All about nuclear energy from Atom to Zirconium

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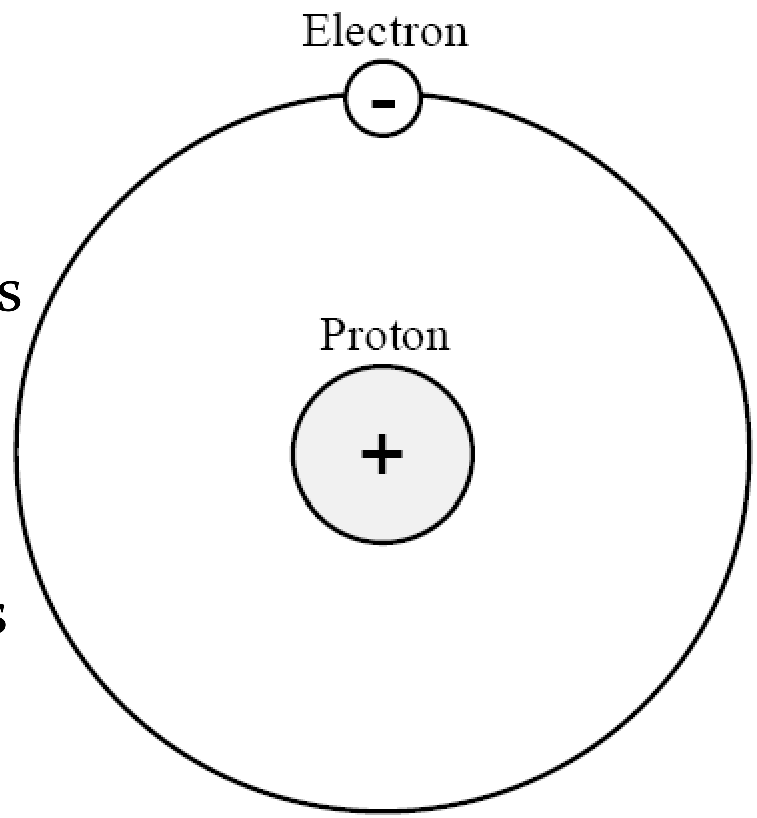
Objectives

- Basic Concepts
- Radiation
- What is nuclear Energy?
- The discovery of fission
- The first pile (reactor)
- What is a nuclear reactor?
- What are different reactor types?
- Why nuclear?

Basic Concepts

- Atoms are composed of positively charged protons in the nucleus and negatively charged electrons orbiting the nucleus.
- The simplest atom is hydrogen, composed of one proton and one electron. Its atomic number, which is equal to the number of protons, is 1.



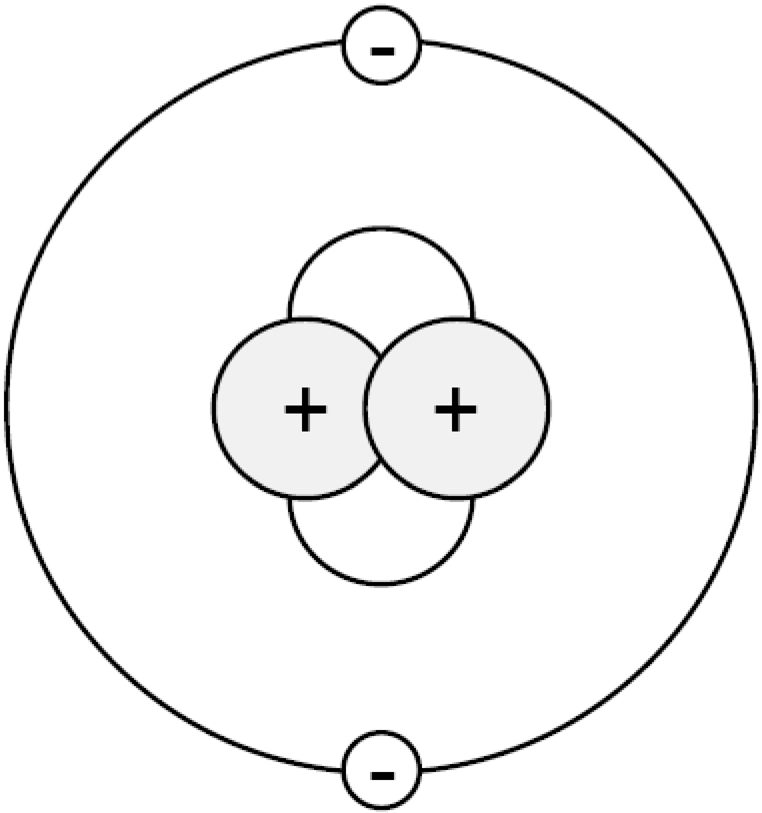
$^{1}_{1}H$

Hydrogen

Basic Concepts

- More complex atoms have more protons and electrons, but each unique combination of protons and electrons represents a different chemical element.
- Helium, for example, with two protons, two neutrons, and two electrons, has an atomic number of 2.

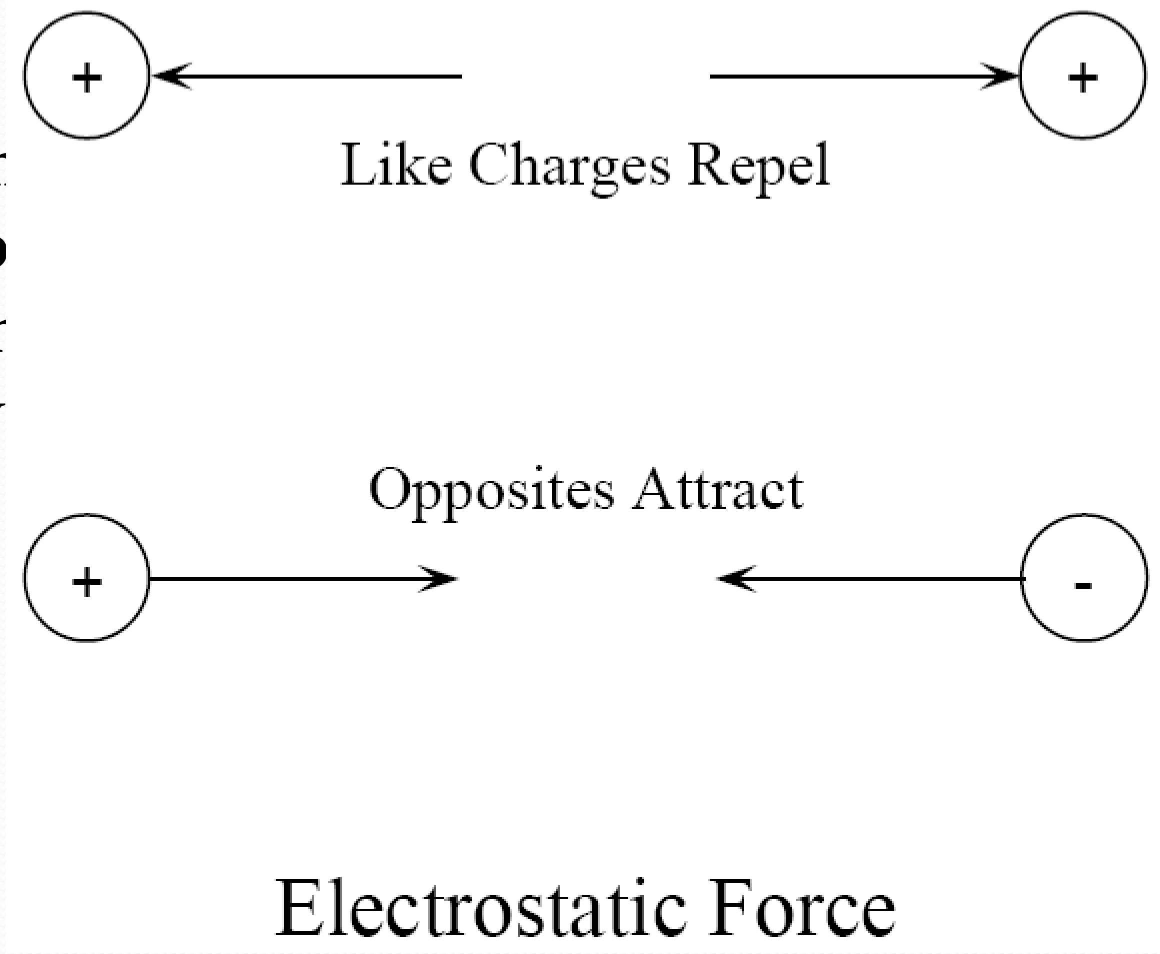
$$^{4}_{2}\mathrm{He}$$



Helium

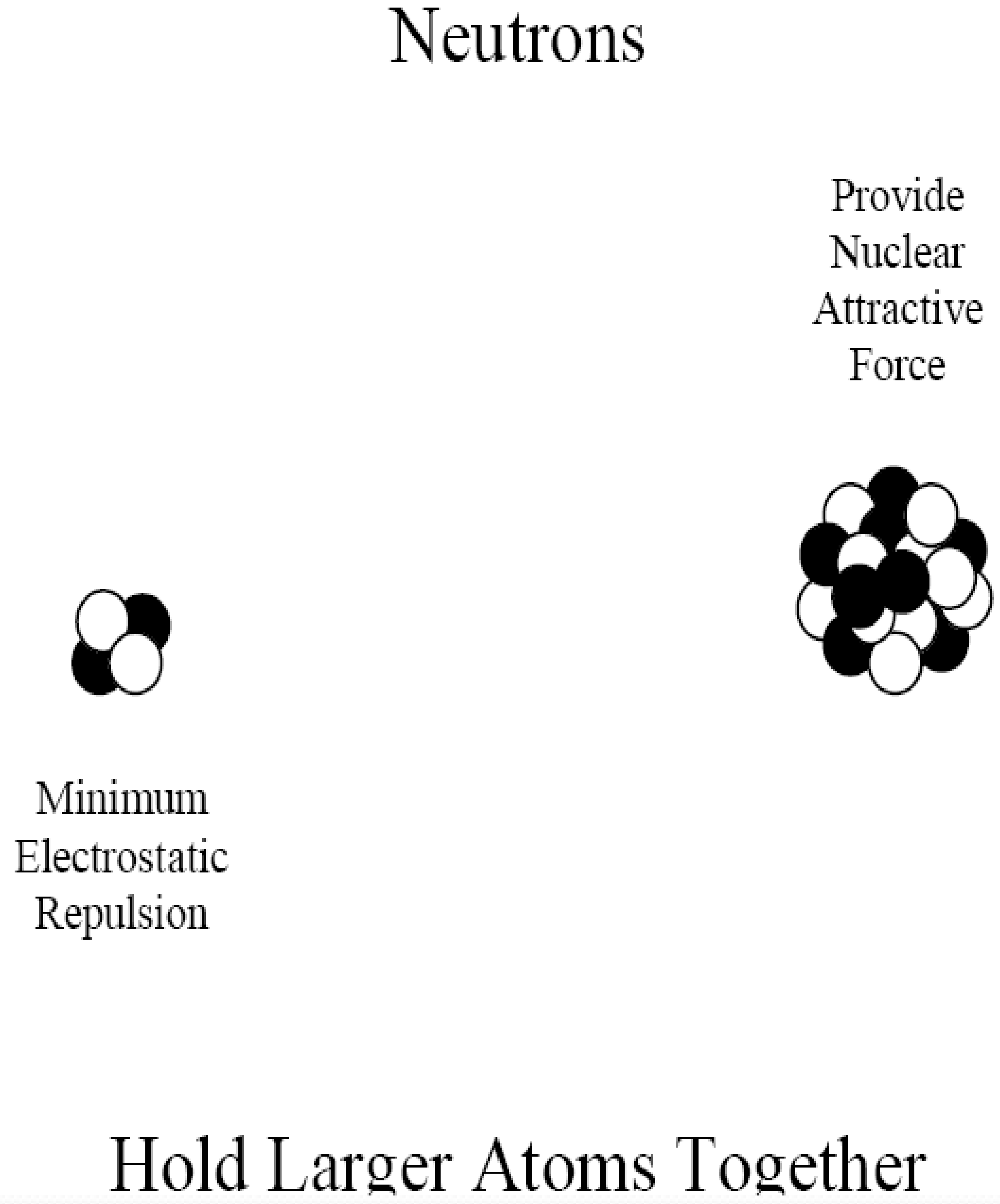
Basic Concepts

- **Since all protons are positively charged, ar since like charges rep electrostatic force ter to push protons away from each other**



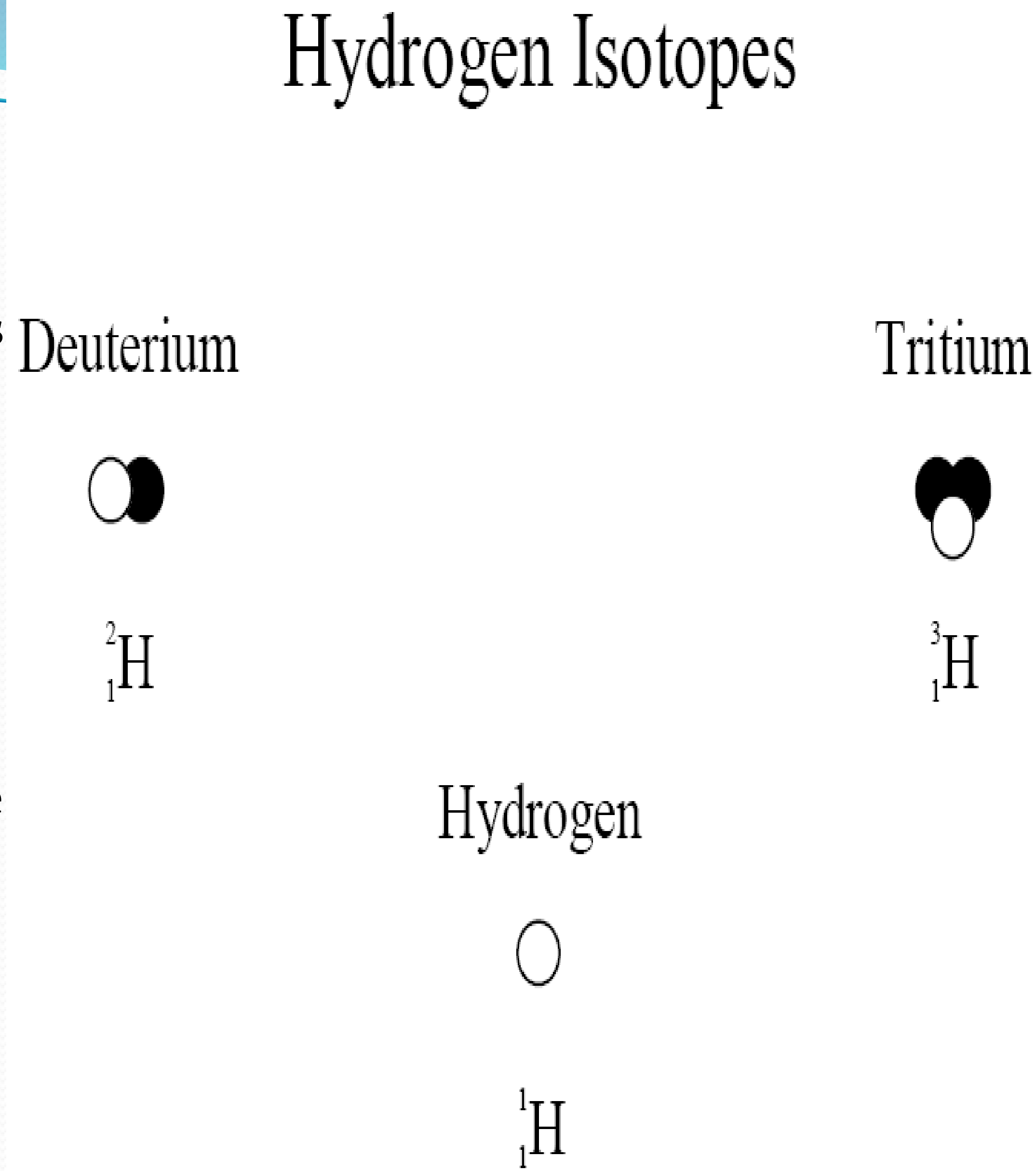
Basic Concepts

- Neutrons, with no electrical charge, provide the attractive nuclear force to offset the electrostatic repulsive forces and hold atoms together.
- All atoms found in nature, except the basic hydrogen atom, have one or more neutrons in their nuclei.



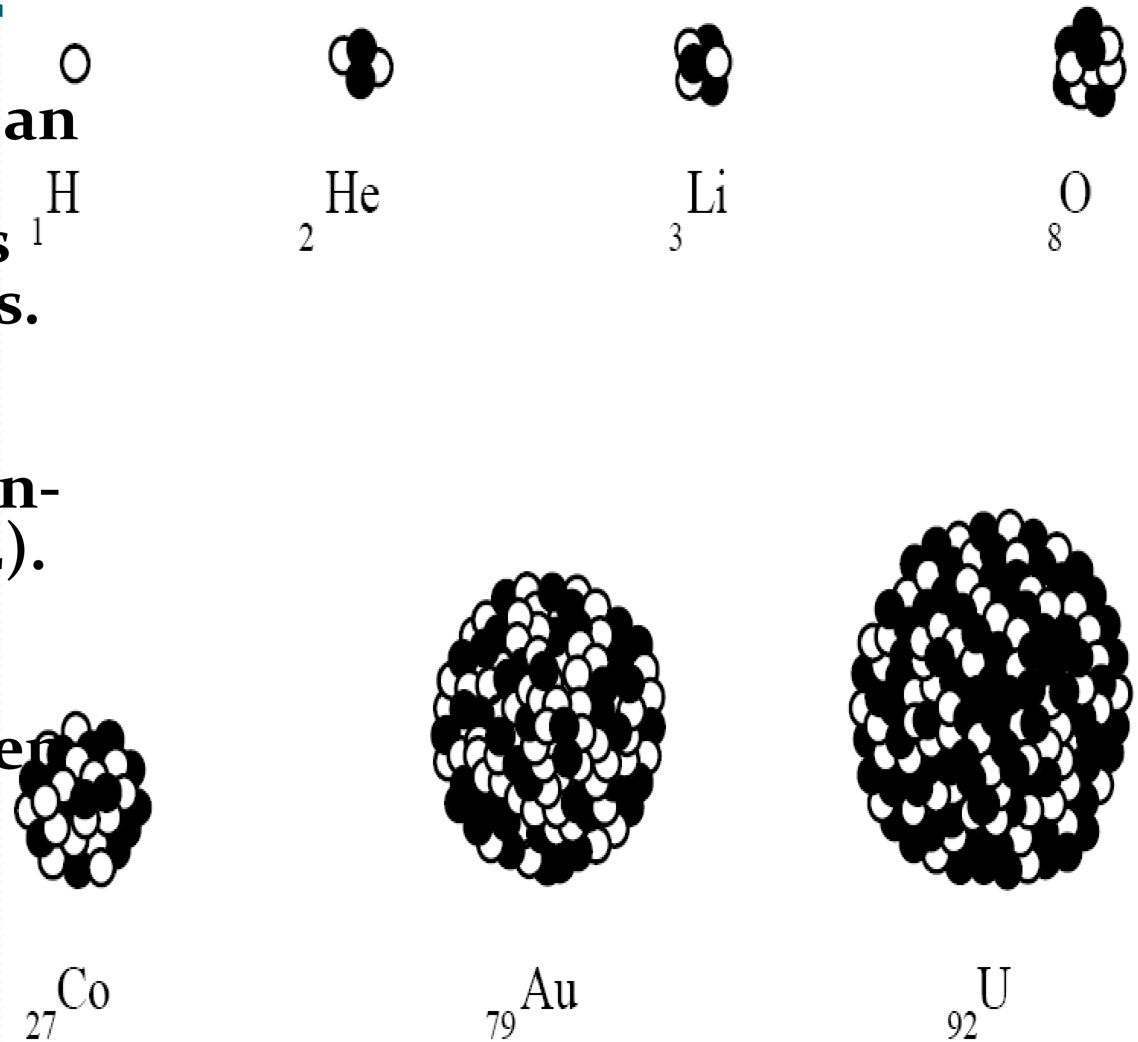
Basic Concepts

- **A chemical element can have several different combinations of protons and neutrons in its nuclei. Hydrogen has three naturally occurring combinations (known as “isotopes”):**
- **1) Basic hydrogen (one proton, one electron, and no neutrons),**
- **2) Deuterium (one proton, one electron, and one neutron), and**
- **3) Tritium (one proton, one electron, and two neutrons).**



Basic Concepts

- The number of protons an element has (atomic number) determines its chemical characteristics. Atomic numbers are always related to the same element (hydrogen-1, cobalt-27, uranium-92).
- When used in technical literature, the atomic number is usually written to the lower left of the chemical symbol



Basic Concepts

- **Since chemical elements can have different numbers of neutrons, the use of isotopic numbers (or mass numbers) is necessary to distinguish one isotope from another.**
- **Naturally occurring isotopes of the element carbon are shown above.**
- **The isotopic number (shown to the upper left hand of the chemical symbol) is the sum of the number of protons and the number of neutrons in the nucleus of an atom**

Naturally Occurring Carbon

$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$
6 Protons	6 Protons	6 Protons
6 Neutrons	7 Neutrons	8 Neutrons

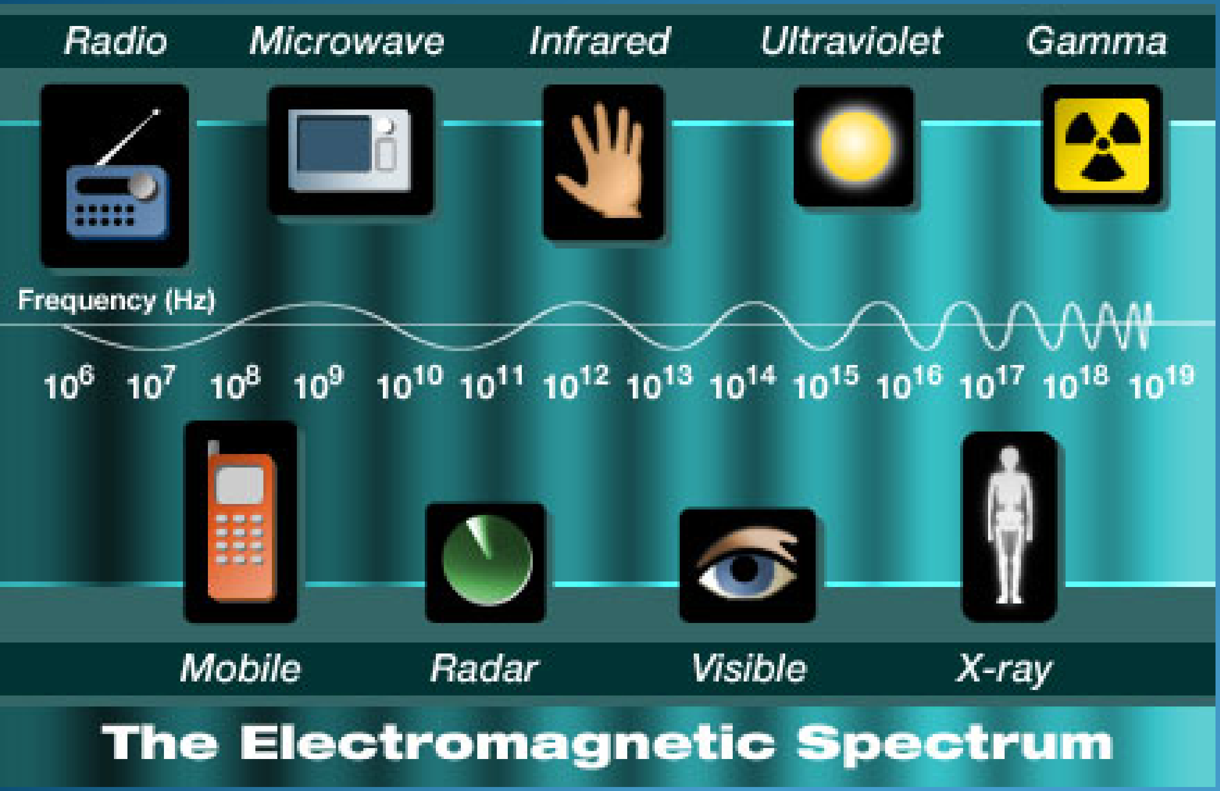
Basic Concepts

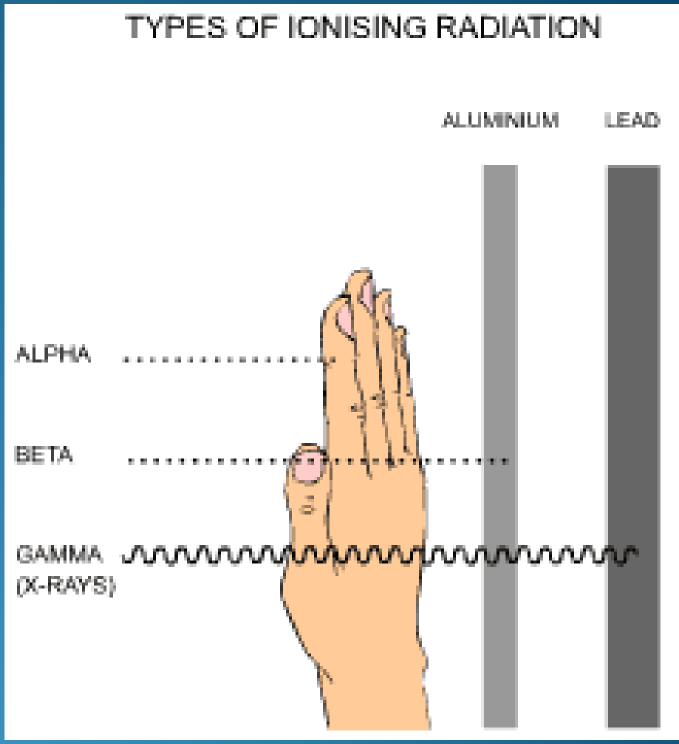
- Power reactors use uranium as fuel.
- The naturally occurring isotopes of uranium are shown above.
- About 99.3% of all uranium atoms are the isotope U-238, and the remaining 0.7% are U-235.
- Trace amounts (far less than 1%) of U-234 can be found. Another isotope, U-233, does not exist naturally, but it can be manufactured and used to fuel some types of reactors.

Naturally Occurring Uranium

$^{234}_{92}U$	$^{235}_{92}U$	$^{238}_{92}U$
92 Protons	92 Protons	92 Protons
142 Neutrons	143 Neutrons	146 Neutrons

Radiation: transmission of energy by particles or waves





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مصدر
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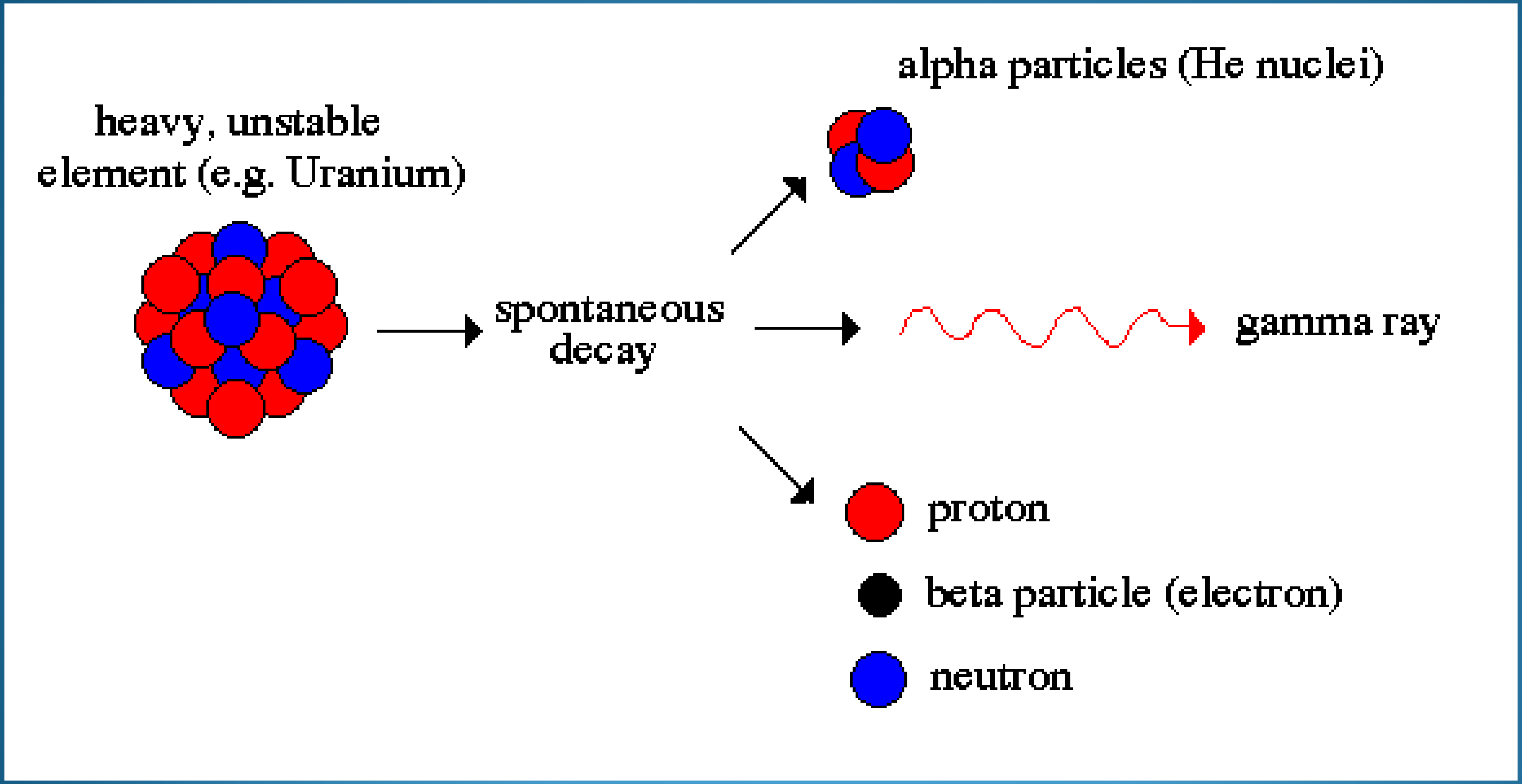
Radioactivity: decay of unstable particles by emission of radiation



Where does radiation come from?

- We receive radiation from both natural and man-made sources. The primary sources of natural radiation are cosmic rays from outer space and naturally radioactive elements in the earth's crust. These sources are *natural background radiation. The altitude at which we* live and the types of rocks that surround us affect the amount of background radiation we receive. Even brick houses and the ground we walk on are slightly radioactive because of the minerals they contain.
- Natural sources of radiation are also found in plants, animals, and the human body. For example, bones contain naturally radioactive potassium, and body tissues contain radioactive carbon.
- We also receive radiation from man-made sources. In the U.S., most man-made radiation comes from mechanical and dental sources, including X-rays, medical diagnoses, and treatment. It also comes from smoke detectors, television sets, nuclear power plants, and emissions from coal-fired power plants.
- In nuclear power plants, uranium fuel becomes intensely radioactive as the reactor produces heat. However, the amount of radiation released during the normal operation of nuclear power plants is very small compared to other man-made and natural sources. A National Academy of Sciences study* estimates that a person living in the U.S. receives, on the average, less than 1 percent of his or her total annual radiation exposure from nuclear power industry operations.

Radiation: Units of Measure

- **The *curie*, *named after the scientists Marie and Pierre* Curie, describes the intensity of a sample of radioactive material in terms of atoms of the material that decay each second. This rate — 37 billion atoms per second for one gram of radium — is the basis of this measurement.**
- **A *rem* *is a measurement of the effects of radiation on* the body, much as degrees Celsius are measurements of the effects of sunlight heating sand on a beach. The unit used most often to measure the radiation exposure for a person is the *millirem (mrem). It is* one-thousandth of a rem. The millirem is used because usually very small amounts of radiation are being measured.**

Is radiation harmful to the public?

- **People have always lived with small amounts of natural background radiation with no ill effects. Yet, we know that extremely large doses of radiation are hazardous. Too much radiation can cause sickness, increased cancer risk, or death. We usually measure the biological effects of radiation in a unit called *a millirem (mrem)*. *Most* people receive a total of about 360 mrem of radiation a year from all sources — both natural and man-made. About 40 mrem per year comes from the natural radioactivity in our own bodies**
- **Radon is a naturally occurring radioactive gas that results from the decay of radium. Radon is the single largest source of radiation exposure. On average, radon accounts for 200 mrem of our exposure each year.**
- **The actual amount of background radiation depends on the location, elevation, rock and soil content, and weather conditions. For example, a person living on the Atlantic coast receives about 65 mrem of natural background radiation per year, while a person in Denver, Colorado, receives about 125 mrem, excluding radon. The difference in the natural background radiation is due in large part to Denver's higher elevation. The higher the elevation, the thinner the atmosphere, meaning that the atmosphere filters out less cosmic radiation.**

Is radiation harmful to the public?

- We are also exposed to man-made sources of radiation, principally dental and medical x-rays, medical tests, and radiotherapy used in treating disease. About 15%, or about 50 mrem, of the radiation exposure that the average American receives comes from medical sources.
- Permitted radiation dose levels for radiation workers are higher than for the public. That is because these workers voluntarily accept employment where they know they might be exposed to radiation.
- The standard overall whole body radiation limit for workers in the nuclear industry is 5,000 mrem (5 rem), including the average background radiation of 300 mrem.
- For some parts of the body, the standard radiation limits set by the NRC are higher. For instance, exposures of 18,750 mrem are allowed for hands and feet.
- The average exposure for each worker in the U.S. nuclear energy industry is 290 mrem, which is only one-third of the 900 mrem per year occupational exposure of airline pilots and cabin crews who regularly fly the high-altitude New York -Tokyo route.

Ionizing Radiation

- **Ionizing radiation is energy that can ionize, or electrically charge, an atom by stripping off electrons. Ionizing radiation can change the chemical composition of many things — including living tissue.**
- **The three main types of ionizing radiation are alpha and beta particles and gamma rays:**
  - ***Alpha* *particles are the most energetic of the* three types of ionizing radiation. But despite their energy, they can travel only a few inches in the air. Alpha particles lose their energy almost as soon as they collide with anything. A sheet of paper or your skin's surface can easily stop them.**
  - ***Beta* *particles are much smaller than alpha* particles. They can travel in the air as much as 100,000 miles per second for a distance of about 10 feet. Beta particles can pass through a sheet of paper, but may be stopped by a thin sheet of aluminum foil or glass.**
  - ***Gamma* *rays, unlike alpha or beta particles, are* waves of electromagnetic energy. Gamma rays travel at the speed of light (186,000 miles per second). Gamma radiation is very penetrating and is best shielded by a thick wall of concrete, lead, or steel.**

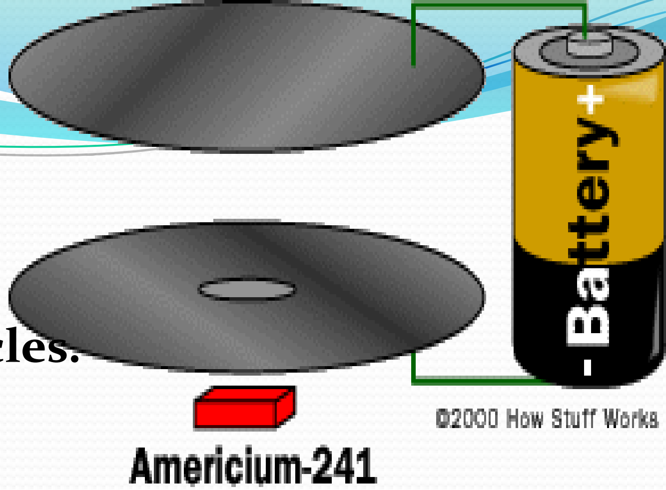
The Health Effects of Radiation

- **Radiation is one of the most widely studied of all natural phenomena. Scientists understand the health effects of high levels of radiation. However, the effects of low levels of radiation are more difficult to determine because the major effect is a very slight increase in cancer risk. But because so many other factors also increase the risk of cancer, it is difficult to know which is the cause in many cases.**
- **Radiation can chemically change living cells. However, cell transformation does not necessarily cause noticeable health effects. If the radiation dose is low, or a person receives it over a long period of time, the body can usually repair or replace the damaged cells without any detectable health effects.**
- **Exposure to high levels of radiation can cause serious health effects, including burns, cell damage, and death. The degree of the effect depends on the intensity of the dose, the length of the exposure, and the type of body cells exposed. Sudden large doses exceeding 100 rem can cause radiation sickness, with short-term symptoms including nausea, vomiting, extreme tiredness, and hair loss. Long-term effects include increased cancer risks. A dose of over 500 rem at one time is usually fatal unless medical treatment is available.**

Using Radiation

- Medical and dental x-rays have been used for over 50 years to diagnose broken bones and tooth decay. Carefully focused radiation can destroy cancer cells without causing major damage to healthy cells nearby. Radioisotopes and computer imaging devices allow doctors to examine internal organs that are not normally visible by x-rays.
- It is now standard practice to use radiation to sterilize medical products such as syringes. Radiation may also be preferable to heat for sterilizing bandages and ointments, which can be damaged by high temperatures.
- In industry, radiography is used in much the same way as doctors use x-rays. This technique is used to locate defects in metal casings and welds that might not show up otherwise, and to determine microscopic thicknesses of materials such as metal foils. Radiography can also be used to locate structural defects in statues and buildings.
- Radiation has applications in a variety of other fields. We use it to test the authenticity of art and date prehistoric objects accurately. We also use it to prevent certain foods from spoiling without significantly reducing the nutritional value, or making the food radioactive.

Using Radiation: Smoke Detectors



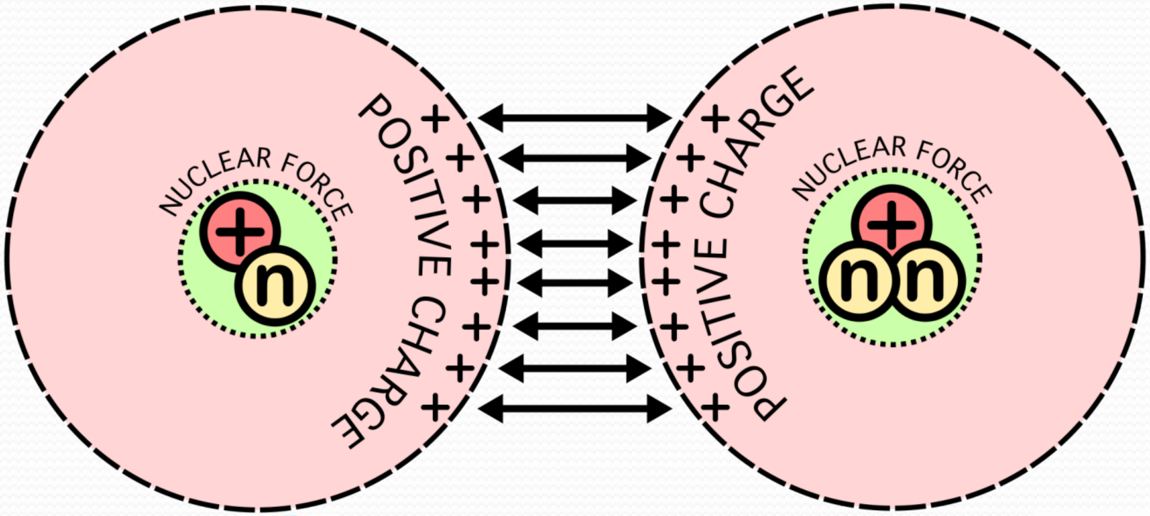
- Ionization smoke detectors, use a small radioactive source as a key component in detecting smoke particles.
- Ionization smoke detectors are more effective at detecting flash fires, while photoelectric smoke detectors are more effective in detecting smoldering fires.
- The radionuclide used in ionization smoke detectors is an oxide of americium-241, which is bonded to a metallic foil and sealed in an ionization chamber.
- Americium-241 is a man-made radioactive metal, first discovered during the Manhattan project. Americium-241 emits alpha particles and low-energy gamma rays.
- The alpha particles generated by the americium ionize the oxygen and nitrogen atoms of the air in the chamber. The negative electron is attracted to the plate with a positive voltage, and the positive atom is attracted to the plate with a negative voltage . The electronics in the smoke detector sense the small amount of electrical current that these electrons and ions moving toward the plates represent.
- When smoke enters the ionization chamber, it disrupts this current -- the smoke particles attach to the ions and neutralize them. The smoke detector senses the drop in current between the plates and sets off the horn.

What is nuclear Energy?

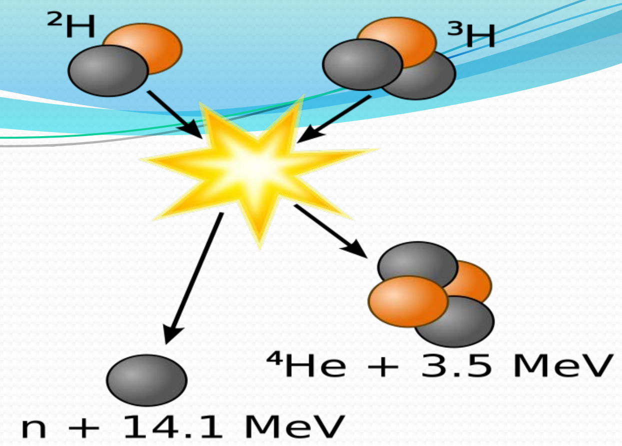
- Nuclear fusion is the process by which multiple like-charged atomic nuclei join together to form a heavier nucleus. It is accompanied by the release or absorption of energy. Large scale fusion processes, involving many atoms fusing at once, must occur in matter which is in a plasma state.
- The fusion of two nuclei with lower mass than iron (which, along with nickel, has the largest binding energy per nucleon) generally releases energy while the fusion of nuclei heavier than iron absorbs energy; vice-versa for the reverse process, nuclear fission. In the simplest case of hydrogen fusion, two protons have to be brought close enough for their mutual electric repulsion to be overcome by the nuclear force and the subsequent release of energy.
- Nuclear fusion occurs naturally in stars. Artificial fusion in human enterprises has also been achieved, although it has not yet been completely controlled. Building upon the nuclear transmutation experiments of Ernest Rutherford done a few years earlier, fusion of light nuclei (hydrogen isotopes) was first observed by Mark Oliphant in 1932; the steps of the main cycle of nuclear fusion in stars were subsequently worked out by Hans Bethe throughout the remainder of that decade. Research into fusion for military purposes began in the early 1940s as part of the Manhattan Project, but was not successful until 1952. Research into controlled fusion for civilian purposes began in the 1950s, and continues to this day.

What is nuclear Energy?

- It takes considerable energy to force nuclei to fuse, even those of the lightest element, hydrogen. This is because all nuclei have a positive charge (due to their protons), and as like charges repel, nuclei strongly resist being put too close together. Accelerated to high speeds (that is, heated to thermonuclear temperatures), they can overcome this electromagnetic repulsion and get close enough for the attractive nuclear force to be sufficiently strong to achieve fusion. The fusion of lighter nuclei, which creates a heavier nucleus and a free neutron, generally releases more energy than it takes to force the nuclei together; this is an exothermic process that can produce self-sustaining reactions.



What is nuclear Energy?

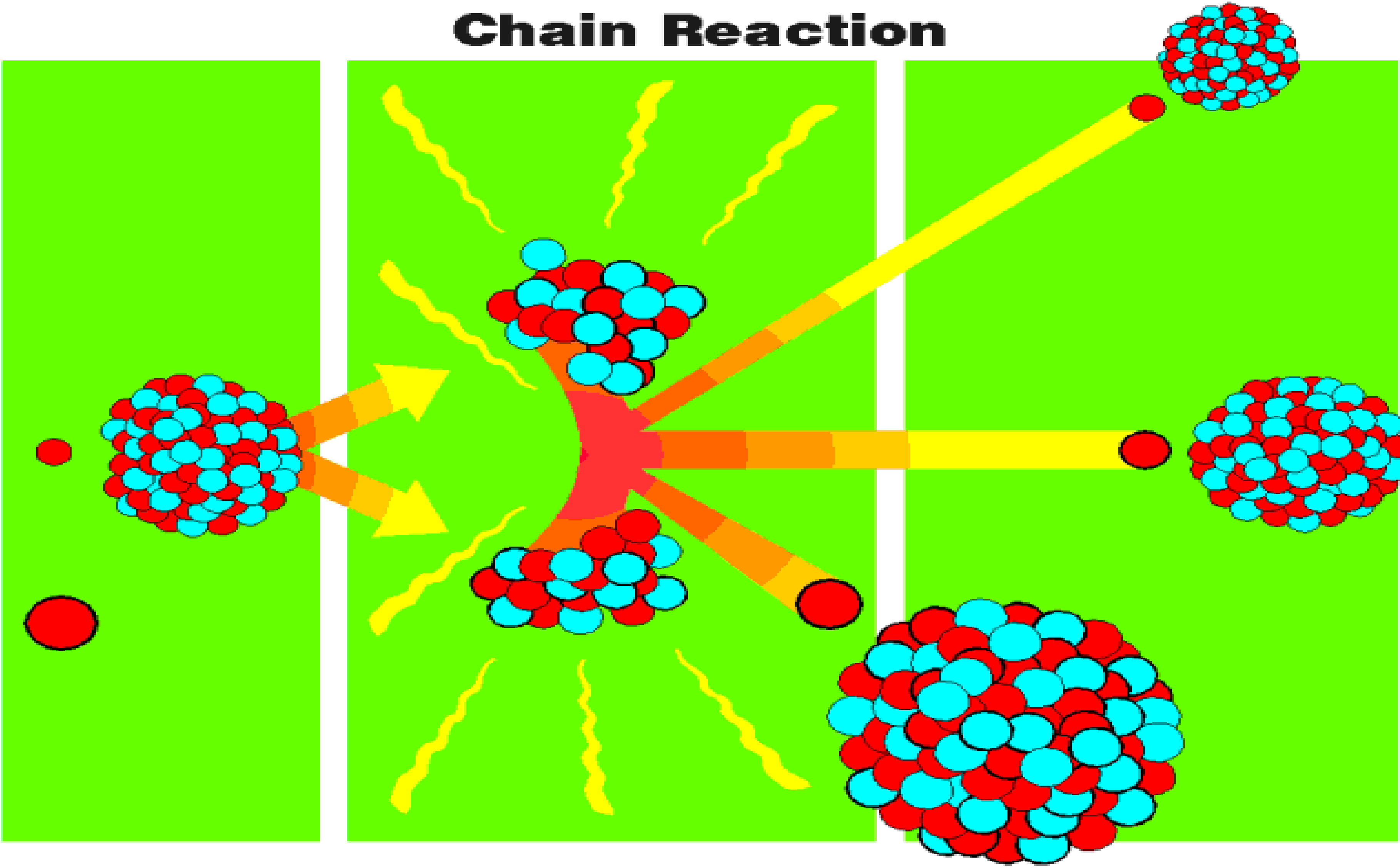


- The energy released in most nuclear reactions is much larger than that in chemical reactions, because the binding energy that holds a nucleus together is far greater than the energy that holds electrons to a nucleus. For example, the ionization energy gained by adding an electron to a hydrogen nucleus is 13.6 eV —less than one-millionth of the 17 MeV released in the deuterium–tritium (D–T) reaction shown in the diagram to the right. Fusion reactions have an energy density many times greater than nuclear fission; the reactions produce far greater energies per unit of mass even though *individual* fission reactions are generally much more energetic than *individual* fusion ones, which are themselves millions of times more energetic than chemical reactions

What is nuclear Energy?

- Although they are tiny, atoms have a large amount of energy holding their nuclei together. Certain *isotopes of some elements can be split and will release* part of their energy as heat. This splitting is called *fission*. *The heat released in fission can be used to* help generate electricity in power plants.
- *Uranium-235 (U-235) is one of the isotopes that* fissions easily. During fission, U-235 atoms absorb loose neutrons. This causes U-235 to become unstable and split into two light atoms called *fission*
- The combined mass of the fission products is less than that of the original U-235. The reduction occurs because some of the matter changes into energy. The energy is released as heat. Two or three neutrons are released along with the heat. These neutrons may hit other atoms, causing more fission.

Chain Reaction



1 A neutron is about to hit the nucleus of a uranium atom.

2 The uranium nucleus splits (fissions) into several smaller atoms, releasing heat and several more neutrons.

3 The chain reaction begins: those neutrons hit other nuclei, causing them to fission. And so on.

What is nuclear Energy?

- **Ancient Greek philosophers first developed the idea that all matter is composed of invisible particles called *atoms*. *The word atom comes* from the Greek word, *atomos*, *meaning indivisible*. Scientists in the 18th and 19th centuries revised the concept based on their experiments. By 1900, physicists knew the atom contains large quantities of energy. British physicist Ernest Rutherford was called the father of nuclear science because of his contribution to the theory of atomic structure. In 1904 he wrote:**

  - ***If it were ever possible to control at will the rate of disintegration of the radio elements, an enormous amount of energy could be obtained from a small amount of matter.***

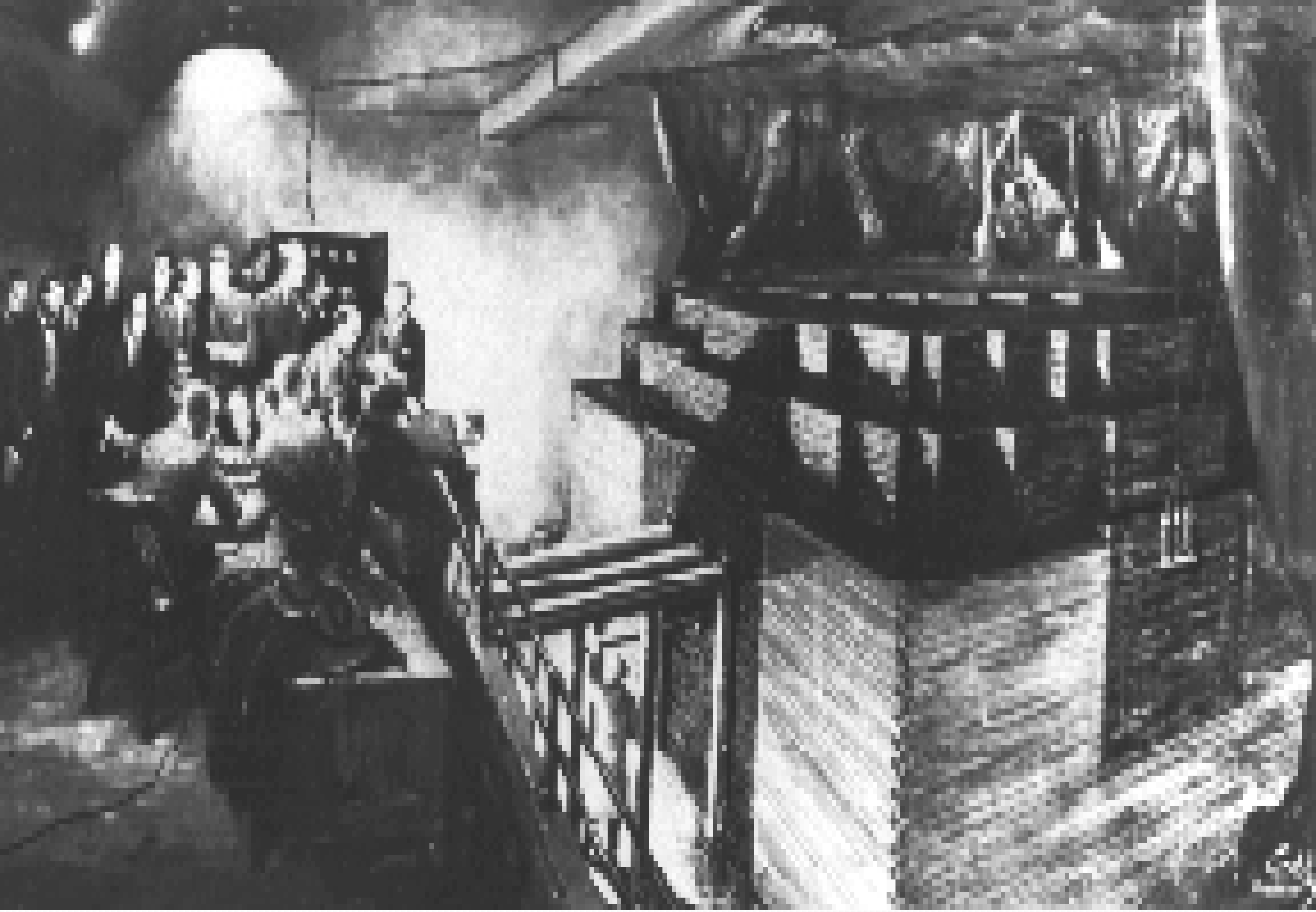
- **Albert Einstein developed his theory of the relationship between mass and energy one year later. The mathematical formula is E=mc 2, or "energy equals mass times the speed of light squared." It took almost 35 years for someone to prove Einstein's theory.**

The Discovery of Fission

- In 1934, physicist Enrico Fermi conducted experiments in Rome that showed neutrons could split many kinds of atoms. The results surprised even Fermi himself. When he bombarded uranium with neutrons, he did not get the elements he expected. The elements were much lighter than uranium.
- In the fall of 1938, German scientists Otto Hahn and Fritz Strassman fired neutrons from a source containing the elements *radium and beryllium into uranium (atomic number 92)*. They were surprised to find lighter elements, such as *barium (atomic number 56), in the* leftover materials.
- These elements had about half the atomic mass of uranium. In previous experiments, the leftover materials were only slightly lighter than uranium.
- Hahn and Strassman contacted Lise Meitner in Copenhagen before publicizing their discovery. She was an Austrian colleague who had been forced to flee Nazi Germany. She worked with Niels Bohr and her nephew, Otto R. Frisch. Meitner and Frisch thought the barium and other light elements in the leftover material resulted from the uranium splitting — or fissioning. However, when she added the atomic masses of the fission products, they did not total the uranium's mass. Meitner used Einstein's theory to show the lost mass changed to energy. This proved fission occurred and confirmed Einstein's work.

The First Self-Sustaining Chain Reaction

- In 1939, Bohr came to America. He shared with Einstein the Hahn-Strassman-Meitner discoveries. Bohr also met Fermi at a conference on theoretical physics in Washington, D.C. They discussed the exciting possibility of a self-sustaining chain reaction. In such a process, atoms could be split to release large amounts of energy.
- On August 2nd 1939, Einstein sent Roosevelt the following letter "Some recent work by E. Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations."
- Early in 1942, a group of scientists led by Fermi gathered at the University of Chicago to develop their theories. By November 1942, they were ready for construction to begin on the world's first nuclear reactor, which became known as *Chicago Pile-1. The pile was erected* on the floor of a squash court beneath the University of Chicago's athletic stadium. In addition to uranium and graphite, it contained control rods made of *cadmium. Cadmium is a* metallic element that absorbs neutrons. When the rods were in the pile, there were fewer neutrons to fission uranium atoms. This slowed the chain reaction. When the rods were pulled out, more neutrons were available to split atoms.



The First Pile (Reactor)

- In the center of the 30- by 60-foot room, shrouded on all but one side by a gray balloon cloth envelope, was a pile of black bricks and wooden timbers, square at the bottom and a flattened sphere on top. Up to half of its height, its sides were straight. The top half was domed, like a beehive.
- Original estimates as to the critical size of the pile were pessimistic. As a further precaution, it was decided to enclose the pile in a balloon cloth bag which could be evacuated to remove the neutron-capturing air.
- This balloon cloth bag was constructed by Goodyear Tire and Rubber Company. Specialists in designing gasbags for lighter-than-air craft, the company's engineers were a bit puzzled about the aerodynamics of a square balloon.
- On the morning of December 2, 1942, the scientists were ready to begin a demonstration of Chicago Pile-1. Fermi ordered the control rods to be withdrawn a few inches at a time during the next several hours. Finally, at 3:25 p.m., Chicago time, the nuclear reaction became self-sustaining. Fermi and his group had successfully transformed scientific theory into technological reality. The world had entered the nuclear age.

The Manhattan Engineer District

- Meantime, in Washington, Vannevar Bush, Director of the Office of Scientific Research and Development, had recommended to President Roosevelt that a special Army Engineer organization be established to take full responsibility for the development of the atomic bomb. During the summer, the Manhattan Engineer District was created, and in September, 1942, Major General L. R. Groves assumed command.
- The Atomic Energy Commission (AEC), a civilian agency, succeeded the Manhattan Engineer District as the governmental organization to control atomic energy on January 1, 1947. On October 11, 1974, President Gerald Ford signed the bill that abolished the AEC. The research and development portions of the AEC were absorbed into the US. Energy Research and Development Administration (ERDA); the regulatory portions of the AEC were absorbed into the Nuclear Regulatory Commission (NRC). On October 1, 1977, the Energy Research and Development Administration became part of the newly created Department of Energy.

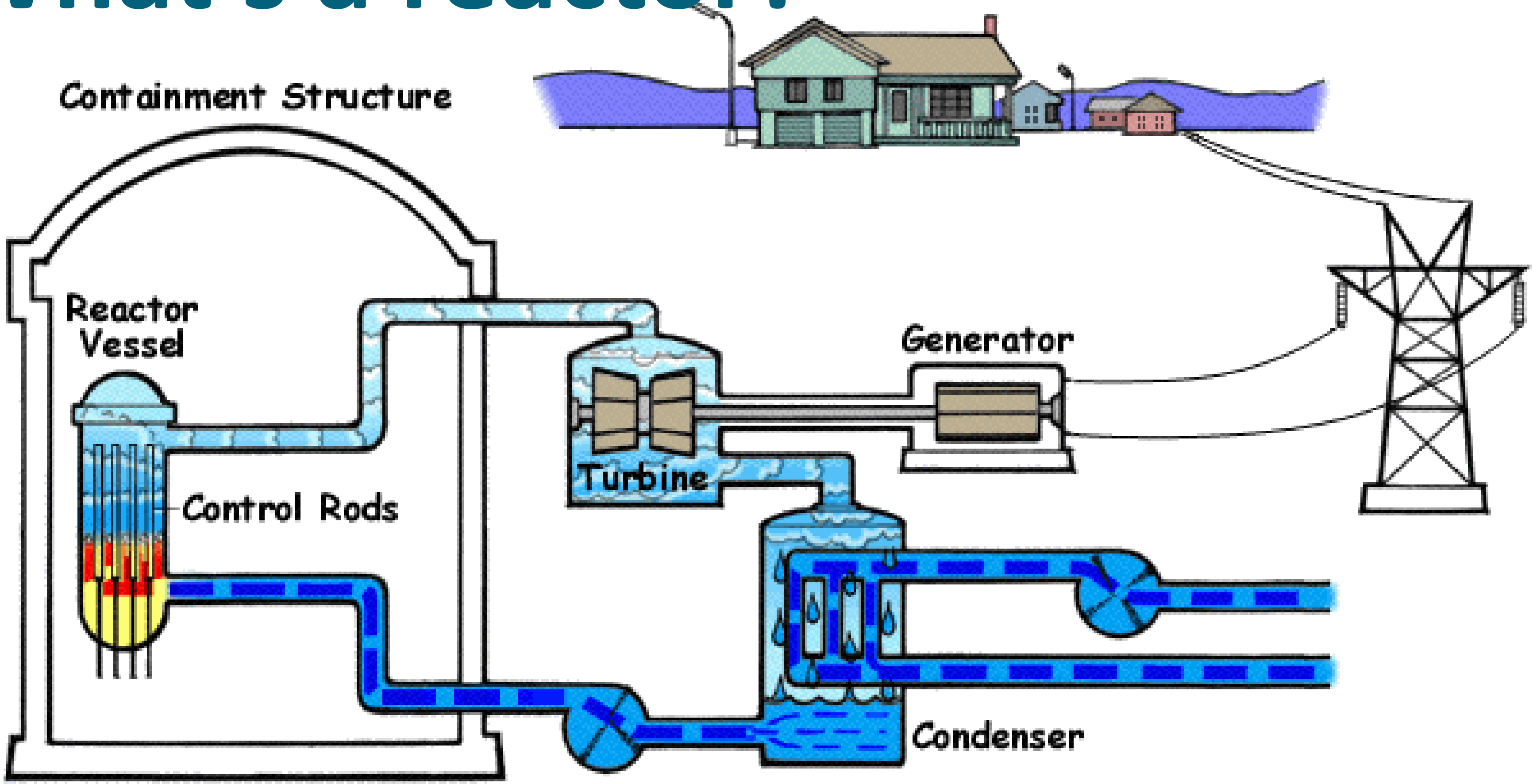
Enrico Fermi

- Fermi was awarded the Nobel Prize in 1938 for his work on transuranic elements. He and his family went to Sweden to receive the prize.
- The Italian Fascist press severely criticized him for not wearing a Fascist uniform and failing to give the Fascist salute when he received the award.
- The Fermis never returned to italy.
- From Sweden, having taken most of his personal possessions with him, Fermi proceeded to London and thence to America where he has remained ever since.

Nuclear Energy for Peaceful Applications

- The first nuclear reactor was only the beginning. Most early atomic research focused on developing an effective weapon for use in World War II. The work was done under the code name *Manhattan Project*.
- A major goal of nuclear research in the mid-1950s was to show that nuclear energy could produce electricity for commercial use. The first commercial electricity-generating plant powered by nuclear energy was located in Shippingport, Pennsylvania. It reached its full design power in 1957. Light-water reactors like Shippingport use ordinary water to cool the reactor core during the chain reaction. They were the best design then available for nuclear power plants.

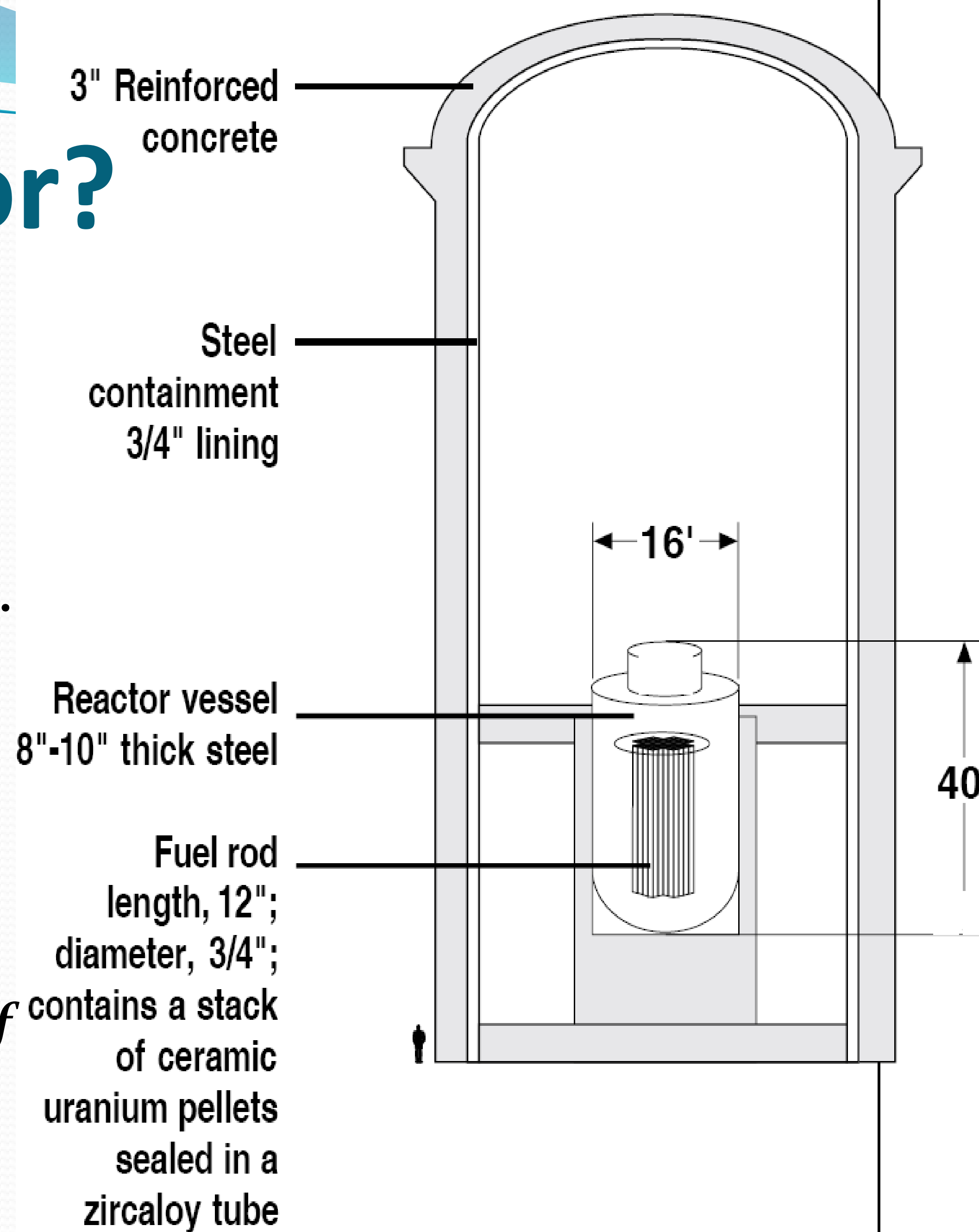
What’s a reactor?



- A nuclear reactor is the heat source of a nuclear power plant. The reactor is the part of the plant that makes it different from other electric power plants. Most electric power plants heat water and convert it into steam. This process drives a turbine generator to produce electricity. Fossil-fueled power plants produce heat by burning coal, oil, or natural gas. Nuclear power plants produce heat by the continuous fissioning of uranium atoms in the reactor. Electricity produced at a nuclear power plant is the same as the electricity produced at other power plants.

What's a reactor?

We use several commercial reactor designs in the U.S. The most widely used design consists of an 8- to 10-inch-thick steel vessel surrounding a reactor core. This vessel is about 40 feet tall and 16 feet in diameter. The reactor core contains the uranium fuel. The fuel is formed into cylindrical ceramic pellets about one-half inch in diameter and sealed in long metal tubes called *fuel pins. Fuel assemblies are groups of fuel pins. A group of* fuel assemblies, in turn, forms the *core of the* reactor.

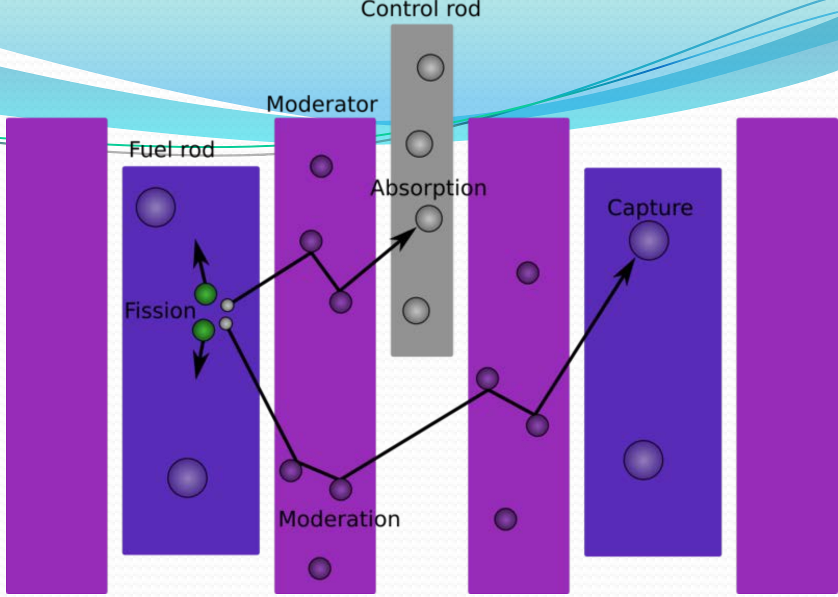


Reactors by type of fission

Atomic No.	Name
89	Actinium
90	Thorium
91	Protactinium
92	Uranium
93	Neptunium
94	Plutonium
95	Americium
96	Curium
97	Berkelium
98	Californium
99	Einsteinium
100	Fermium
101	Mendelevium
102	Nobelium
103	Lawrencium

- Thermal reactors use slow or thermal neutrons. Most power reactors are of this type. These are characterized by neutron moderator materials that slow neutrons until they approach the average kinetic energy of the surrounding particles, that is, until they are *thermalized*. Thermal neutrons have a far higher probability of fissioning uranium-235, and a lower probability of capture by uranium-238 than the faster neutrons that result from fission. As well as the moderator, thermal reactors have fuel (fissionable material), containments, pressure vessels, shielding, and instrumentation to monitor and control the reactor's systems.
- Fast neutron reactors use fast neutrons to sustain the fission chain reaction. They are characterized by an absence of moderating material. Initiating the chain reaction requires enriched uranium (and/or enrichment with plutonium 239), due to the lower probability of fissioning U-235, and a higher probability of capture by U-238 (as compared to a moderated, thermal neutrons). Fast reactors have the potential to produce less trnasuranic waste because all actinoids are fissionable with fast neutrons, but they are more difficult to build and more expensive to operate. Overall, fast reactors are less common than thermal reactors in most applications. Some early power stations were fast reactors, as are some Russian naval propulsion units.

Reactors by moderator type



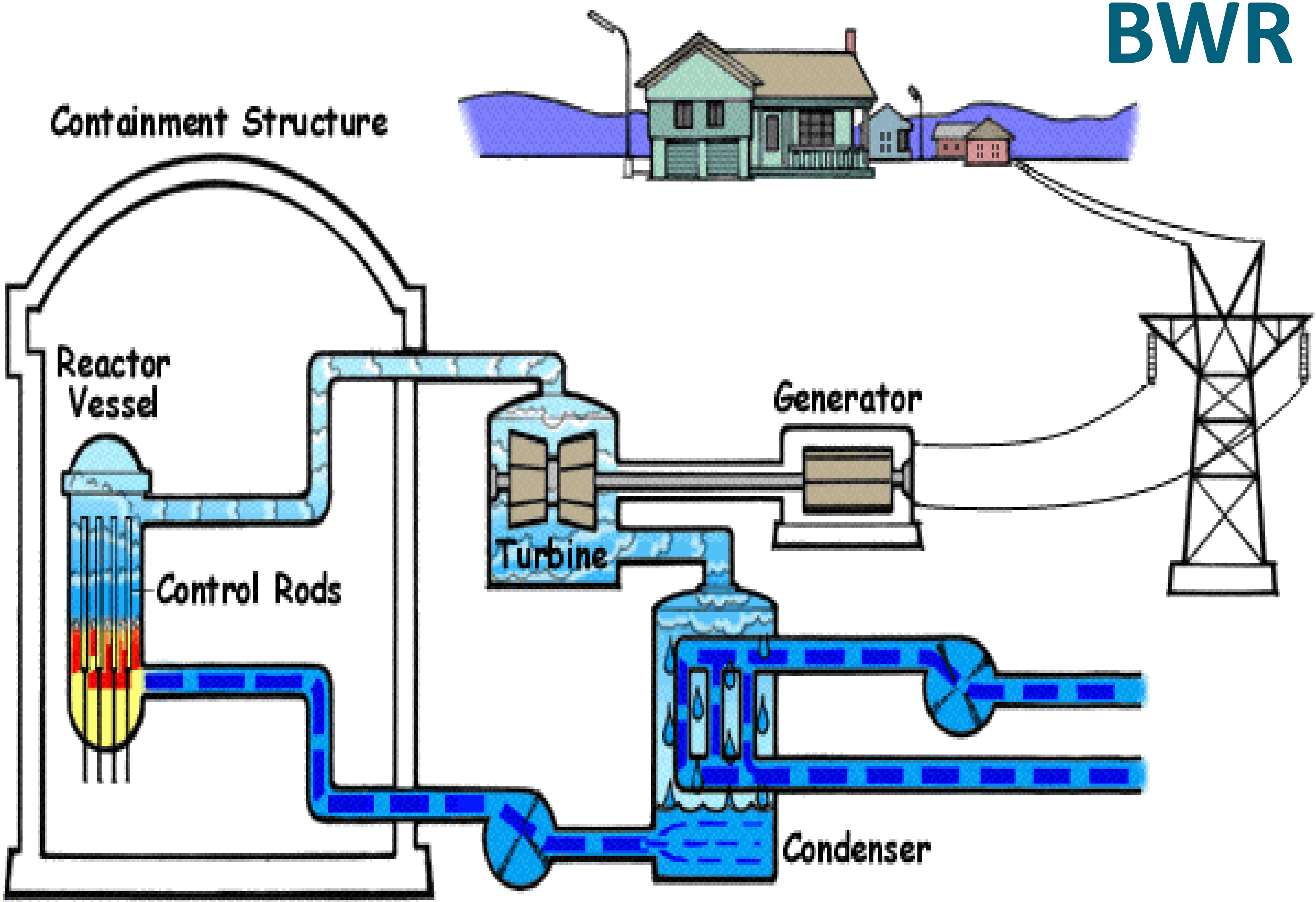
- Graphite moderated reactors
- Water moderated reactors
  - Heavy water reactors
  - Light water moderated reactors (LWRs).

    Light water reactors use ordinary water to moderate and cool the reactors. When at operating temperature, if the temperature of the water increases, its density drops, and fewer neutrons passing through it are slowed enough to trigger further reactions. That negative feedback stabilizes the reaction rate. Graphite and heavy water reactors tend to be more thoroughly thermalised than light water reactors.
- Light element moderated reactors. These reactors are moderated by lithium or beryllium.
  - Molten salt reactors (MSRs) are moderated by a light elements such as lithium or beryllium, which are constituents of the coolant/fuel matrix salts LiF and BeF_2.
  - Liquid metal cooled reactors, such as one whose coolant is a mixture of Lead and Bismuth, may use BeO as a moderator.
- Organically moderated reactors (OMR) use biphenyl and terphrnyl as moderator and coolant

Reactors by coolant type

- Water cooled reactor
  - Pressurized water reactor (PWR)
    - A primary characteristic of PWRs is a pressurizer, a specialized pressure vessel. Most commercial PWRs and naval reactors use pressurizers. During normal operation, a pressurizer is partially filled with water, and a steam bubble is maintained above it by heating the water with submerged heaters. During normal operation, the pressurizer is connected to the primary reactor pressure vessel (RPV) and the pressurizer "bubble" provides an expansion space for changes in water volume in the reactor.
    - Pressurised channels. Channel-type reactors can be refueled under load.
  - Boiling water reactor (BWR)
    - BWRs are characterized by boiling water around the fuel rods in the lower portion of primary reactor pressure vessel. During normal operation, pressure control is accomplished by controlling the amount of steam flowing from the reactor pressure vessel to the turbine.

BWR



Containment Structure
Reactor Vessel
Control Rods
Generator
Turbine
Condenser

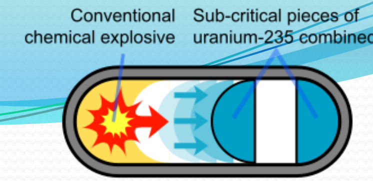
Reactors by coolant type

- **Liquid metal cooled reactor. Since water is a moderator, it cannot be used as a coolant in a fast reactor. Liquid metal coolants have included sodium, NaK, lead, lead-bismuth eutectic, and in early reactors, mercury.**
  - Sodium-cooled fast reactor
  - Lead-cooled fast reactor
- **Gas cooled reactors are cooled by a circulating inert gas, usually helium. Nitrogen and carbon dioxide have also been used. Utilization of the heat varies, depending on the reactor. Some reactors run hot enough that the gas can directly power a gas turbine. Older designs usually run the gas through a heat exchanger to make steam for a steam turbine.**
- **Molten Salt Reactors (MSRs) are cooled by circulating a molten salt, typically a eutectic mixture of fluoride salts, such as LiF and BeF_2. In a typical MSR, the coolant is also used a matrix in which the fissile material is dissolved.**

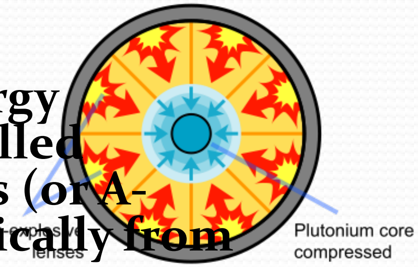
Reactors by use

- Electricity
  - Nuclear power plants
- Propulsion
  - Nuclear marine propulsion
  - Various proposed forms of rocket propulsion
- Other uses of heat
  - Desalination
  - Heat for domestic and industrial heating
  - Hydrogen production for use in a hydrogen economy
- Production reactors for transmutation of elements
  - Breeder reactors. Fast breeder reactors are capable of enriching Uranium during the fission chain reaction (by converting fertile U-238 to Pu-239) which allows an operational fast reactor to generate more fissile material than it consumes. Thus, a breeder reactor, once running, can be re-fueled with natural or even depleted uranium.
  - Creating various radioactive isotopes, such as americium for use in smoke detectors, and cobalt-60, molybdenum-99 and others, used for imaging and medical treatment.
  - Production of materials for nuclear weapons such as weapons-grade plutonium
- Providing a source of neutron radiation
- Research reactor: Typically reactors used for research and training, materials testing, or the production of radioisotopes for medicine and industry. These are much smaller than power reactors or those propelling ships, and many are on university campuses. There are about 280 such reactors operating, in 56 countries. Some operate with high-enriched uranium fuel, and international efforts are underway to substitute low-enriched fuel.

Nuclear Weapons



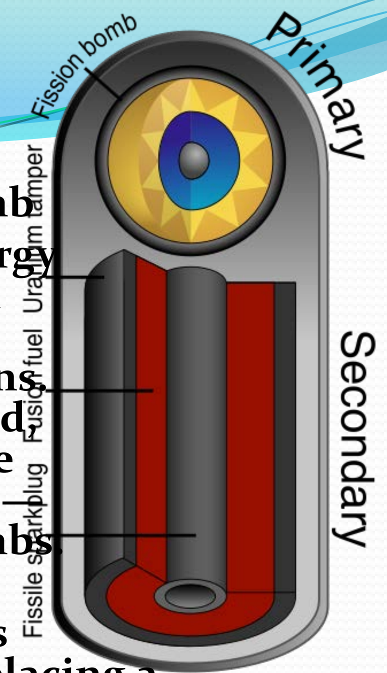
Gun-type assembly method



Implosion assembly method

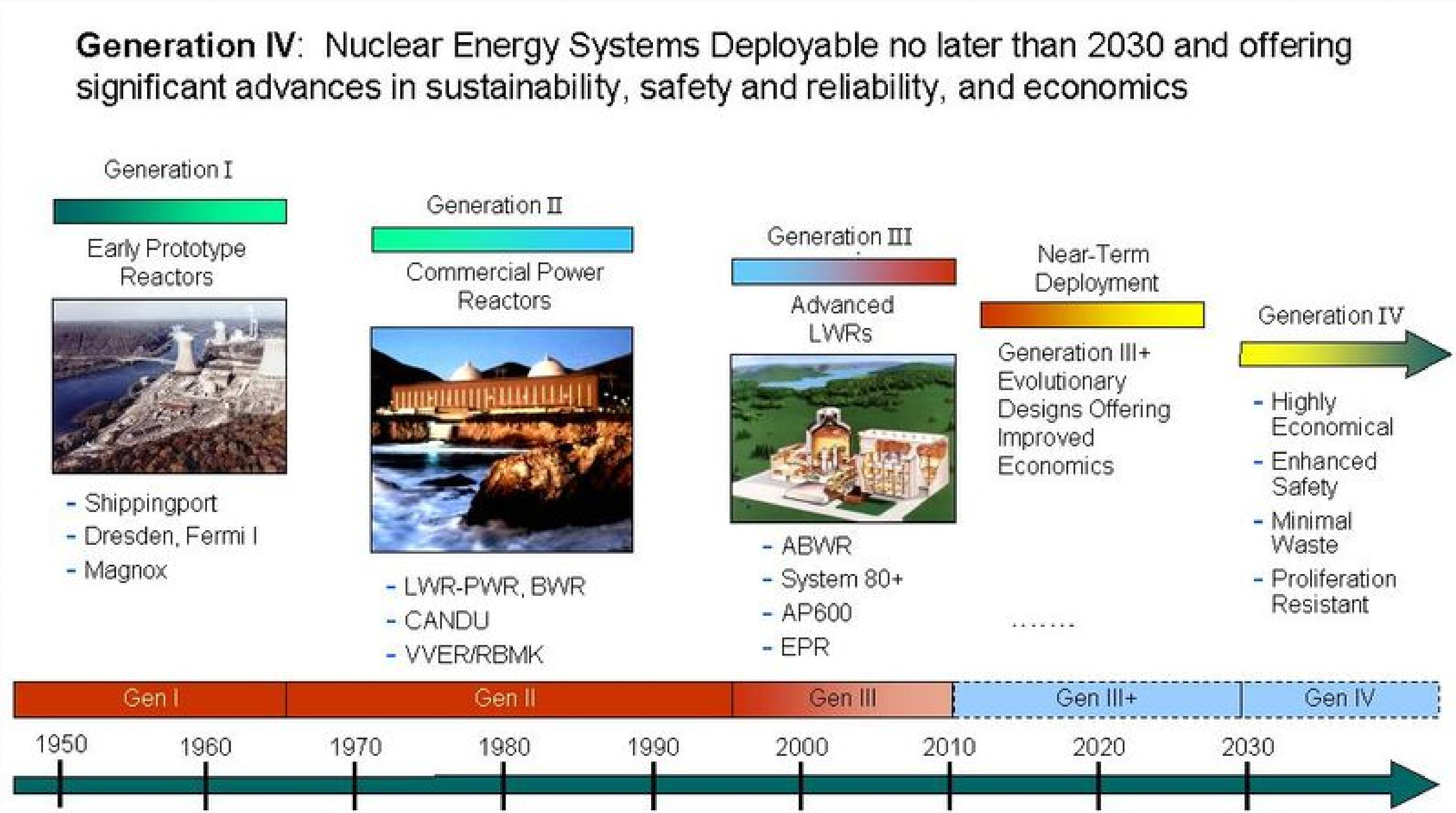
- **Fission bomb or atomic/atom bomb (A-bomb)**
- **The first basic type of nuclear weapon produces explosive energy through nuclear fission reactions alone. These weapons are called fission bombs. They have also been called atomic/atom bombs (or A-bombs) since their first use, though their energy comes specifically from the nucleus of the atom.**
- **In fission weapons, a mass of fissile material (enriched uranium or plutonium) is assembled into a supercritical mass—the amount of material needed to start an exponentially growing nuclear chain reaction—either by shooting one piece of sub-critical material into another (the "gun" method), or by using chemical explosives to compress a sub-critical sphere of material to many times its original density (the "implosion" method). The latter approach is considered more sophisticated than the former, and only the latter approach can be used if plutonium is the fissile material.**
- **A major challenge in all nuclear weapon designs is to ensure that a significant fraction of the fuel is consumed before the weapon destroys itself. The amount of energy released by fission bombs can range between the equivalent of less than a ton of TNT upwards to around 500,000 tons (500 kilotons) of TNT**

Nuclear Weapons



- Fusion bomb, hydrogen bomb (H-bomb), or thermonuclear weapon/bomb
- The second basic type of nuclear weapon produces a large amount of energy through nuclear fusion reactions. Historically, they have also been called H-bombs, as they rely on fusion reactions between isotopes of hydrogen, though all such weapons derive most of their energy from fission reactions. Because fusion material cannot go overcritical no matter the amount used, and because fusion weapons can be staged, these kind of weapons may be made significantly more powerful than fission bombs. Only six countries—US, Russia, UK, China, France, and India—have detonated hydrogen bombs.
- Fusion bombs work by using the energy of a fission bomb in order to compress and heat fusion fuel. In the Teller-Ulam design, which accounts for most multi-megaton yield hydrogen bombs, this is accomplished by placing a fission bomb and fusion fuel (tritium and deuterium) in proximity within a special, radiation-reflecting container.
- When the fission bomb is detonated, gamma and X-rays emitted first compress the fusion fuel, then heat it to thermonuclear temperatures. The ensuing fusion reaction creates enormous numbers of high-speed neutrons, which then can induce fission in materials which normally are not prone to it, such as depleted uranium. Each of these components is known as a "stage," with the fission bomb as the "primary" and the fusion capsule as the "secondary." In large hydrogen bombs, about half of the yield, and much of the resulting nuclear fallout, comes from the final fissioning of depleted uranium.
- By chaining together numerous stages with increasing amounts of fusion fuel, thermonuclear weapons can be made to an almost arbitrary yield; the largest ever detonated (the Tsar Bomb of the USSR) released an energy equivalent to over 50 million tons (50 megatons) of TNT. Most thermonuclear weapons are considerably smaller than this, due for instance to practical constraints in fitting them into the space and weight requirements of missile warheads.

Reactors by Generation



Reactor Generations

- The line between a generation I reactor and one of generation II is sometimes hard to draw, for example the later Magnox plants share some of the characteristics of each.
- Generation II
  - PWR, CANDU, BWR and AGR
- Generation III reactors
  - Advanced Boiling Water Reactor or ABWR - A GE design which first went online in Japan in 1996.
  - AP600 - A Westinghouse Electric Company design which received final design approval from the NRC in 1998 - none were built due to the economics of new nuclear power plants.
  - System 80+ - a Combustion Engineering (now incorporated into Westinghouse) design.
  - European Pressurized Reactor or EPR - an evolutionary descendant of the Framatome N4 and Siemens Power Generation Division KONVOI reactors.
- Generation III+ designs are generally extensions of the Generation III concept which include advanced passive safety features. These designs can maintain the safe state without the use of any active control components.
  - Advanced CANDU Reactor (ACR)
  - AP1000 - based on the AP600
  - Economic Simplified Boiling Water Reactor (ESBWR) - based on the ABWR
  - APR-1400 - an advanced PWR design evolved from the U.S. System 80+ which is the basis for the Korean Next Generation Reactor or KNGR

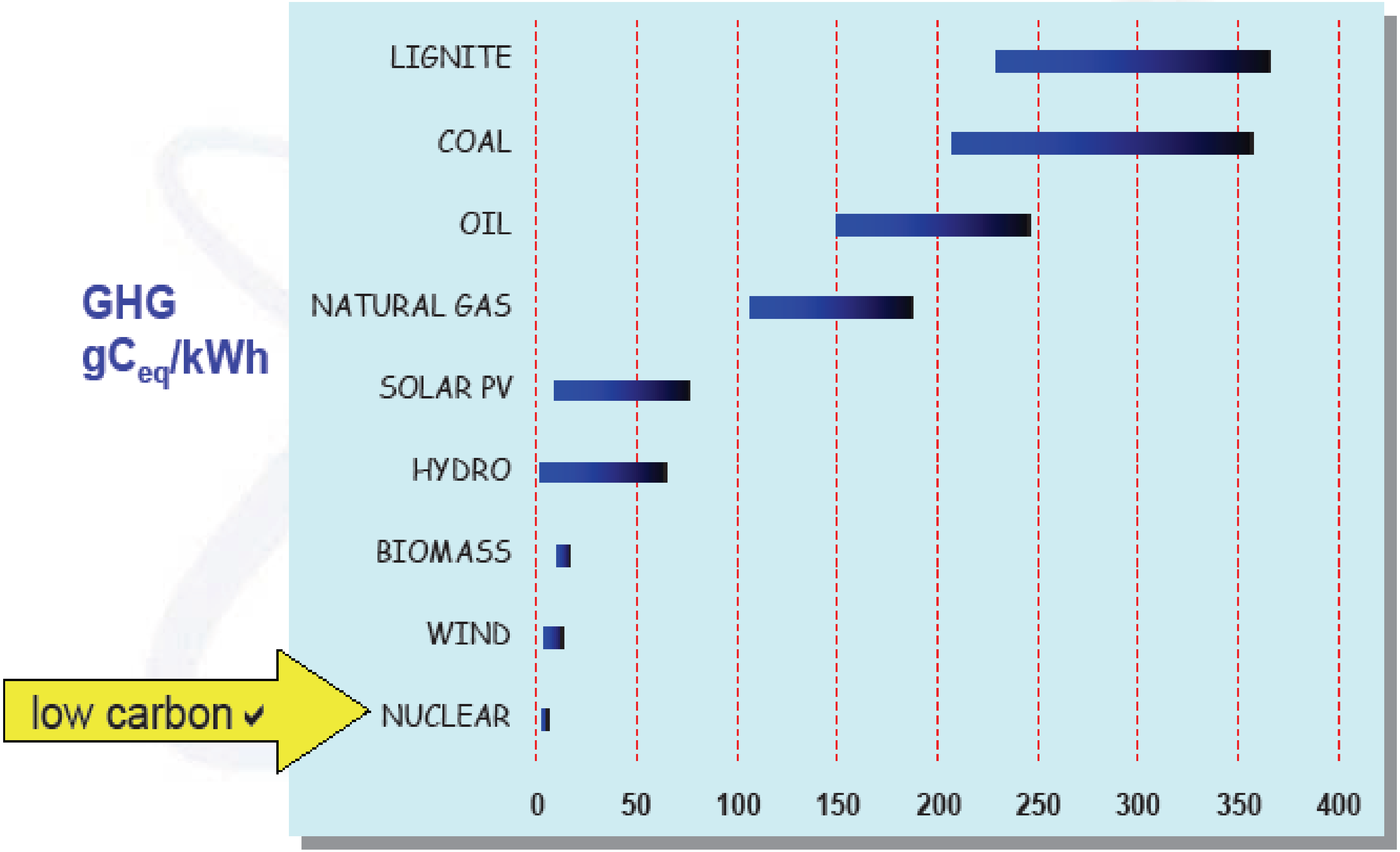
Generation IV reactors

- Reactor types
  - Thermal reactors
    - Very-High-Temperature Reactor (VHTR)
    - Supercritical-Water-Cooled Reactor (SCWR)
    - Molten Salt Reactor (MSR)
  - Fast reactors
    - Gas-Cooled Fast Reactor (GFR)
    - Sodium-Cooled Fast Reactor (SFR)
    - Lead-Cooled Fast Reactor (LFR

Why Nuclear?

- **Low carbon emission technology**
- **Affordable**
- **Sustainable**
- **Safe**
- **Accepted**
- **Doesn’t leave a mess**
- **Consistent with international policy**
- **Expandable**
- **Proliferation resistant**

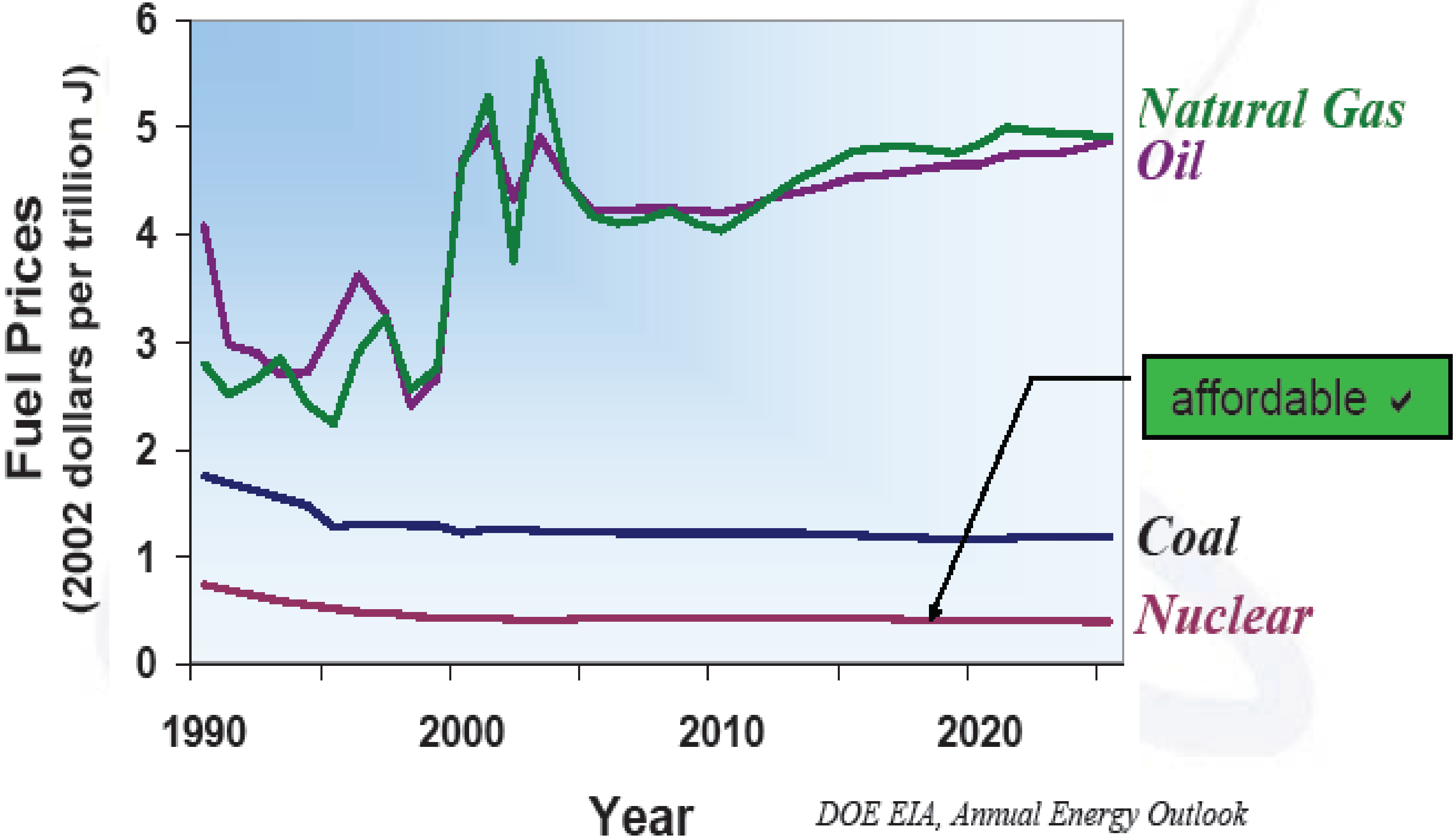
Greenhouse gas (GHG) emissions



Source: Sokolov, IAEA, 2005

Idaho National Laboratory

U.S. fuel prices to electricity generators

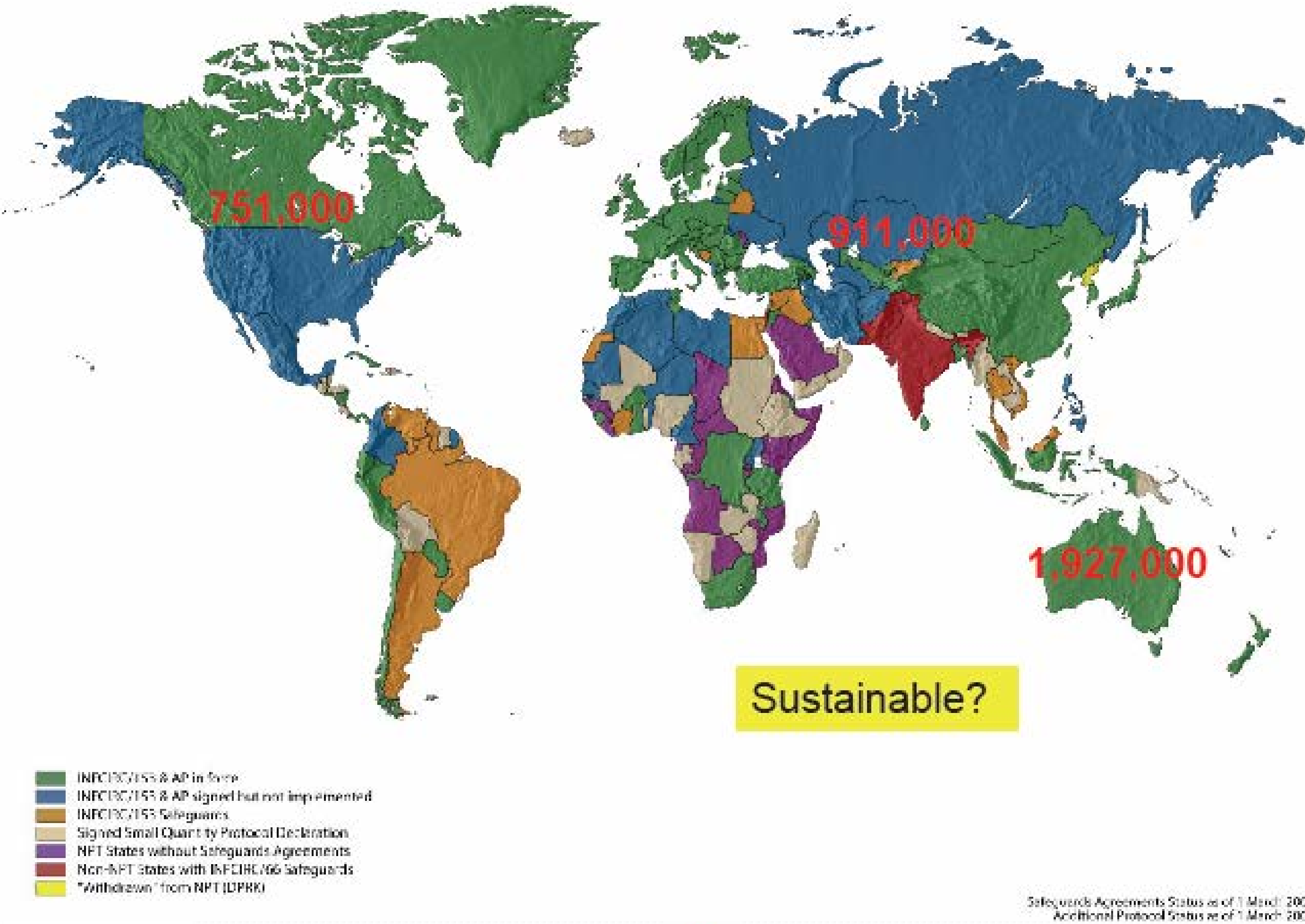


DOE EIA, Annual Energy Outlook 2004, Figure 73

Table 1: Costs of Electric Generation Alternatives

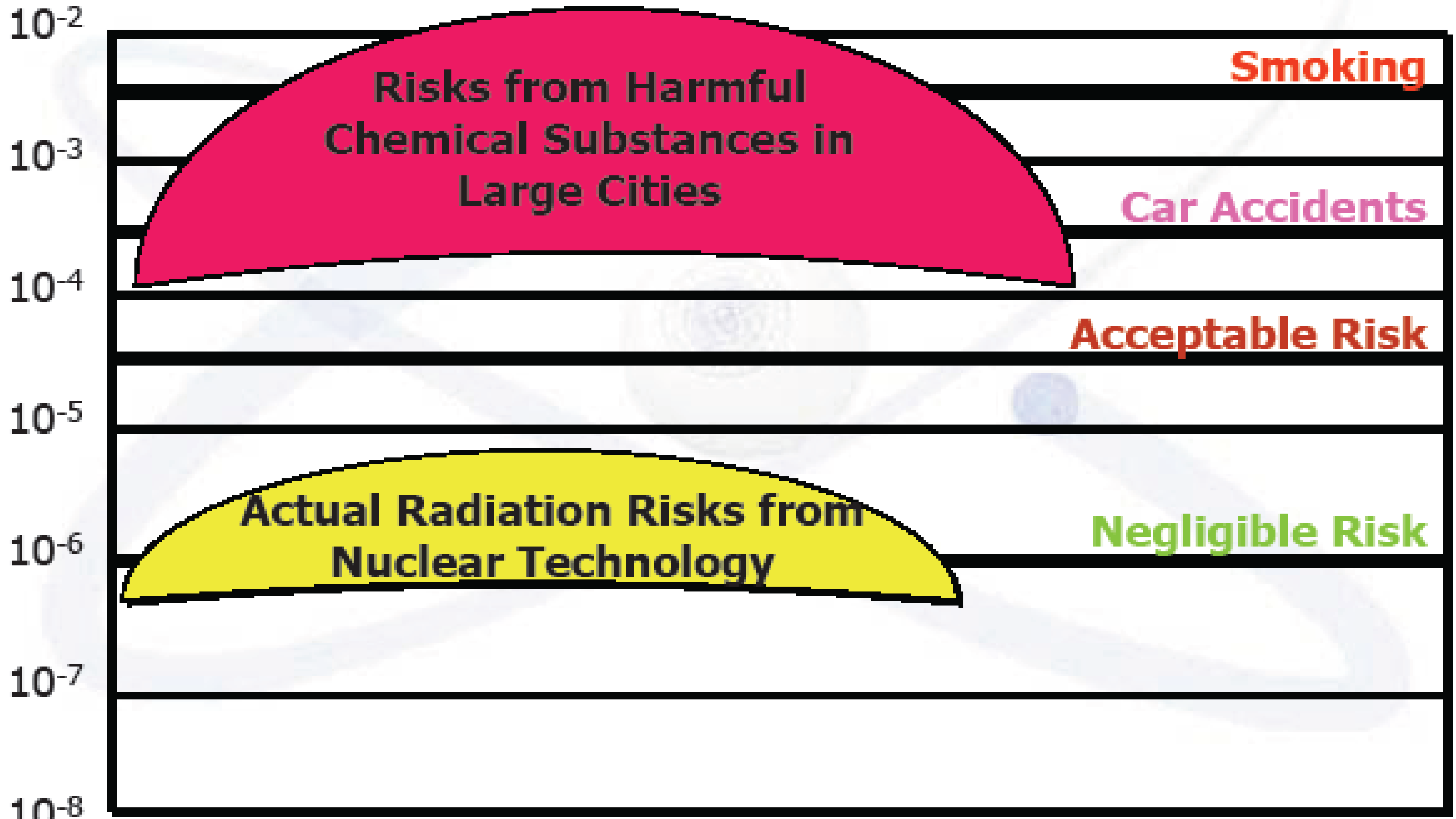
			LCOE		
	Overnight Cost	Fuel Cost	Base Case	w/ carbon charge $25/$tCO_2$	w/ same cost of capital
	$/kW	$/mmBtu	¢/kWh	¢/kWh	¢/kWh
	[A]	[B]	[C]	[D]	[E]
MIT (2003)					
$2002					
[1] Nuclear	2,000	0.47	6.7		5.5
[2] Coal	1,300	1.20	4.3	6.4	
[3] Gas	500	3.50	4.1	5.1	
Update					
$2007					
[4] Nuclear	4,000	0.67	8.4		6.6
[5] Coal	2,300	2.60	6.2	8.3	
[6] Gas	850	7.00	6.5	7.4	

Uranium resources are ample



Nuclear technology has low risk

safe ✓

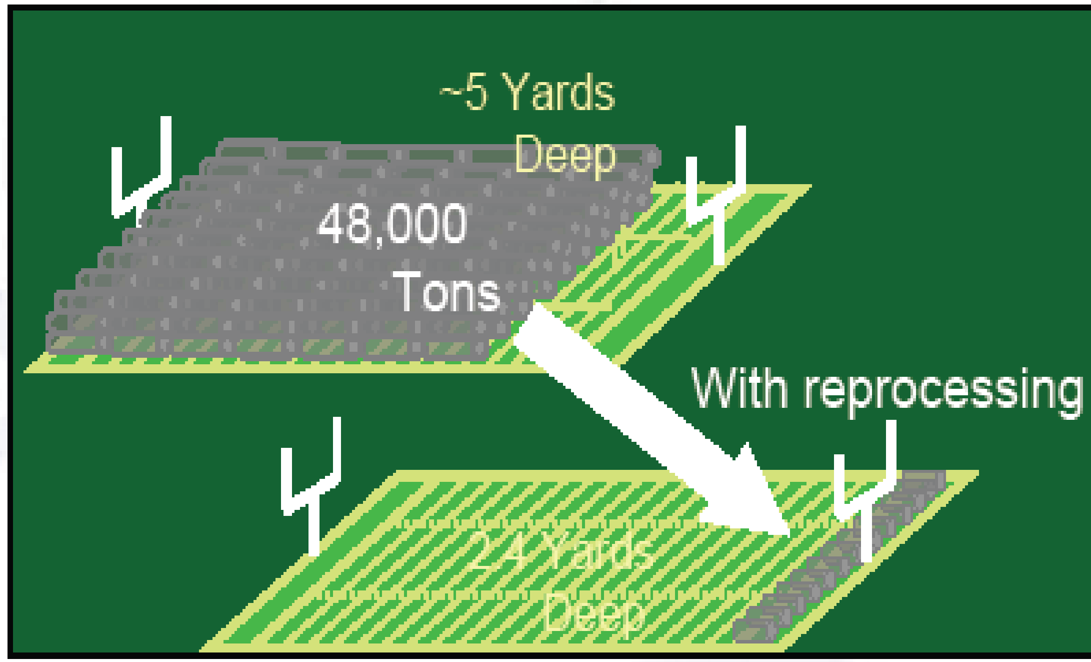


Sokolov, IAEA

Total amount of used fuel generated is relatively small and readily manageable

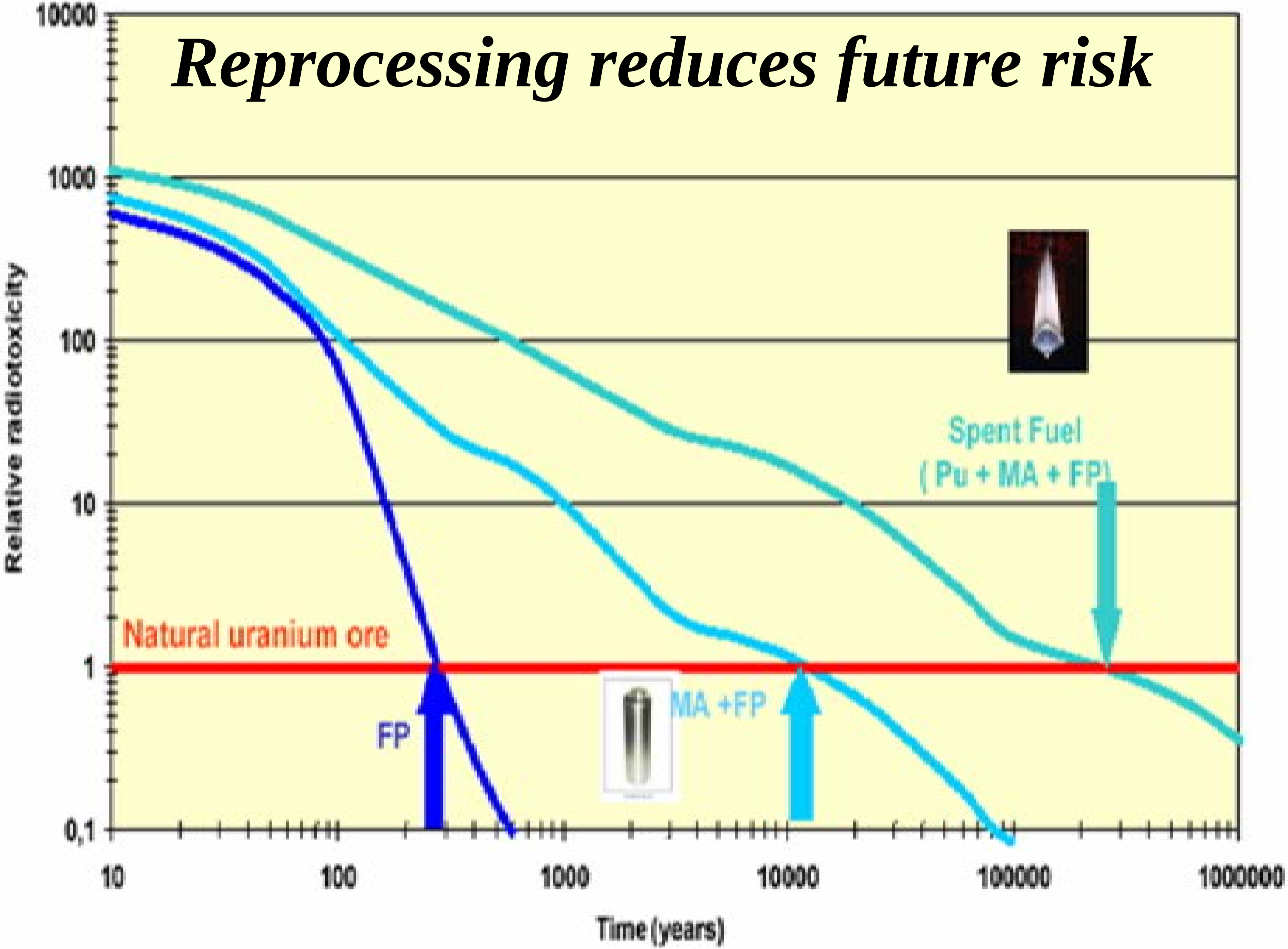
Current high-level waste volume after 40 years of operations would fill an area about the size of a football field five yards deep

- ~48,000 metric tons
- ~½ ton per fuel assembly
- ~ 100,000 assemblies
- Only ~5% is waste



No environmental mess

Reprocessing reduces future risk



International Policy

- **G-8 Ministers Statement - 21 March 2006**

"For those countries that wish, wide-scale development of safe and secure nuclear energy is crucial for long-term environmentally sustainable diversification of energy supply."

France and UAE sign key nuclear deal

PROVIDES FRAMEWORK FOR COOPERATION FOR USE OF ENERGY FOR PEACEFUL PURPOSES

WAM

Prestigious

Shaikh Khalifa presents Sarkozy with the Zayed Order. Shaikh Khalifa's talks with Sarkozy covered ways to boost bilateral relations, especially in the political, economic and cultural sectors.

Abu Dhabi (WAM) The UAE and France yesterday signed two agreements on nuclear and military cooperation and three memorandums of understanding on intellectual property, transport and education.

President His Highness Shaikh Khalifa Bin Zayed Al Nahyan and French President Nicholas Sarkozy attended the signing of the landmark nuclear cooperation agreement between the UAE and France.

Signed by Shaikh Abdullah Bin Zayed Al Nahyan, Foreign Minister, and French Foreign and European Affairs Minister Bernard Kouchner, the nuclear agreement provides a framework for cooperation between the two countries in the evaluation and potential use of nuclear energy for peaceful purposes.

Under the agreement, the UAE and France will set up a high-level joint committee to supervise cooperation in the areas of nuclear power generation, water desalination, basic and applied research, as well as in agronomy, earth sciences, medicine and indusrry.

The UAE is undertaking high-level government-to-government consultations with the United States, Germany, France, Russia, China, the United Kingdom, Japan and South Korea, specifically with regard to drafting a UAE policy document on the evaluation and possible implementation of a peaceful nuclear programme in the UAE, Shaikh Abdullah said.

Similar direct consultations are also being sought with the International Atomic Energy Agency (IAEA), Shaikh Abdullah said, adding that: "It is the UAE's hope that the final policy may also serve as a replicable model for non-nuclear countries to evaluate and potentially implement peaceful nuclear programme with full support from the international community."

He reaffirmed the UAE's commitment to be part of the GCC-wide initiative to explore the potential for peaceful nuclear power generation in the Gulf region.

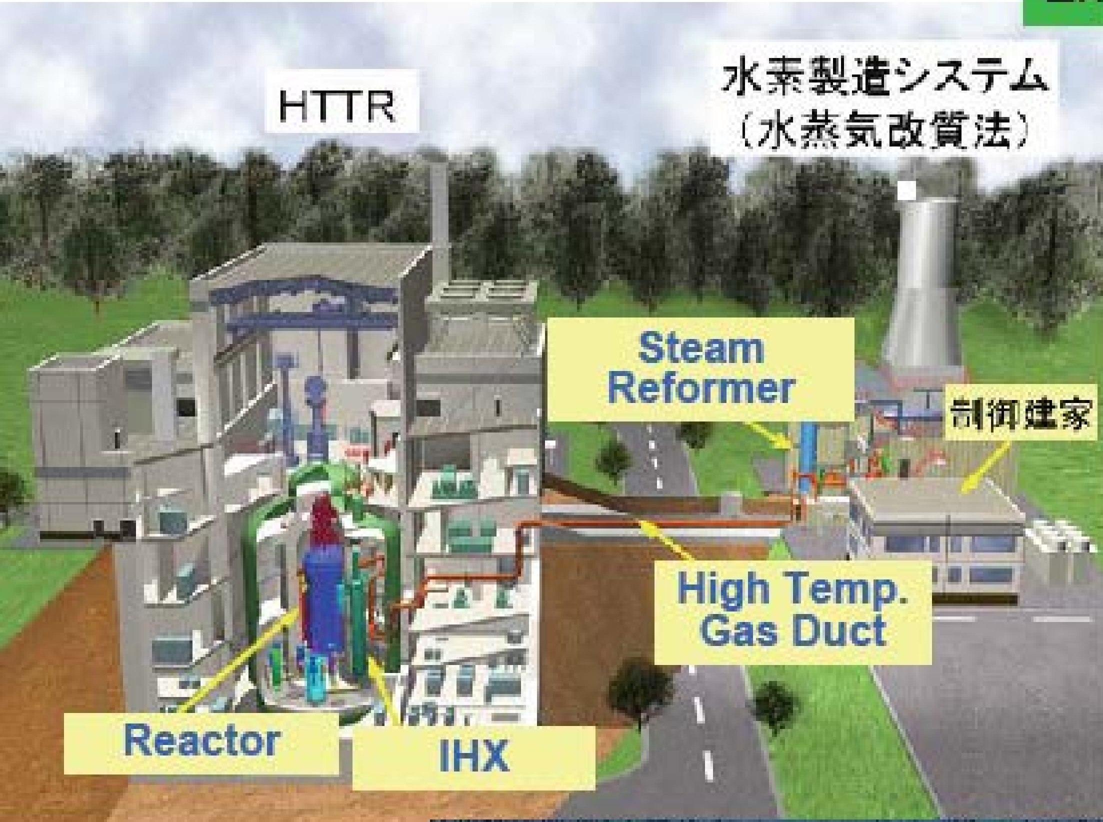
Shaikh Khalifa's talks yesterday with Sarkozy, in the presence of General Shaikh Mohammad Bin Zayed Al Nahyan, Abu Dhabi Crown Prince and Deputy Supreme Commander of the UAE Armed Forces, covered bilateral ties and ways to enhance them in various fields, especially political, economic, military, cultural and investment sectors. The talks were also attended by Lieutenant General Shaikh Saif Bin Zayed Al Nahyan, Interior Minister, Shaikh Mansour Bin Zayed Al Nahyan, Minister of Presidential Affairs and Shaikh Abdullah.

Khalifa reiterated the UAE's keenness to widen the avenues of joint cooperation and investment between both nations and valued the successful cultural and scientific convergence between the UAE and France, which was reflected by the establishment of the Louvre Abu Dhabi Museum in the Saadiyat Island and the Paris-Sorbonne University Abu Dhabi.

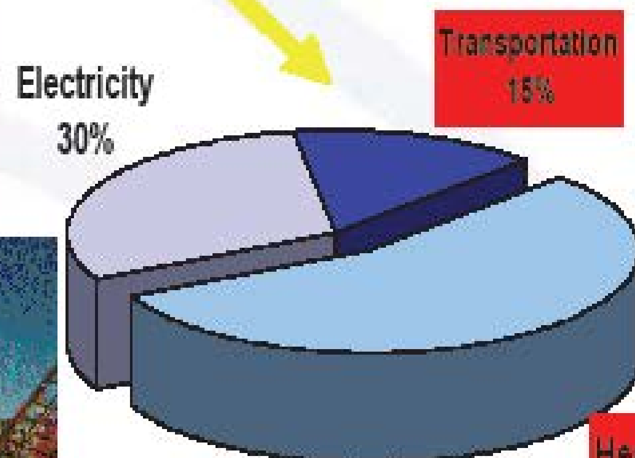
Non-electricity applications of nuclear energy

Expandable to other applications ✓

- Sea-water desalination
- Industrial and district heating
- Hydrogen production



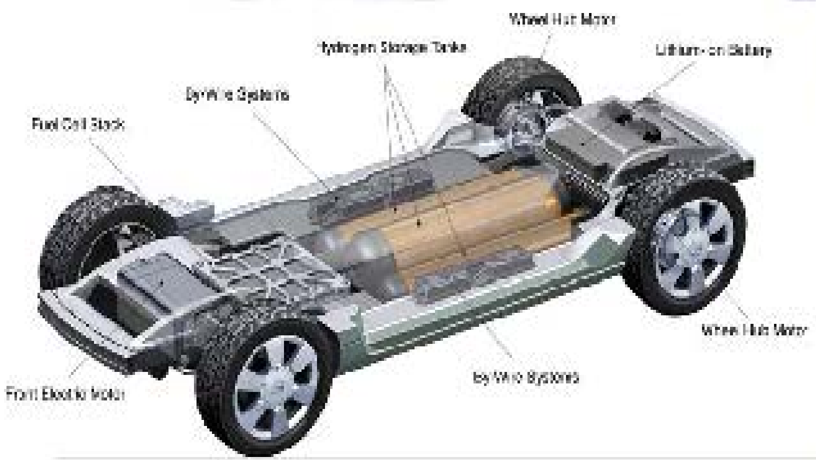
Kazakhstan, BN-350



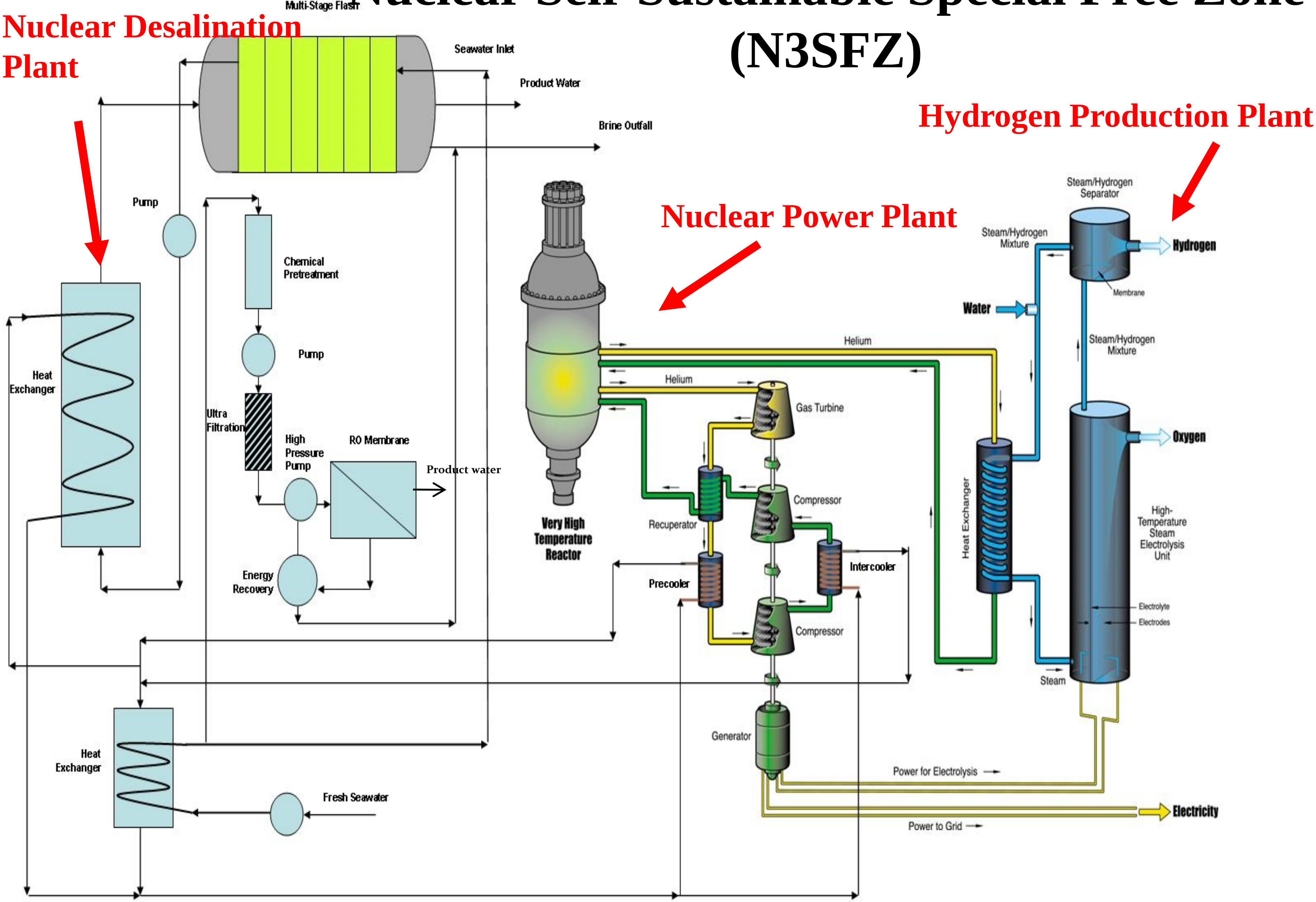
Sokolov IAEA

Idaho Nati

Eventually we will have viable fuel cells - hydrogen fuel & water out the tailpipes

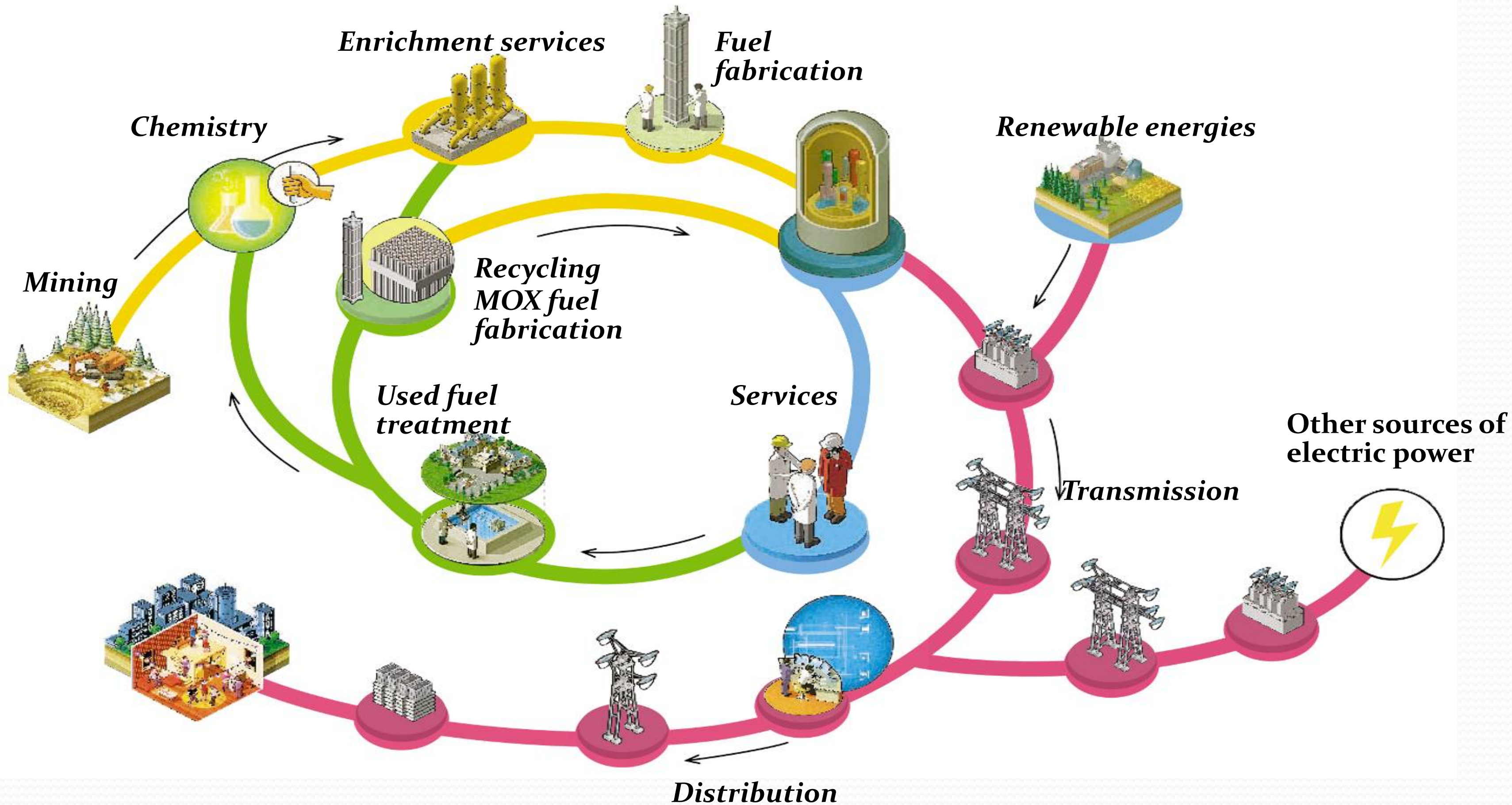


Nuclear Self-Sustainable Special Free Zone (N3SFZ)



LWR Nuclear Fuel Cycle

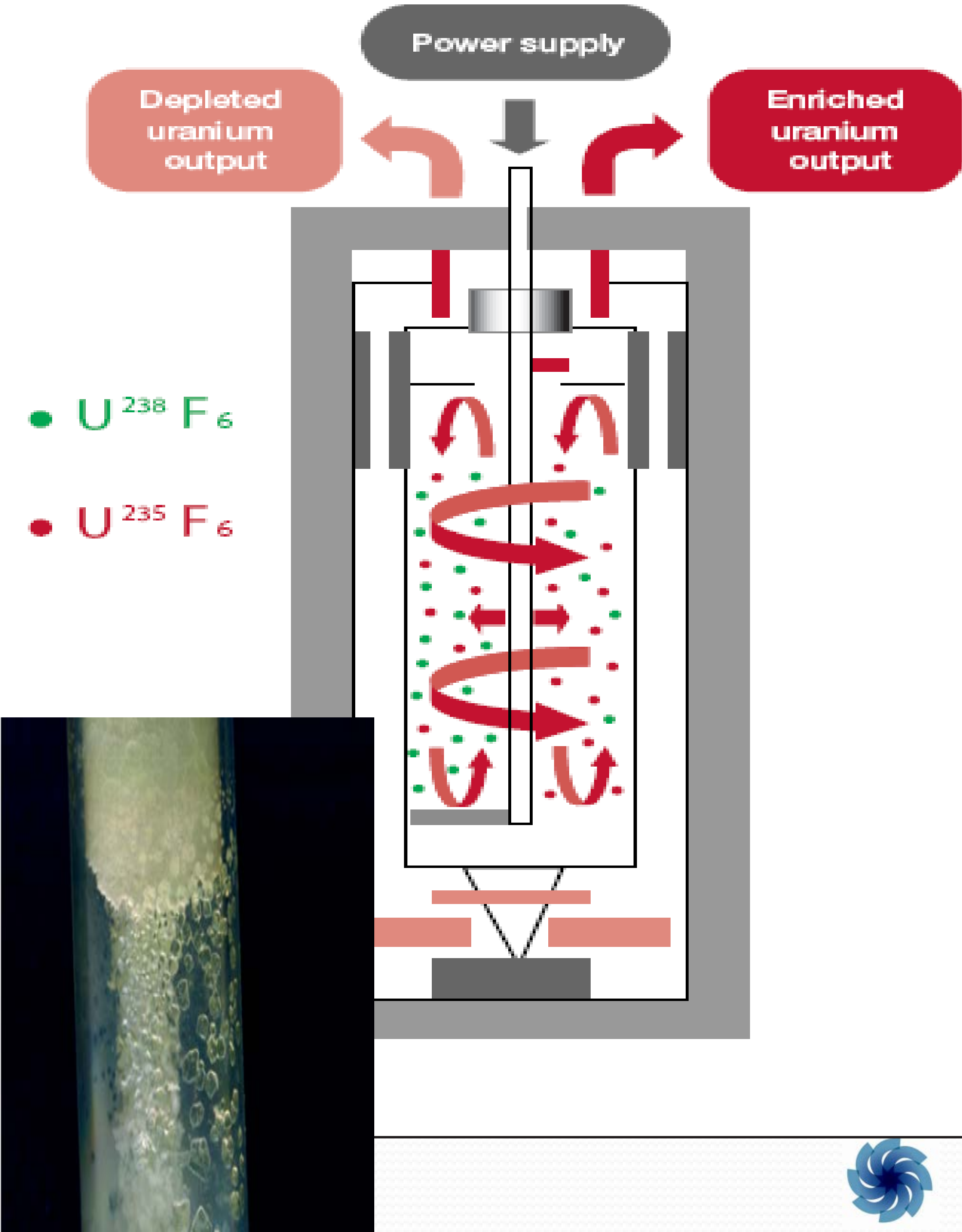
Front End	*Reactors and Services*	*Back End*	*Transmission & Distribution*



Enrichment

- Nuclear fuel must contain a sufficient quantity of fissile material to initiate a chain reaction in a light water reactor. To achieve this result, the proportion of the isotope U-235 in the fuel must be increased from the 0.7% found in natural uranium to 3 to 5%. One speaks then of “enriching” the uranium in the fissile isotope.
- The isotopic separation enrichment plant uses UF6 to produce 3.5% enriched uranium, representing approximately 16% of the initial volume of UF6, and depleted uranium, representing approximately 84% of the initial volume.
- Uranium is said to be “depleted” when the proportion of the U-235 isotope it contains is less than 0.7%, i.e. the proportion contained in natural uranium.
- Since the differences in the chemical properties between uranium isotopes are very small, an effective way of separating them is to use the difference in atomic mass. The world’s two industrial-scale enrichment processes, gaseous diffusion and ultracentrifugation, are based on this concept.
- These processes can only separate a limited quantity of isotopes in a single stage. The diffusers used in the gaseous diffusion process and the centrifuges used in centrifugation must therefore be arranged in a cascade, or series of stages, where each enrichment step is repeated a number of times until the required enrichment level is achieved.

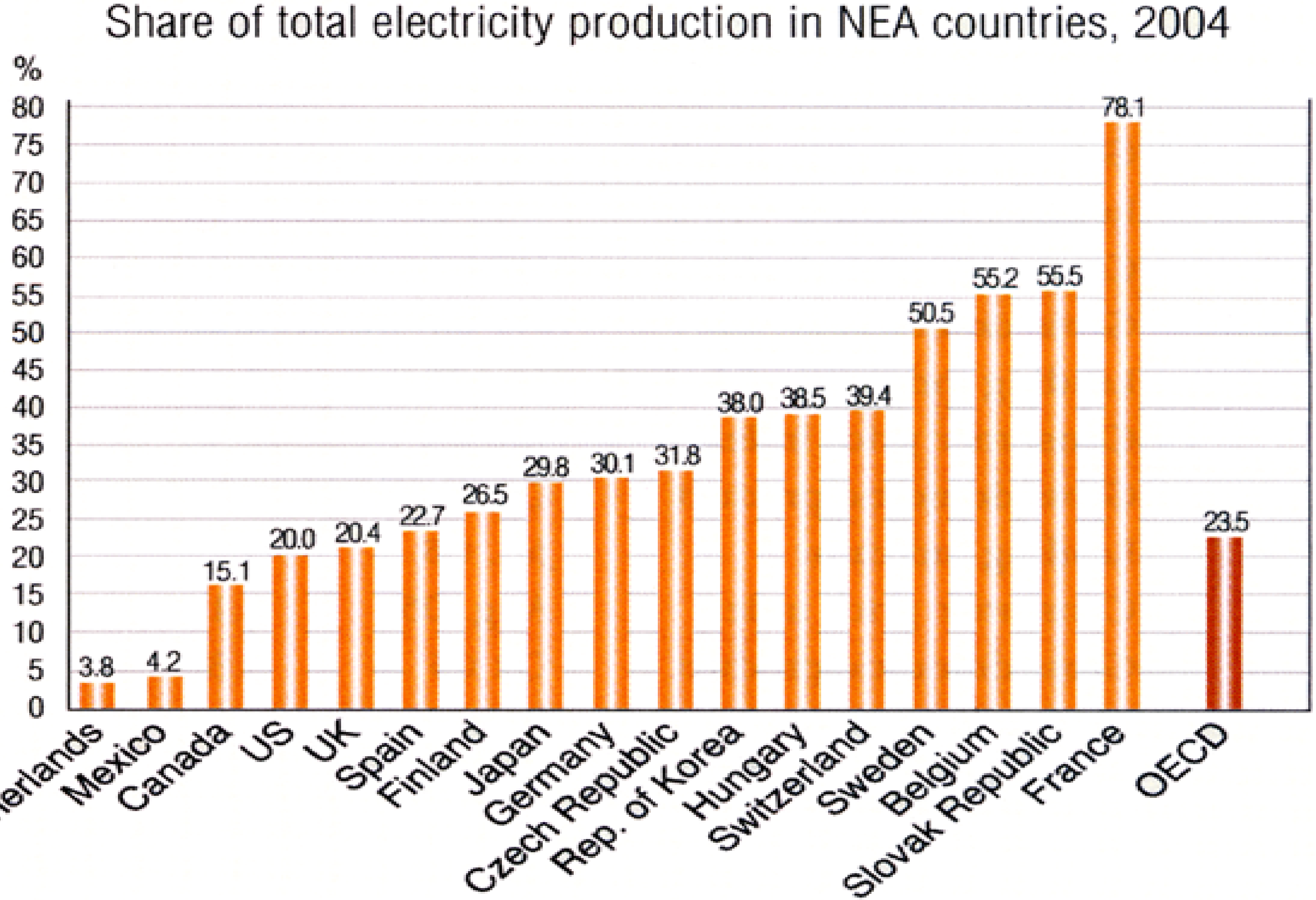
Ultracentrifugation



- The number of separation steps required is much lower in ultracentrifugation than in gaseous diffusion for identical levels of enrichment.
- Isotopic separation is achieved by rotating cylinders containing the UF6 gas at very high speed. Through centrifugal force, the heaviest particles concentrate at the edges of the cylinder while the lighter particles migrate towards the center, creating isotopic separation.
- The UF6 gas is fed in and removed by scoops at either end of the cylinder. This creates a counter-current along the vertical rotational axis of the centrifuge which converts the radial isotopic gradient into an axial gradient.
- With this optimized axial current, a centrifuge works rather like a distillation column: the current flowing upwards is gradually enriched with U-235, while the downward current is depleted.

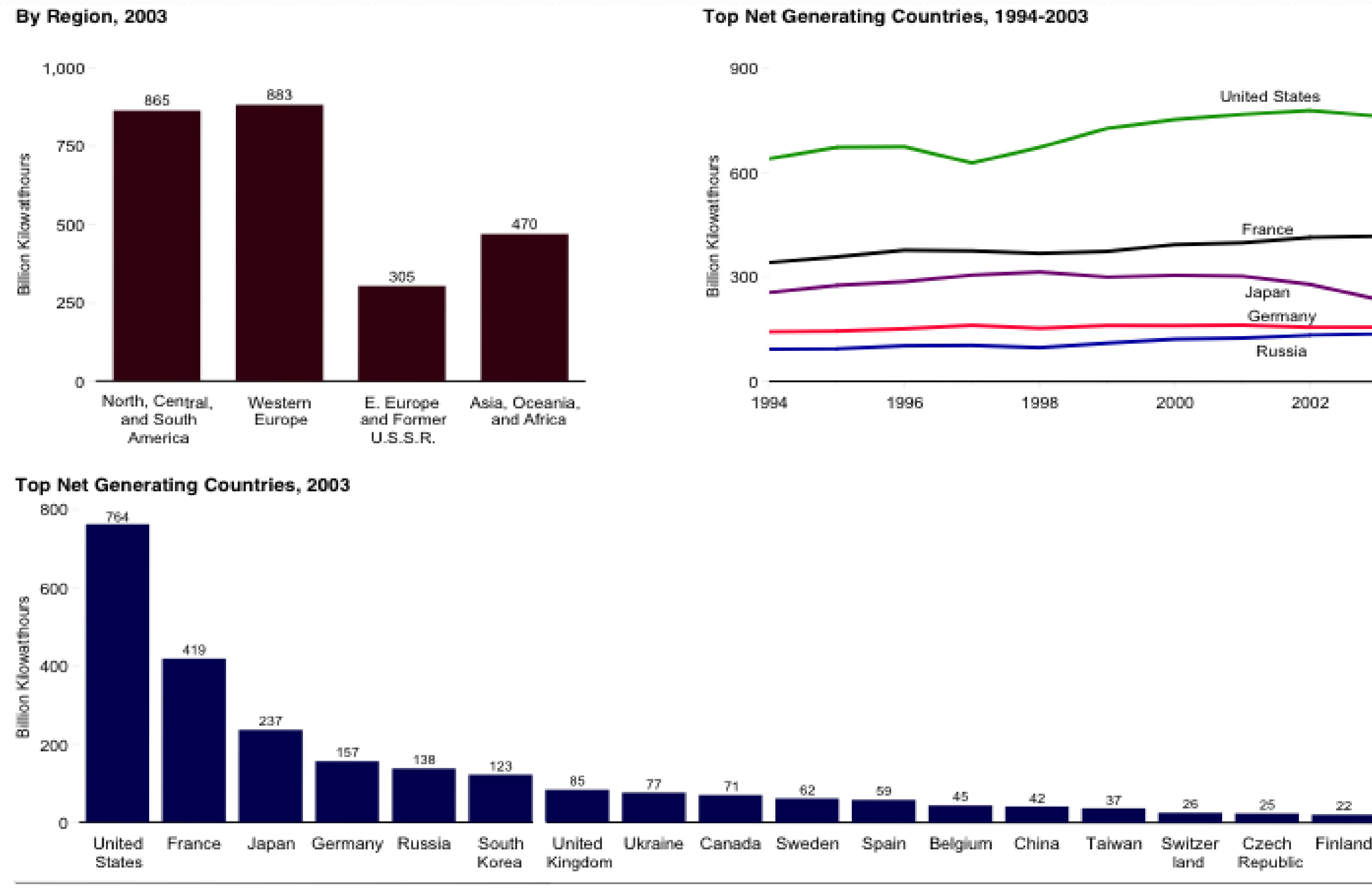
Centrifuges

Nuclear Energy



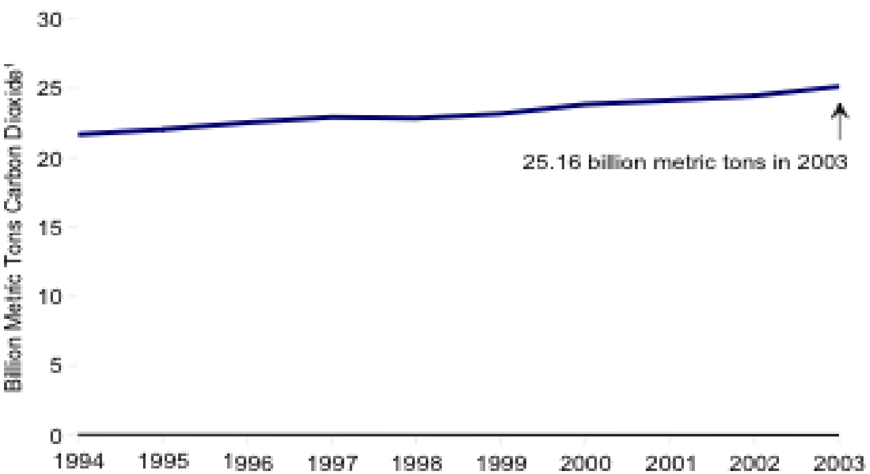
Source : OECD NEA (2005), *Nuclear Energy Data*, ISBN 9264011013.

World Nuclear Electricity Net Generation

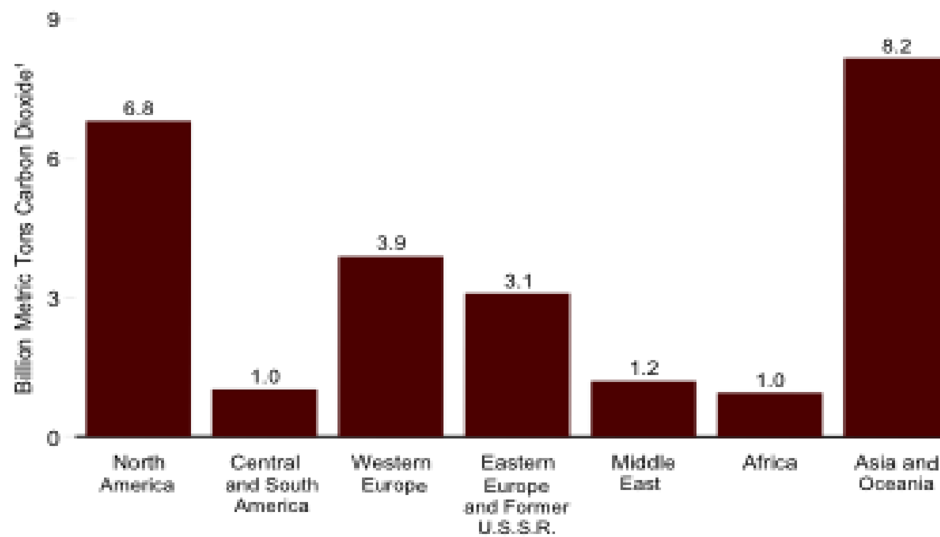


World Carbon Dioxide Emissions From Energy Consumption

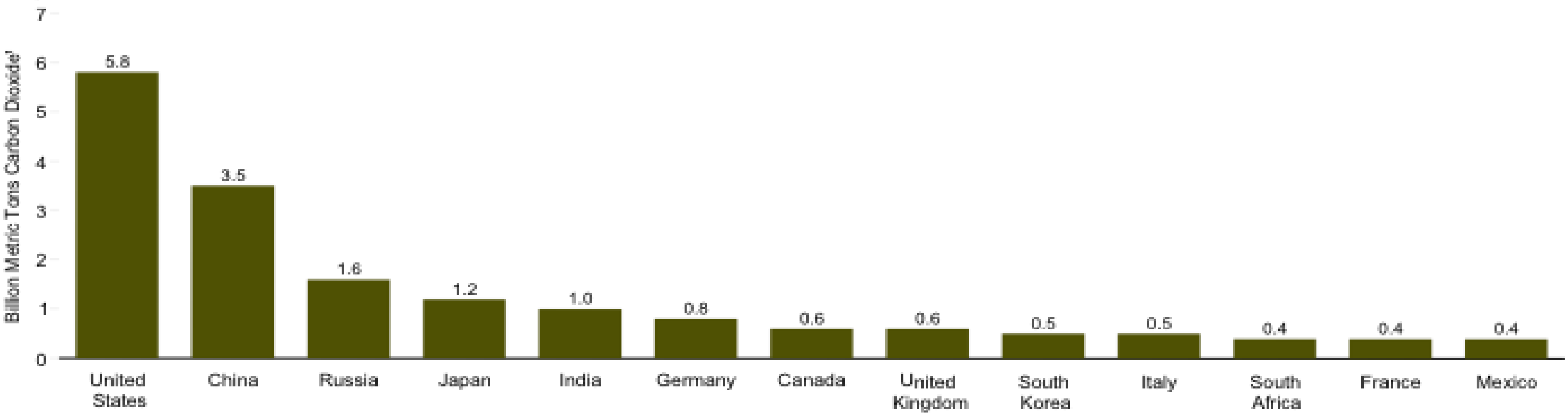
World, 1994-2003



World by Region, 2003



Top Countries, 2003



[1] Metric tons of carbon dioxide can be converted to metric tons of carbon equivalent by multiplying by 12/44.

Notes: • Data include carbon dioxide emissions from fossil-fuel energy consumption and natural gas venting and flaring. • Because vertical scales differ, graphs should not be compared.

Source: Table 11.19.

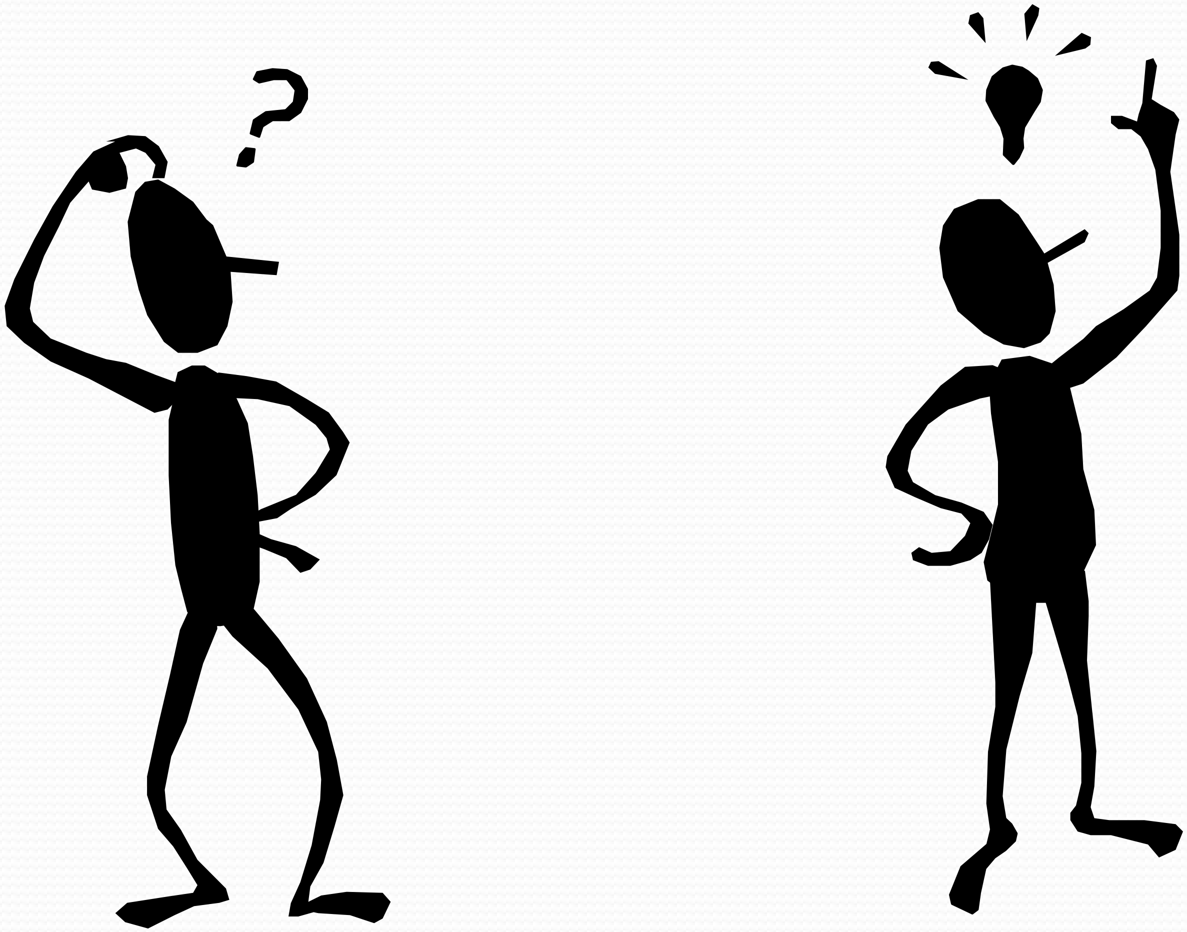
Energy Information Administration / Annual Energy Review 2004

Assignment

- **Is nuclear (fission) power sustainable? Why?**

  Please include in your answer technological, economical, environmental, health and safety, political, social and ethical arguments.

Q & A



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INSTITUTE OF SCIENCE AND TECHNOLOGY

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