Fission, Fusion, Binding Energy
Nuclear Fission
• Naturally occurring Uranium contains 2 major isotopes
• Uranium-238 (99.3%)
• Uranium-235 (0.7%)
• The only isotope of Uranium that can undergo fission is Uranium-235 because it is naturally unstable and will decay by alpha radiation
• $^{235}_{92}U + \frac{1}{0}n \rightarrow ^{236}_{92}U^*$
• And $10^{-14}$ seconds later…
• $^{236}_{92}U^* \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + \frac{1}{0}n + \frac{1}{0}n + \frac{1}{0}n + \text{ENERGY}$
• 50 possible sets of fission products (sum of atomic numbers = 92)
• 3 neutrons released for ONE $^{235}_{92}U$
• Each neutron can split another $^{235}_{92}U$
• CREATES A CHAIN REACTION
• If amount of $^{235}_{92}U$ is sufficient (CRITICAL MASS) then the number of neutrons generated is high enough to result in a nuclear explosion
Fission Chain Reaction
Critical Mass Needed for Chain Reaction

Subcritical mass (chain reaction stops)

Supercritical mass (chain reaction accelerates)
• Uranium-235
• Plutonium-239 (extremely rare)
• During WWII, Scientists discovered that bombarding Uranium-238 (the abundant form of Uranium) with a neutron created Uranium-239 + gamma radiation. Uranium-239 would then undergo beta decay and create Neptunium-239, which would beta decay and create Plutonium-239.

Other Fuels for Fission Chain Reaction
Development of the Atomic Bomb

- During WWII the Americans developed the “Manhattan Project” in secret
- By 1945, they developed 2 types of nuclear bombs
  - U-235 Fission bomb
  - Pu-239 Fission bomb
Fat Man and Little Boy
Conventional chemical explosive
Sub-critical pieces of uranium-235 combined

Gun-type assembly method

Implosion assembly method

Explosion of an Atomic Bomb

Before explosion
Trigger explosion
Fission
• Arrangement of U-235 in a critical mass, where there’s enough U-235 in a small space so that the neutrons cause a chain reaction is very difficult to control

• How can this conversion of small amounts of mass into great amounts of energy be used to produce electricity?

• In 1930, Enrico Fermi, an Italian Physicist discovered that Uranium can be arranged into Fission Piles (organized rows of Uranium)
• By arranging the Uranium fuel in a lattice structure, **Control Rods** could be inserted between the Uranium fuel rods to stop the flow of neutrons between rods (slowing/stopping the reaction).

• Water is used to slow the neutrons down within the reactor so that they are more likely to strike the Uranium fuel rods.

• Water acts as a **Moderator**

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**Arranging U-235 to get a Controlled Reaction**
• By arranging the Uranium fuel in a lattice structure, there is NO POSSIBILITY of an uncontrolled nuclear explosion (like in a nuclear warhead).

• The threat of a nuclear explosion within a nuclear power plant is an imagined danger.

• The Uranium is not close enough together to start an uncontrolled chain reaction.
• Walls of reactors are made of Graphite, which slows down the neutrons, increasing the chance that neutrons will strike U-235
• Control Rods made of Cd or B, which absorb large quantities of neutrons and stop the flow of neutrons without releasing energy
• Water is used as a moderator to slow down fast moving neutrons
• Modern reactors have a containment building made of 6 feet of concrete, used to contain radioactive material in the event of an accident
- Small Nuclei Combine
\[ \frac{2}{1} H + \frac{3}{1} H \rightarrow \frac{4}{2} He + \frac{1}{0} n + ENERGY \]
- Occurs in the sun and other stars

Nuclear Fusion
• Excessive heat cannot be contained
• Attempts at “cold” fusion have FAILED
• “Hot” fusion is very difficult to contain
  (How the Universe Built your Car Vid)
• Experimentally observed that the mass of an atom (containing neutrons) is always slightly less than the sum of the masses of its component particles. The difference between the atomic mass and the sum of the masses of its protons, neutrons, and electrons is called MASS DEFECT
Can calculate the Energy given off by a nuclear reaction based on the weight difference from reactants to products based on Einstein’s equation.

\[ E=mc^2 \]
• Calculate the energy released (per mole of tritium consumed) for the fusion reaction of tritium and deuterium

\[
\frac{2}{1}H + \frac{3}{1}H \rightarrow \frac{4}{2}He + \frac{1}{0}n + \text{ENERGY}
\]

\[(c = 3.00 \times 10^8 \text{ m/s})\]

<table>
<thead>
<tr>
<th>Particle</th>
<th>mass (g/mol)</th>
<th>Mass Reactants = 3.01605 + 2.0140g</th>
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<tbody>
<tr>
<td>Proton</td>
<td>1.007825</td>
<td>Mass Reactants = 5.03005g</td>
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<tr>
<td>Neutron</td>
<td>1.008665</td>
<td>Mass Products = 4.00260 + 1.008665g</td>
</tr>
<tr>
<td>Deuterium</td>
<td>2.0140</td>
<td>Mass Products = 5.011265g</td>
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<tr>
<td>Tritium</td>
<td>3.01605</td>
<td>Mass Diff = Mass R – Mass P</td>
</tr>
<tr>
<td>Helium</td>
<td>4.00260</td>
<td>Mass Difference = 0.018785g</td>
</tr>
</tbody>
</table>
Calculation of Nuclear Energy Released

\[ E = mc^2 = 1.8785 \times 10^{-5} \text{kg} \times (3.00 \times 10^8 \text{ m/s})^2 \]

\[ E = 1.69 \times 10^{12} \text{ kg-m}^2/\text{s}^2 = 1.69 \times 10^{12} \text{ J} \]