

Dirty Bombs and Nuclear Devices

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Outline

- What are isotopes?
- Fertile and fissile materials
- Fission and Fusion reactions
- Isotope enrichment
 - Are all isotopes the same?
- Reactor types
 - LWR, HWR, Breeders, Military
- Reprocessing
- Radiation decay schemes
 - α , β , γ

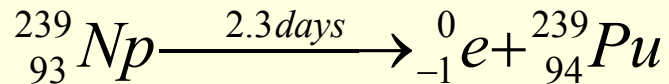
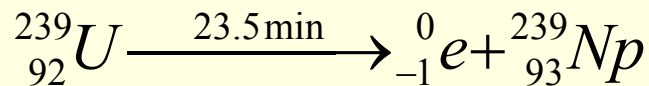
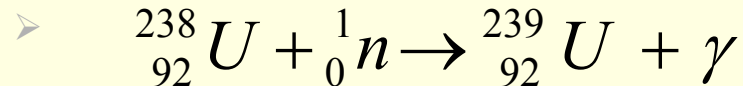
Atoms, Ions & Isotopes

- Atom - neutral, e.g., Sn, Fe, U, Pu
 - Atomic number (number of protons) is signature
- Ions - charged, e.g., Cu^+ , Ba^{2+} , Cl^- , O^{2-}
 - Variation in number of electrons
- Isotopes - neutral, e.g., ${}_{92}^{238}\text{U}$, ${}_{53}^{131}\text{I}$
 - Variation in number of neutron
 - No charge difference; small difference in mass

Fertile and Fissile Materials

- Fission: The splitting of a heavy nucleus into two fragments, with release of neutrons and energy
- Natural uranium: 99.3% ${}_{92}^{238}\text{U}$, 0.7% ${}_{92}^{235}\text{U}$
- Fissile materials: will fission upon "capturing" a neutron, e.g., ${}_{92}^{235}\text{U}$
- Fertile materials: becomes fertile upon "capturing" a neutron, and subsequent "decay", e.g., ${}_{92}^{238}\text{U}$
- Natural uranium does not contain sufficient fissile material to sustain a chain reaction
- ${}^{235}\text{U}$ is the only naturally occurring fissile material
- Major world resources of uranium: USA, Canada, South Africa
- Other locations: France, Spain, Portugal, Australia, Argentina, Niger, Gabon, Morocco

The Fission Reaction



The extent to which these neutrons are captured for further reactions determines criticality

- ${}^{235}\text{U}$ and ${}^{239}\text{Pu}$ are fissile materials
- ${}^{238}\text{U}$ is a fertile material

Isotope Enrichment

- If natural uranium is to be used in nuclear reactors, then "heavy water" is necessary
- If "light water" is to be used, then natural uranium must be enriched in ^{235}U
- Enrichment is necessary for (a) Heavy water, or (b) ^{235}U
- Heavy water is ~ 150 ppm in light water

Enrichment Processes

- Heavy water
 - Fractional distillation (1.4 enrichment ratio per stage)
 - Chemical exchange (2.3 enrichment ratio per stage)
- Uranium
 - Gaseous diffusion (1.0043 enrichment ratio per stage)
 - Gas centrifuge (1.058 enrichment ratio per stage)
 - The uranium needs to be converted to UF_6 first for either of the above processes
- Both processes are extremely expensive
- Uranium enrichment uses toxic chemicals - UF_6

Power Reactors

- Light Water Reactors (LWR)
 - Uses "light water" and slightly enriched uranium - between 2 ~ 3% ^{235}U
- Heavy Water Reactors (HWR)
 - Uses "heavy water" and natural uranium
- Breeder Reactors
 - Uses Pu as fissile material, ^{238}U as fertile material, and liquid sodium as moderator
- LWR or HWR is necessary to begin operation of Breeder Reactors
- Breeder Reactors require fuel reprocessing for extraction of Pu

Plutonium

- Source of plutonium: ^{238}U
- Reprocessing of spent nuclear fuel is necessary for production of plutonium
- Not all plutoniums are the same
- ^{239}Pu , ^{241}Pu are fissile
- ^{240}Pu , ^{242}Pu are neutron poisons
- ^{239}Pu concentration highest with lower irradiation levels - "clean" Pu
- Spent nuclear fuel from power reactors are not "clean"

Bomb Material

- ^{235}U - produced from uranium enrichment
- ^{239}Pu - produced by reprocessing irradiated ^{238}U

Spent Fuel Constituents

Element	~ Wt (kg)	β activity (curies)	γ activity (curies)
U	998	0.7	0.03
Pu	0.8		
Cs	110	6,500	2,600
Sr	40	41,500	
Ba	40	1,700	2,500
Y	20	51,000	
Ce	100	157,000	17,000
Rare Earths	155	15,00	
Zr	115	57,000	55,000
Nb	5	100,000	103,000
Ru	55	22,000	15,000
Others	40	2,000	

Radioactive Decay Schemes

- α particles - helium nucleus
- β particles - negatively charged electron expelled by the neutron
- γ particles - electromagnetic radiation

Units, Definitions

- Curie: 3.7×10^{10} disintegrations per second
- Half life: the time required for one-half of the atoms originally present to decay

Decay Schemes

Isotope	Half-life	Decay Type	Predominant Energies (MeV)
^{137}Cs	30 y	β , γ γ	0.51, 0.66 (92%) 1.17 (8%)
^{90}Sr	27.7 y	β	0.545
^{90}Y	64.2 h	β	2.26
^{144}Ce	285 d	β	0.309
^{60}Co	5.24 y	β , γ_1 , γ_2	0.302, 1.33, 1.17
^{131}I	8.08 d	β , γ β , γ	0.608, 0.364 (87.2%) 0.335, 0.638 (9.3%)

In Closing

- A nuclear bomb is not an easy thing to make
- Fissile materials for a nuclear bomb are also not easy to make
- Power reactors will not melt down and explode
- Power reactors do not produce bomb-grade material, especially if maximum power is drawn from them