# Nuclear Energy



## Introduction to the lecture

- Nuclear energy lecture provides an overview of fundamentals of nuclear energy, nuclear history, nuclear reactor, nuclear power plant, fuel cycle, radioactivity, nuclear waste, nuclear recycling, and journey of uranium from mine to reactor (i.e. mining, milling, conversion and enrichment.
- This lecture discusses the mechanism of a reactor, components of a reactor, and types of reactor. It also provides knowledge on the electricity generation from a reactor.



## Introduction to the lecture

- This lecture focuses on the nuclear waste, waste composition, recycling, nuclear accident (Three Mile Island, Chernobyl and Fukushima), disadvantage and advantages of nuclear energy.



## Aim and Learning outcomes

- This lecture aims to provide core knowledge of nuclear power plant and to develop a critical awareness of the nuclear basics, reactor basics, reactor operation and design, waste disposal, and key issues relating to health and safety.
- On completion of lecture Nuclear Energy, students will be able to:
  - Know the fundamentals and history of nuclear energy.



## Aim and Learning outcomes

- On completion of lecture Nuclear Energy, students will be able to:
  - Identify and discuss the purpose of key components of nuclear power plant for a variety of different configurations.
  - Identify and discuss the purpose of key components of nuclear power plant for a variety of different configurations.
  - Have a critical understanding of nuclear plant health, safety and environmental issues



## Hiroshima - Before – During

# Hiroshima - After - Bombing

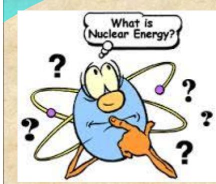


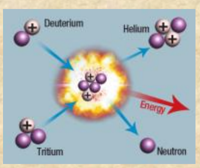

# Talk outline

- Introduction – Nuclear Energy
- Nuclear History
- Nuclear Reactor
- Nuclear Power Plant
- Fuel Cycle
- Radioactivity
- Nuclear waste
- Nuclear recycling
- Fast and Thermal Reactor
- Nuclear Accident
- Environmental Safety



# Overview of Nuclear Power – What is Nuclear




- Nuclear energy is natural resources that turn into heat and electricity
- We can extract more heat and electricity from a given amount of it than from an equivalent amount of anything else
- A chunk of coal and chunk of natural uranium, both weighing the same (1 kg)
- If we could suck all the energy out of the coal, it would run a 100W light-bulb for about 4 days



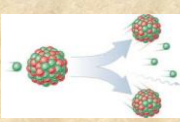
# Overview of Nuclear Power – What is Nuclear


- Uranium-run the bulb for about 180 years
- Sucked all the energy from uranium, the light bulb could burn for 24,000 years
- Nuclear reactors produce energy without releasing any pollutants into the environment.



# Overview of Nuclear Power – What is Nuclear

## So why do we still use coal or anything else ?????

- The reactors to split atoms and release the energy are mostly large, complicated, and expensive
- However, Once built, reactor operation costs very little
- Buying a few tonnes of uranium every 4 years is much cheaper than buying weekly trainloads of coal
- The high cost of constructing nuclear reactors has caused much financial trouble for nuclear energy



# Overview of Nuclear Power – What is Nuclear

## So why do we still use coal or anything else ?????


- Several facilities involved in the nuclear fuel cycle can be used to produce materials that could be used in nuclear weapons
- Enrichment plants can theoretically produce weapons-grade material along with reactor-grade
- Recycling plants separate plutonium from nuclear waste, which can be stolen and used in bombs
- This fact complicates progress in advanced nuclear technology, politically

## Overview of Nuclear Power – What is Nuclear

### So why do we still use coal or anything else ?????



- The relatively small amount of nuclear fuel that goes into reactors becomes very nasty radioactive **nuclear waste** when it comes out.
- The nature of **radioactive** waste is terrifying to all -- you can't see it, smell it, or taste it, but it can be in the room **hurting you**
- Nuclear scientists **know ways** to turn this waste into something that decays to harmlessness
- But the processes developed so far are expensive and challenging.



## Overview of Nuclear Power – What is Nuclear

### So why do we still use coal or anything else ?????

- Nuclear power is perceived as dangerous because of the accidents at Fukushima, Chernobyl, and Three Mile Island
- These high-profile accidents compared to those associated with coal and gas
- However, where coal and gas usually only kill or injure coal miners and gas refinery workers,
- Nuclear accidents are indiscriminate



## Overview of Nuclear Power – What is Nuclear

### So what do you think ?????




## Promise and Problems of Nuclear Energy

**Dhiman Roy PhD**

**Date: November 3, 2013**



## Talk outline

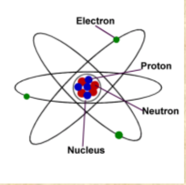
- Introduction – Nuclear Energy
- Nuclear History
- Fuel Cycle
- Nuclear Reactor
- Nuclear Power Plant
- Radioactivity
- Nuclear waste
- Nuclear recycling
- Fast and Thermal Reactor
- Nuclear Accident
- Environmental Safety

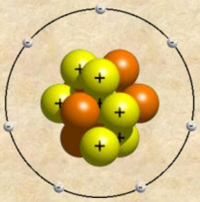


## What is Nuclear Energy?


- Nuclear energy comes from mass to energy conversion
- Splitting heavier atom
- Joining smaller atoms
- Follows Einstein's formula $E=MC^2$ ; M= mass, C= speed of light

## What is Nuclear Energy - Atom

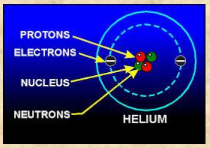


- An atom is the basic unit of an element.
- An atom is a form of matter which may not be further broken down using any chemical means.
- A typical atom consists of protons, neutrons and electrons.
- Hydrogen, helium, oxygen and uranium are examples of atoms.



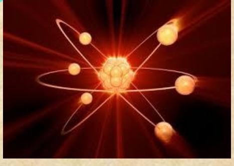
## What is Nuclear Energy – Atom Characteristics




- Each proton has a positive electrical charge and electron—negative electrical charge
- Each neutron is electrically neutral
- The nucleus of an atom contains protons and neutrons.
- The nucleus carries a positive electrical charge.



## What is Nuclear Energy?



- 1930s and '40s, recognized as a potential energy as a weapon.
- Technology developed used this energy in a chain reaction
- To create bombs
- We will discuss this history……

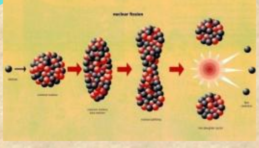


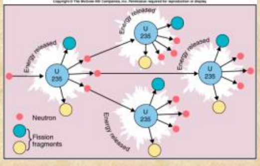
## What is Nuclear Energy - Today

- Nuclear reactor produce 20% and 76% electricity in the USA and France respectively
- They produce electricity without emitting any pollutants into atmosphere
- However, they create radioactive nuclear waste



## Nuclear Energy- Fission and Fusion

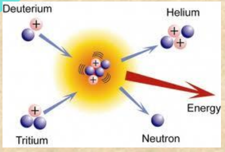


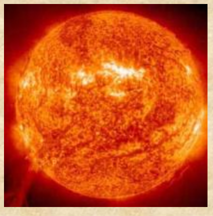


- Fission is the splitting of a large atom such as Uranium or Plutonium
- Into two smaller atoms, called fission products
- During fission---release---Neutrons +Energy
- That enable chain reaction
- All commercial nuclear plants use fission reaction to generate electricity



## Nuclear Energy- Fission and Fusion



- Fusion is the combining of two small atoms such as Hydrogen or Helium
- To produce heavier atoms and energy
- These energy can release more energy than fission
- Without producing radioactive by products
- This type of reaction occur in sun
- Using hydrogen as a fuel and producing helium as a waste

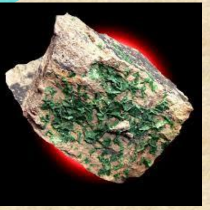
## Energy Density of Various Fossil Sources

How long a 100 Watt light bulb could run from using 1 kg of various materials

| Material | Energy Density (MJ/kg) | 100W light bulb time (1kg) |
|---|---|---|
| Wood | 10 | 1.2 days |
| Ethanol | 26.8 | 3.1 days |
| Coal | 32.5 | 3.8 days |
| Crude oil | 41.9 | 4.8 days |
| Diesel | 45.8 | 5.3 days |
| Natural Uranium | $5.7 \times 10^5$ | 182 *years* |
| Reactor Grade Uranium | $3.7 \times 10^6$ | 1171 *years* |



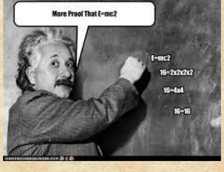
## Cont'd




- Natural Uranium has undergone no enrichment – 0.7% U-235 and 99.03% U-238
- After processing reactor grade uranium has 5% U-235
- However, 1 kg weapons grade uranium has 95% U-235
- Need to know mining, processing and milling of uranium



## History of Nuclear energy



- **What about Nuclear History**

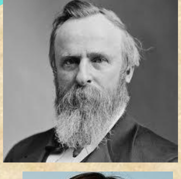



## History of Nuclear Energy


- No scientific work started aiming nuclear energy product
- Actually, Roentgen discovered the X-ray (1895)
- Foundation of medical technology
- In France one scientist noticed - ray emitted spontaneously from Uranium salt
- Maries curie and her husband identify radioactivity from element- polonium and Radium



## History of Nuclear Energy




- Then Rutherford discovered two types rays; alpha and beta
- Hahn and Strassman shoot neutrons at uranium atoms and saw some strange behaviors
- Meitner and her nephew identify fission; releasing energy
- Szilard recognized that fission as a potential way to get energy through chain reaction



## History of Nuclear Energy


- Szilard and others wrote a letter to USA president Roosevelt, warning of nuclear energy (with Einstein sign)
- Roosevelt authorized a small study into uranium
- Fermi (1942) successfully created first man made uranium chain reaction
- Manhattan project on nuclear energy started

## History of Nuclear Energy

- Finally, they got nuclear energy in the form of two bombs
- One by Uranium and another by plutonium
- Then you saw the first use of that nuclear power in the form of bombing at Hiroshima and Nagasaki (world war-II)
- Atomic bomb- Little Boy and Fat Man
- Public realized that the US developed bombs



## Fission energy- Application

- An experimental liquid-metal cooled reactor in Idaho called EBR-I was attached to a generator in 1951, producing the first nuclear-generated electricity
- Admiral Rickover pushed to use reactors to power submarines, since they wouldn't need to refuel, or to use oxygen for combustion



## Fission energy- Expansion

- Through the 60s and 70s, lots of nuclear reactors are built for making electricity
- They work well and produce cheap, emission-free electricity with a very low mining and transportation
- In 1974, France decided to make a major push for nuclear energy, and ended up with 75% of their electricity coming from nuclear reactors



## Fission energy- Expansion

- The 1979 Three Mile Island accident and the 1986 Chernobyl accident further slowed the development of nuclear reactors
- Tighter regulations brought costs higher



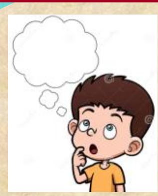
## Why/what need to know????



- But the things how you will get uranium?
- From where you will get these uranium?
- Is it possible to use uranium just after mining?
- If not or the answer is not known then we need to go for some fundamentals talk like--- mining ---- milling----- conversion----- enrichment.



## Why need to know????




- So, let's go to see the mining and processing of uranium
- Then we will go– how to use this uranium to get huge energy to upgrade your life style.....

## A Journey of Uranium from Mine to Reactor

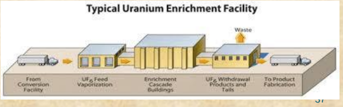
- Life cycle of Uranium involves

  **Mining**

  **Milling**

  **Conversion and**

  **Enrichment**





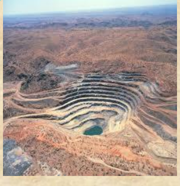

## A Journey – Need Separation Process

- Uranium is mined can not be fed directly into nuclear power station
- Uranium contain chemical impurities U-235 – 0.7%; U-238 isotopes 99.3%
- Therefore, a number of chemical and physical separation processes are required to convert uranium ore to optimized nuclear fuel

**Mining ----- Milling ----- Conversion ------ Enrichment**



## A Journey – Need Separation Process



- Uranium ore exploration: Activities related to finding and development of the uranium ores for uranium production
- Uranium ore mining: activities related to the extracting uranium ore from ground
- Uranium ore processing: activities related to the milling and refining of the ore to produce uranium concentrates including in-situ leaching

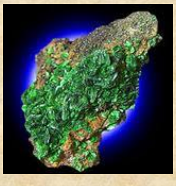


## A Journey – Need Separation Process

- Conversion: activities related to the refining and conversion
- Enrichment: related to the isotopic enrichment of UF6 to obtain enriched U-235
- Uranium fuel fabrication: related to the production of nuclear fuel to be inserted in the nuclear reactor



## A Journey – Uranium Abundance, Occurrence



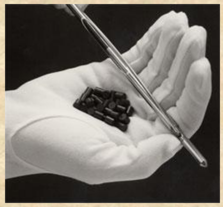
- Abundance: average concentration of U in the crust is 2-4 ppm
- U is more abundant (4 times) than antimony, cadmium, silver
- Occurrence: occurs in hundreds of minerals– Uranite, autinite, monazite sands and associated as Rare Earth Elements (REEs)
- Deposits: vein in granite rocks; sandstone deposits, porphyry deposit



## A Journey – Uranium

- Oil, coal, natural gas, and uranium are energy resources, for electricity generation
- The fuel for a nuclear power plant is uranium, which is relatively abundant in the Earth's crust
- Uranium is 500 times more common than gold and about as common as tin.

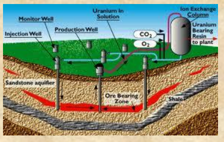
## A Journey – Uranium



- Natural uranium consists of the isotopes U-238 (approx. 99.3%) and U-235 (approx. 0.7%), and traces of U-234
- Natural uranium is not dangerous from a purely radiation point of view,
- But it is a chemically toxic, heavy metal that is hazardous if allowed to enter the body.



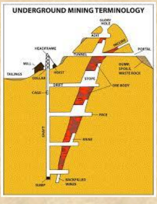
## A Journey – Uranium-Mining (extraction)



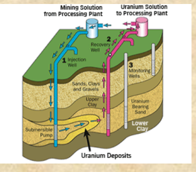

- Uranium is extracted from the Earth's crust in different ways, Open Pit Mining, Under-ground Mining and In-Situ Leaching.
- The choice depends on relative costs and factors such as size, shape, depth, and concentration of the ore deposits
- Several substances are often extracted from the same mine in order to achieve a profitable operation.



## A Journey – Uranium-Mining - Methods




- There are three basic methods of obtaining uranium from ores:
  - Open pit mining
  - Underground mining
  - In-situ Leaching






## A Journey – Uranium - Open pit mining

- Open-pit mining, open-cut mining or opencast mining is a surface mining technique of extracting rock or minerals from the earth by their removal from an open pit or borrow
- The ore is hauled to a mill for milling

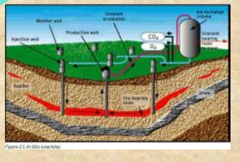


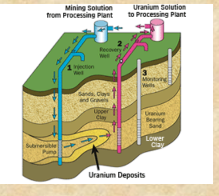
## A Journey – Uranium – Underground mining

- Underground mining (soft rock) refers to a group of underground mining techniques used to extract coal, oil shale and other minerals or geological materials from sedimentary rocks
- The ore is hauled to a mill for milling



## A Journey – Uranium – In-situ Leaching






- A large number of vertical bore holes to introduce a leaching solution and to extract it from shallow deposit between impermeable layers (??-migration)
- 36% world production
- Dissolution of uranium
- Injection wells pump a weak solvent across ore deposit
- Remove loaded solvent
- Uranium removed by solvent extraction

## A Journey – Uranium-Milling

- Delivery of ore to processing plant by trucks or conveyors
- Primary and secondary crushing to provide a fine powder
- Leaching of U from solid by acid to separate U from many insoluble impurities
- Filtration and clarification of U solid and other elements; send to a trailing pond



## A Journey – Uranium-Milling

- Treated with ammonia to yield a uranium dioxide powder with U content approximately 70%
- Known as "yellow cake"
- Packing in 200 liter steel drums for delivery to customer



## A Journey – Uranium- Conversion

- The uranium concentrate, must be further refined before it can be used as fuel for nu- clear reactors
- Nitric acid is added, yielding a uranyl nitrate solution
- Solids are extracted from the uranyl nitrate solution in three steps



## A Journey – Uranium- Conversion

- Water is vaporized, yielding a concentrated uranyl nitrate hexahydrate solution
- Concentrated uranyl nitrate hexahydrate is heated to yield uranium trioxide (UO3)



## A Journey – Uranium- Conversion

- Hydrofluoric acid is added to uranium trioxide (UO3) to yield uranium tetrafluoride (UF4)
- Then UF4 reacts with fluorine gas to yield hexa fluoride gas (UF6)
- The UF6 gas is passed through several filters and finally through cold traps, and collected as crystalline UF6
- The UF6 is liquefied by heating and drained into specially designed steel cylinders for shipment



## A Journey – Uranium- Enrichment

- Most nuclear reactors require fuel with a U-235 content of 3–5%
- At 65°C and warmer UF6 is a gas and can be enriched either by gaseous diffusion or by gas centrifugation
- Both processes enrich UF6 from 0.7% U-235 to the required level (the rest of the uranium is U-238)

## A Journey – Uranium- Fabrication

- The uranium arrives as enriched, solid $UF_6$ at the fuel fabrication facility
- It is heated into gaseous state.
- Ammonia, gaseous oxygen, and gaseous hydrogen are added to yield uranium dioxide powder
- The $UO_2$ powder is compressed into cylindrical pellets weighing 6–7 grams.

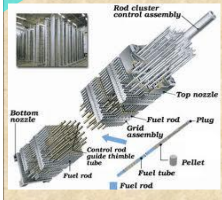


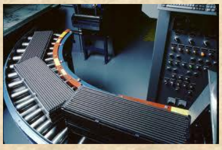
## A Journey – Uranium- Fabrication

- The pellets are entered to a structure resembling ceramics
- 300–370 of them are placed in zirconium alloy (zircaloy) tubes
- Zircaloy is an alloy of zirconium (98%), tin (1,5%), and small amounts of iron, nickel, and chromium.



## A Journey – Uranium- Fabrication

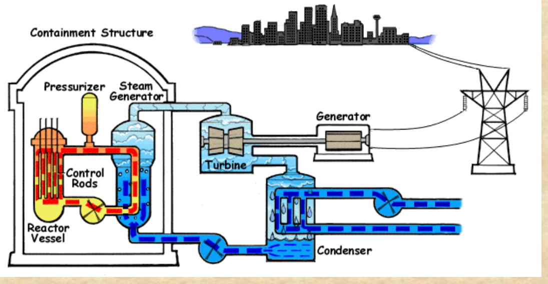


- The tubes are pressurized with helium and sealed to form fuel rods
- Then bundled into fuel assemblies
- A boiling water reactor (BWR) holds between 400 and 700 fuel assemblies comprising a maximum of 70 000 fuel rods
- A pressurized water reactor (PWR) holds some 160 fuel assemblies with a maximum of 42 000 fuel rods.



# Mechanism of a Reactor



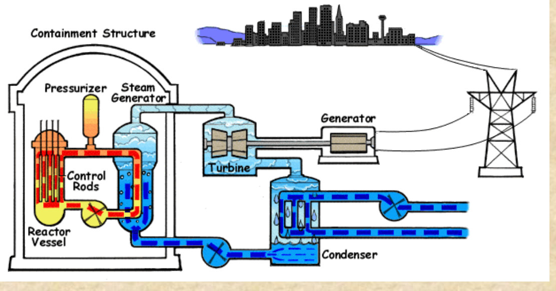



## What is a Nuclear Reactor

- A nuclear reactor is a system that contains and controls sustained nuclear chain reactions
- Reactors are used for generating electricity, moving aircraft carriers and submarines etc
- Fuel-- made up of heavy atoms that split when they absorb neutrons, is placed into the reactor vessel (basically a large tank) along with a small neutron source.

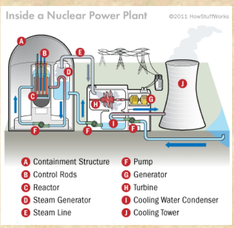


## Nuclear Reactor: Components




- Core, Coolant, Turbine, Containment, Cooling Tower

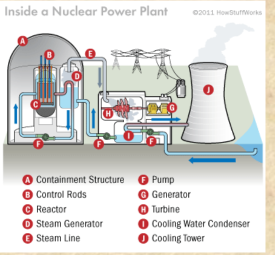
## Nuclear Reactor: Components




- **Core:** of the reactor contains all of the nuclear fuel and generates all of the heat
- **Coolant:** is the material that passes through the core, transferring the heat from the fuel to a turbine. It could be water, heavy-water, liquid sodium, helium, or something else
- **Turbine:** transfers the heat from the coolant to electricity, just like in a fossil-fuel plant.



## Nuclear Reactor: Components




- **Containment:** is the structure that separates the reactor from the environment
- These are usually dome-shaped, made of high-density, steel-reinforced concrete
- **Cooling Tower:** are needed by some plants to dump the excess heat that cannot be converted to energy



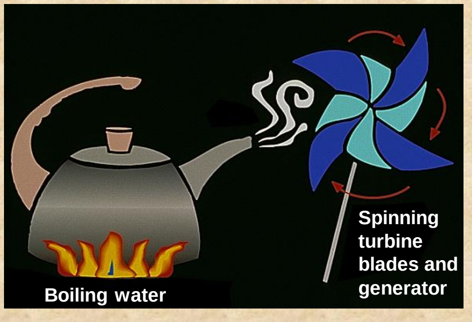
## Nuclear Reactor: Types

- There are very many different types of nuclear reactors with different fuels, coolants, fuel cycles, purposes--

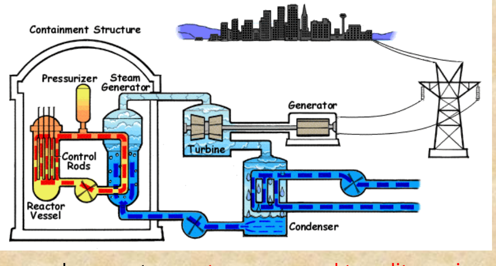
- Pressurized water reactor
- Boiling water reactor
- Sodium cooled fast reactor
- Liquid Fluoride thorium reactor
- Canada Deutorium-Uranium reactor
- High temperature gas cooled reactor



## Idea of a Nuclear Power Plant



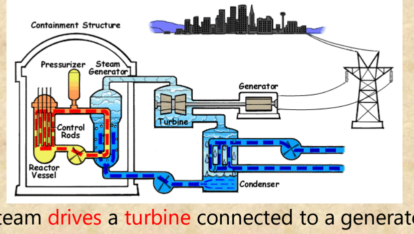

## Mechanism of Reactor – Electricity Generation



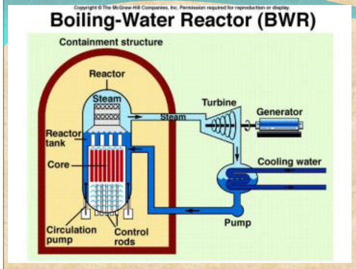

- In a nuclear reactor neutrons are used to split uranium nuclei
- The energy is transformed to heat,
- Which in turn is used to heat the water in the reactor.



## Mechanism of Reactor – Electricity Generation

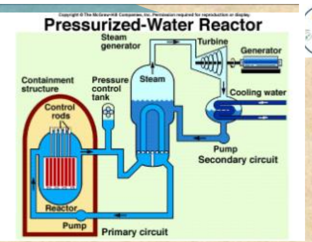



- The steam drives a turbine connected to a generator
- Which converts the energy to electricity
- After passing through the turbine the steam is condensed to water in a condenser
- Through heat exchange with a cooling agent (seawater), and after filtering the water is re-circulated into the reactor.




➢The heat generated by the fission of or uranium releases energy that heats water to produce steam to turn turbines to generate electricity.

➢ In addition to fuel rods containing uranium, reactors contain control rods of cadmium, boron, graphite, or some other non-fissionable material used to control the rate fission by absorbing neutrons.



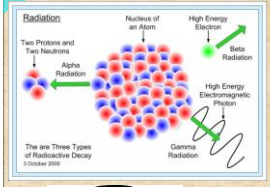

➢ In the PWR (70% of reactors in the world) the water is kept under high pressure so that steam is not formed in the reactor

➢ Such an arrangement reduces the risk of radiation in the steam but adds to the cost of construction by requiring a secondary loop for the steam generator.

# Nuclear Waste




## Nuclear Waste - Radioactivity





➢ Radioactivity is the emission of energetic particles or waves from atoms

➢ Natural radiation occurs when unstable nuclei transform to some other nucleus by emitting radiation

➢ Alpha, Beta and Gamma radiation



## Nuclear Waste

➢ Nuclear waste is the material that nuclear fuel becomes after it is used in a reactor

➢ It looks exactly like the fuel that was loaded into the reactor

➢ But since nuclear reactions have occurred, the contents aren't quite the same

➢ Before producing power, the fuel was mostly Uranium (or Thorium),



## Cont'd

➢ Afterwards, many Uranium atoms have split into various isotopes

➢ The waste, sometimes called spent fuel, is dangerous radioactive, and remains so for thousands of years

➢ When it first comes out of the reactor, it is so toxic

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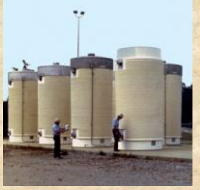


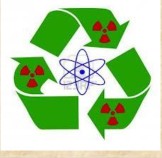
- After about 3-4 years of use, the Fuel rods become spent-level of fission drops beneath a certain level
- Rods are taken out of reactor stored nearby in water filled pools
- Stored until they cool down enough to be shipped for permanent storage or to be recycled
- These storage facilities are next to the reactor plants, vulnerable to terrorist attack or accidents

## Nuclear Waste - Composition

| | Charge | Discharge |
|---|---|---|
| Uranium | 100% | 93.4% |
| Enrichment | 4.20% | 0.71% |
| Plutonium | 0.00% | 1.27% |
| Minor Actinides | 0.00% | 0.14% |
| Fission products | 0.00% | 5.15% |

Heavy metal composition of 4.2% enriched nuclear fuel before and after running for about 3 years. Minor actinides include neptunium, americium, and curium.

## Nuclear Waste - Recycling



- Nuclear waste is recyclable
- Once Uranium fuel is used in a reactor, it can be treated and put into another reactor as fuel
- In fact, typical reactors only extract a few percent of the energy in their fuel



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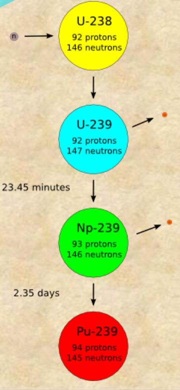


- The "useless" U-238 is the secret to recycling nuclear fuel
- When it absorbs a single neutron, it goes through a series of nuclear reactions and turns into isotope of Plutonium, Pu-239
- Then it is possible to use that Pu-239 to continue powering reactor
- When a nucleus has more neutrons than it would like to have, it often beta-decays by breaking a neutron into a proton and an electron.



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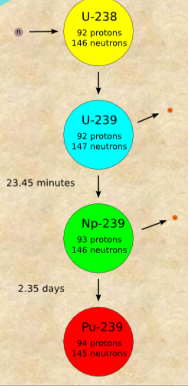



- When U-238 absorbs a neutron in a nuclear reactor, it becomes U-239
- Which is just the isotope of Uranium with one extra neutron than U-238
- This beta-decays quickly and becomes Np-239
- Then, the Np-239 beta-decays again to become Pu-239
- Which is a fissile isotope that can power nuclear reactors.



## Nuclear Accident

- Let's investigate why the nuclear power industry has not grown, despite it's obvious promise. We should begin with the dangers of nuclear power.
- **Myth**: The risk of explosion is the greatest problem with nuclear plants
  - **Fact**: Nuclear plants can't blow up like nuclear bombs because of the distribution of material and insufficient enrichment of uranium-235
  - Human error is the biggest threat (i.e. **Chernobyl** and **Three Mile Island**)
    - In the two examples above, a loss of cooling water lead to overheating, which caused the core to melt.
      - Meltdown can result in the release of radioactive material

## Nuclear Accident

- Three major accidents
  - Three mile island accident (1979)
  - Chernobyl accident (1986)
  - Fukushima accident (2011)



## Nuclear Accident - Three mile island accident

- The first ever incident of reactor meltdown in nuclear power history in the USA on 28 March 1979
- The accident began with a malfunction in the secondary cooling circuit
- Due to misleading instrumentation, the operator made an incorrect response which finally led to a loss of reactor cooling and a partial meltdown of the fuel in the reactor
- Residents nearby took initiatives and evacuated themselves temporarily after the incident
- There was no reported case of injury or death



## Nuclear Accident - Chernobyl

- Explosions occurred at Chernobyl Nuclear Power Plant in the former Union of Soviet Socialist Republics (USSR) on 26 April 1986.
- The large amount of radioactivity subsequently released affected areas as far as several hundred kilometers away from the plant
- These resulted in a steam explosion within the reactor
- Within a few weeks, the accident had caused the deaths of 30 workers and radiation injuries to over a hundred others
- Some 335,000 people were evacuated. At present, apart from approximately 7,000 cases of thyroid cancer recorded



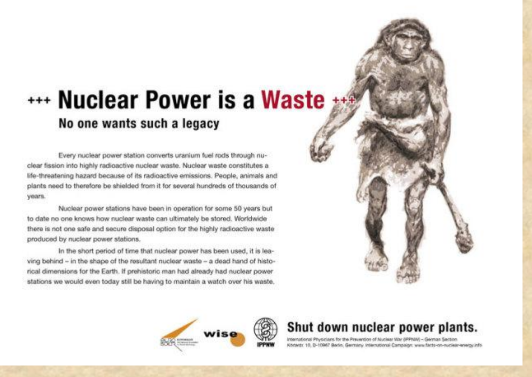
## Nuclear Accident - Fukushima

- On 11 March 2011, a Richter Scale 9 earthquake triggered a massive (15m) tsunami east of Sendai in Japan
- Which disabled electric power in five out of six generating units at Fukushima Daiichi Nuclear Power Plant in Japan
- Although Units 1 to 3 of the plant have automatically shut down at the earthquake
- The loss of electric power for reactor cooling eventually led to the meltdown of the nuclear reactors
- Around 100,000 people up to 40km were evacuated..



## Disadvantage of Nuclear Power


- Possibly catastrophic accidents
- Nuclear waste dangerous for thousands of years
- Risk of nuclear proliferation associated with some designs
- High capital costs
- Long construction periods
- High maintenance costs
- High cost of decommissioning plants
- Designs of current plants are all large-scale

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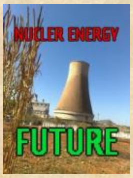
## Advantage of Nuclear Power


- Huge energy producing capability
- No greenhouse gas emissions during operation
- Does not produce air pollutants
- The quantity of waste produced is small
- Small number of major accidents
- Low fuel costs; Large fuel reserves
- Future designs may be small and modular

## Group Discussion

### Topic:

**Nuclear power is a safe source of energy**

## Video on Nuclear Reactor

### How it is working