Nuclear Energy and the Principles of Nuclear Power Generation

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Le Rêve De l'énergie

- ÇatalHöyük

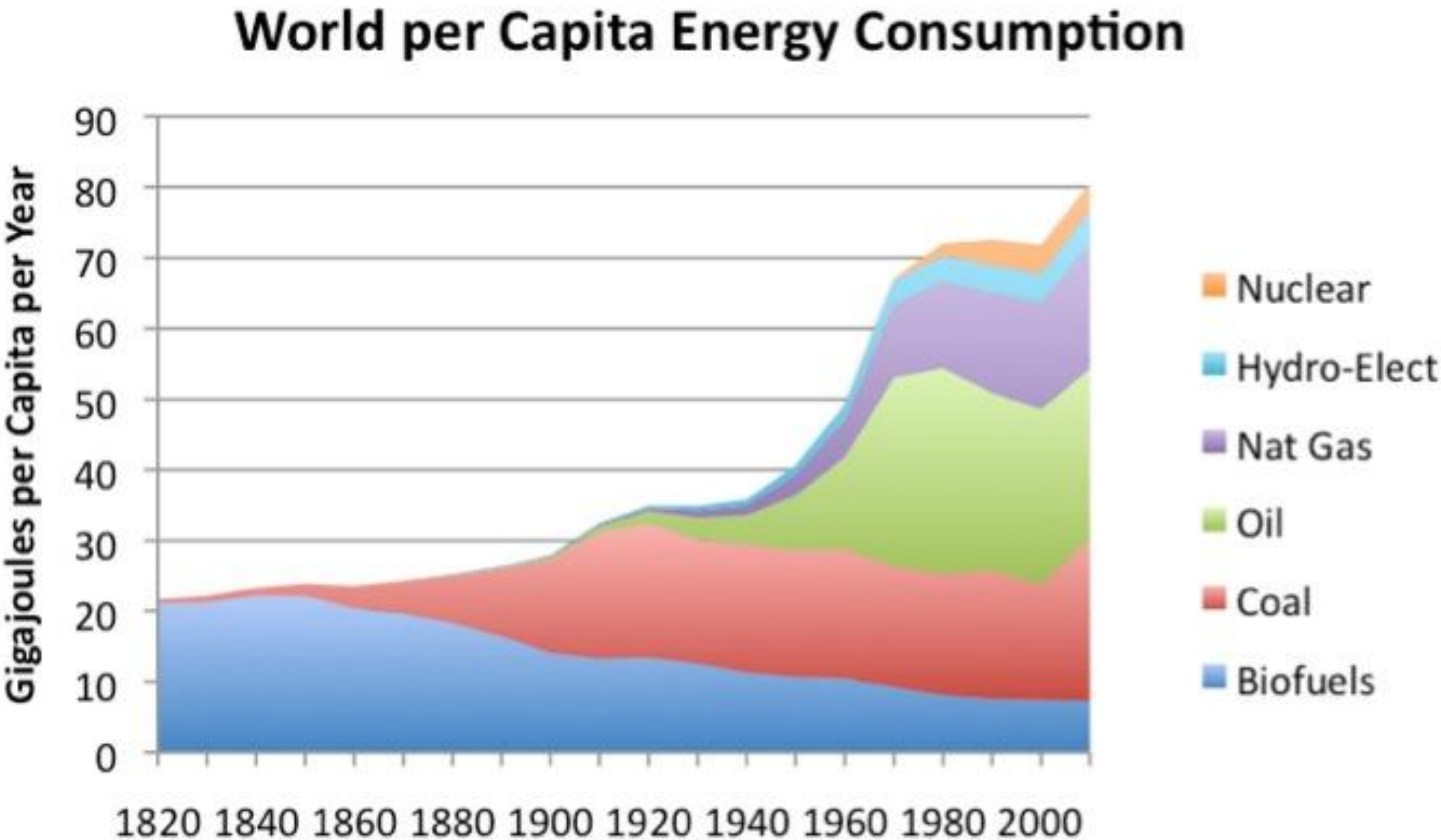
  8000 BC

Göbeklitepe

9600 BC

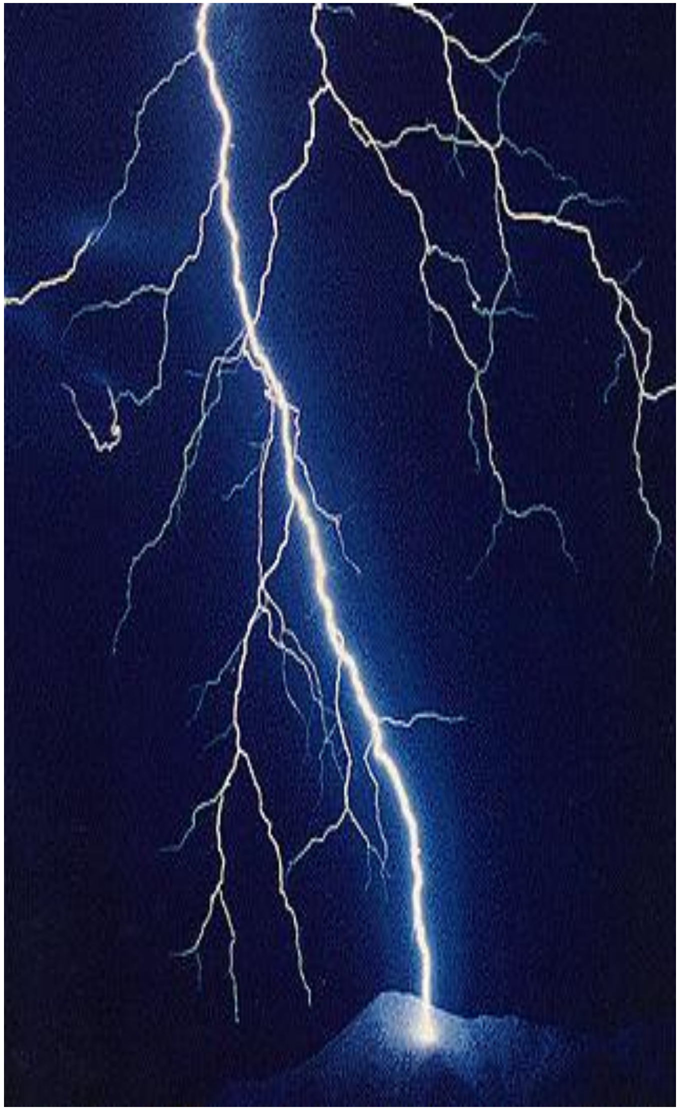
World History & War & Energy

World Per Capita Energy Consumption

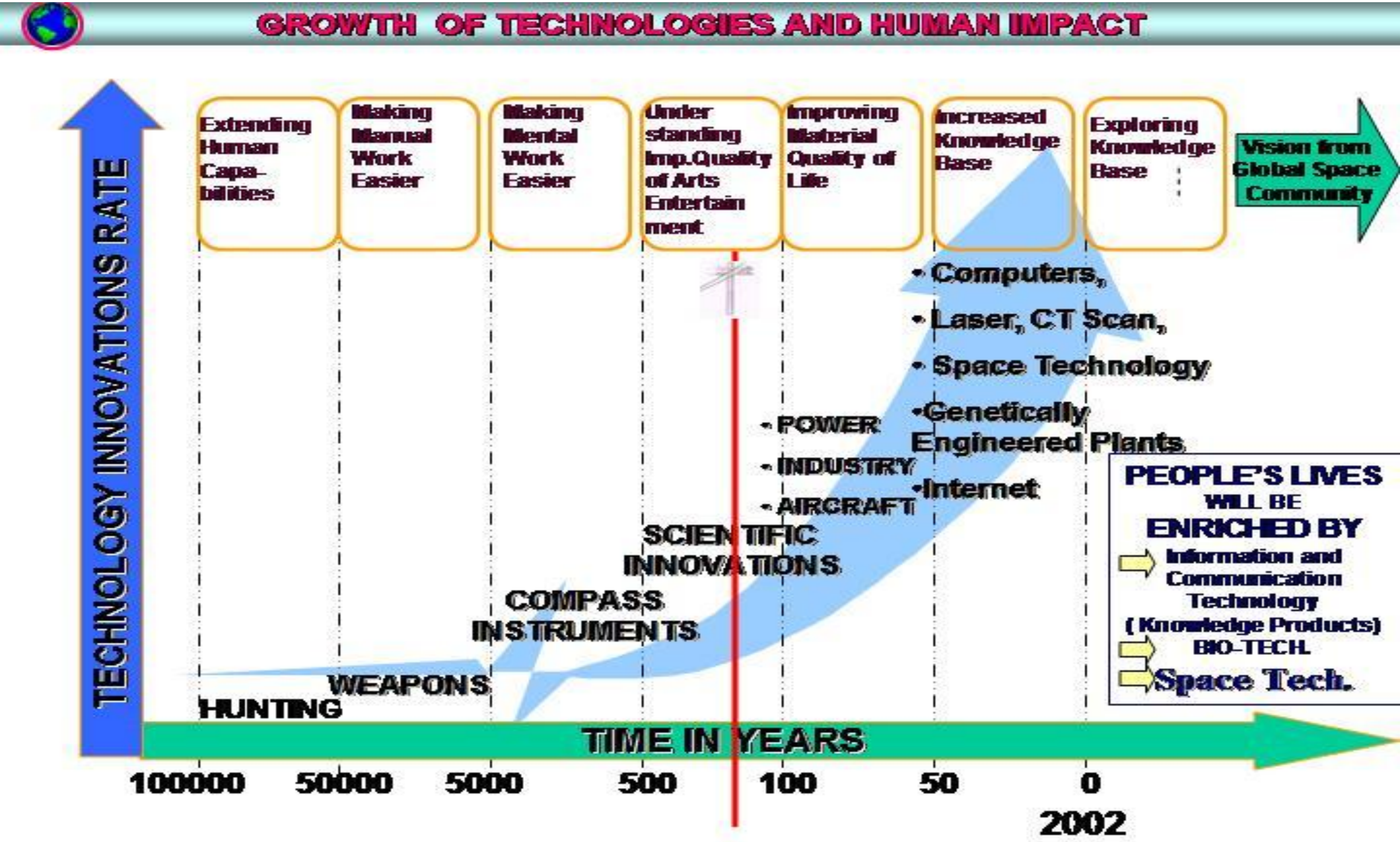


Energy as a Key to Our Future

- Energy is the single most important commodity for humanity.
- Without enough energy, production will stop, economics will fall and the civilization will crumble.
- The most widely utilized form of energy for industry and for domestic use is electricity.

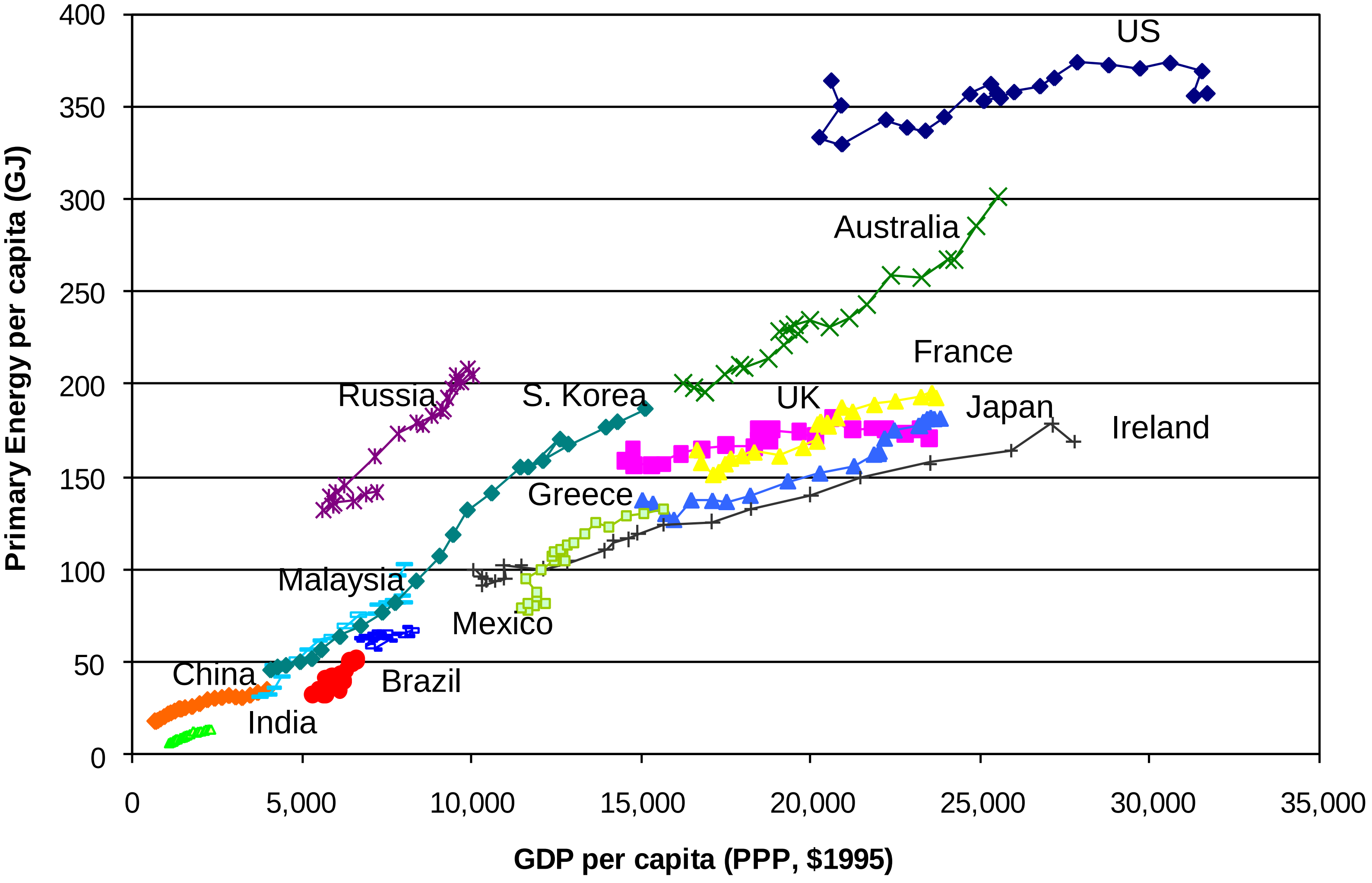


Growth of Technology = Power

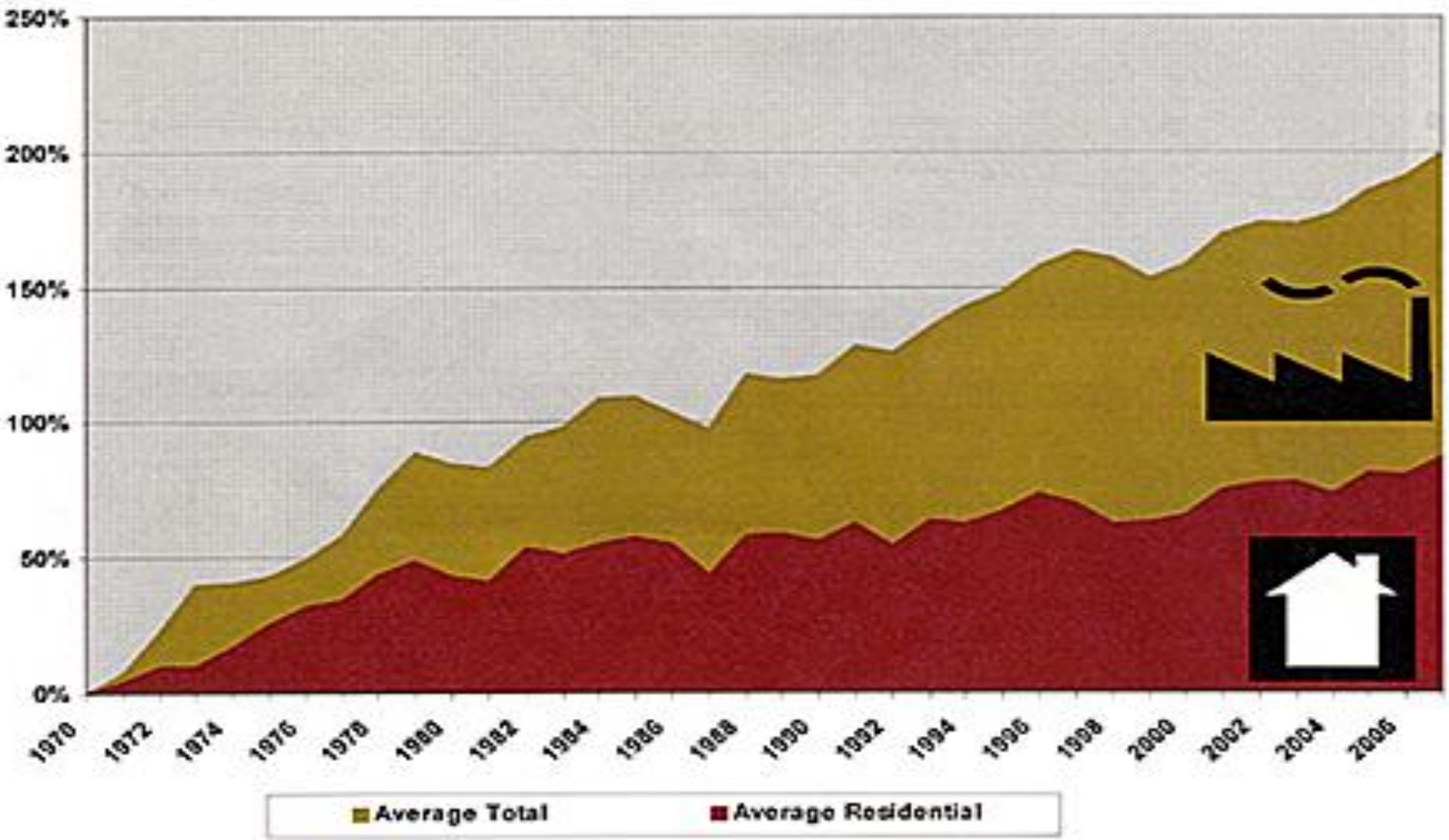


Energy Use Grows With Economic Development

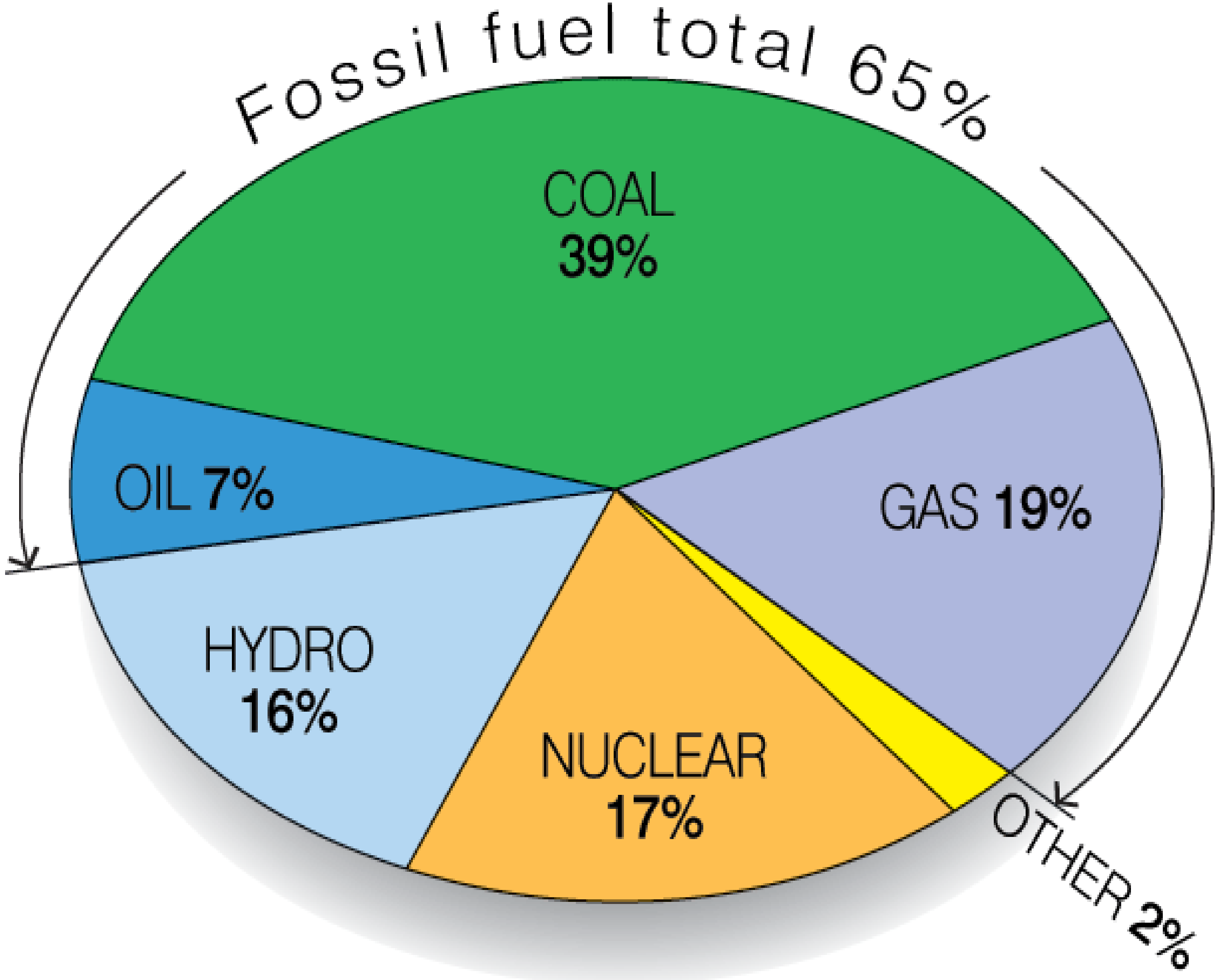
energy demand and GDP per capita (1980-2002)



The Demand for Electricity has Tripled Since 1970



The Distribution of Energy Sources for Producing Electricity (2008)



Use of Fossil Fuels are Causing Irreversible Damage to our World

- Everyone agrees that the use of fossil fuels are causing irreparable and irreversible damage to our environment.
- Many modern diseases (such as Cardiovascular Disorders, Cancer, High Blood Pressure) are partially caused by Fossil Fuel Pollution in the Environment.
- With the present consumption of fossil fuels, the world's energy needs will not be met sufficiently in 30 years.

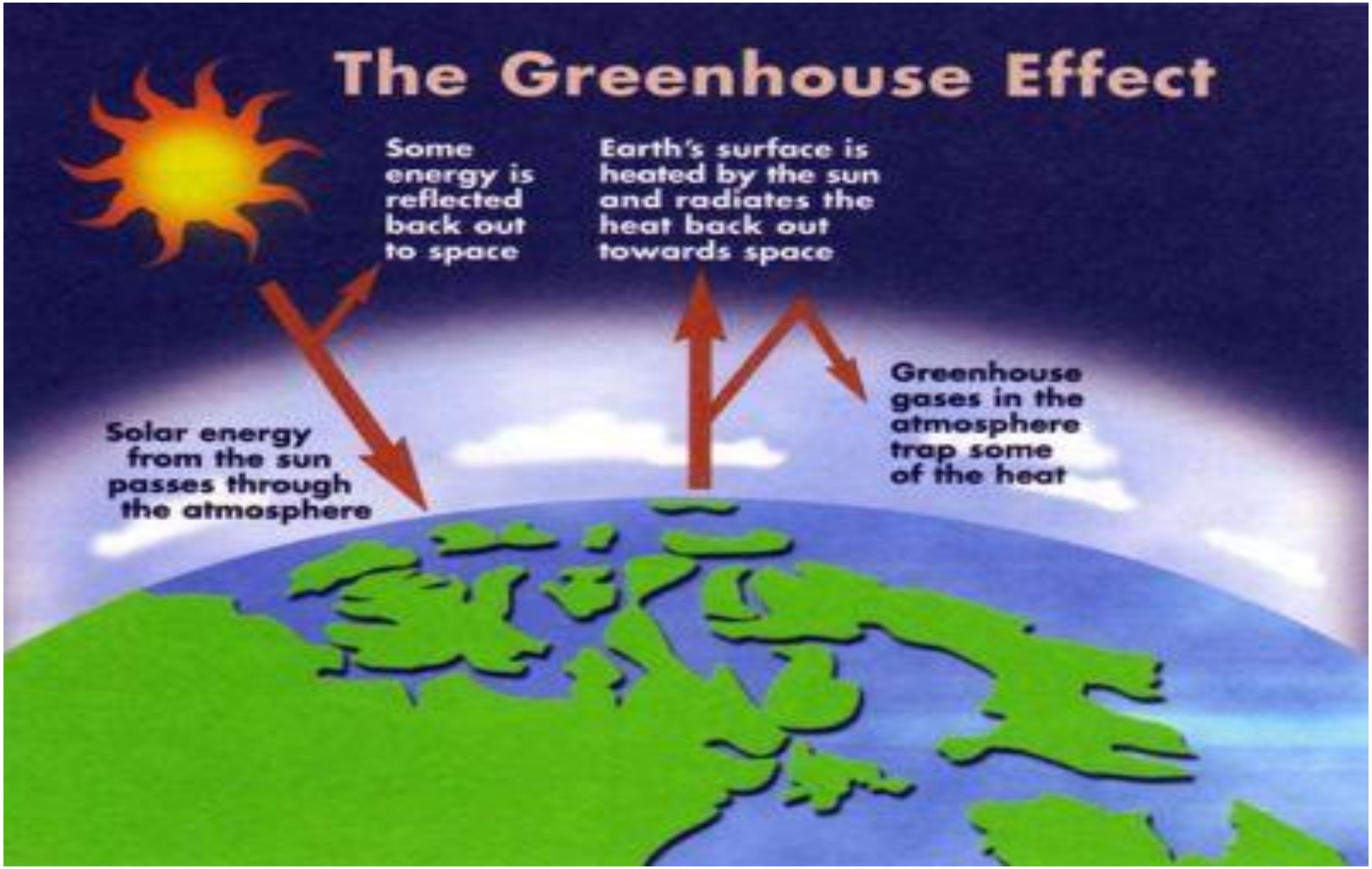
Fossil Fuel Damage to the Environment

- Especially the burning of coal for production of electricity releases carbon dioxide, as well as nitrogen oxide and sulfur dioxide.
- Nearly 50% of the nitrogen oxide in the atmosphere and 70% of sulfur dioxide are direct result of emissions released when coal is burned

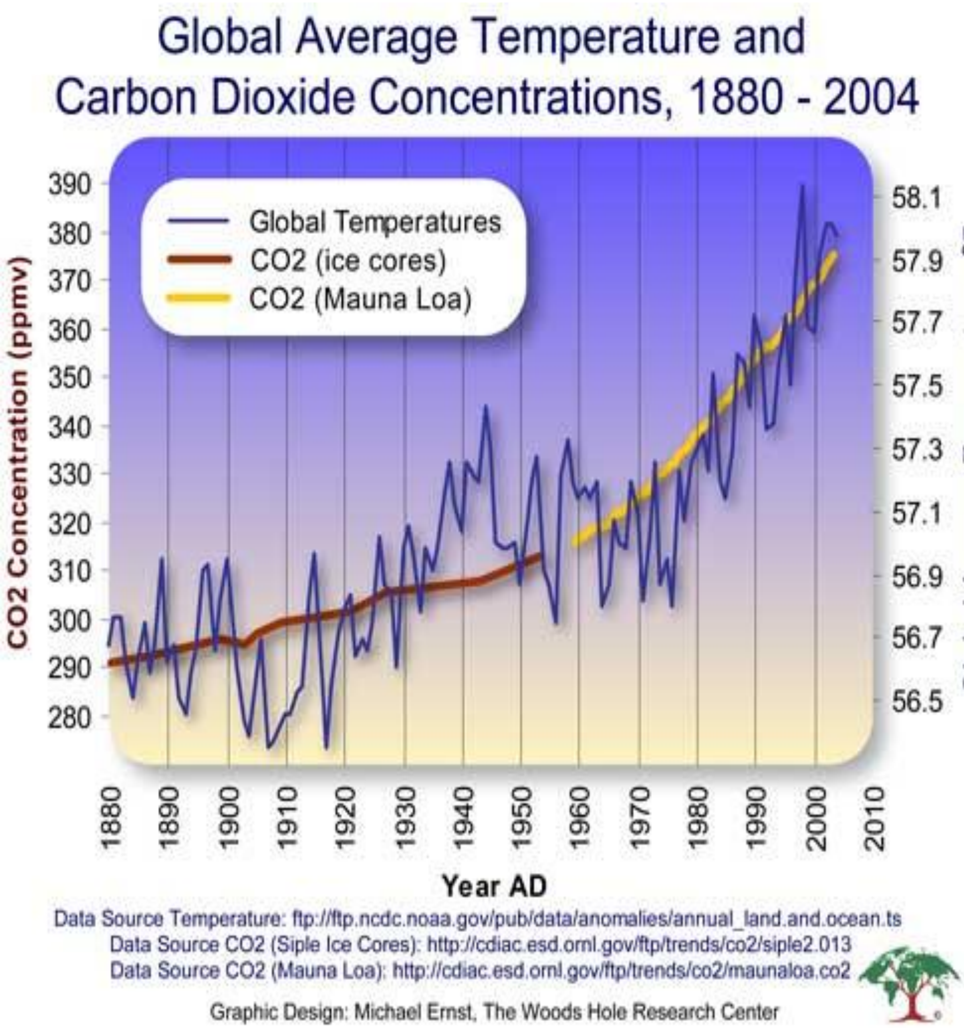
Alternatives to Fossil Fuels for Electricity

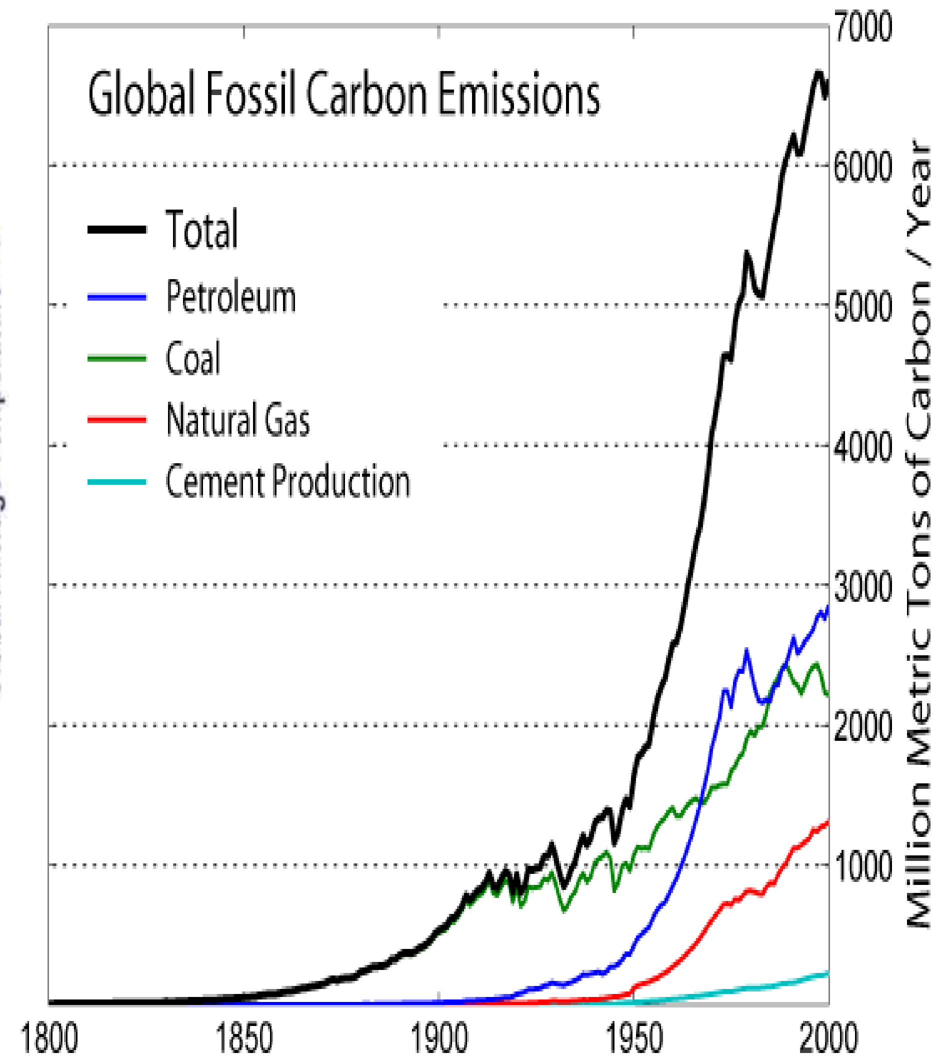
- Use of Fossil Fuels for Electricity are Destroying the Environment for Future Generations. The alternatives:
- Renewable Energy Sources
- Hydrodynamic Power Production
- Nuclear Energy Production

The Greenhouse Effect

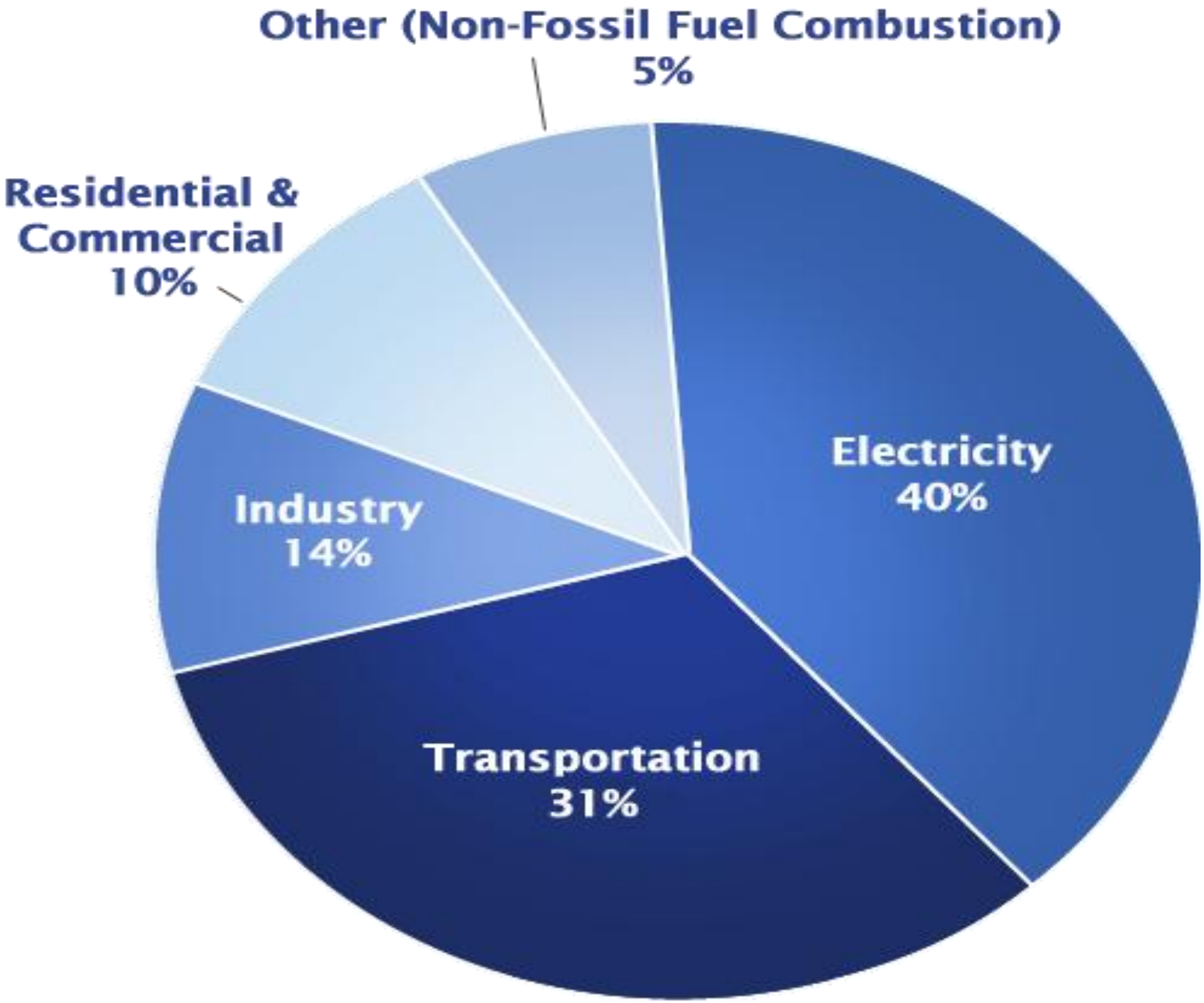


Global Warming and CO2





Carbon Dioxide and USA



Oil is Running Out

The Oil Problem

Nations that **HAVE** oil (% of Global Reserves)	
Saudi Arabia	26%
Iraq	11%
Kuwait	10%
Iran	9%
UAE	8%
Venezuela	6%
Russia	5%
Mexico	3%
Libya	3%
China	3%
Nigeria	2%
U.S.	**2%**

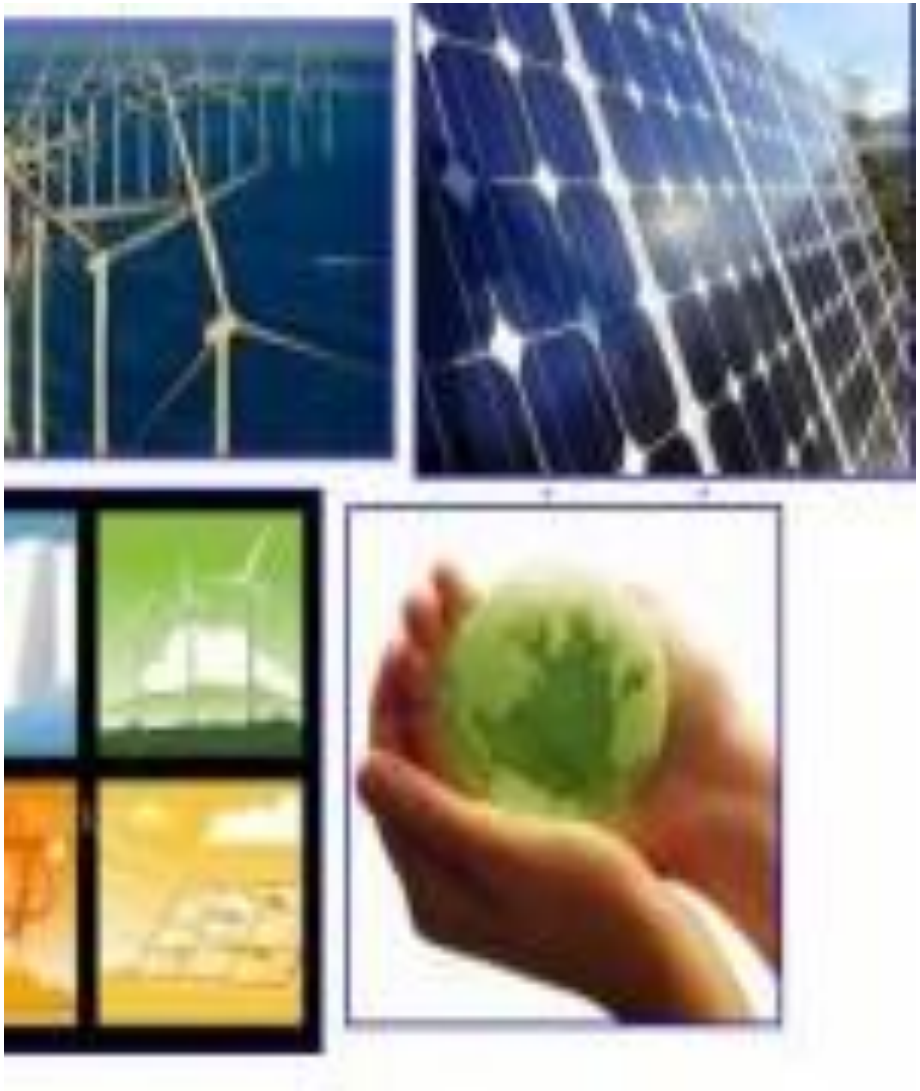
Nations that **NEED** oil (% of Global Consumption)	
U.S.	**26%**
Japan	7%
China	6%
Germany	4%
Russia	3%
S. Korea	3%
France	3%
Italy	3%
Mexico	3%
Brazil	3%
Canada	3%
India	3%

Alternatives to Fossil Fuels for Electricity

- Use of Fossil Fuels for Electricity are Destroying the Environment for Future Generations. The alternatives:
- Renewable Energy Sources
- Hydrodynamic Power Production
- Nuclear Energy Production

Renewable Energy Supplies Cant Be Used Efficiently

- Renewable energy sources for electricity are diverse, from solar, tidal and wave energy to hydro, geothermal and biomass-based power generation.
- Apart from hydro power in the few places where it is very plentiful, none of these renewable energy sources are suitable, intrinsically or economically, for large-scale base-load power generation.

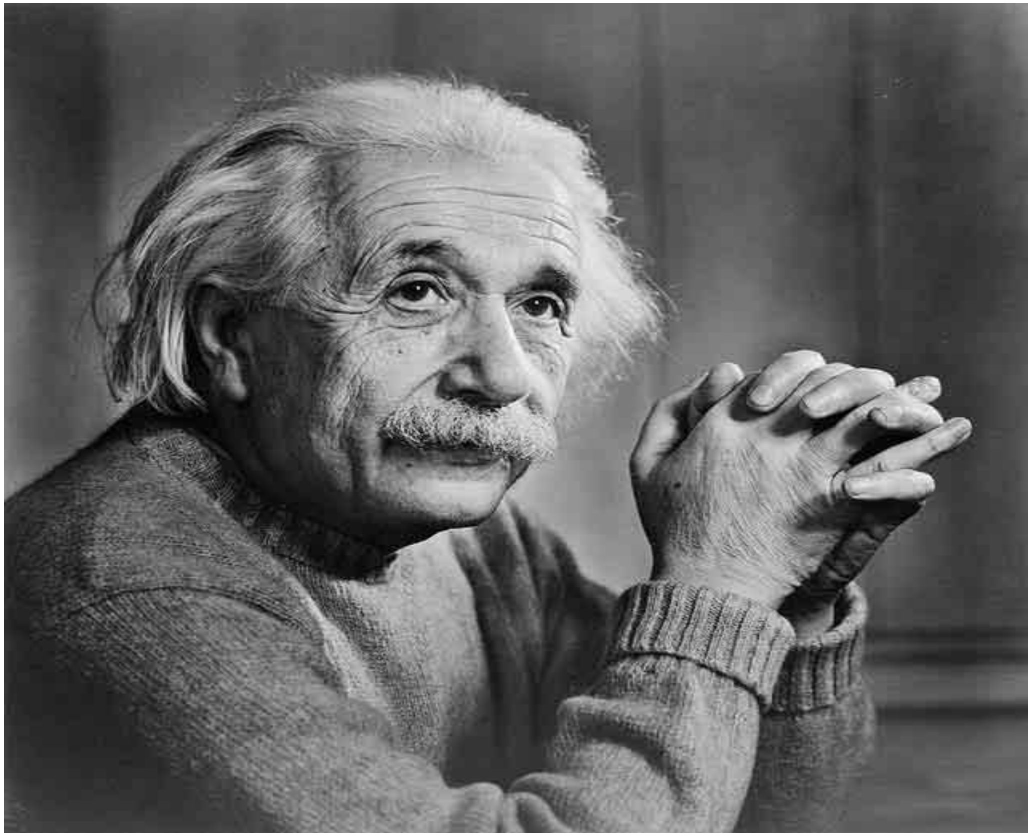


Nuclear Energy can be the Only Feasible Solution to World’s Energy Problems

- Carbon based fuels are diminishing and they will be finished in 30 – 50 years. Moreover, use of carbon fuels are damaging the environment irreparably.
- Renewable Energy Sources are not yet efficient enough to solve the world’s energy needs.
- Nuclear Energy is the only viable alternative to producing enough electricity for our civilization.

What is Nuclear Energy?

- Albert Einstein with his famous law of E= mc^2 was responsible for the idea that mass can be converted into energy.
- In essence, Nuclear Energy is the energy utilized from converting mass to energy through nuclear processes.



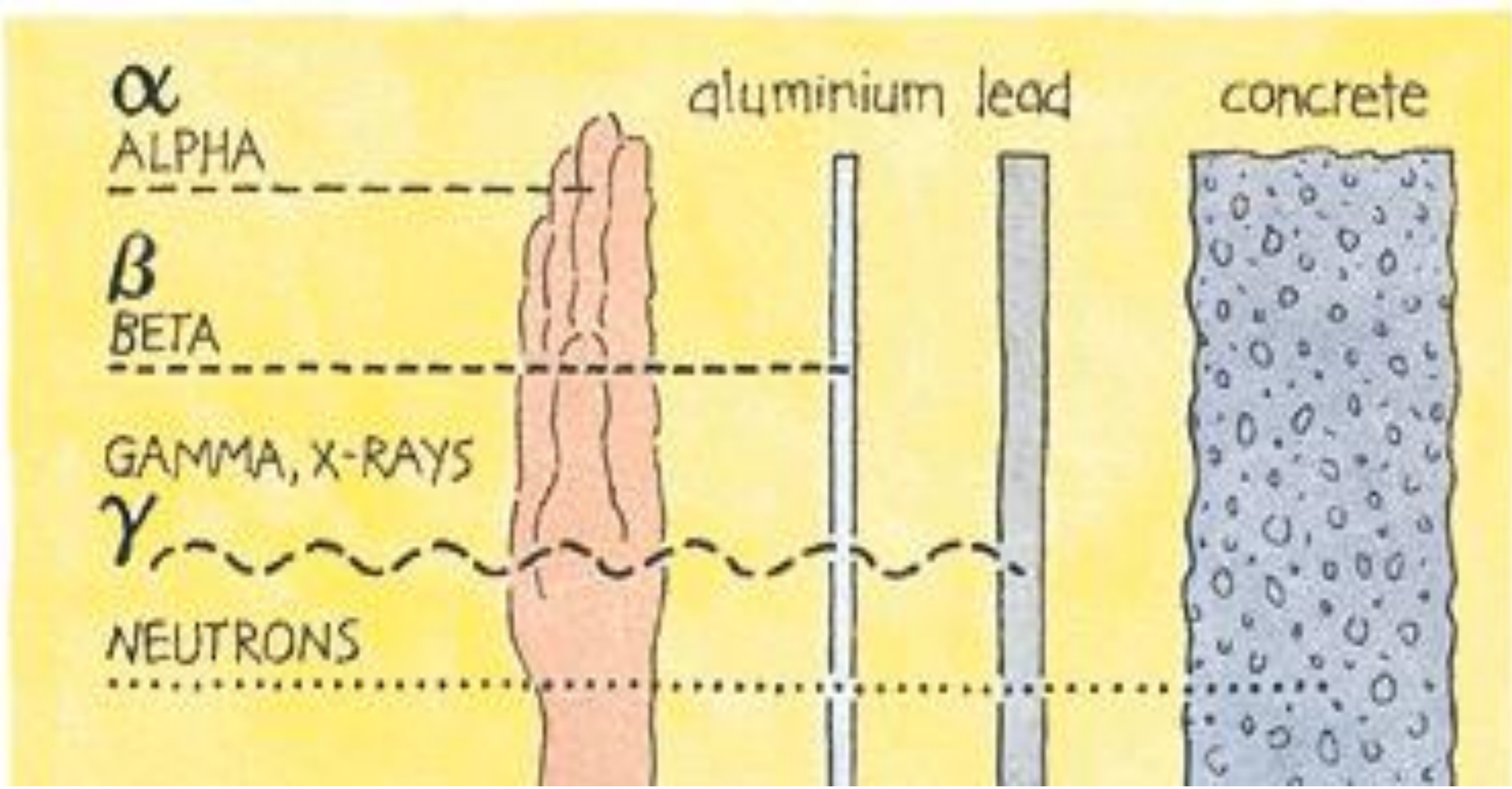
What is Radioactivity and Radiation ?

- Radioactivity is the spontaneous emission of energy or ionizing particles from unstable atoms.
- Radiation is energy that comes from a source and travels through space and may be able to penetrate various materials. TV signals, cell phone signals, radio and microwaves are all types of radiation as well as ionizing forms such as gamma rays and cosmic rays.

Ionizing Radiation

- Ionizing radiation will penetrate the outer layer of an atom and it can strip an electron or add an electron causing the atom to have an electric charge. (such as alpha, beta and gamma radiation)
- Non ionizing radiation such as TV signals and radio waves will not penetrate the atom's outer layer, but they can be effective in creating an electromagnetic field

Radiation Protection



Time, **D**istance, **S**hielding. If you reduce the time you are exposed to a radiation source, maximize the distance from the radiation source, and place some object or other form of shielding between you and the radiation source, you can reduce your radiation exposure

Radiation Units

Table 5
Units of Radiation and Radioactivity

Common Units USA	Abbreviation	Used to Measure
Roentgen	R	— Exposure (obsolete) — Measure of the amount of ionizations in a mass of air, gamma and x-rays only, only in air — 1 R = 2.58×10^{-4} coulombs per kg of dry air
Rad (radiation absorbed dose)	rad	— Absorbed dose, measure of amount of energy absorbed in a material, any type radiation, any type material — 1 rad = 100 ergs per gram of material
Rem (roentgen equivalent man)	rem	— Equivalent dose, relates absorbed dose in human tissue to the effective biological damage; "rem" doses which are equal but from different types of radiation produce the same amount of biological damage — rem = rad $\times$ Q (the quality factor) — Q = 1 for x-rays, up to 20 for neutron or alpha
Curie	Ci	— Radioactivity — 1 Ci = quantity of material that has 3.7×10^{10} disintegrations/second

SI Units International Standard	Abbreviation	Used to Measure
Gray	Gy	— Absorbed dose (equivalent to rad) — 1 Gy = 1 joule per kg of material — 1 Gy = 100 rads
Sievert	Sv	— Equivalent dose (equivalent to rem) — 1 Sv = Gy $\times$ Q — 1 Sv = 100 rem
Becquerel	Bq	— Radioactivity (equivalent to Ci) — 1 Bq = 1 disintegration/second — 3.7×10^{10} Bq = 37 billion Bq = 1 Ci

Note: frequently units are prefixed with milli (m) (one thousandth) or micro (μ) (one millionth), i.e., 1 millirem = 1 mrem = 0.001 rem, 1 microCi = 1 μCi = 0.000001 Ci.

Standard Radiation Levels

- A coal plant would emit three times the radiation of a nuclear power plant due to the presence of natural uranium in the coal
- Up to 5000 mRem per year can be taken safely A 40 year old can have a maximum of 200 Rem. Anything above 300 Rem increases chance of cancer by 10%
- Normal exposure is 300 mRem per year
- A person emits about 40 mRem of radiation due to natural Carbon 14 found in the body. Sitting next to two persons would double the exposure
- A person who smokes a pack of cigarettes gains 3 .5mRem of radiation corresponding to ¼ annual dose. A chain smoker has been exposed to more radiation overall as compared to those near nuclear plants

Radiation from Natural Sources

Table 3
Radioactivity of Some Natural and Man-Made Materials

Material	Amount	Becquerels	
Source for radiotherapy	1	100,000,000,000,000	(100 trillion)
50-year old high level nuclear waste	1 kg	10,000,000,000,000	(10 trillion)
Uranium	1 ton	10,000,000,000	(10 billion)
Medical isotope for diagnosis	1	70,000,000	(70 million)
Coal ash	1 ton	2,000,000	(2 million)
Low level nuclear waste	1 kg	1,000,000	(1 million)
Fertilizer — super phosphate	25 kg	125,000	
Human adult	1	3,000	
Coffee	1 kg	1,000	
Bread	1 loaf	70	
Hamburger	4 oz.	29	
Red kidney beans	1/2 cup	29	
Sunflower seeds	3.5 oz	28	
French fries	3.5 oz	20	
2% Milk	1 cup	11	
Banana	Small	9	
Hot chocolate	1 packet	6	
Oatmeal	1 cup	4	

Annual Radiation Doses

Radiation Doses in Millirem from Various Exposures (Annual Dose Unless Otherwise Stated)	
10,000.0	Dose to Chernobyl evacuees
5,000.0	U.S. Occupational Dose limit
2,000.0	Tobacco smoking
1,500.0	Underground uranium mines
400 – 800.0	St. Peters Square, Rome
600.0*	Pelvic x-ray exam
500.0*	Barium enema x-ray exam
500.0	U.S. Occupational Dose limit for pregnant women per 9 months
500.0	N.Y. Grand Central Station entrance
480.0	Denver, Colorado
360.0	Average U.S. dose
170.0*	Gall bladder x-ray exam
140.0*	Rib cage x-ray exam
100.0	Airplane flight crew yearly dose
100.0	Dental x-ray dose to center of cheek
20.0	1 Chernobyl per year
15.0*	Chest x-ray
7.0	Nuclear testing (peak year)
4.0	Fallout
2.0	Airplane trip coast to coast
1.0	Nuclear power
0.5	TV at surface
0.1	Sleeping with another human

Sources of Radiation Dose

U.S. National Annual Average   Effective Dose Equivalent = 360 mrem

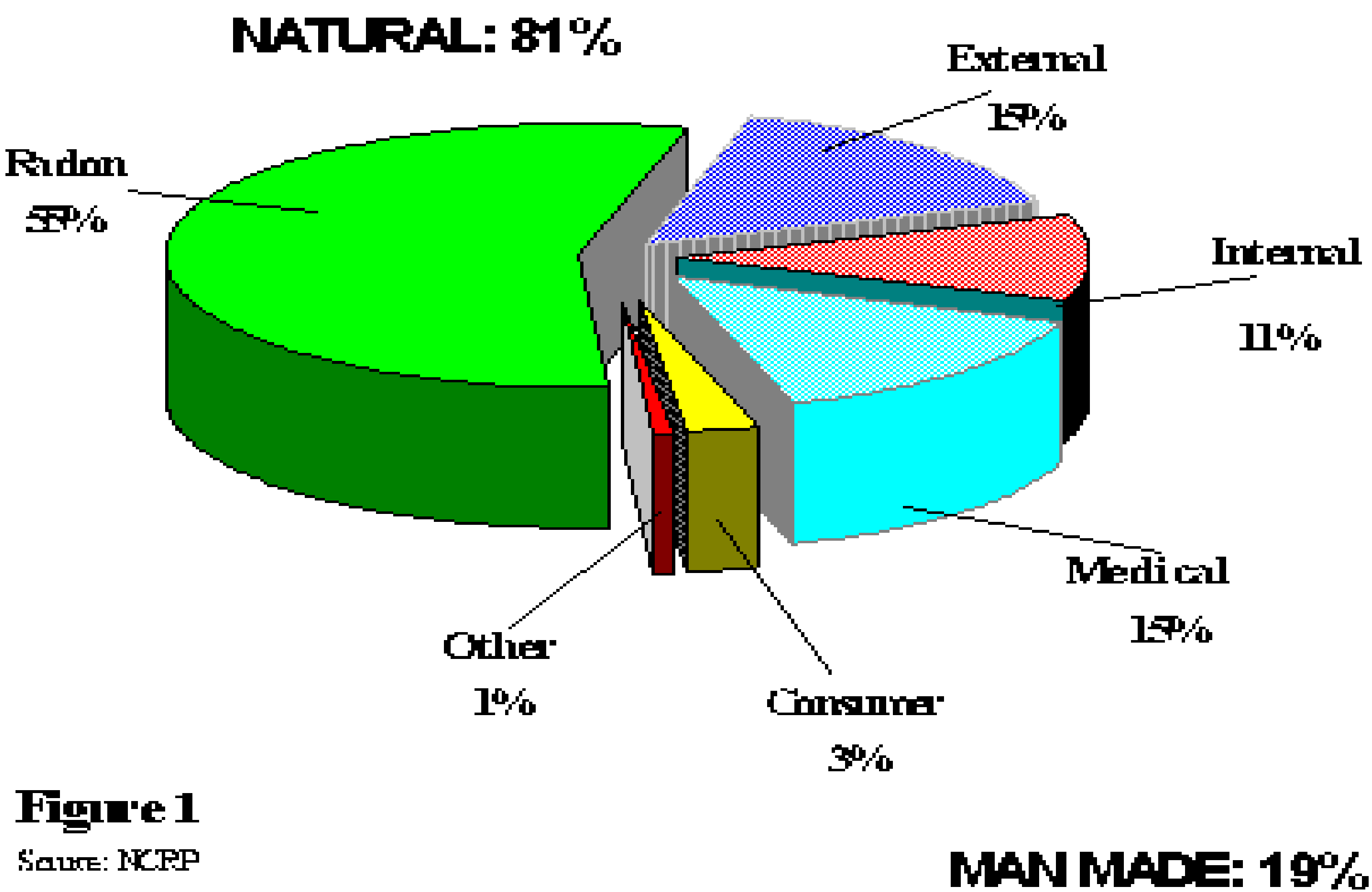
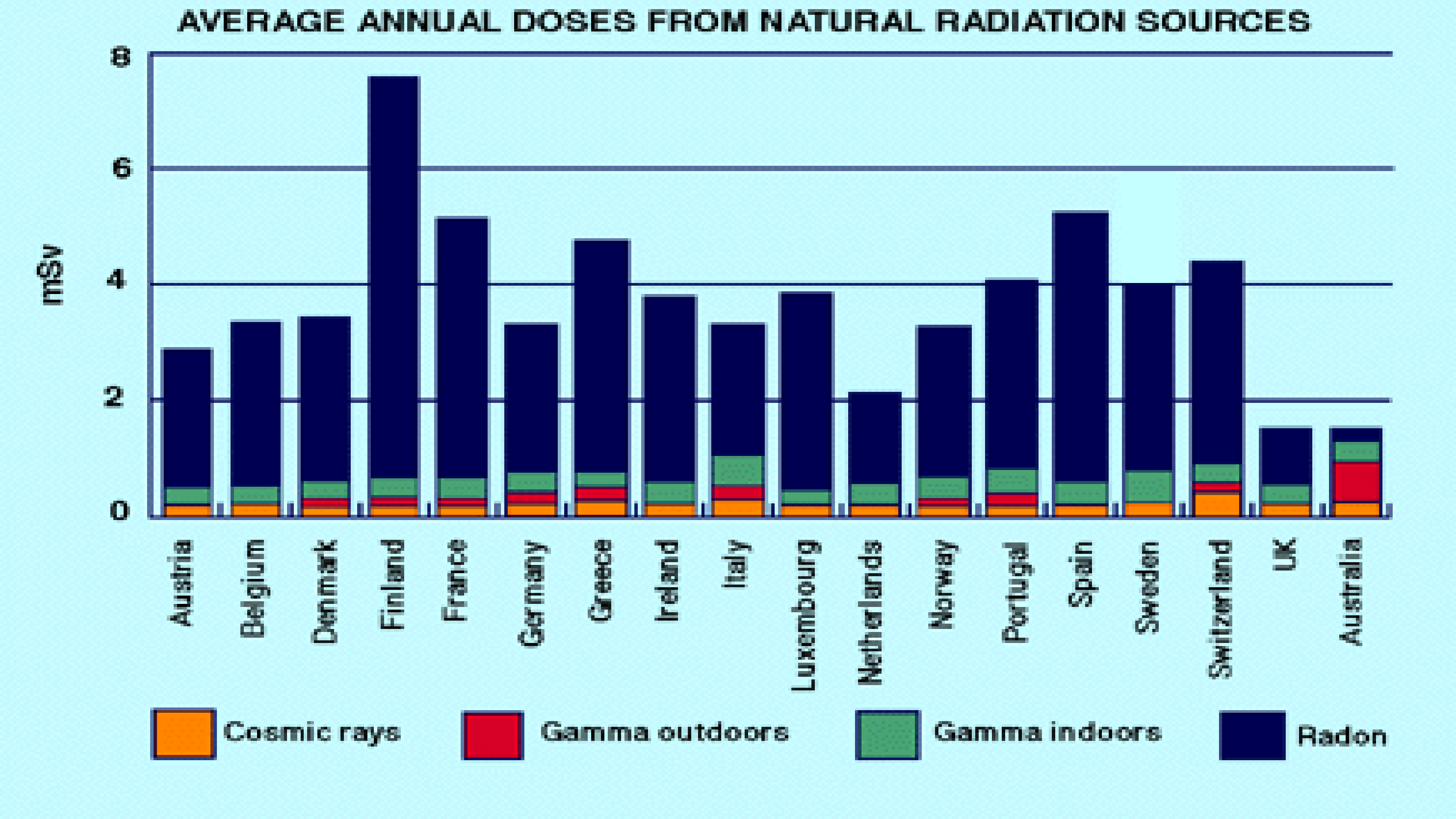


Figure 1

Source: NCRP

Radiation Exposure in Different Countries



How Much Radiation is Safe?

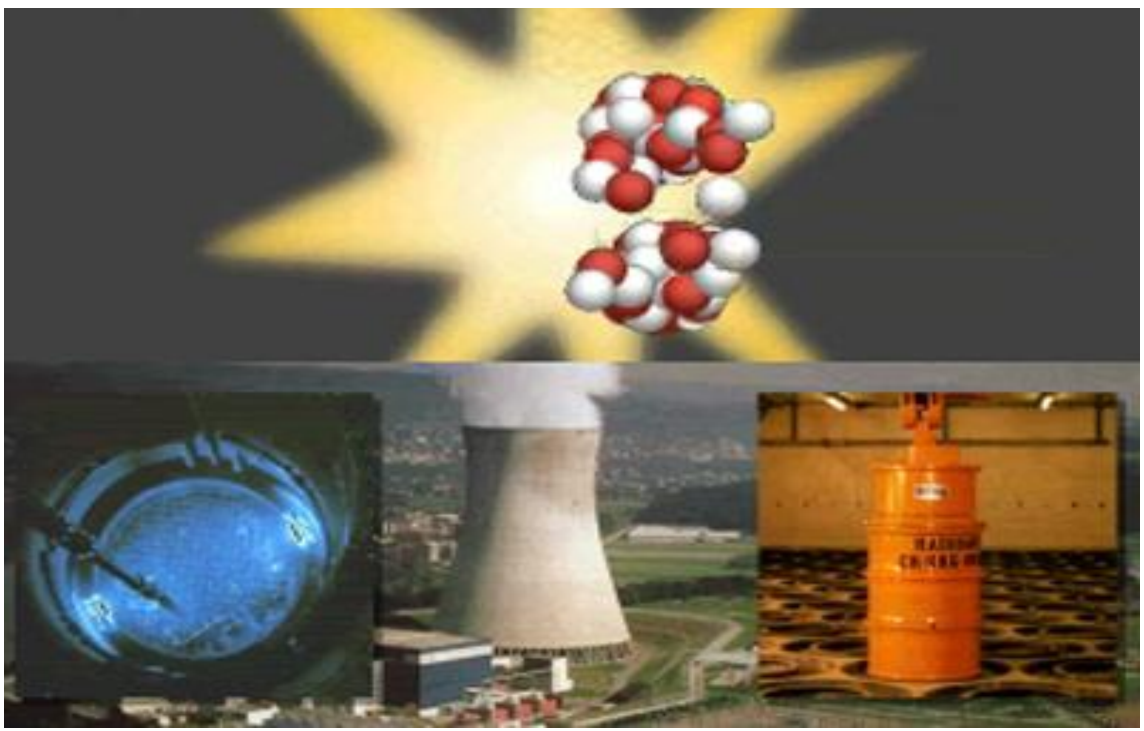
- The current US Atomic Energy Administration Guidelines state that 5000 Millirems of radiation per year is safe, while for minors it is 500 Millirems per year.
- A person on average is exposed to 400 Millirems of radiation annually. This will increase as the altitude of the city increases.
- Your lifetime exposure should not be more then your age multiplied by 1000 Millirems.

How is Nuclear Energy Produced?

- Nuclear Energy is produced through two different means:

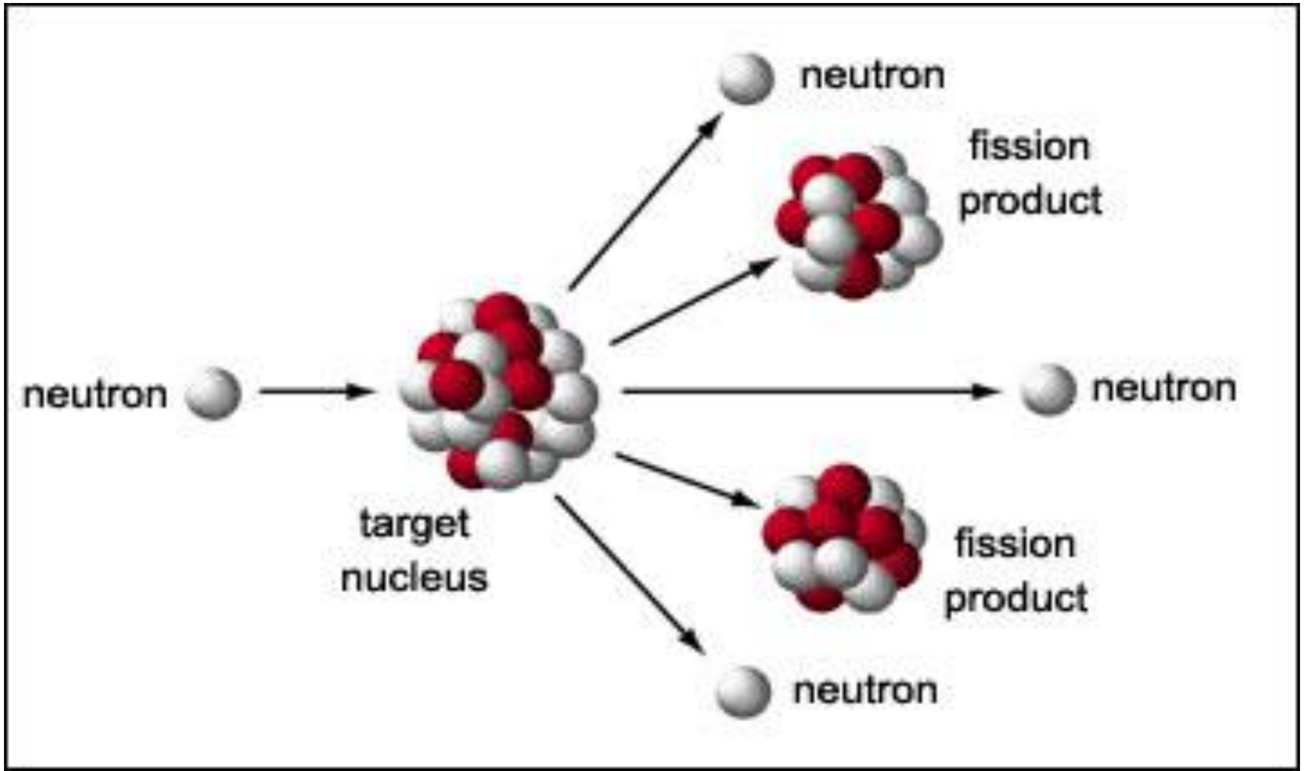
  1) Nuclear Fission of Splitting Atoms

  2) Nuclear Fusion of Combining Atoms



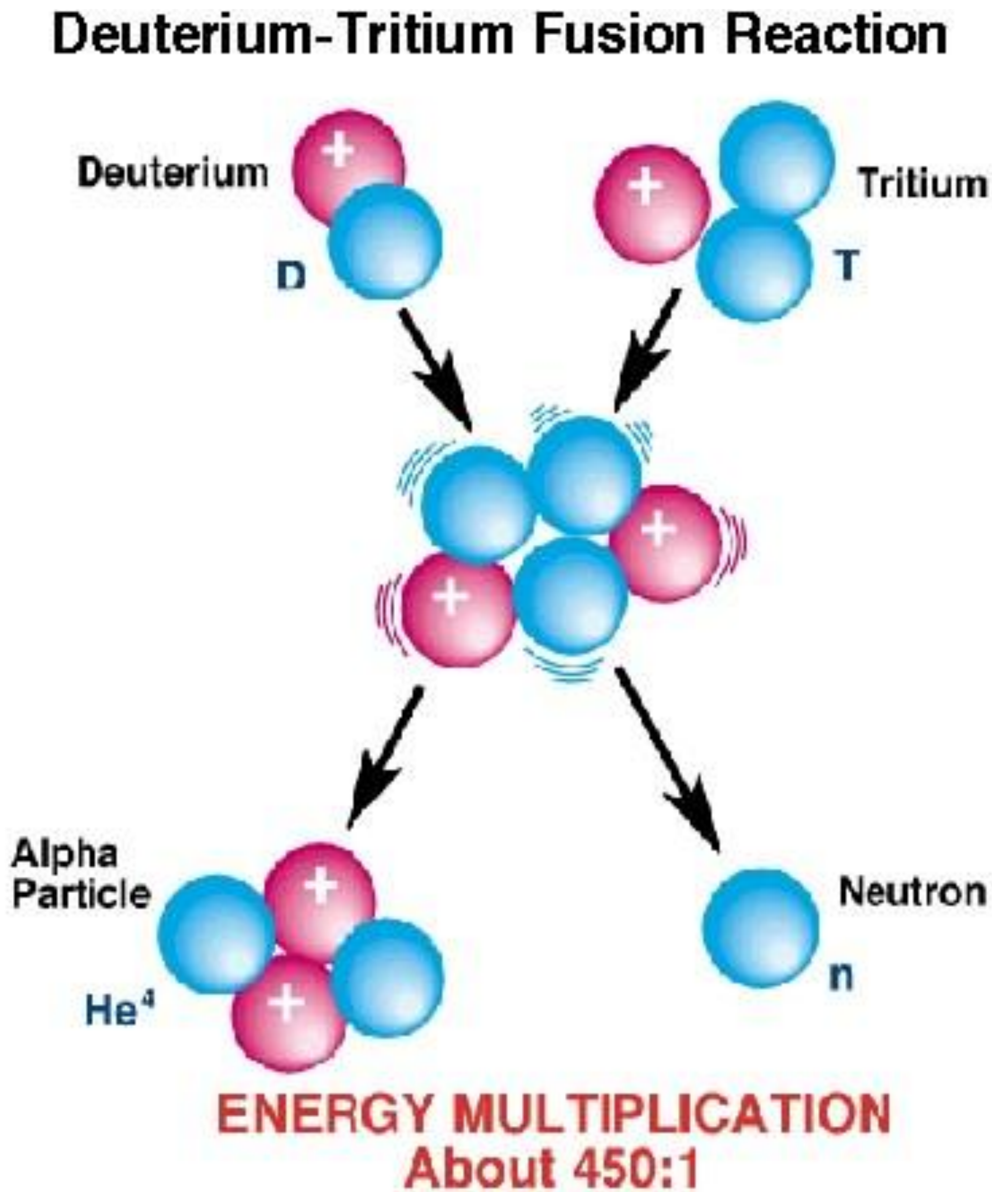
Power of Fission

- Fission is one of the most powerful sources of energy in the world. In essence, a molecule of fissile material is bombarded by neutrons, so that it separates into two or more articles. During this process, **some mass is converted to pure energy** (expressed as heat)



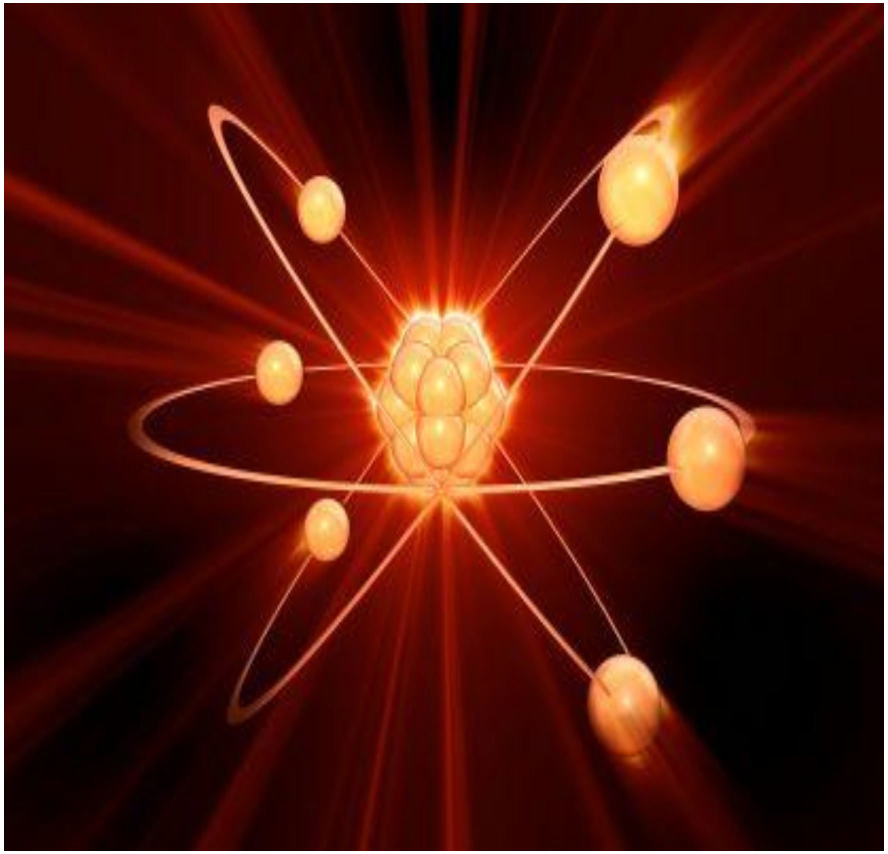
Power of Fusion

- Fusion is the process of combining atoms to make new ones. During this process, great amounts of energy is released.
- **<u>Sun is the best example for Fusion Energy</u>**.
- In the sun, Hydrogen molecules fuse to become Helium molecules.



How Can We Harness Nuclear Energy?

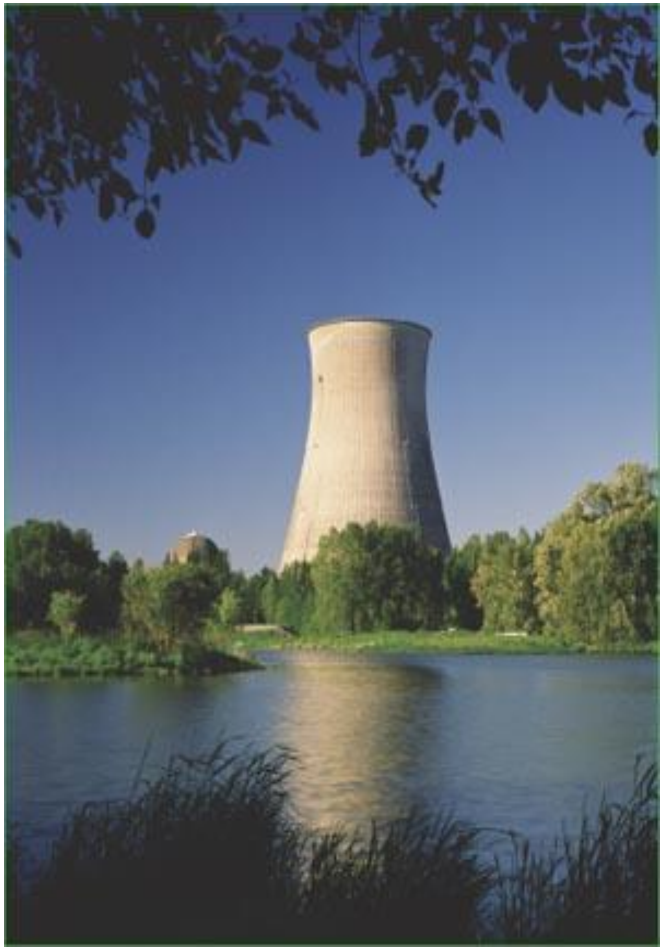
- Nuclear Energy is achieved through natural processes and nuclear reactions have been going on for millions of years.



- Nuclear Reactions are abundantly found on our Sun as well as in the billions of stars found in our galaxy. Moreover, even Earth is full with nuclear reactions and natural radioactivity.

Nuclear Energy can Be Harnessed Through Nuclear Reactors

- Currently **fission is the only way to** feasibly harness the energy that is available through nuclear reactions.
- By **containing the fission reaction within a nuclear reactor,** it can be possible to harness the nuclear energy and convert it into electricity through various means.

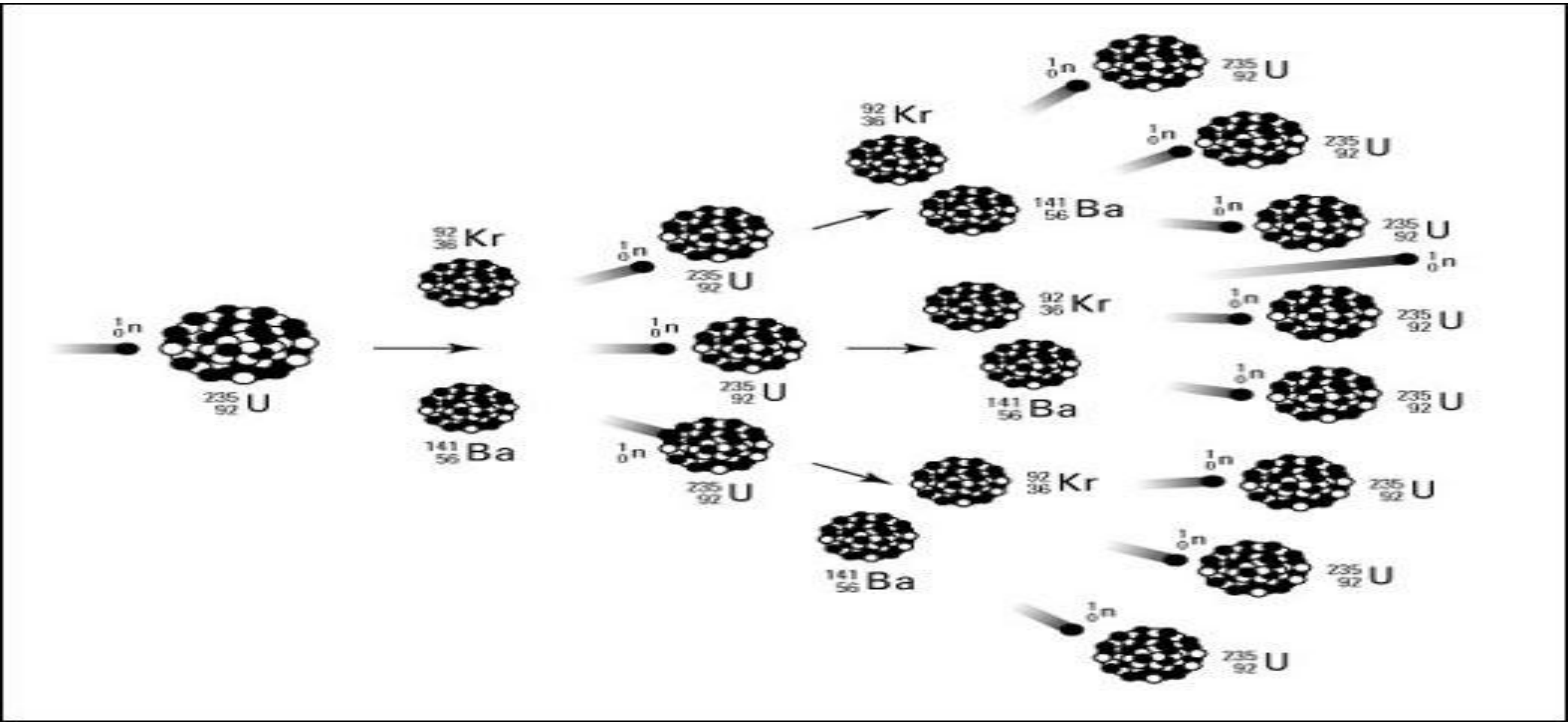


Fission Chain Reaction

- Fission Reaction Formula in general is:

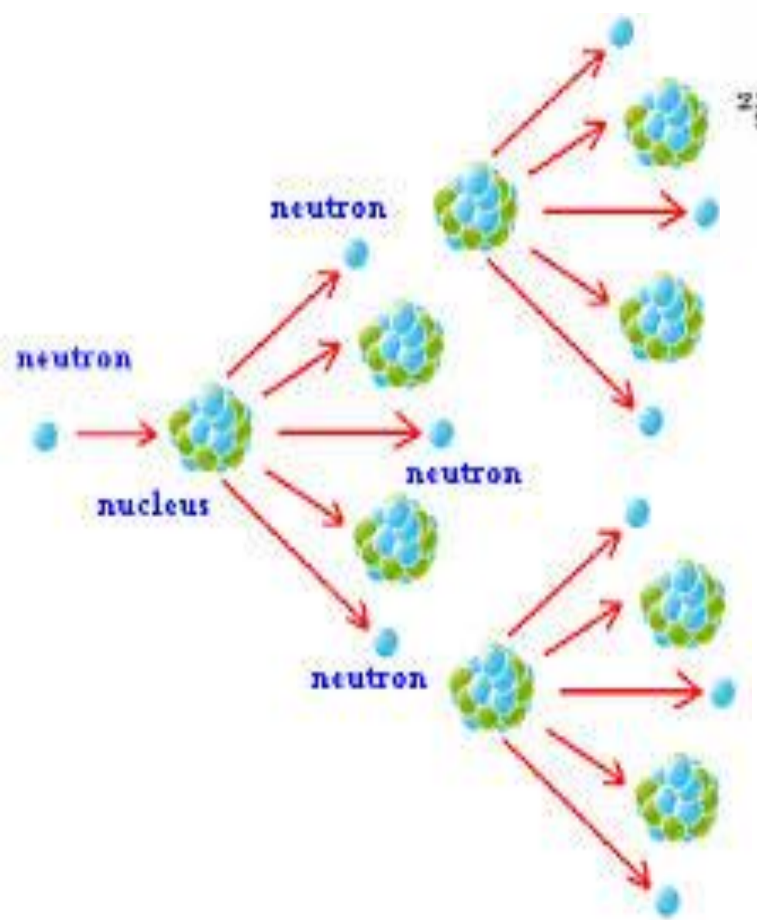
$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\,^{1}_{0}n$$

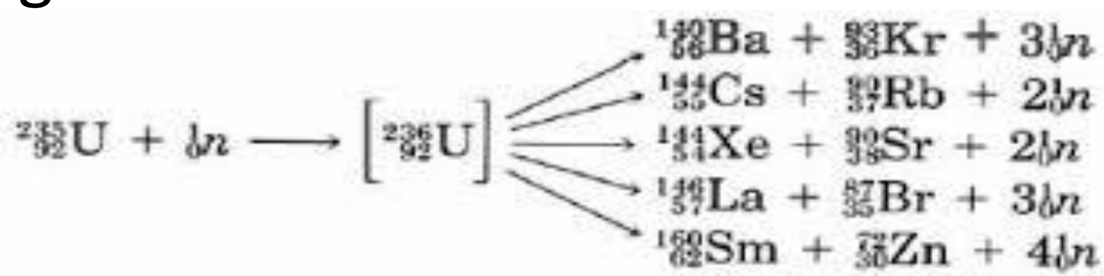
- Fission must be a chain reaction to sustain itself

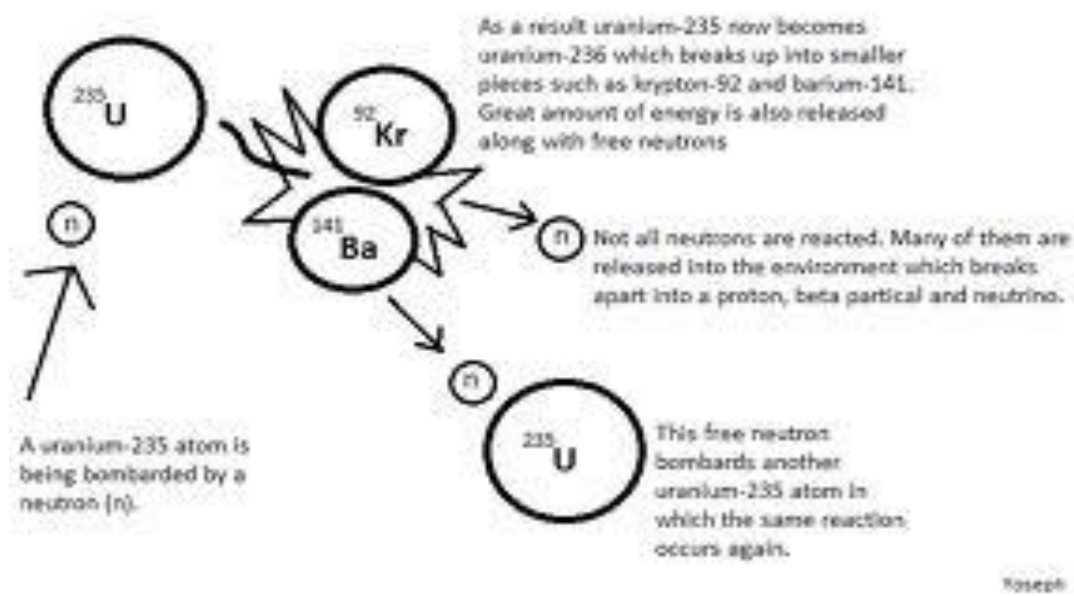


Neutron Multiplication in Fission Chain Reaction

- AN average of 2.7 neutrons are released per reaction. This allows the neutrons to multiply and hit many more Nuclear fuel molecules causing a chain reaction.







World's First Nuclear Reactor?

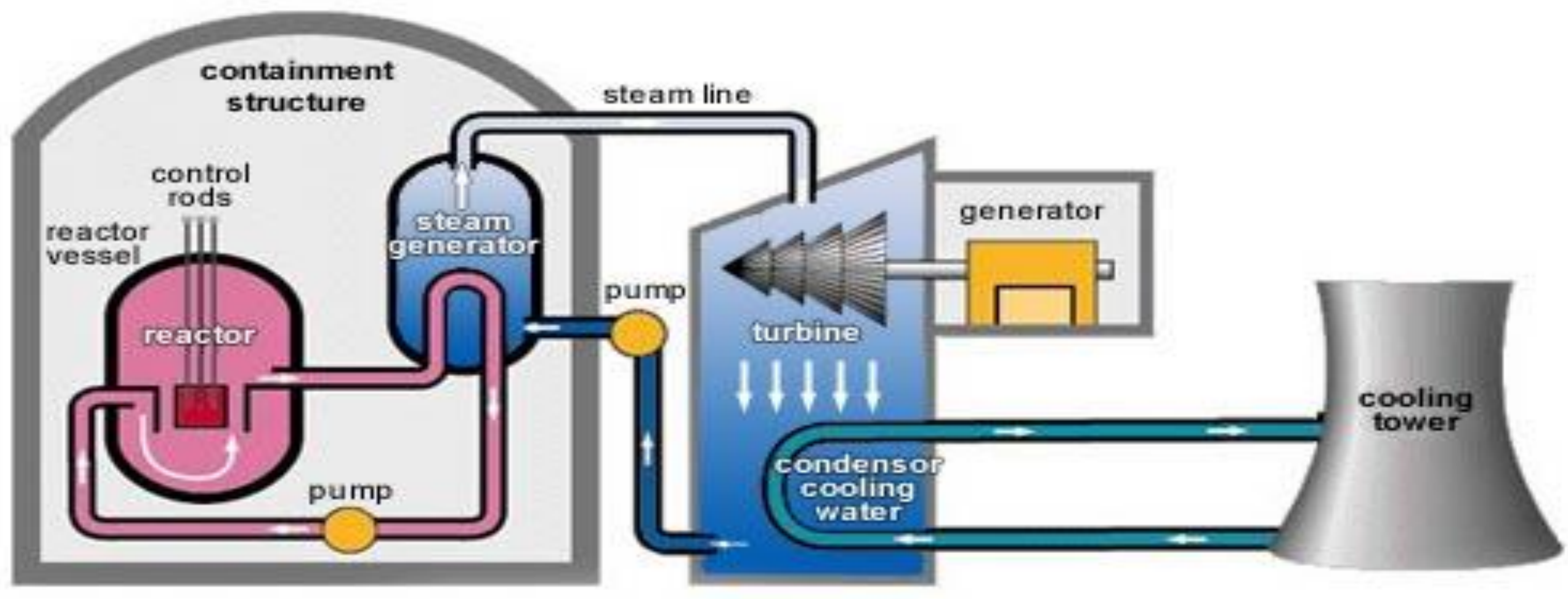
- The actual first nuclear reactor in the world was working 2 billion years ago.
- The first nuclear reactor was a natural reactor found in Oklo, Gabon in the African continent.

Nuclear Power Plant

- A Nuclear Power Plant is a special type of power plant in which nuclear fission reaction is used to generate electricity through various processes.

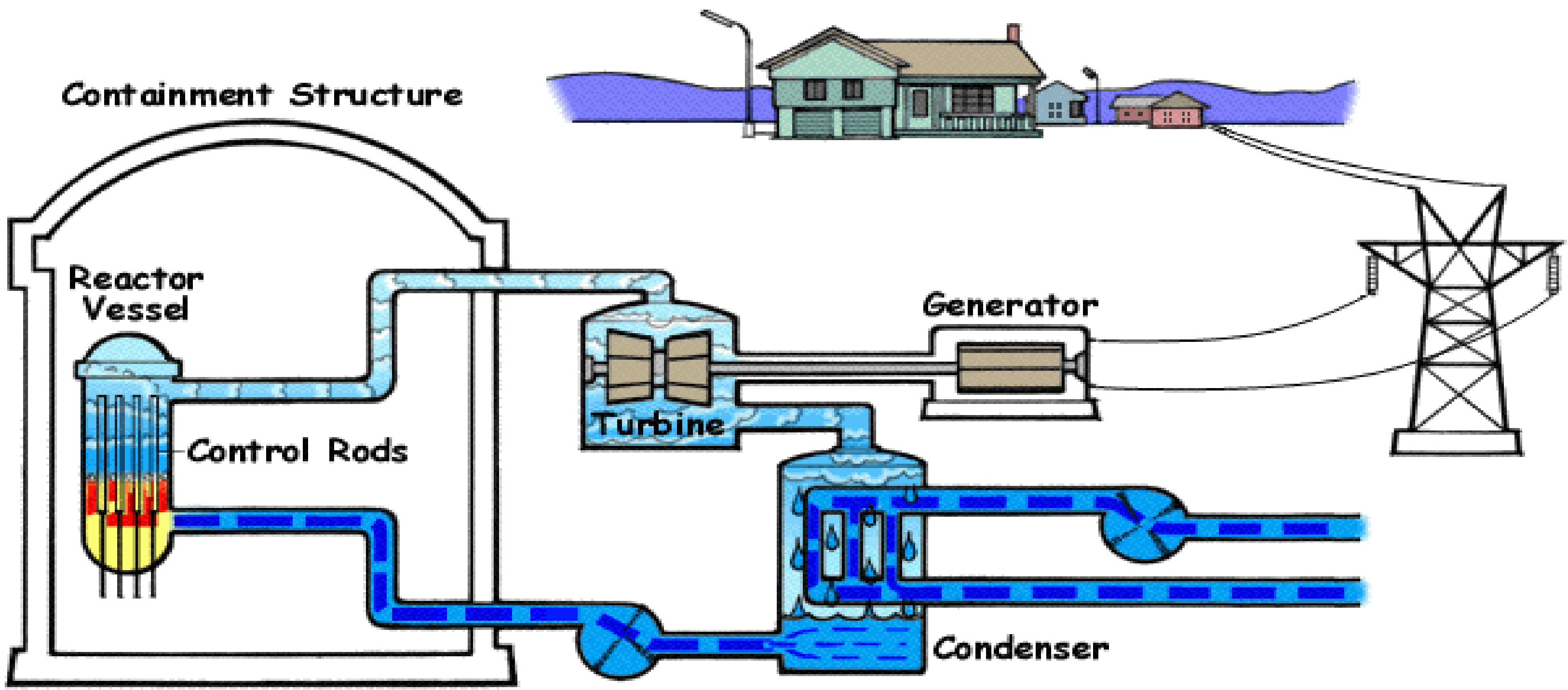
How Does a Nuclear Power Plant Generate Electricity?

- A nuclear power plant doesn’t just convert nuclear energy to electrical energy directly.
- Instead a nuclear reaction is simply used as a heat source to generate steam, which is then run through a turbine to produce electricity.



A Nuclear Power Plant Operates on the Same Principles

- A nuclear power plant is not really a special thing. Instead of using fossil fuels to generate heat, which in turn produces steam; nuclear reactors produce higher heat through a contained fission reaction.



Components of a Nuclear Reactor

- Components of a Nuclear reactor include:

  - Nuclear Fuel

  - Control Rods

  - Moderator to Slow the Neutrons

  - Reflector to Stop Neutrons from Escaping

  - Coolant to Cool the Reactor Core

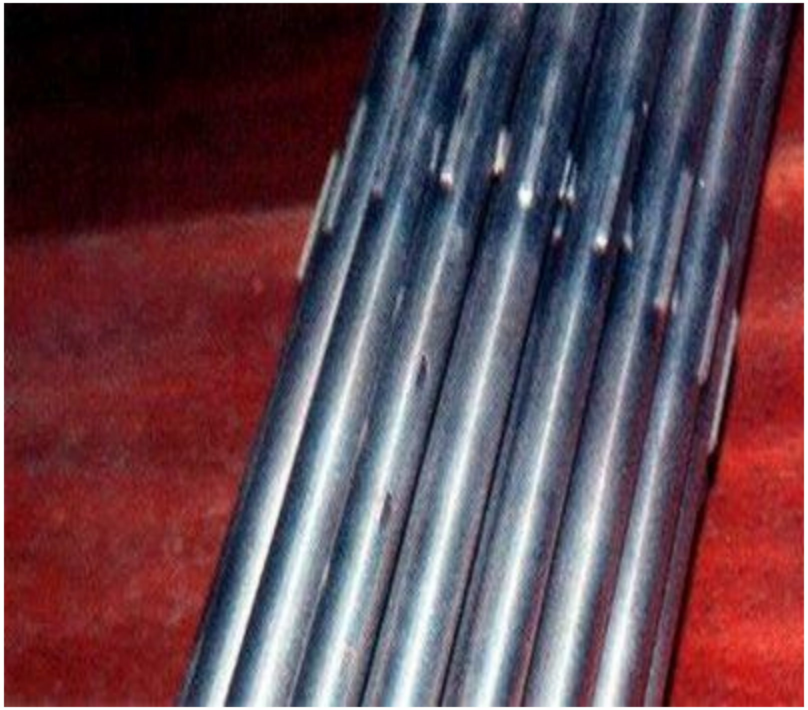
  - Shielding to Protect Against Radiation from Escaping the Reactor

The Insides of a Nuclear Reactor

Nuclear Fuels

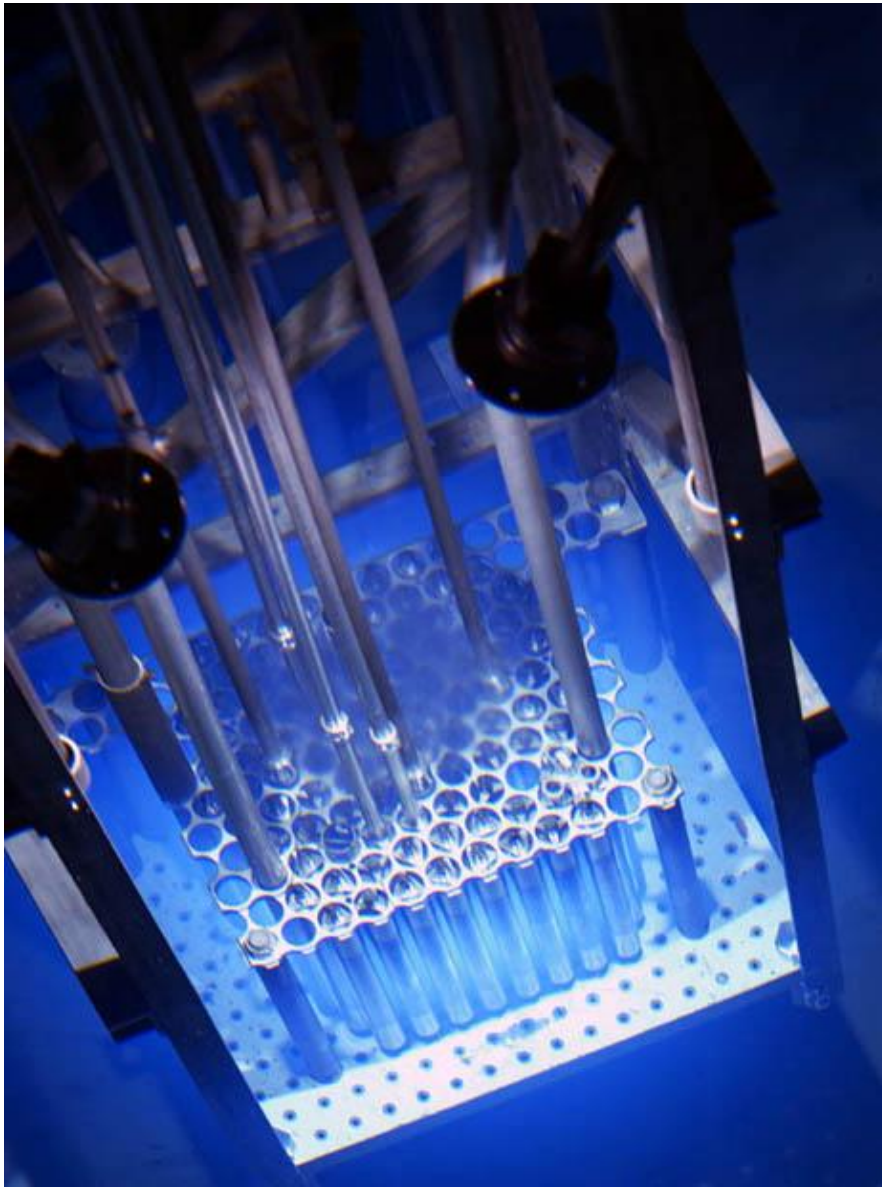
- Nuclear Fuels can be in different forms made from a fissile material and a decorroser:

  - **<u>Solid Nuclear Fuels</u>** (in form of fuel rods)
  - **<u>Liquid Nuclear Fuels</u>**
  - **<u>Gaseous Nuclear Fuels</u>**



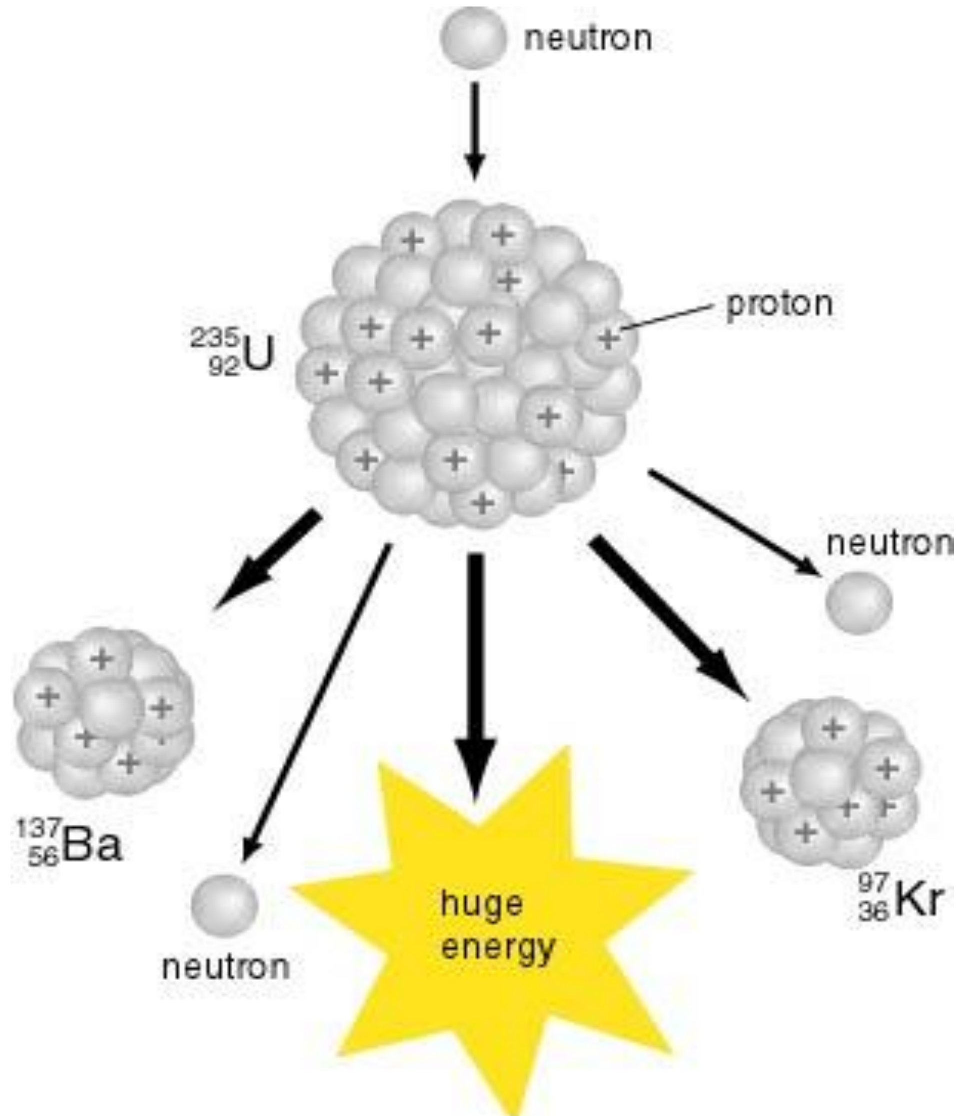
Nuclear Reactivity Control

- Nuclear reactivity (the rate of fission reaction) is controlled by **control rods**.
- These are the most important components in a nuclear reactor, as they allow you to increase or decrease the rate of the reaction by absorbing the neutrons in the reactor environment.



Nuclear Fuel and Actinides

- In order to sustain a nuclear reaction, the nuclear fuel must be [uranium-235](), [plutonium-239](), or [plutonium-241]().
- Only these actinides will split in two, when they are bombarded by thermalized neutrons. (Neutrons which have lost their speed by lowering their temperature)

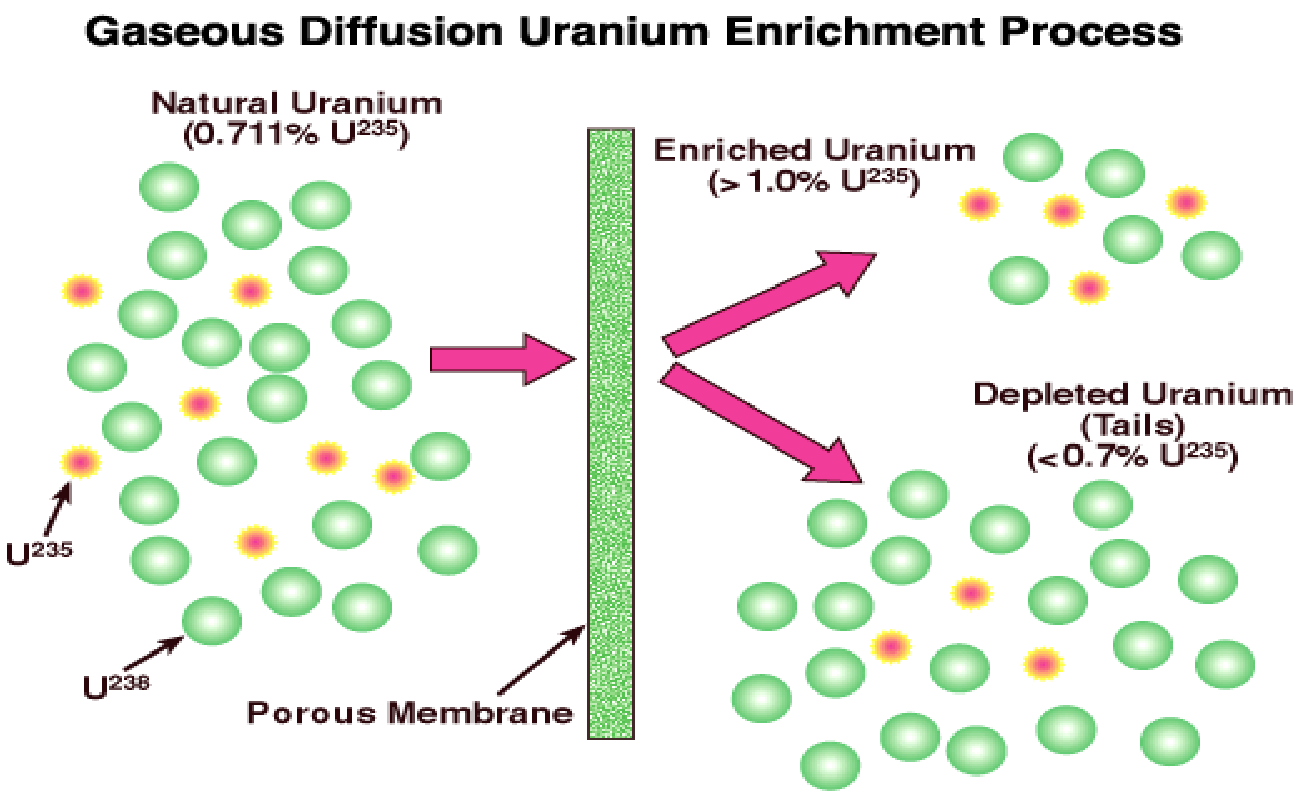


Natural Uranium

- The only naturally found readily fissile material on Earth is Uranium – 235. It comprises only of 0.7 % of natural uranium, which is a mixture of Uranium-238 and Uranium-235.
- Natural Uranium is abundantly found sometimes even without mining.

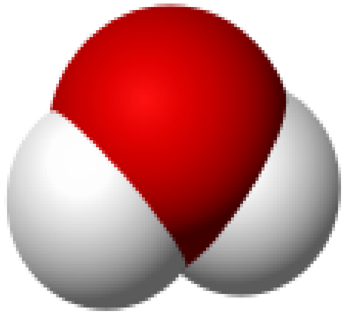
Nuclear Fuel Enrichment

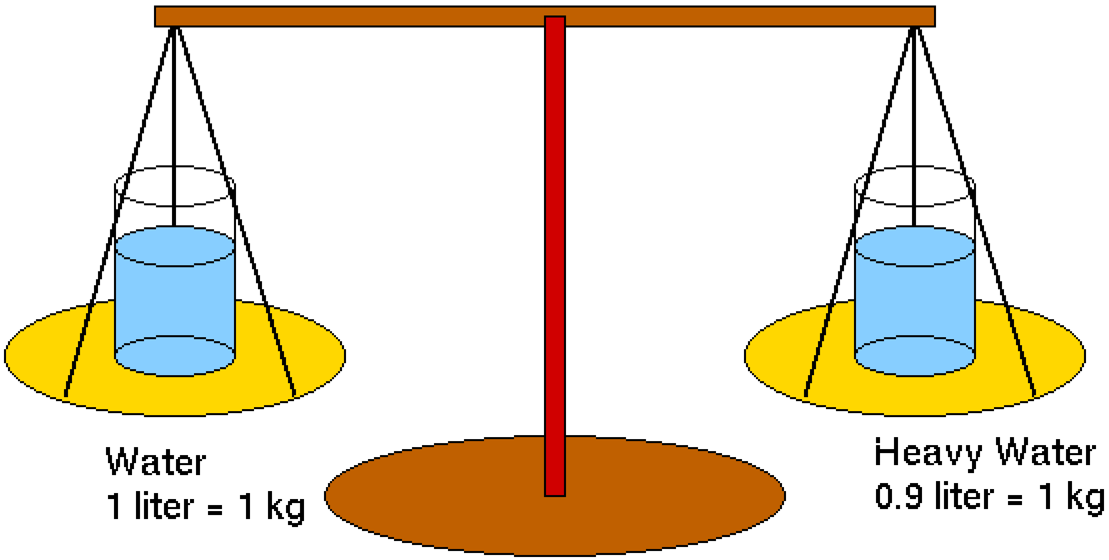
- In order to sustain a nuclear reaction, the nuclear fuel must be uranium-235, plutonium-239, and plutonium-241. However, Uranium 235 is found only in 0.7 % abundance on Earth.
- Thus, the Uranium mined is usually Uranium 238, which can not undergo fission when used with natural water as coolant and moderator. You need to use Heavy Water with Uranium 238 in order to use less enriched fuel.



Heavy Water

- Hence, if you have abundance of Uranium 235, you can use natural water reactor, which has less costs to operate.
- Or you can use Uranium 238 in which case you must use heavy water (D_2O) as moderator. However, heavy water is expensive to make. Out of every 3200 molecules of water, only one is heavy water in nature.





Nuclear Strategy

- On a national level, if you have abundant sources of Uranium 235, then you can easily use natural water reactors.
- However, most countries possess Uranium 238 and you will need to use heavy water or heavy graphite to moderate the neutrons, so that they will become slow enough to undergo reaction.
- India has enough Uranium 238 to last for 100 years, even with triple capacity of what it can use today.

Nuclear Power Plants in India

- As of 2010, **India has 19 nuclear power plants in operation** generating 4,560 MW while 4 other are under construction and are expected to generate an additional 2,720 MW.
- As of 2009, India stands **9th in the world** in terms of number of operational nuclear power reactors and is constructing 9 more.

Future Power Plant Technologies

- In the United States, there is heavy work on using gas core reactors which have less nuclear waste and more efficiency.
- Thorium reactors are the next generation in Nuclear Energy production, as India holds one quarter of the world's thorium reserves.

Nuclear Power Plant Safety

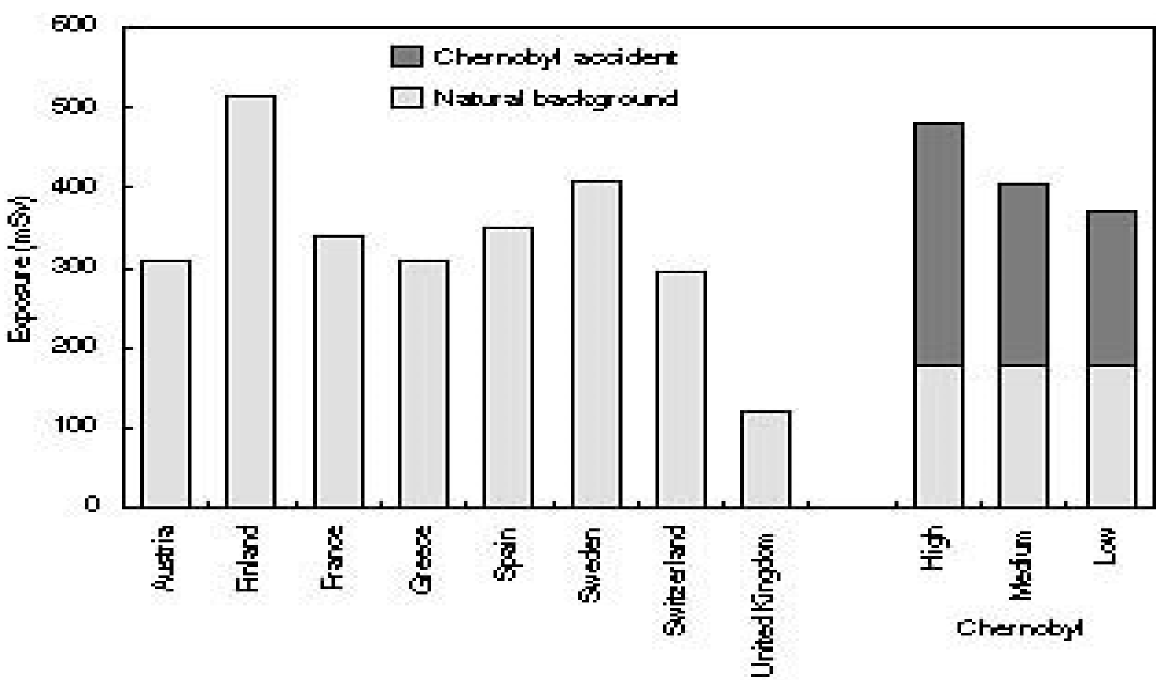
- Contrary to popular belief, Nuclear Power Plants are one of the safest and efficient forms of producing electricity.
- With proper planning and safety procedures (especially with the know-how today), it is practically impossible for a nuclear reactor to have a catastrophic reaction.
- With advanced nuclear waste management techniques, (also from knowledge collected from Gabon Natural Reactor site); we know that we can safely store waste nuclear fuel.

Atomic Explosions can Only Happen with Nuclear Bombs

- As soon as a nuclear reactor starts going critical, its nuclear control rods can easily be lowered in which case the nuclear reaction will stop immediately. A nuclear fission reaction takes place only when it is forced.
- Most nuclear reactor designs (fuel rod and control rod assembly) will stop working immediately when they overheat.
- The only way a nuclear explosion can take place is through a nuclear bomb. In fact, majority of nuclear bombs are fusion bombs and not fission (atom) bombs.

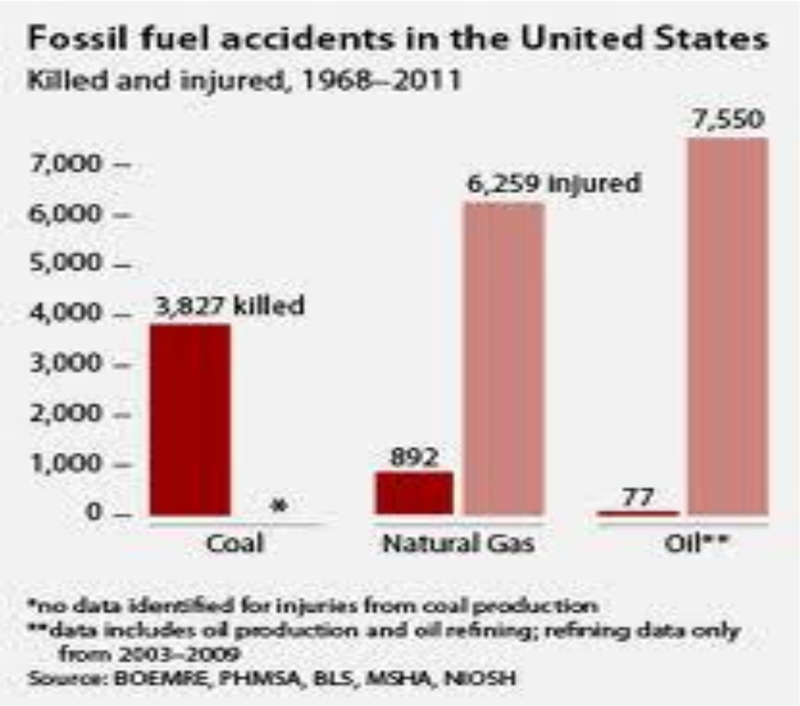
Nuclear Incidents

- Almost all nuclear incidents have happened due to some sort of a human errors.
- The only exception is the Japan Fukushima Incident and the French incident which has happened due to natural disasters.

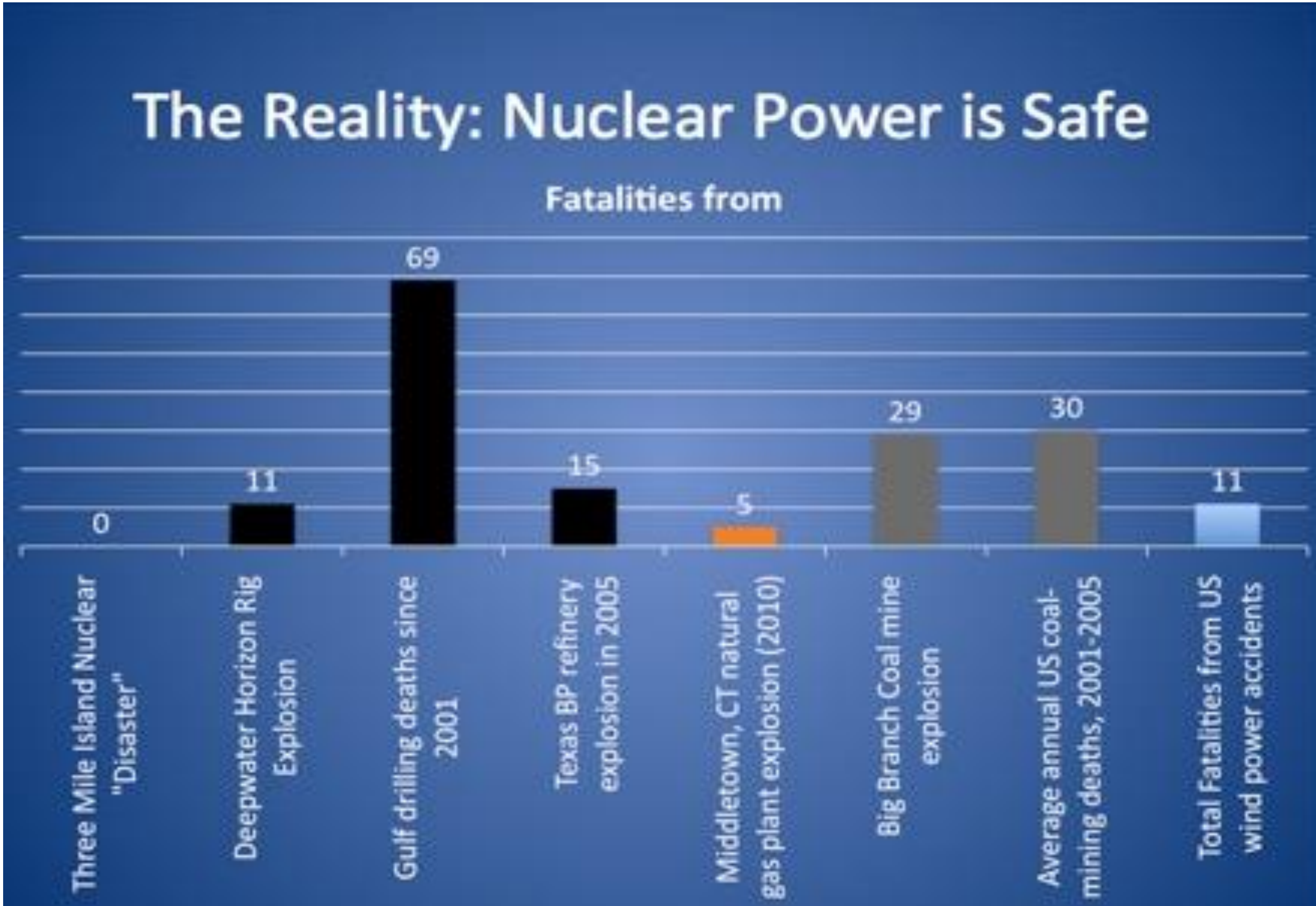


Nuclear Deaths vs Fossil Fuel Deaths

- Fine particles from coal power plants kill an **estimated 20,500 people each year** in the U.S.
- The World Health Organization and other sources attribute about **1 million deaths/year** to coal air pollution
- This would be 161 deaths/TWh.
- According to Kofi Annan, global warming deaths is **300,000 people / year** with **$ 125 billion in economic losses**



Power Related Deaths in USA



Radiation Safety

- Every human being is subjected to radiation every day. Sources vary from the sun, natural water, the food that we eat, cell phones to even from getting an X-ray for a checkup. There are always trace amounts of radioactive substance in everything we ingest.
- Remember, there is nothing unique about radiation. There are no detrimental health effects caused by radiation that are not also caused by one or more physical, chemical, or biological agents. **Keep in mind that giant spiders, mutant crabs, and other fearsome creatures are created in the Special Effects Department of Hollywood** — not by radiation.

Nuclear Power Plants Can be Considered Green Energy

- Nuclear power plants do not emit any carbon dioxide, nor any sulphur dioxide or nitrogen oxides. Their wastes end up as solids and, though requiring careful handling, are very much less than the wastes from burning coal.

Nuclear Wastes Can Be Managed

- Especially with the new techniques available today (such as Gas Core Reactors), it is possible to make the impact of nuclear energy on the environment virtually non existent.

- A regular checkup of all nuclear waste sites in the world is mandatory by International Atomic Energy Agency. (IAEA)

- Nuclear Reactors and properly processed Nuclear Wastes don't emit any radiation to the outside environment.

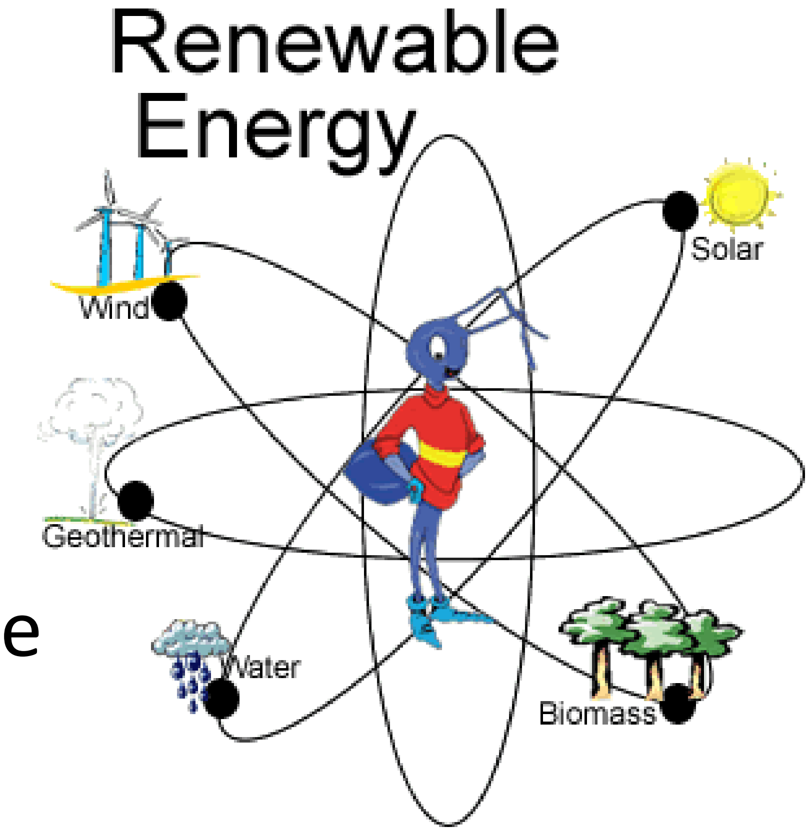
Nuclear Energy can Be Considered as Renewable Energy

- EIA defines Renewable Energy as any source of energy with

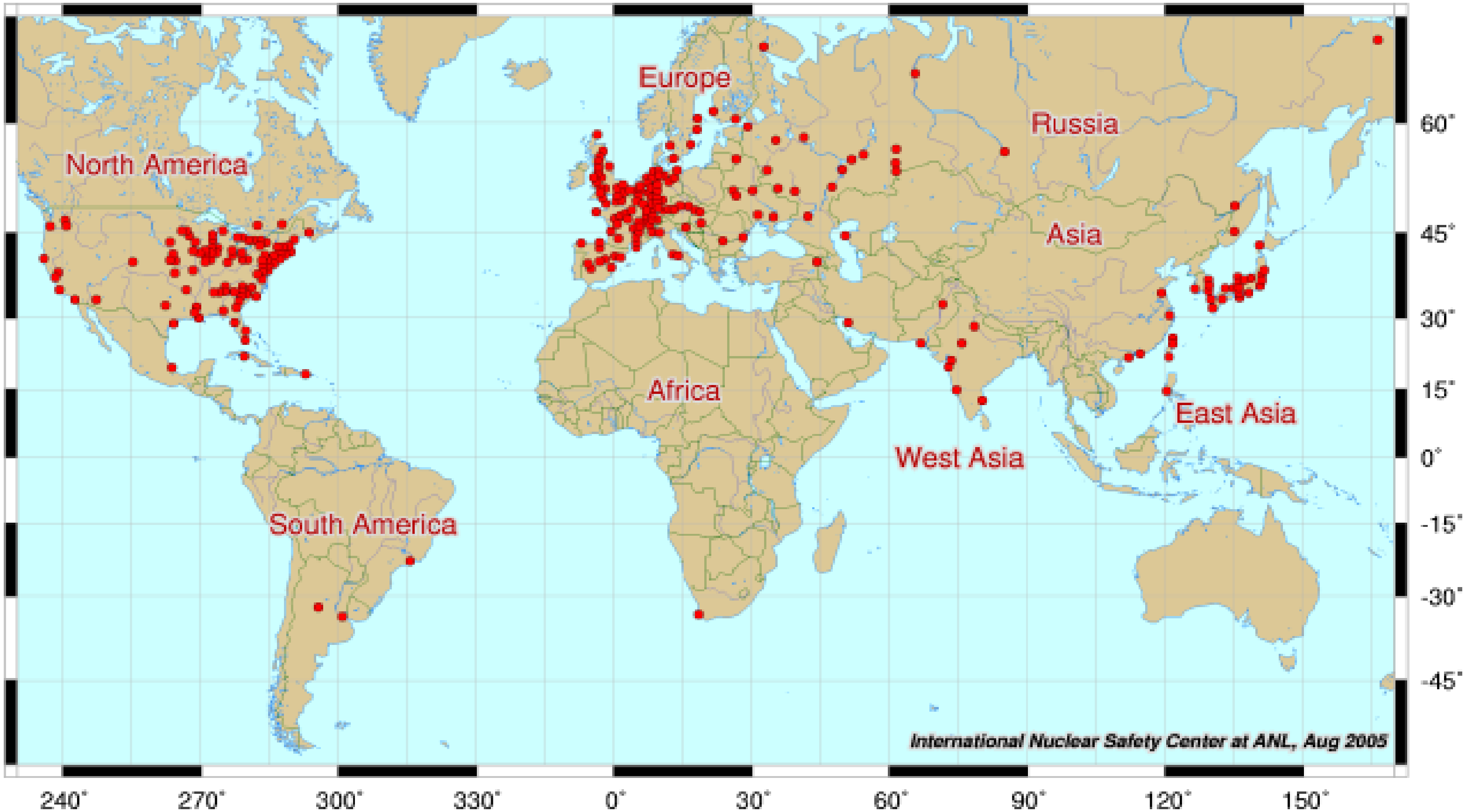
  a) Naturally Replenished

  b) Virtually Inexhaustible

Both of these conditions are met by Nuclear Energy



Present State of Nuclear Power Plants



The total number of reactors in the world is 400 at present which produce 376,341 megawatts of electricity (Nuclear News, March 2008) and the number of reactors under construction are 61

Nuclear Reactor Power Plants are a Safe Way to Meet the Energy Demands of our Future

- If they are used and maintained properly, nuclear power plants are the most efficient way of producing enough energy to meet the world's needs.