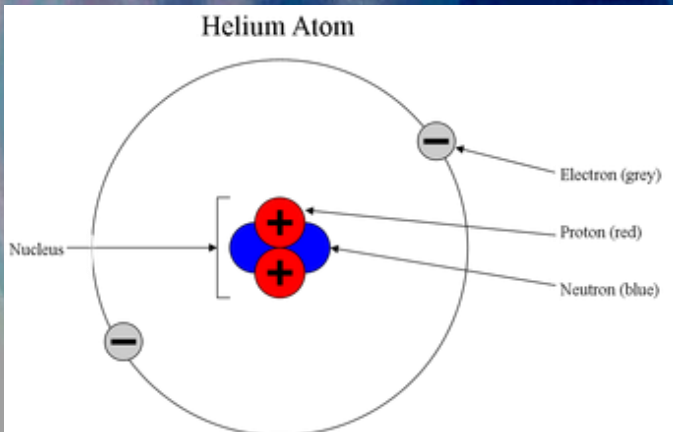
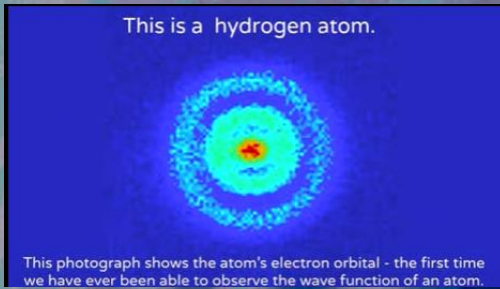
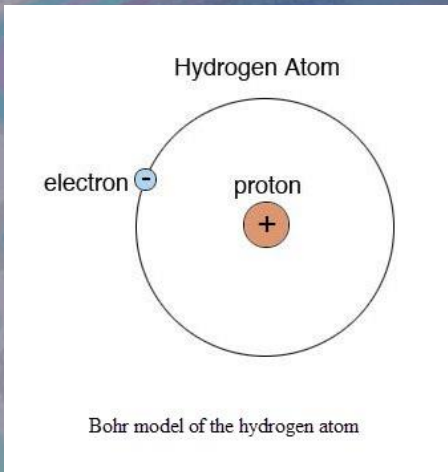


Background: The ATOM



The ATOM:

1. Smallest unit of all matter
2. Basic building block for everything around us
3. Atom size about $1/100,000^{\text{th}}$ the width of a hair

ATOMS consist of:

1. Protons (+) and Neutrons (0) in NUCLEUS
2. Electrons (-) orbiting the nucleus

WHAT HOLDS the ATOM TOGETHER?

1. 4 FORCES

1. Gravitational (all subatomic particles)
2. ELECTROMAGNETIC - Electrons & Protons
3. STRONG FORCE - Nucleus Protons & Neutrons
4. WEAK FORCE - within the proton and the neutron

= each FORCE is associated with ENERGY

Background: Elements

- Element = atoms all contain the same number of protons

Periodic Table of Elements

| | | | | | | | | | | | | | | | | | |
|---|------------------------------------|--|------------------------------------|---|-------------------------------------|-------------------------------------|---------------------------------------|--|--|--------------------------------------|---------------------------------------|---|---|--|--|--|----------------------------------|
| <div style="display: flex; justify-content: space-between;"> <div style="text-align: right;"> <p>Atomic Number → 7</p> <p>Chemical Name → NITROGEN</p> </div> <div style="border: 1px solid black; padding: 5px; text-align: center;"> <p>N</p> <p>14</p> </div> <div style="text-align: left;"> <p>← Chemical Symbol</p> <p>← Atomic Weight</p> </div> </div> | | | | | | | | | | | | | | | | | |
| <div style="display: flex; justify-content: space-between;"> <div style="width: 45%; text-align: center;"> <p>METALS</p> </div> <div style="width: 45%; text-align: center;"> <p>NON-METALS</p> </div> </div> | | | | | | | | | | | | | | | | | |
| 1 H HYDROGEN 1 | | | | | | | | | | | | | | | | | 2 He HELIUM 4 |
| 3 Li LITHIUM 7 | 4 Be BERYLLIUM 9 | | | | | | | | | | | | | | | 10 Ne NEON 20 | |
| 11 Na SODIUM 23 | 12 Mg MAGNESIUM 24 | | | | | | | | | | | | | | | 18 Ar ARGON 40 | |
| 19 K POTASSIUM 39 | 20 Ca CALCIUM 40 | 21 Sc SCANDIUM 45 | 22 Ti TITANIUM 48 | 23 V VANADIUM 51 | 24 Cr CHROMIUM 52 | 25 Mn MANGANESE 55 | 26 Fe IRON 56 | 27 Co COBALT 59 | 28 Ni NICKEL 59 | 29 Cu COPPER 64 | 30 Zn ZINC 65 | 31 Ga GALLIUM 70 | 32 Ge GERMANIUM 73 | 33 As ARSENIC 75 | 34 Se SELENIUM 79 | 35 Br BROMINE 80 | 36 Kr KRYPTON 84 |
| 37 Rb RUBIDIUM 85 | 38 Sr STRONTIUM 88 | 39 Y YTTORIUM 89 | 40 Zr ZIRCONIUM 91 | 41 Nb NIObium 93 | 42 Mo MOLYBDENUM 96 | 43 Tc TECHNETIUM 98 | 44 Ru RUTHENIUM 101 | 45 Rh RHODIUM 103 | 46 Pd PALLADIUM 106 | 47 Ag SILVER 108 | 48 Cd CADMIUM 112 | 49 In INDIUM 115 | 50 Sn TIN 119 | 51 Sb ANTIMONY 122 | 52 Te TELLURIUM 128 | 53 I IODINE 127 | 54 Xe XENON 131 |
| 55 Cs CESIUM 133 | 56 Ba BARIUM 137 | | | | | | | | | | | | | | | | |
| | | 72 Hf HAFNIUM 178 | 73 Ta TANTALUM 181 | 74 W TUNGSTEN 184 | 75 Re RHENIUM 186 | 76 Os OSMIUM 190 | 77 Ir IRIDIUM 192 | 78 Pt PLATINUM 195 | 79 Au GOLD 197 | 80 Hg MERCURY 201 | 81 Tl THALLIUM 204 | 82 Pb LEAD 207 | 83 Bi BISMUTH 209 | 84 Po POLONIUM 209 | 85 At ASTATINE 210 | 86 Rn RADON 222 | |
| 87 Fr FRANCIUM 223 | 88 Ra RADIUM 226 | | | | | | | | | | | | | | | | |
| | | 104 Rf RUTHERFORDIUM 267 | 105 Db DUBNIUM 268 | 106 Sg SEABORGHIIUM 271 | 107 Bh BOHRIUM 272 | 108 Hs HASSIUM 277 | 109 Mt MEITNERIUM 276 | 110 Ds DARMSTADIUM 281 | 111 Rg ROENTGENIUM 280 | 112 Cp COPECNIUM 285 | 113 Uut UNUNTRIUM 284 | 114 Uuq UNUNQUADIUM 289 | 115 Uup UNUNPENTIUM 288 | 116 Uuh UNUNHEXIUM 291 | 117 Uus UNUNSEPTIUM not yet observed | 118 Uuo UNUNOCTIUM 294 | |

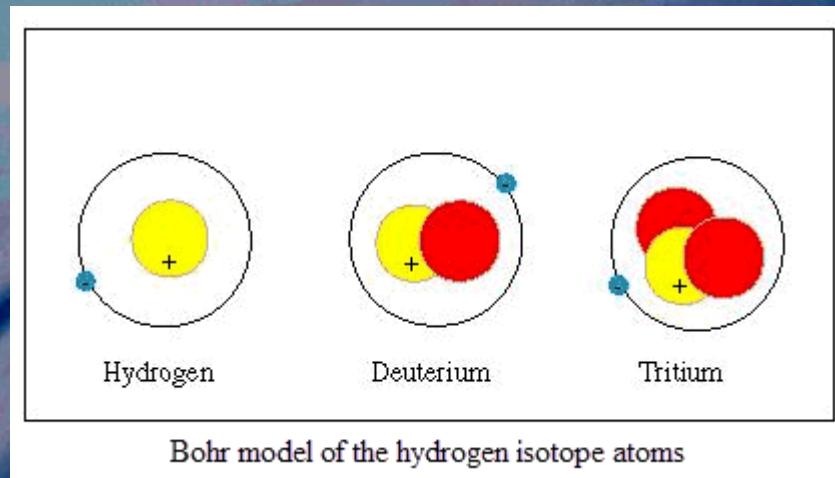
| KEY | |
|-----|----------------------|
| ■ | SOLID at room temp |
| 💧 | LIQUID at room temp |
| ☁ | GAS at room temp |
| ☢ | RADIOACTIVE |
| 🧪 | Artificially created |

| | | | | | | | | | | | | | | |
|-------------------------------------|-----------------------------------|--|-------------------------------------|--------------------------------------|-------------------------------------|-------------------------------------|--------------------------------------|-------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|--|-------------------------------------|---------------------------------------|
| 57 La LANTHANUM 139 | 58 Ce CERIUM 140 | 59 Pr PRASEODYMIUM 141 | 60 Nd NEODYMIUM 144 | 61 Pm PROMETHIUM 145 | 62 Sm SAMARIUM 150 | 63 Eu EUROPIUM 152 | 64 Gd GADOLINIUM 157 | 65 Tb TERBIUM 159 | 66 Dy DYSPROSIUM 163 | 67 Ho HOLMIUM 165 | 68 Er ERBIUM 167 | 69 Tm THULIUM 169 | 70 Yb YTTERIUM 173 | 71 Lu LUTETIUM 175 |
| 89 Ac ACTINIUM 227 | 90 Th THORIUM 232 | 91 Pa PROTACTINIUM 231 | 92 U URANIUM 238 | 93 Np NEPTUNIUM 237 | 94 Pu PLUTONIUM 244 | 95 Am AMERICIUM 243 | 96 Cm CURIUM 247 | 97 Bk BERKELIUM 247 | 98 Cf CALIFORNIUM 251 | 99 Es EINSTEINIUM 252 | 100 Fm FERMIUM 257 | 101 Md MENDELEVIUM 258 | 102 No NOBELIUM 259 | 103 Lr LAWRENCIUM 262 |



Background: Isotopes

- **Isotopes** = variations of a chemical element
 - Isotopes of an element have the same number of protons in each atom but different numbers of neutrons.



| Isotope | a.k.a | Atomic Weight | = | # Protons | + | # Neutrons |
|-----------------|--------------|---------------|---|-----------|---|------------|
| H (Protium) | ^1H | 1 | = | 1 | + | 0 |
| H-2 (Deuterium) | ^2H | 2 | = | 1 | + | 1 |
| H-3 (Tritium) | ^3H | 3 | = | 1 | + | 2 |

Background: Isotopes

- **Isotopes** = variations of a chemical element
- Isotopes of an element have the same number of protons in each atom but different numbers of neutrons.

Periodic Table of the Elements

Atomic Number
of Protons

Atomic Weight
the average Mass of all the Isotopes that exist for this natural element (Uranium)

| Isotope | a.k.a | Atomic Weight | = | # Protons | + | #Neutrons |
|---------|------------------|---------------|---|-----------|---|-----------|
| U-238 | ^{238}U | 238 | = | 92 | + | 146 |
| U-235 | ^{235}U | 235 | = | 92 | + | 143 |
| U-234 | ^{234}U | 234 | = | 92 | + | 142 |

Background: Radiation

- **Radiation** = ENERGY that is emitted or transmitted in the form of rays, electromagnetic waves, and/or particles.
- Radiation can be either non-ionizing (low energy) or IONIZING (high energy)

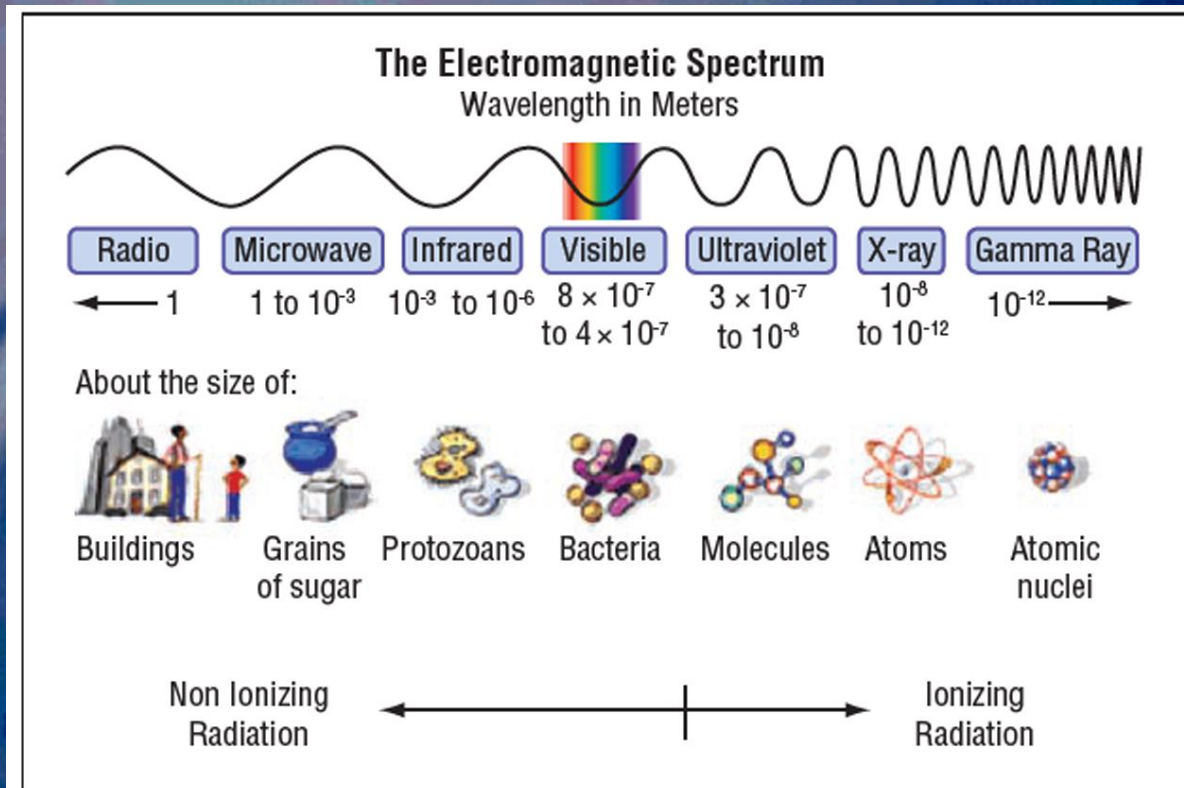


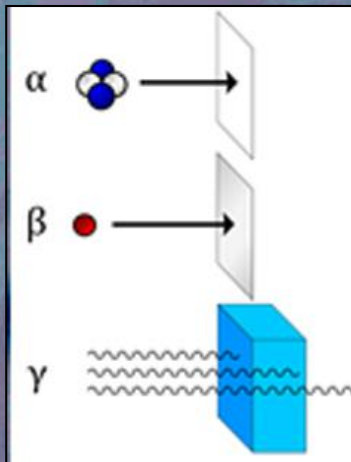
Image Credit: NASA.

http://www.nasa.gov/pdf/284273main_Radiation_HS_Mod1.pdf



Background: Radioactive Materials

- An atom is **STABLE** if the forces among the particles in the nucleus are balanced.
- An atom is **UNSTABLE** if the forces among the particles in the nucleus are unbalanced.
- When an atom is **UNSTABLE**, it will lose particles or energy to become **STABLE**.
- **Radioactive decay, radioactivity** - process by which the nucleus of an unstable atom loses **ENERGY** by emitting particles of **IONIZING RADIATION**.
- **IONIZING RADIATION** includes alpha particles, beta particles, and gamma rays



Paper stops an alpha particle (a Helium nucleus of $2p + 2n$)

Aluminum sheet stops a beta particle (an electron)

Lead & Dense Materials stop gamma rays (a photon)

A Material that contains unstable atoms which undergo radioactive decay is **Radioactive Material**



Background: Isotopes & Half-Life

- The **CHEMICAL PROPERTIES** of an elements **ISOTOPES** are similar and do not differ significantly. *
- The **NUCLEAR PROPERTIES** of an elements **ISOTOPES** do differ significantly.
- **STABLE ISOTOPES** do not undergo radioactive decay
- **UNSTABLE ISOTOPES** undergo radioactive decay - are "radioactive"
 - Referred to as "radionuclides"

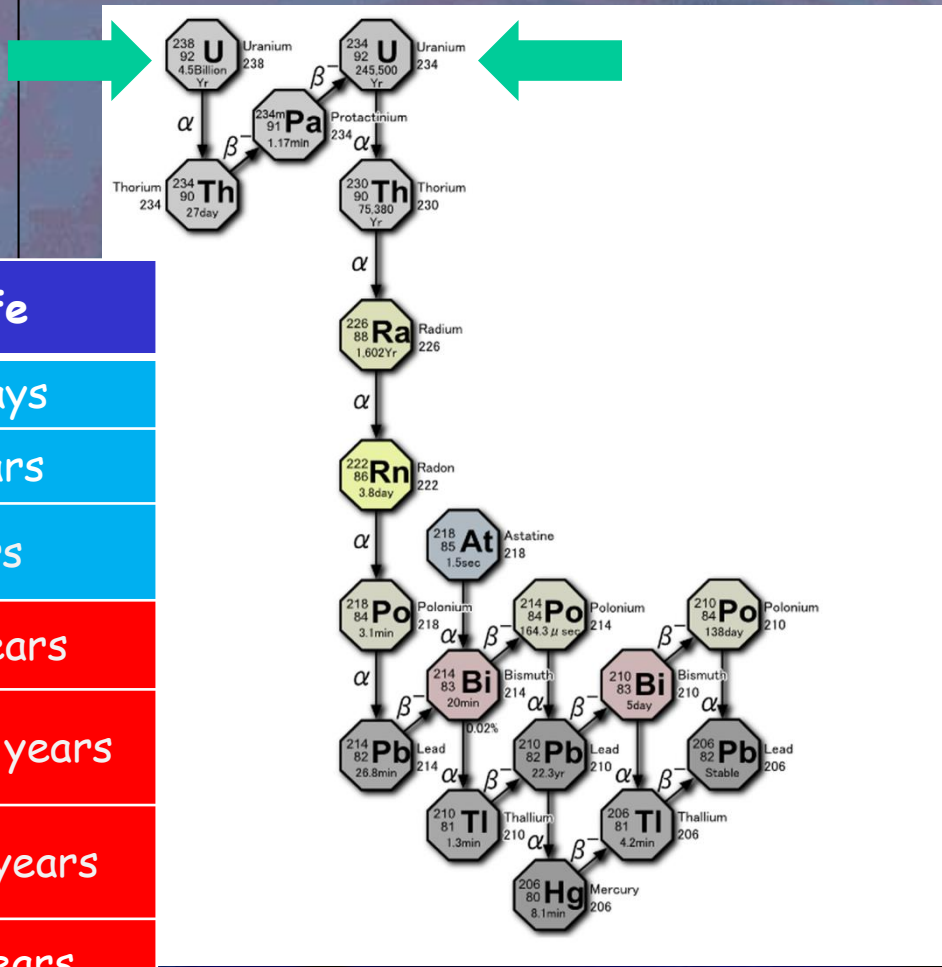
Background: Isotopes & Half-Life

- STABLE ISOTOPES do not undergo radioactive decay
- UNSTABLE ISOTOPES undergo radioactive decay - are "radioactive"
 - Referred to as "radionuclides"
- Each UNSTABLE ISOTOPE has:
 - A unique HALF-LIFE
 - The HALF-LIFE ($t_{1/2}$) of an isotope refers to the amount of time required for one-half of the atoms to undergo radioactive decay.
 - A unique DECAY CHAIN
 - = a series of ISOTOPES (daughter products) that are created as radioactive decay progresses.
 - A unique set of ENERGY emissions
 - Observed or measured as keV - meV emission spectra.
 - Alpha, Beta, Gamma, etc.
 - Measurement of emission spectra used to identify specific ISOTOPES in lab and field



Background: Isotopes & Half-Life

Complete U-238 DECAY CHAIN



| Isotope | Half-Life |
|--------------------------------|---------------------|
| Iodine-131 (¹³¹ I) | 8.0197 days |
| Tritium (³ H) | 12.32 years |
| Technetium-99m* | 6.6 hours |
| Technetium-99 | 211,000 years |
| → U-238 | 4.468 billion years |
| U-235 | 703 million years |
| U-234 ← | 246,000 years |

Half-lives of Natural, Medical, Man-made Radionuclides

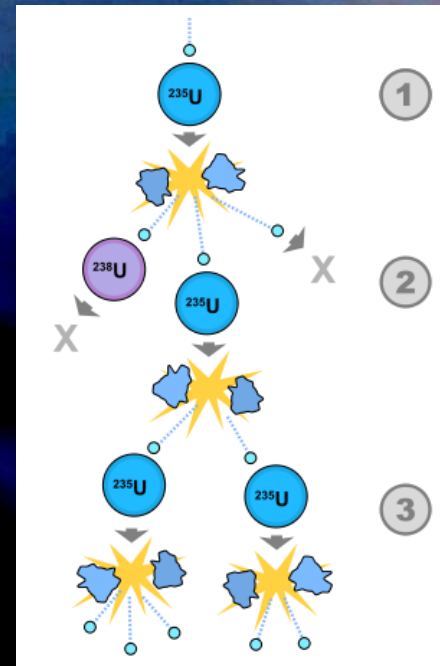
Red Shading indicates PGDP Radionuclides

* "m" for metastable - a very short half life (used for medical diagnostics)



Background: Fission for Energy

- **FISSION** is a self-sustaining nuclear reaction caused by radioactive decay or induced, for example, by bombardment with neutrons
 - Results in the nucleus of a particle splitting into smaller parts (lighter nuclei) which are ejected along with **ENERGY**
 - Releases very large amounts of **ENERGY**
- **Nuclear power reactors harness the energy and heat from nuclear FISSION to produce the steam that runs turbines which, in turn, generate electricity**
- The amount of available **ENERGY** contained in nuclear fuel is millions of times the amount of available **ENERGY** contained in a similar mass of chemical fuel such as petroleum or natural gas.
- One kilogram of enriched uranium-235 has the capacity to produce as much energy as 1,500,000 kilograms (1,500 tons) of coal



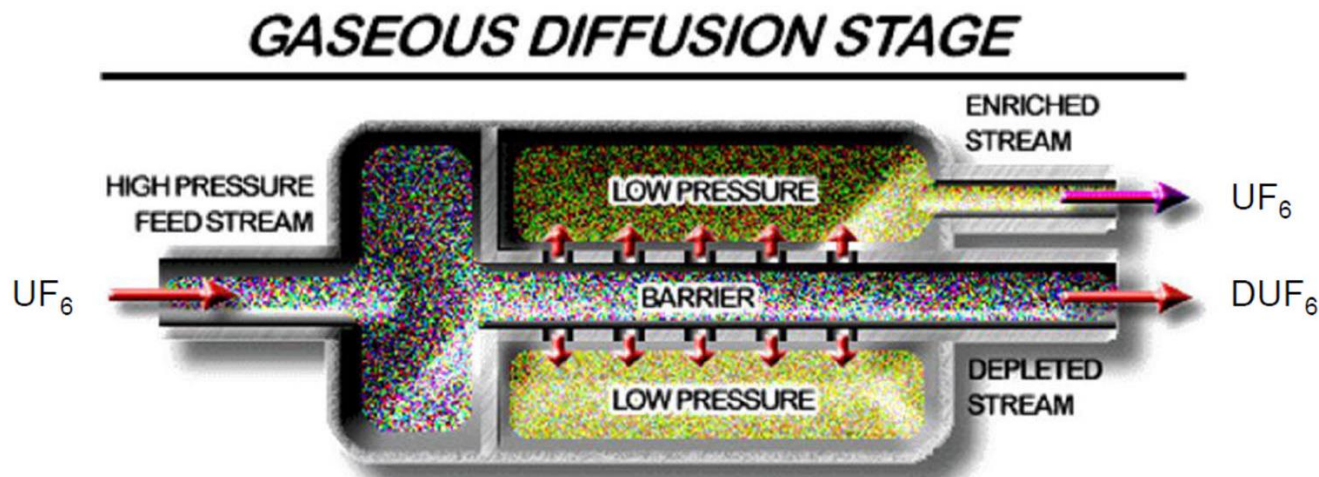
Background: Uranium Enrichment

- Naturally Occurring Uranium has 3 isotopes with similar chemical but different nuclear properties
 - U-238 The most plentiful/abundant; over 99% of natural U
 - U-235 The only **FISSILE** naturally occurring U isotope; approximately 0.72% of natural U
 - U-234 Less plentiful U isotope; approximately 0.0055% of natural U
- **FISSION** is a self-sustaining nuclear reaction caused by radioactive decay or induced, for example, by bombardment with neutrons
 - Results in the nucleus of a particle splitting into smaller parts (lighter nuclei) which are ejected along with **ENERGY**
 - Releases very large amounts of **ENERGY**
- **FISSILE** material can sustain a nuclear reaction which results in a release of **ENERGY** as **HEAT**
- The **HEAT** from **FISSION** is used to drive turbines and generate electricity
- **PGDP MUST INCREASE (ENRICH) THE NATURAL ABUNDANCE OF FISSILE U-235 FOR USE AS A FUEL SOURCE (from 0.7% to 5%)**



Background: Uranium Enrichment

- The GASEOUS DIFFUSION PROCESS was used at PGDP to increase the abundance of U-235 in URANIUM.
- URANIUM is blended with FLUORINE GAS at high temperature and pressure to produce URANIUM HEXAFLUORIDE GAS (UF_6)
- U-235 separated from U-238 by DIFFUSION thru membranes (a STAGE)
- A volume of UF_6 gas is passed thru $> 1,800$ STAGES before enrichment is complete



This process of uranium enrichment increases the concentration of U-235 from 0.7% up to 5.0%



This process of uranium enrichment increases the concentration of U-235 from 0.7% up to 5.0%

Enrichment



The 8th Stage Converter (of 1,760) from PGDP's diffusion process

Citations

http://www.ukrcee.org/Outreach/Education/gaseous_diffusion.aspx

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