### **Nuclear Weapons**

## Question:

Is it possible to have 100 tons of plutonium and not have it explode?

## Observations About Nuclear Weapons

- · They release enormous amounts of energy
- They produce incredible temperatures
- They produce radioactive fallout
- They are relatively hard to make
- They use chain reactions

#### **Atomic Nucleus**

- · Atoms are usually electrically neutral
  - They must have as many + charges as charges
  - Each electron must be matched by a + charge
- At the center of an atom is its nucleus
  - Extremely small (1/100,000th of the atom's diameter)
  - Contains most of the atom's mass
  - Also contains most of the atom's potential energy
    - Evidence is related to:  $E=mc^2$

#### Structure of Nucleus

- Nucleus contains two kinds of nucleons
  - Protons are positively charged
  - Neutrons are neutral
- Two forces are active in a nucleus
  - Electrostatic repulsion between protons Sodium nucleus (11 protons, 12 neutrons)
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  - Nuclear force attraction between touching nucleons
  - At short distances, nuclear force is stronger than electric
  - At long distances, electric force is stronger than nuclear

## **Nuclear Stability**

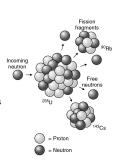
- In a nucleus, nucleons are in equilibrium
- To be classically stable, equilibrium must be stable
- To be quantum-mechanically stable, equilibrium must also be the potential energy minimum
- Quantum mechanics and the Heisenberg uncertainty principle allow the nucleons to try out arrangements outside their equilibrium positions
- If they find a path to a new equilibrium, they may take it and the nucleus may fall apart

## Radioactivity

- Protons repel one another & neutrons are unstable
- Large nuclei have two problems:
  - Too many protons, then too much electrostatic potential
  - Too many neutrons, then neutrons are unstable
  - Delicate balance between protons and neutrons
- Large nuclei tend to fall apart spontaneously
- · Such decay is called fission
- · Fission is a type of radioactivity

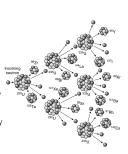
#### **Induced Fission**

- Large nuclei can break when struck
  - Collision knocks nucleons out of stable equilibrium
  - Hard collisions are best at inducing fission
  - Neutrons make ideal projectiles for inducing fission



#### Chain Reaction

- · Neutrons can induce fission
- Induced fission releases neutrons
- This cycle can repeat
  - Chain reaction!
- · Each fission releases energy
  - Many fissions release prodigious amounts of energy
  - Sudden energy release produces immense explosion



#### Requirement for a Bomb

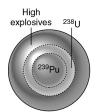
- 1. Initial neutron source
- 2. Fissionable material (allowing induced fission)
- 3. Fissions must release additional neutrons
- 4. Material must use fissions efficiently (critical mass)

#### Fissionable Materials

- <sup>235</sup>U and <sup>239</sup>Pu are fissionable materials
- <sup>235</sup>U is rare and must be separated from <sup>238</sup>U
- <sup>239</sup>Pu is made by exposing <sup>238</sup>U to neutrons

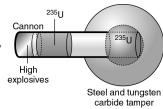
## Gadget & Fat Man

- <sup>239</sup>Pu sphere below critical mass (6 kg)
- · Crushed by explosives to above critical mass
- Shell of <sup>238</sup>U assisted implosion



# Little Boy

- <sup>235</sup>U hollow sphere below critical mass (60 kg)
- Cannon fired plug through sphere to exceed critical mass
- Tungsten-carbide shell contained explosion initially



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