Reactor Plutonium and Nuclear Explosives

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Outline

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Radioactivity & Heat

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A Nuclear Explosive

Comments on Dilution

Summary

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- All plutonium isotopes can be used directly in nuclear explosives.
- The concept of “denatured” plutonium (Pu which is not suitable for nuclear explosives) is fallacious.
- A high content of the Pu-240 isotope is a complication, but not a preventative.

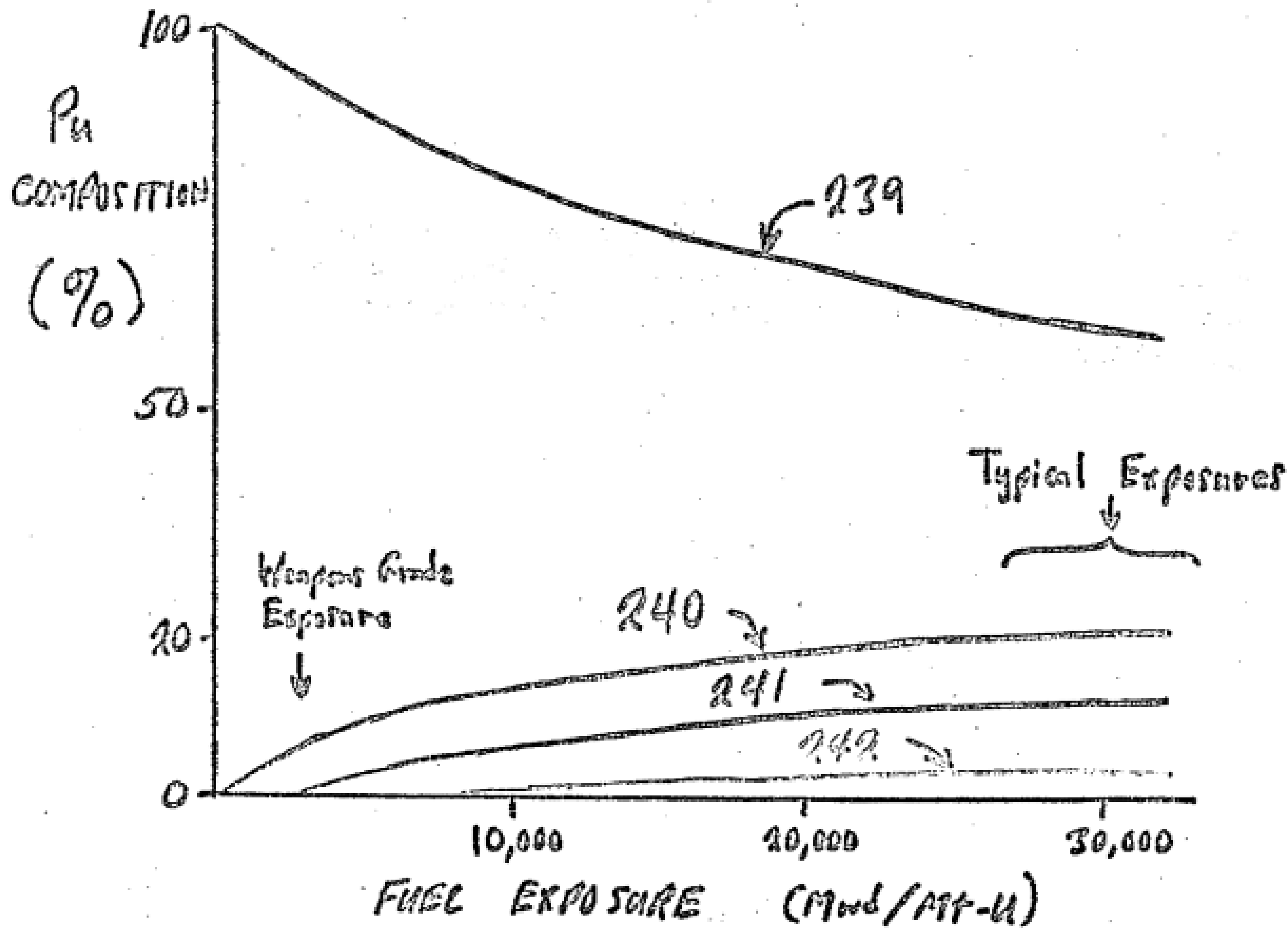
Plutonium

- Plutonium is produced from Uranium in a reactor. The length of time the plutonium is left in the reactor affects its isotopic composition.

Typical Pu Isotopic Composition

	238	239	240	241	242
"Reactor Grade" Pu	1.5	58	24	11.5	5
"Weapons Grade" Pu	---	93.5	6	0.5	---

Pu ISOTOPIC COMPOSITION vs REACTOR EXPOSURE



Properties of Fissile Materials

- There are three properties of any fissile material which are especially important for nuclear explosives.

(1) Nuclear Reactivity

Critical Mass

(2) Handling

Radioactivity and Heat Generation

(3) Neutron Background

Spontaneous fission rate

Nuclear Reactivity

- The most useful comparison of fissile materials for nuclear explosives is the comparison of fast (or “prompt”) critical mass.

Material	Bare Sphere Critical Mass (kg)
Weapons Grade Pu	11
Reactor Grade Pu	13
Uranium 233	16
Highly Enriched U (93.5% U-235)	56

Nuclear Reactivity (cont'd)

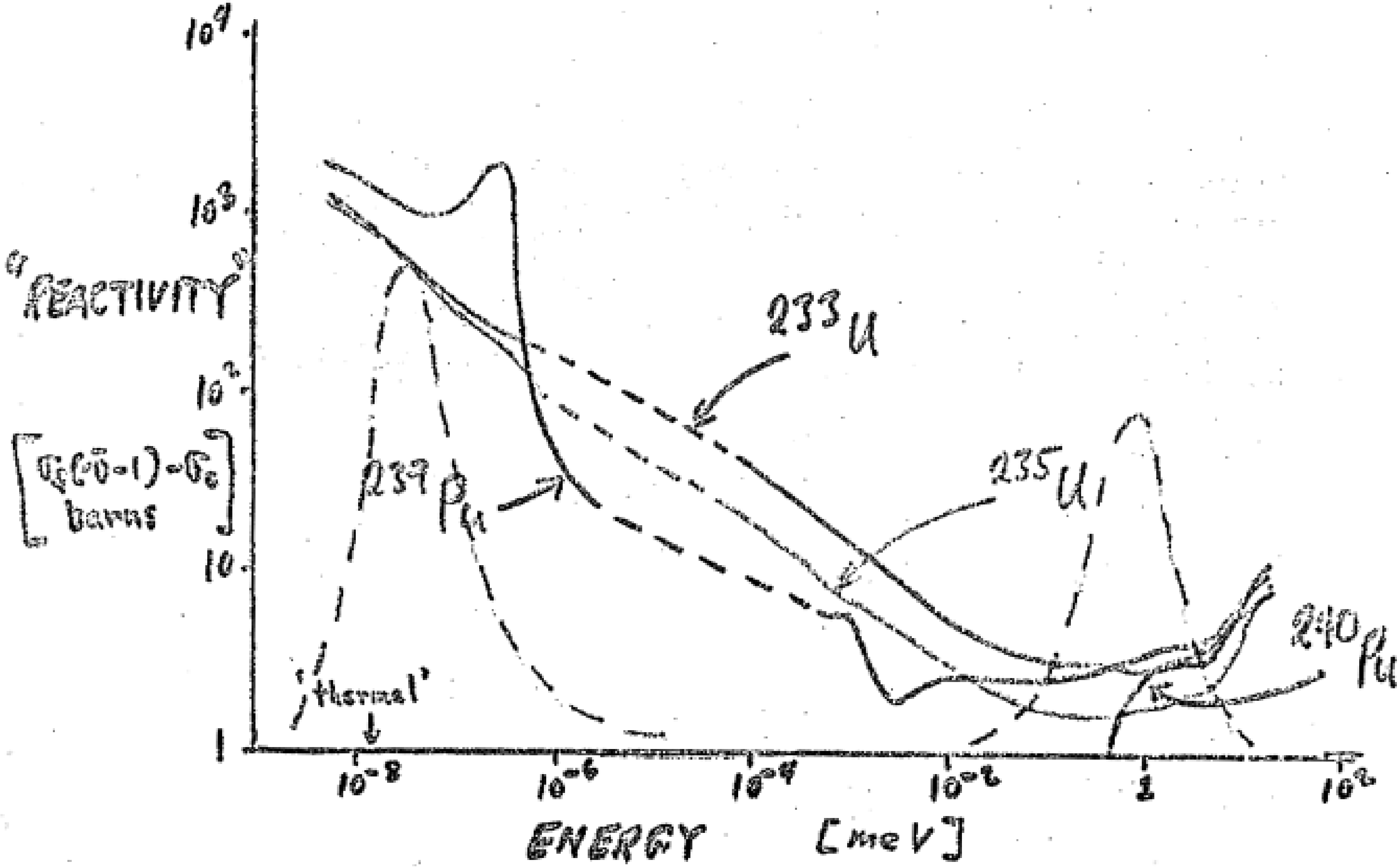
- All Pu isotopes are fissile for fast neutrons.

Isotope	Bare Sphere Critical Mass (kg)
Pu-238	10
Pu-239	10
Pu-240	~40
Pu-241	12
Pu-242	~100
U-235	52

Nuclear Reactivity (cont'd)

- There is a misunderstanding by some in the reactor community about the role of the isotope plutonium 240 in an explosive.
- Pu-240 does not fission with slow neutrons, which are the neutrons in all power reactors.
  - Thus the production of Pu 240 reduces the reactivity of the fissile material in the reactor.
- But Pu-240 is a reasonably good fissile material with fast neutrons – the neutrons in a nuclear explosion.

FISSION "REACTIVITY" VS INCIDENT NEUTRON ENERGY



Handling

- All Pu isotopes are radioactive and require handling precautions.
- The half life (time for half of the material to decay) is a good way to show the relative radioactivity.

Isotope	Half Life (yrs)
Pu-238	86
Pu-239	20000
Pu-240	7000
Pu-241	13
Pu-242	400000
U-235	700000000

Handling (cont'd)

- The issue for this discussion is the comparison of power reactor grade Pu with weapons grade Pu.

	Weapons Grade	Reactor Grade
Radioactivity (curies/gm)	3	10
Heat (watts/kg)	3	10
Neutron Output (n/sec/gm)	100	500

- Differences in radioactivity of several factors of ten would be needed to have a major impact on handling.
- For a program constructing new facilities, the handling of reactor grade Pu is essentially the same as handling weapons grade Pu.

Neutron Background

- The neutron background is important for a nuclear explosive because it may affect when the multiplying chain reaction (that leads to the explosion) is initiated.
- A condition that has been called “pre-initiation” has been widely cited as a key problem that reactor grade plutonium poses for creating a nuclear explosion.
- It is important to explain what this is in order to discuss the differences between reactor and weapons plutonium in a nuclear explosive.

Neutron Background (cont’d)

- The key to obtaining an explosion is for the supercriticality to be high enough so that the multiplying chain reaction produces the desired amount of energy before the thermal expansion reduces the supercriticality and shuts off the chain reaction.
  - It is a race between the fission chain reaction producing energy and the thermal expansion that ultimately wins and shuts off the reaction.
- A multiplying chain reaction that leads to an explosion can only happen with fast neutrons in a supercritical mass of fissile material. Thermal neutrons in a reactor *cannot* produce a *nuclear* explosion – the thermal expansion wins right away.
- The concept of “pre-initiation” is that neutrons are introduced into a fissile mass that is being assembled before it has reached the desired level of supercriticality, starting the chain reaction too soon, and allowing the thermal expansion to limit the fission energy produced.

Neutron Background (cont'd)

- The chance for "pre-initiation" is dependent on the number of neutrons present in the time between first critical and the desired level of supercriticality.
- The number of neutrons present is a property of the fissile material, and are mostly due to spontaneous fissions.
  - Neutron Output (n/sec/gm): 100(wpns) 500(reactor)
- The time between first critical and the desired level of supercriticality depends on the speed of assembly of the fissile material.

Neutron Background (cont’d)

- Pre-initiation results in a predictable statistical distribution in fission yield between predictable low and high values.
- A low velocity assembly in a high neutron background will result in very low fission yield. (expansion wins)
- However, it is possible to achieve assembly velocities high enough so that plutonium can produce a significant yield.

Conclusion

- A militarily useful “low technology” nuclear explosive using reactor grade plutonium can be designed to produce nuclear yield in the multi-kiloton range.

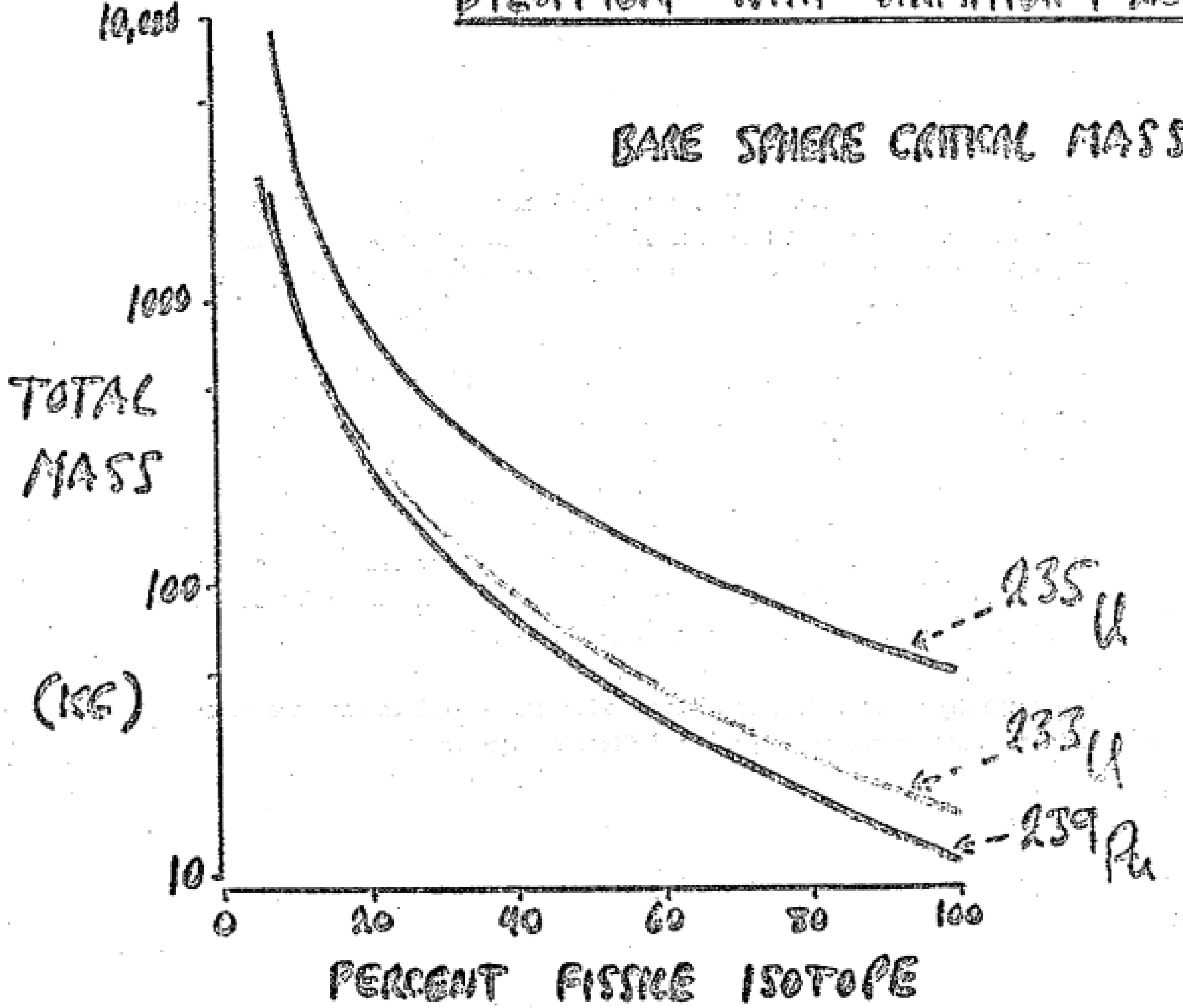
The Trinity Device is an Example

- The Trinity Device was the world’s first nuclear explosive. It was very large, relatively unsophisticated, and used weapons grade plutonium.
- The yield of the Trinity explosion was 20 kilotons.
- With reactor grade plutonium, the yield would have been more than 1 kiloton.

Comments on Dilution

- The dilution of a fissile material with a non-fissile material can require additional processing to make the fissile material useable in a nuclear explosive.
- Removing non-fissile material will either require isotope separation or chemical processing. Both are known industrial processes.
  - Isotope separation is by far more difficult. No Pu isotopes would need to be separated, but U-235 does need to be separated from the U-238 in natural or low enrichment uranium.

DILUTION WITH URANIUM-238



Comments on Dilution (cont'd)

- Plutonium oxide may appear in a reactor fuel cycle. The oxygen is a diluent for purposes of a nuclear explosive, but its use is still possible.

- The critical mass tells the story:

Reactor Grade Pu	Bare Sphere Critical Mass (kg)
Pu metal	13
Pu oxide (crystal density)	35
Pu oxide (0.5 crystal density)	140

Comments on Dilution (cont'd)

- There is no material which will "poison" a fissile material so that it cannot be used to build a nuclear explosive.
- Boron is a material that absorbs neutrons and is used to shut down reactors. It is not an effective "poison" for fast neutrons, as shown by theoretically substituting boron for oxygen:

Reactor Grade Pu	Bare Sphere Critical Mass (kg)
Pu oxide (full density)	35
"Pu boride" (full density)	70

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