Main Types of Particles

- Alpha particles (nucleus of \( ^{4}\text{He} \))
- Beta particles (high speed electrons)
- Gamma particles (similar to X-rays)

Electromagnetic Spectrum

Fission

Nuclear Fission

Chain Reaction

Half Lives and Activities

By the way, we still use Curies as the unit in the US.
1 Curie = 40 GBq (10^9 Bq) = 3.7e10 particles/second!
Effect of Moderator

- **Moderator**: material that slows down the neutrons in order to maintain the chain reaction
- **Moderators**:
  - Increase the fission rate
  - Rapidly reduce speed of neutrons without absorbing them
  - Are light atoms (like hydrogen, carbon, or heavy water)

Fission Probability vs Neutron Energy

From Energy and the Environment, by Ristinen and Kraushaar

(#4) Safety Precautions

- Reactor construction
  - Strong Pressure vessel (air-tight)
  - Primary concrete shield
  - Steel liner
  - Concrete containment
- Coolant systems
  - Primary
  - Secondary
  - Tertiary
  - Quaternary...
- Fuel
  - Enriched very little
  - Well below critical mass
- Fission Control
  - Control rods absorb neutrons to keep reactor critical
  - Boron is incorporated into cooling fluids to absorb neutrons
  - (Moderator is not fission control, but fission enhancer!!!)

Pressurized Water Reactor (PWR)

- Common type (especially in US)
- Primary water is high pressure so it does not boil (like BYU heating plant)
- Pressurizer has heater and cooler in water with steam head
  - Remember this when discussing 3-Mile Island next time
- Uses regular (light) water, not deuterium or tritium

Pressurized Water Reactor (PWR)

90% availability!

RBMK is a Russian acronym translated roughly as "reactor cooled by water and moderated by graphite"

This same type was used at Chernobyl


**CANDU Process**

![CANDU Process](image)

**AGR**

![AGR](image)

**LMFBR**  
(Liquid metal fast breeder reactor)

![LMFBR](image)

**Other Reactors**

![Other Reactors](image)

**Advantages**

<table>
<thead>
<tr>
<th></th>
<th>PWR</th>
<th>BWR</th>
<th>RBMK</th>
<th>CANDU</th>
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<td>On-Line Refueling</td>
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<td>Capital Costs</td>
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<td>Worker Radiation</td>
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<tr>
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</tbody>
</table>

From http://www.nucleartours.com/type/benefits.htm

**(#6) Uranium Enrichment**

- **Gaseous Diffusion**  
  - Heavier isotope diffuses more slowly
- **Centrifuge**  
  - Heavier isotopes are forced outwards
- **Electromagnetic**  
  - Like mass-spec (very low thru-put, very high purity)
- **Laser**  
  - Specially tuned laser preferentially ionizes atoms of preferred isotope that are then extracted electromagnetically

http://www.wordiq.com/definition/Isotope_separation
Products (1000 kg of spent fuel)

<table>
<thead>
<tr>
<th>Product</th>
<th>Quantity (kg)</th>
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<tbody>
<tr>
<td>Plutonium</td>
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<tr>
<td>Tailings</td>
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<tr>
<td>Activity, U-234, etc.</td>
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</tbody>
</table>

Additional Notes
- 0.7% U-235
- 99.3% U-238
- Enrich for LWR
- 3% U-235
- 97% U-238
- Tailings, LWR
- ~1% U-235
- ~1% Pu-239
- 95% U-238
- Fission products
- 3% Pu-239
- 97% U-238
- + Fission products

Reprocessing

Advantages
- Greatly extends supply of uranium
  - From 50 yrs to 1000 yrs?
- Significantly reduces quantity of waste

Disadvantages
- Separating and storing large quantities of plutonium
  - Only 10 g needed to build bomb
  - Instructions on internet!
  - 10 g out of tons is easy to hide

U.S. position — No reprocessing (Jimmy Carter, 1978)
— set example and world will follow (not all have followed, though)

Plasma-Generated Fusion

Energy from Fusion

\[ ^2H + ^2H \rightarrow ^4He + n + 17.6 \text{ MeV} \]

D + T reaction:

\[ ^2H + ^3H \rightarrow ^4He + n + 3.2 \text{ MeV} \]

D + D reaction:

\[ ^2H + ^3H \rightarrow ^4He + n + 4.0 \text{ MeV} \]

Laser-Generated Fusion

From Energy and the Environment, by Ristinen and Kraushaar
Terminology/Units

- Light water
- Heavy Water
- Enrichment
- Critical Mass
- Half Life
- Activity
- Chain Reaction
- Plutonium

- MeV
- Curie
- Bq