ISIS Course

Nuclear Explosive Materials

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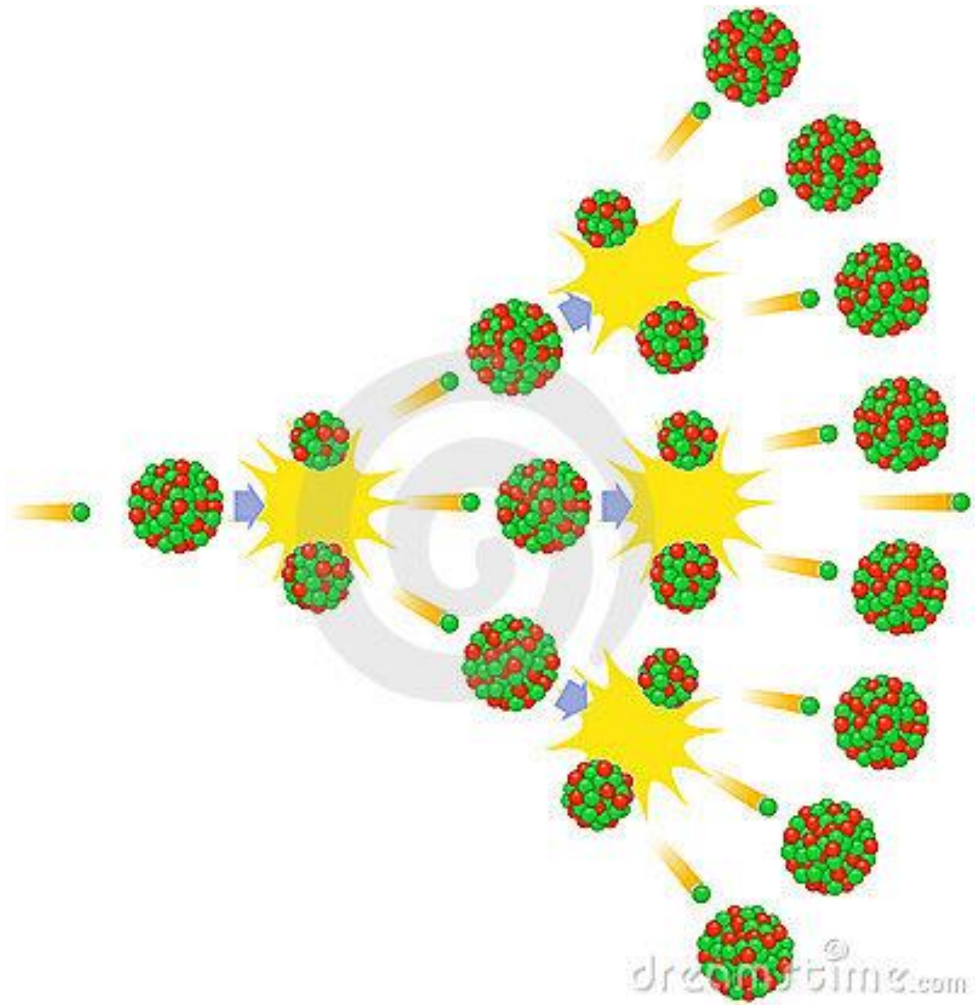
The Long Pole in the Tent

- Nuclear weapons require nuclear explosive materials
- The most difficult part of building a nuclear weapon from scratch is making the nuclear explosive materials.
- Today's discussion centers on the most important nuclear explosive materials
  - Plutonium
  - Highly enriched uranium
  - Neptunium and Americium

What is the Essential Property of Nuclear Explosive Materials?

- One nuclei fissions and creates on average of more than one neutron, which in turn cause more fissions of nuclei
- Materials able to undergo an uncontrolled nuclear chain reaction



Nuclear Explosive Materials: Definition

- Materials able to sustain chain reactions and thus create large amounts of explosive (or controlled) releases of energy.
- **DEF:** A **nuclear chain reaction** occurs when one **nuclear reaction** causes an average of one or more **nuclear** reactions, thus leading to a self-propagating series of these reactions.

Difficult to Produce

- Nuclear explosive materials are expensive, difficult, and often dangerous to produce.
- Their production requires large capital investments and the mastery of a wide range of technologies.
- The production processes for different types of nuclear explosive materials can differ markedly.

Nuclear Explosive Materials

- The complex challenge of producing nuclear explosive materials inhibits nuclear proliferation.
- But with determined work and outside help, many countries have succeeded in making nuclear explosive materials.
- Thus, nations attach great importance to controlling the production and distribution of these materials and the technologies associated with making them. That struggle continues today and remains a central priority of the United States.
- Two recent examples are the Joint Plan of Action between Iran and the P5+1 and the Nuclear Security Summits.
- The constant efforts to improve export controls reflects this priority as well.

Main Types

- Highly Enriched Uranium (HEU)
- Plutonium
- Neptunium 237
- Americium
- Uranium 233 (not covered in this module)

Highly Enriched Uranium Basic Information

- Uranium isotopes have nearly identical chemical and physical properties but different nuclear properties.
- They have the same number of protons (92) but differing numbers of neutrons
- The key isotopes are uranium 235 and uranium 238
- Uranium 235 is “fissile” which means it fissions when struck by relatively low energy (“thermal”) neutrons, allowing heat to be released under controlled conditions in reactors.
- Both uranium 235 and uranium 238 fission when struck by high energy (“fast”) neutrons.

Common Grades of Uranium

- **Natural uranium**, containing 0.71 percent uranium 235
- **Depleted uranium**, containing less than 0.71 percent uranium 235
- **Low enriched uranium (LEU),** containing more than 0.71 percent uranium 235 and less than 20 percent uranium 235
- **Highly Enriched Uranium (HEU),** containing greater than or equal to 20 percent uranium 235.
- Weapon-grade uranium (WGU) is HEU containing greater than or equal to 90 percent uranium 235

Why we care about HEU

- A self-sustaining chain reaction in a nuclear weapon cannot occur in depleted or natural uranium
- It is theoretically possible to achieve a self-sustaining chain reaction in LEU enriched to roughly 10 percent, but in practical terms, uranium enriched to 20 percent is needed.
- In practice, a nuclear weapon would require enriched uranium with high fractions of uranium 235, say more than 80 percent enriched.
- Thus, enriched uranium used in conventional nuclear power has no military value. However, its possession provides an important head start on producing HEU, in particular weapon-grade uranium.

Plutonium

- Unlike uranium, all but trace quantities of plutonium do not occur naturally and must be manufactured.
- **Plutonium 239** is the most desirable isotope for nuclear weapons.
- Plutonium 239 is produced by neutron irradiation of uranium 238, which means in practical terms reactors are the main producer of plutonium.
- Plutonium 239's half life, or the time for half of a given quantity of the material to radioactively decay, is much shorter than uranium 235 or 238, meaning that plutonium 239 is much more radioactive and requires great care in reducing radiation doses to those involved in its production or handling.
- But smaller amounts of plutonium will sustain a chain reaction than HEU. Consider IAEA safeguards criteria--25 kg of uranium 235 in weapon-grade uranium vs. 8 kg of plutonium is viewed as sufficient to build a nuclear weapon.

Other Plutonium Isotopes

- But further irradiation of the plutonium 239 in a reactor produces other plutonium isotopes that are less desirable for nuclear weapons. The main ones are **plutonium 240, 241, and 242**.
- Plutonium 240 is particularly challenging, because its half life is relatively short, meaning it produces heat and more neutrons, which can complicate the ability of a nuclear weapon to detonate effectively.

Plutonium

- Nuclear weapons designers prefer using plutonium 239, and we will find that all national nuclear weapon programs produce plutonium with a very high fraction of plutonium 239
- However, plutonium with a significant fraction of plutonium 240, 241, and 242 can also be used to make nuclear weapons, albeit with a reduction in the explosive yield (unless specially compensated for); additional heat production issues, and a much greater chance of the chain reaction starting too early and thus “fizzling”, meaning that only a very low explosive yield is achieved.
- Terrorists may almost prefer reactor-grade plutonium, however.

Grades of Plutonium: US Definition

- **Weapon-grade plutonium**, containing less than 7 percent plutonium 240
- **Fuel-grade plutonium**, containing from 7-18 percent plutonium 240
- **Reactor-grade plutonium**, containing more than 18 percent plutonium 240

Table 2.1. Plutonium half-lives, and weapon-grade and reactor-grade isotopic concentrations, at given fuel discharges

Half-lives are given in years; concentrations are percentages.

		Weapon-grade isotopic concentrations	Reactor-grade isotopic concentrations (typical)		
Isotope	Half-life	(typical)	PWR[a] (33 000 MWd/t[d])	Magnox reactor[b] (5000 MWd/t)	CANDU[c] (7500 MWd/t)
^{238}Pu	86.4	. .	1.3	. .	. .
^{239}Pu	2.4×10^4	93.0	56.6	68.5	66.6
^{240}Pu	6.6×10^3	6.5	23.2	25.0	26.6
^{241}Pu	13.2	0.5	13.9	5.3	5.3
^{242}Pu	3.8×10^5	. .	4.7	1.2	1.5

[a] Pressurized water reactor.
[b] Gas-cooled reactor with metallic fuel.
[c] Canadian deuterium–uranium reactor.
[d] Megawatt-days per tonne of uranium fuel.

Sources: Organisation for Economic Co-operation and Development, Nuclear Energy Agency, *Plutonium Fuel: An Assessment* (OECD: Paris, 1989), tables 2 and 4; and authors' data.

Neptunium 237

- Neptunium 237 is routinely produced in nuclear reactors as a result of neutron irradiation of uranium 235 and 238. It is also a decay product of americium 241.
- In terms of nuclear weapons, it is similar to HEU.
- Its very long half life means that it has no heat or radiation properties that would complicate its use in nuclear weapons, like plutonium.

Neptunium 237

- No country is known to build nuclear weapons out of neptunium 237
- However, it is believed that at least one country may have tested a nuclear device with neptunium 237.
- Neptunium 237 is found in nuclear waste resulting from the chemical separation of plutonium from irradiated fuel. Under comprehensive safeguards agreements, this neptunium is outside inspections or declarations.

Americium

- Americium is generally considered less useful in making nuclear weapons than the above nuclear explosive materials because of its higher output of heat and radiation (neutrons in particular).
- The most important isotopes are americium 241, 242, and 243.
- Americium originates from the decay of plutonium 241.