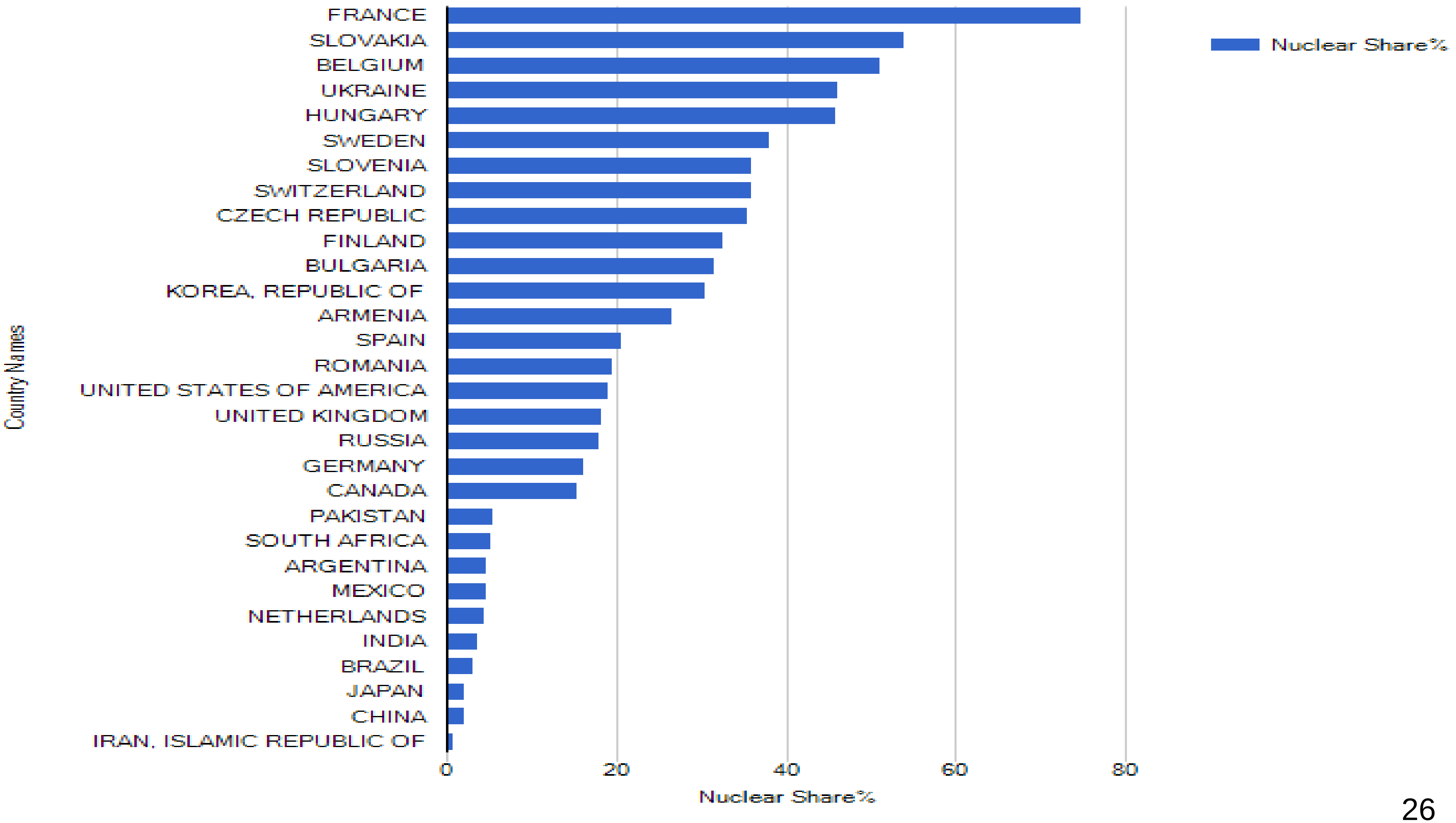
World Electricity Production, 2010



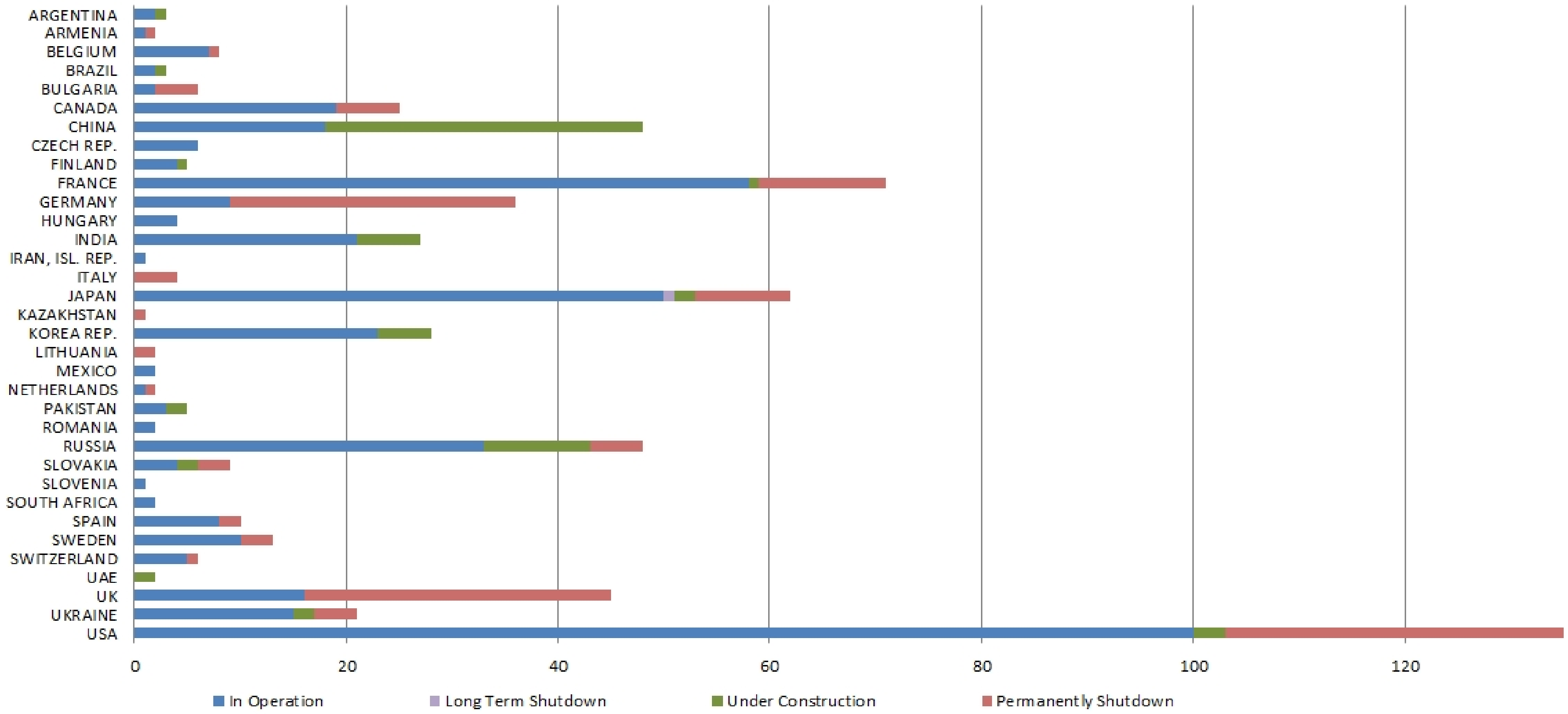
Electricity Supplied from Nuclear to the Grid



Nuclear Share of Electricity Generation, 2012

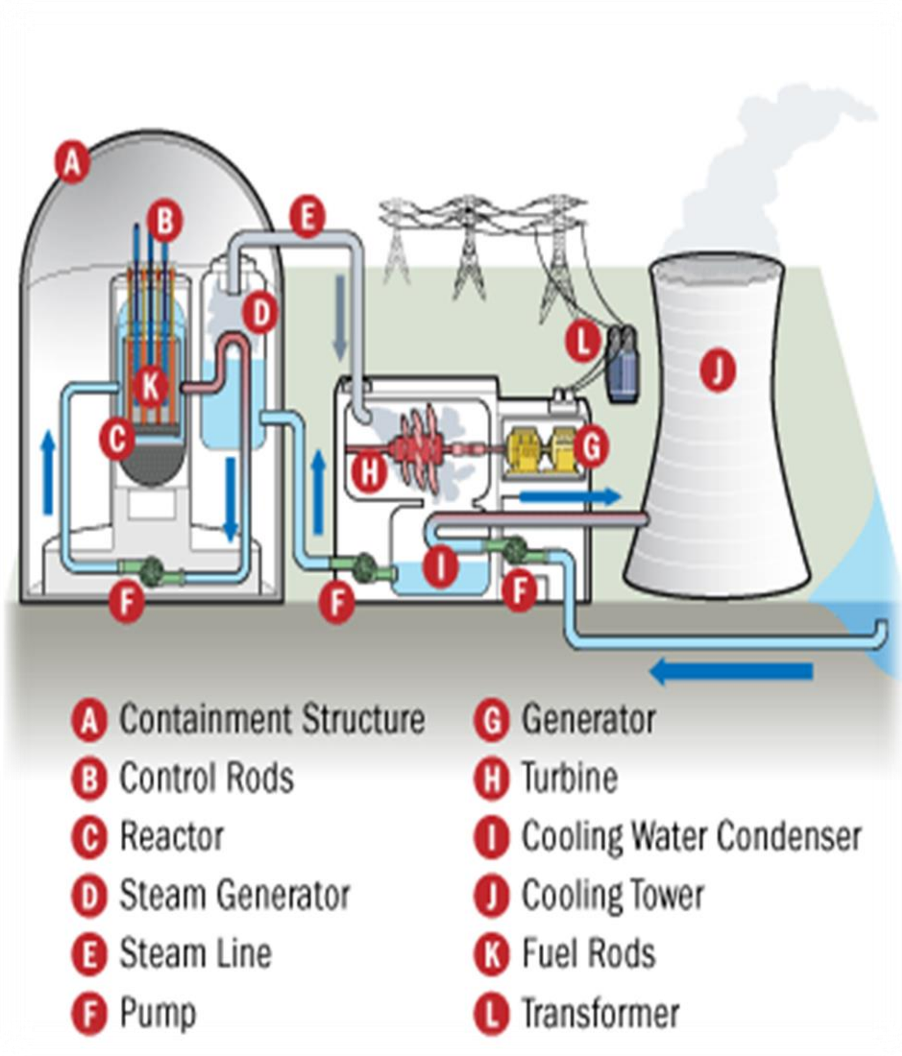


Number of Reactors and Status



As of January 18, 2013 in 31 countries 437 nuclear power plant units with an installed electric net capacity of about 372 GW are in operation and 68 plants with an installed capacity of 65 GW are in 15 countries under construction.

Electricity Generation



- The basic principle nuclear power plant is based on obtaining heat energy through nuclear fission core comestible atoms. With this heat energy, which have a vapor of water, will convert into mechanical energy in a turbine, and finally convert mechanical energy into electrical energy by a generator.

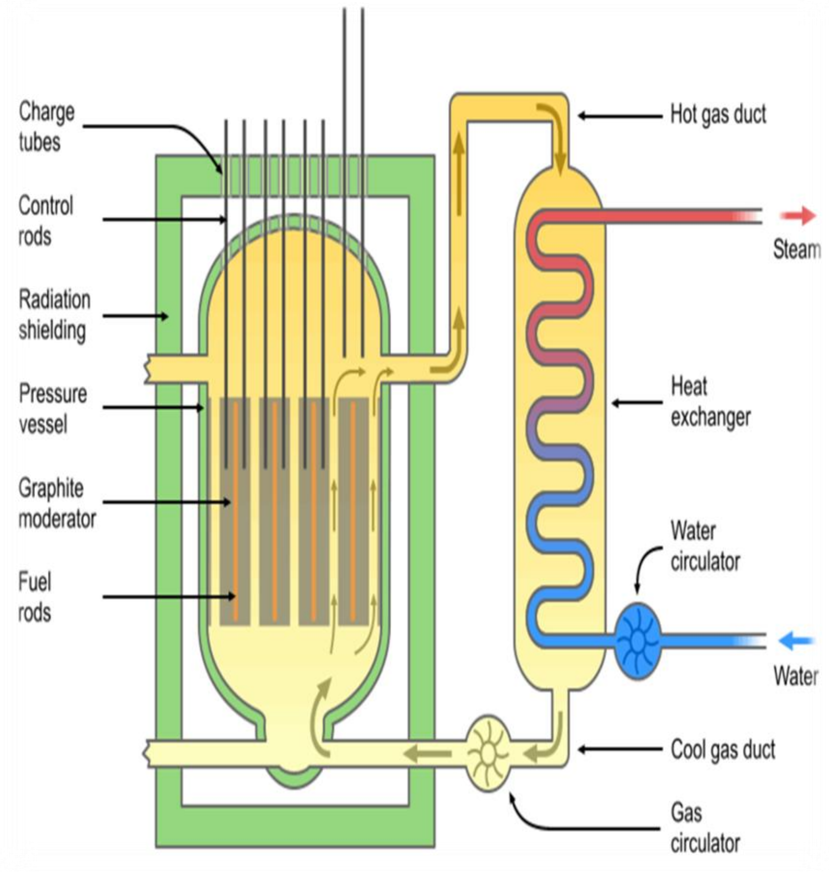
- The nuclear reactor is responsible for rising and handling this atomic fission generates a lot of heat

Nuclear Reactor Classification

- Purpose (Research, Production and Power)
- Type of Fission (Slow, Intermediate and Fast)
- Fuel Used (Natural Uranium, Enriched Uranium and Plutonium)
- Sate of Fuel (Liquid and Solid)
- Fuel Cycle (Burner, Converter and Breeder)
- Arrangement of Fissile and Fertile Materials (One Region and Two Region)
- Arrangement of Fuel and Moderator (Homogeneous and Heterogeneous)
- Moderator Material (Heavy Water, Graphite, Ordinary Water etc.)
- Cooling System (Direct and Indirect)
- Coolant Used (Gas, Water, Heavy Water, Liquid Metal)

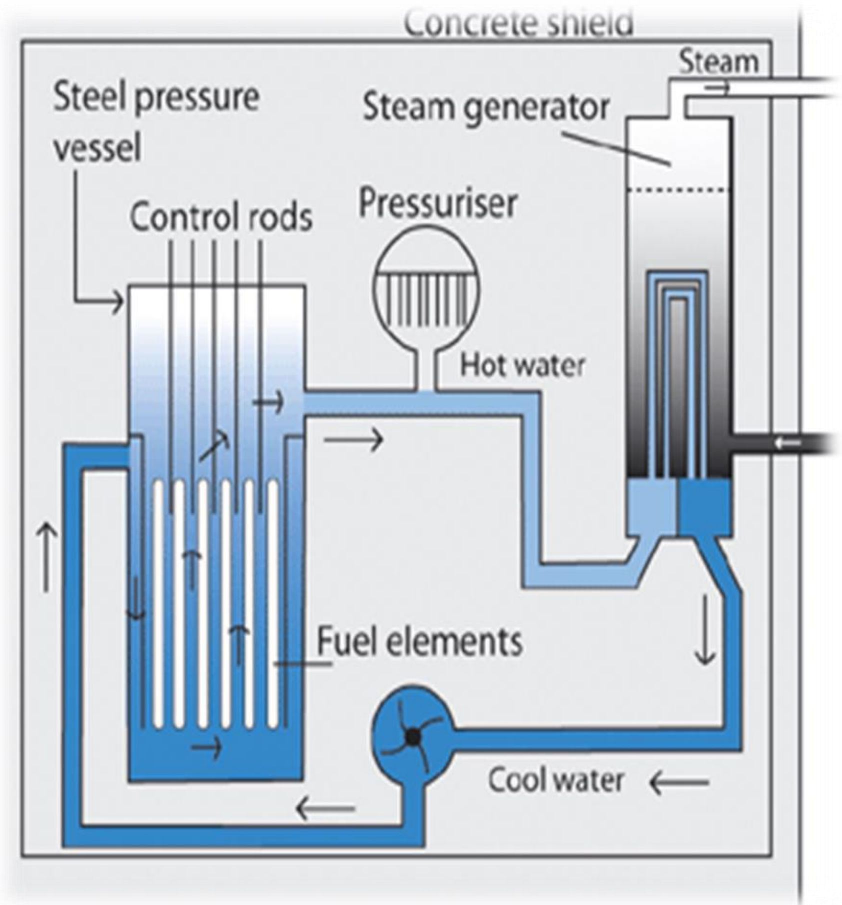
Advanced Gas Reactor (AGR)

- This reactor use the uranium dioxide as a fuel
- The reactor can be refueled on load which is an operational advantage
- The coolant is CO_2
- Graphite is used as moderator
- This reactor is economical when the load factor is more than 75%
- Its overall efficiency is about 40%
- Oak Bridge, USA



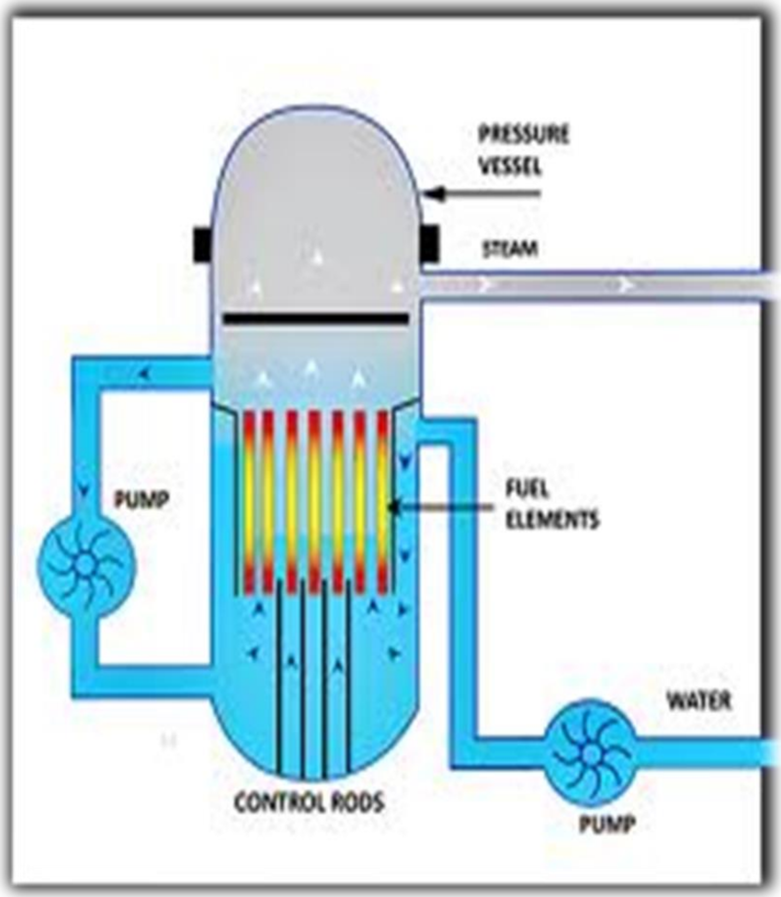
Pressurized Water Reactor (PWR)

- The fuel used in PWR is enriched Uranium Dioxide
- The pressurized water is used as coolant and moderator
- One of the main drawback of this reactor is the design of high strength pressure vessel
- The advantage is that the steam supplied to the turbine is completely free from contamination
- Its overall efficiency is about 33%
- Rajasthan Atomic Power Station, India



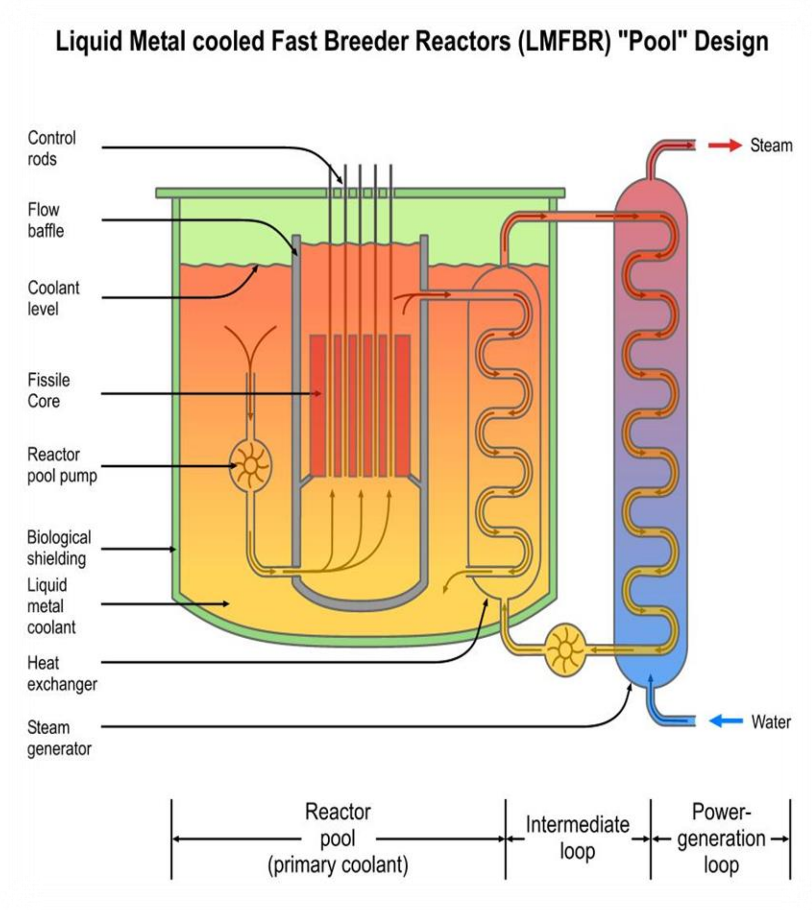
Boiling Water Reactor (BWR)

- The fuel used in BWR is also the enriched Uranium Dioxide
- The ordinary water is used as coolant and moderator
- The advantage include a small size pressure vessel and the simple construction
- Its overall efficiency is about 33%
- Tarapur Atomic Power Station, India

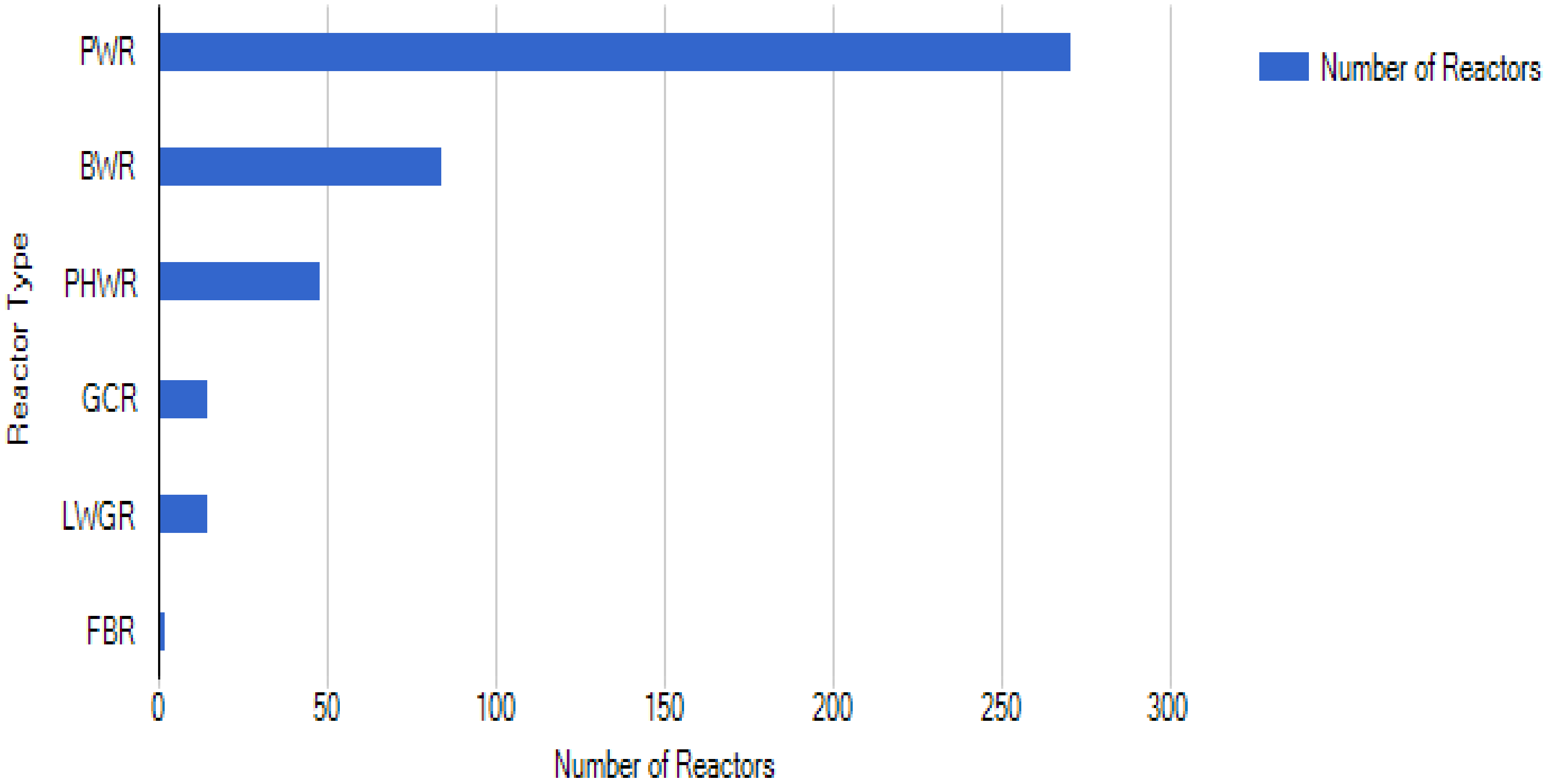


Liquid Metal Fuelled Reactor (LMFR)

- Used fuel is liquid metal fuel e.g. Uranium In Sodium
- Sodium or Potassium is used as coolant
- Two heat exchangers are used coolant-coolant, coolant-water
- No moderator is needed
- Heat transfer and control problem need a special attention in this reactor
- Its overall efficiency is about 40%



Use of Reactors Types, 2012



Non-Electric Application

- Nuclear Medicine: Nuclear medicine uses radiation to provide

  - ✓ **Diagnostic** information about the functioning of a person's specific organs, or to treat them. Diagnostic procedures are now routine.

  - ✓ **Radiotherapy** can be used to treat some medical conditions, especially cancer, using radiation to weaken or destroy particular targeted cells.

Nuclear Medicine

- Tens of millions of nuclear medicine procedures are performed each year, and demand for radioisotopes is increasing rapidly.

- Over 10,000 hospitals worldwide use radioisotopes in medicine, and about 90% of the procedures are for diagnosis. The most common radioisotope used in diagnosis is technetium-99, with some 40 million procedures per year, accounting for 80% of all nuclear medicine procedures worldwide

Nuclear Propulsion: Nuclear Submarine

A nuclear submarine is a submarine powered by a nuclear reactor.

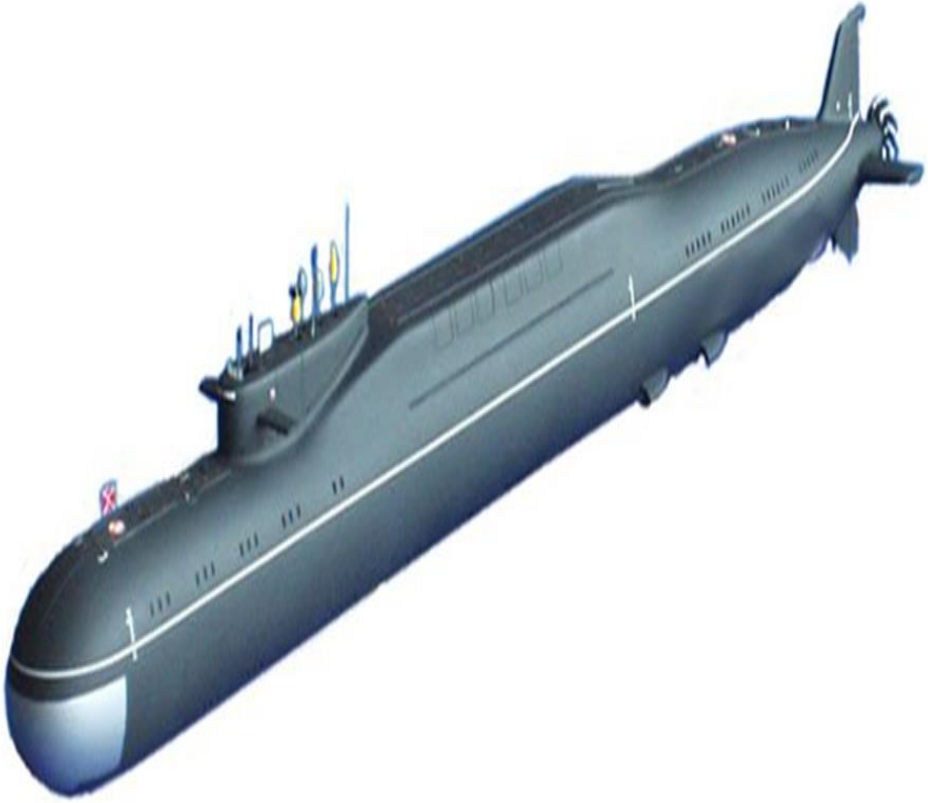
The performance advantages of nuclear submarines over "conventional" (typically diesel-electric) submarines are considerable:

- Completely independent of air, frees the submarine from the need to surface frequently, as is necessary for conventional submarines
- The large amount of power generated by a nuclear reactor allows nuclear submarines to operate at high speed for long durations; and the long interval between refueling grants a range limited only by consumables such as food.

Nuclear Submarine

The high cost of nuclear technology means that relatively few states have fielded nuclear submarines

Current generations of nuclear submarines never need to be refueled throughout their 25-year lifespan



Nuclear Bomb

Nuclear Bomb

A nuclear weapon is an explosive device that derives its destructive force from nuclear reactions, either **fission or a combination of fission and fusion.** Both reactions release vast quantities of energy from relatively small amounts of matter.

Nuclear weapons are considered weapons of mass destruction, and their use and control have been a major focus of international relations policy since their debut.

Nuclear weapons have been used twice in the course of warfare (Hiroshima, Nagasaki), both times by the United States near the end of World War II. These two bombings resulted in the deaths of approximately 200,000 people—mostly civilians—from acute injuries sustained from the explosions.

Industrial Application

- Gauging

  Radioisotopes are used during manufacturing processes in a number of different ways. One application is in gauging (measuring precisely). Gauging works because radiation loses energy as it passes through substances

  This principle can be used to measure the presence or the absence of material between the source and the detector

Gauging

The radiation that passes through a material is measured and compared with the radiation that would pass through a required thickness of the material. If more radiation is measured, the material is too thin; if less radiation is measured, the material is too thick.

Some machines, that manufacture plastic film use radioisotope gauging to measure the thickness of the plastic film.

Advantages and Disadvantages

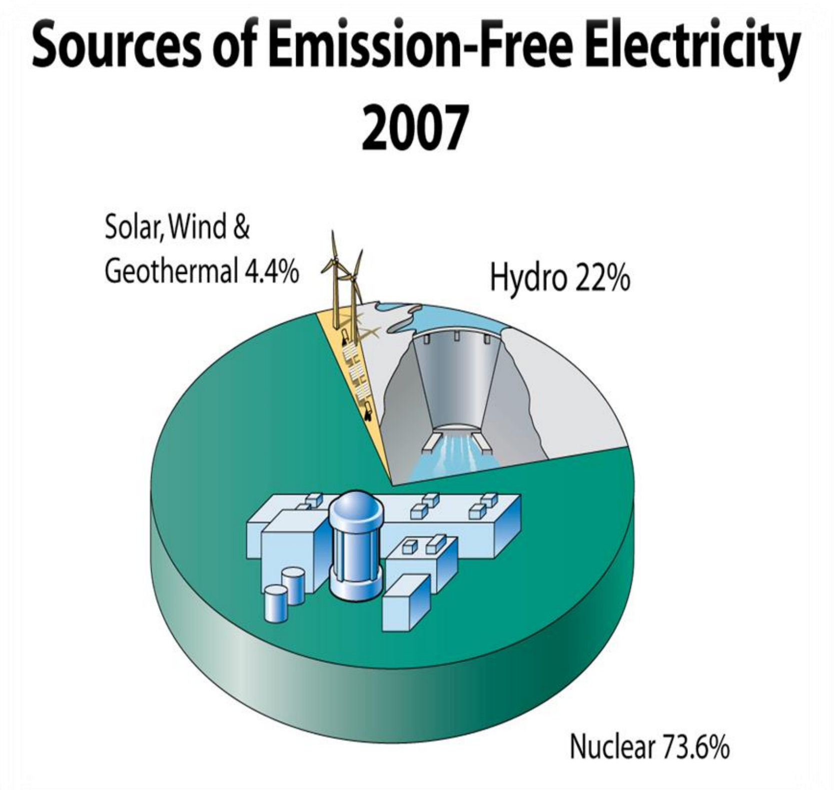
Advantages

- Produces Little or No Harmful Emissions
  - ✓ Nuclear energy is a form of energy that does not emit any greenhouse gas i.e. carbon dioxide, methane, nitrous oxide, and others or any gas causing acid rain or photochemical air pollution (sulfur dioxide, nitrogen oxides)
  - ✓ Amount of avoided CO_2 emissions due to the use of nuclear power in Year 2000 was 2.5 billion tons of CO_2 (10% of total worldwide CO_2 emissions)

Advantages

- Power sector;

CO_2 emissions was 8.5 billion tons of CO_2 (34% of total emissions) Avoided emissions due to the use of nuclear power: 29% of total emissions of the power sector



Advantages

- Less Fuel For Energy Generation

Source	Can Produce
1 kg of coal	~ 3 kWh
1 kg of wood	~ 2 kWh
1 kg of oil	~ 4 kWh
1 m^3 of natural gas	~ 6 kWh
1 kg of natural uranium	~ 60,000 kWh (PWRa) 3,000,000 kWh (FBRb)

✓ Accordingly, the burden of nuclear power facilities in the fuel transportation infrastructure is extremely low when compared with fossil fuel facilities, due to the different order of magnitude of the required quantities of fuel which need to be transported. Also, for the same reason, nuclear power plants require much less space for fuel storage at site.

Advantages

- Less Land for Area Required for the Power Plant
  - ✓ Nuclear power does not require large areas because it is a highly concentrated form of energy. Hence, its environmental impact on land, forests, and waters is minimal
  - ✓ Land area required for 1000 MW electricity generation:

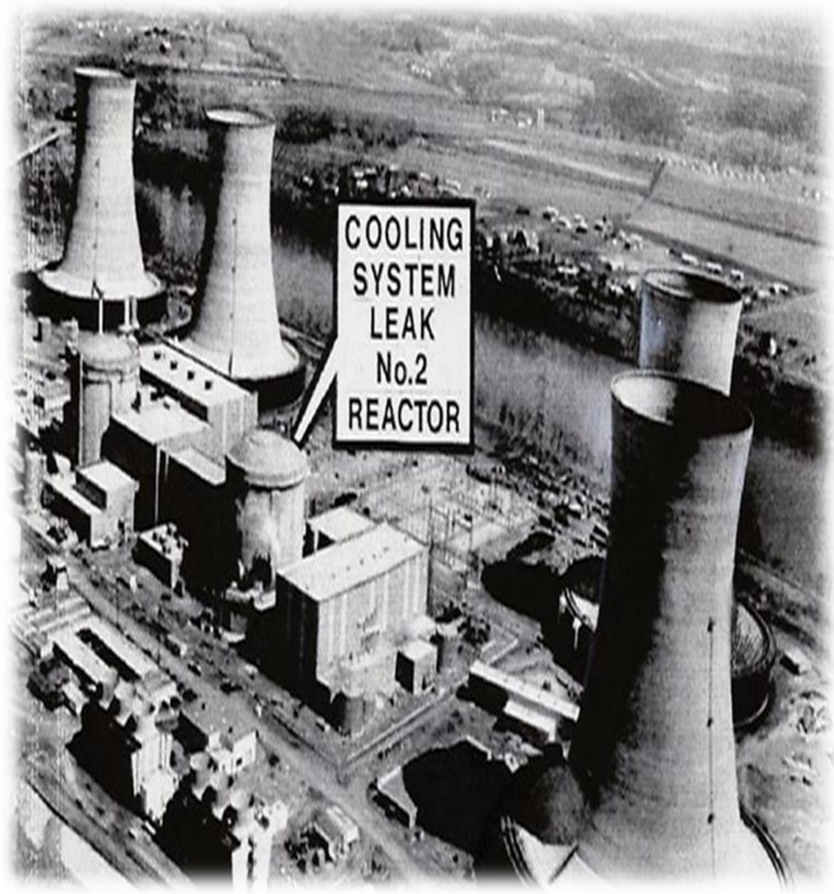
Plant	Required Land Area
Fossil and nuclear sites	1–4 km^2
Solar thermal or photovoltaic (PV)	20–50 km^2
Wind field	50–150 km^2
Biomass plantations	4000–6000 km^2

Disadvantages

- Nuclear Power Plant Safety Issue
  - ✓ Nuclear safety is a global issue; a serious event in one country may have a significant impact on its neighbors; the nuclear industry has, and must keep, safety and environmental protection as its top priorities. Site of major accident:
    - Three-Mile Island
    - Chernobyl
    - Fukushima Daiichi
  - ✓ The considerations of safety affect the overall cost of nuclear power

Three-Mile Island, 1979

- March 28, 1979- most serious reactor accident in US
- 50% meltdown of reactor core
  - ✓ Containment building kept radiation from escaping
  - ✓ No substantial environmental damage
  - ✓ No human casualties
- Elevated public apprehension of nuclear energy
  - ✓ Led to cancellation of many new plants in US

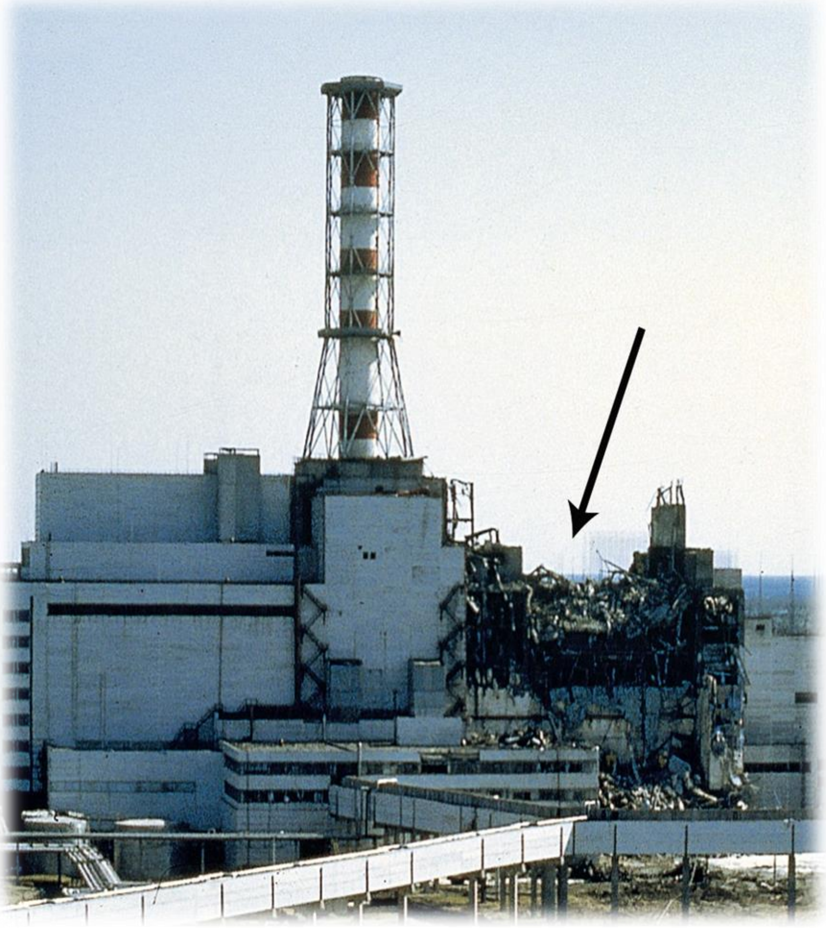


Chernobyl, 1986

- April 26, 1986- worst accident in history

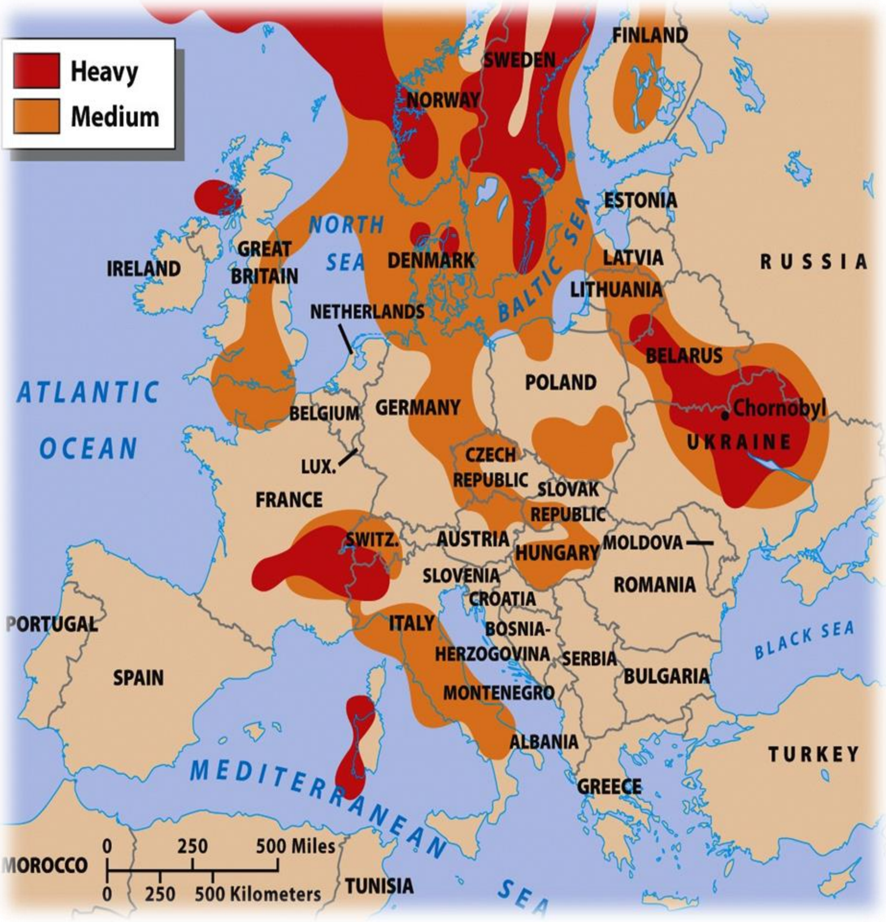
- 1 or 2 explosions destroyed the nuclear reactor
  - ✓ Large amounts of radiation escaped into atmosphere'

- Spread across large portions of Europe



Chernobyl, 1986

- Radiation spread was unpredictable
- Radiation fallout was dumped unevenly
- Death toll is 10,000 ~ 100,000



Fukushima Daiichi, 2011

- March 11, 2011 massive earthquake of magnitude 9.0 on the Richter scale jolted the eastern coast of Japan
- An hour after the earthquake, a 14-15 m tsunami, hit the Pacific coastline
- It led to loss of all onsite power sources resulting in serious accidents at the three operating Fukushima Daiichi units

Disadvantages

- Waste Disposal and Decommissioning
  - ✓ Because disposal of spent nuclear fuel and high-level waste from reprocessing has not yet been implemented, it is thought by some to be technically difficult or even impossible.
  - ✓ Nuclear Power Plant reactor can not simply be dismantled and the ground cleared for future use. Some parts of the reactor - the solid moderator and other core materials in gas-cooled reactors, the pressure vessel and possibly other parts of the primary cooling circuit, the spent fuel cooling pond - will be contaminated with radioactivity. This complicates both the process of dismantling and the disposal of the resulting remains
  - ✓ Waste management and decommissioning costs for nuclear power plants represent approximately 3% of overall nuclear electricity generation costs.

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