*Reactor Plutonium Utility in Nuclear Explosives**

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*drawn from the work of Robert Selden

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Outline

Bottom Line Up Front

Plutonium Description

Critical Mass

Radioactivity & Heat

Neutron Background

A Nuclear Explosive

Conclusions

Summary

Bottom line up front

- "A potential proliferating state or subnational group using designs and technologies no more sophisticated than those used in first-generation nuclear weapons could build a nuclear weapon from reactor grade plutonium that would have an assured, reliable yield of one or a few kilotons (and a probable yield significantly higher than that)" *

- "An advanced nuclear weapon states such as the United States and Russia, using modern designs, could produce weapons from reactor grade plutonium having reliable explosive yields, weight, and other characteristics generally comparable to those of weapons made from weapons grade plutonium" *

* Quoted from: US Department of Energy Publication "Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives, January 1997 http://www.osti.gov/scitech/biblio/425259

Plutonium

- **Plutonium is produced from Uranium in a reactor**

- **The length of time plutonium is left in the reactor determines 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%	---

*Reactor grade often defined as any Pu with more than 18% Pu-240

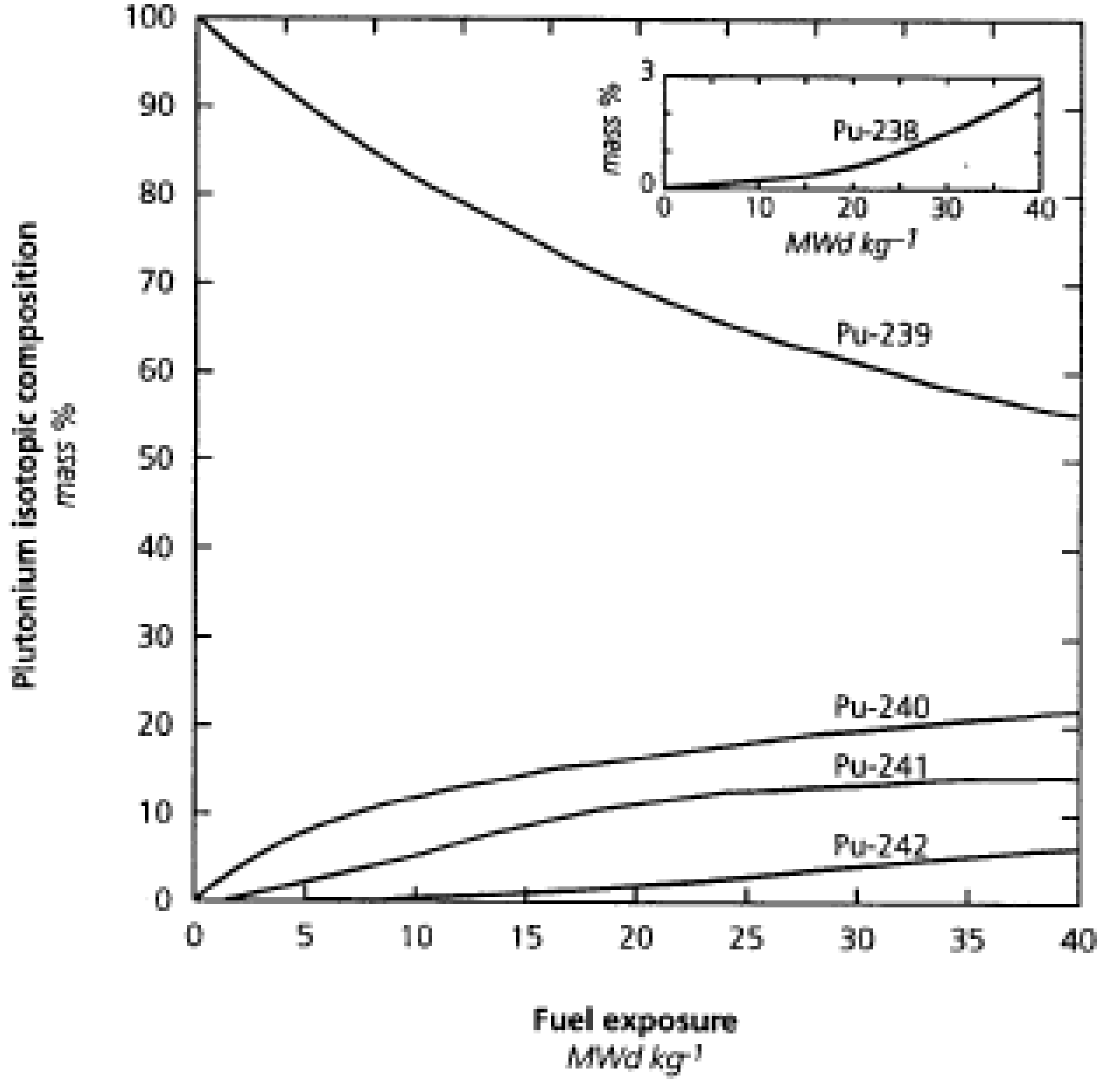

Figure 1: Plutonium isotope composition as a function of fuel exposure in a pressurized-water reactor, upon discharge.

Properties of Fissile Materials

- There are three aspects of fissile material important in nuclear explosives
  - Fissile material reactivity

    Critical Mass
  - Ease of handling

    Radioactivity and Heat Generation
  - Neutron background

    Spontaneous fission rate

Nuclear Reactivity

The most useful way to compare fissile materials for nuclear explosives is to compare fast (or “prompt”) critical mass:

Fissile material	critical mass (kg-bare sphere)
Weapons grade Pu	11
Reactor grade Pu	13
Uranium 233	16
HEU* 93.5% U-235	56

* Highly Enriched Uranium

The lower the critical mass,

the less material is needed per weapon

Nuclear Reactivity - continued

All Pu isotopes are fissile for fast neutrons

Isotope		Critical mass (kg – bare sphere)
Pu-238		10
Pu-239		10
Pu-240	~	40
Pu-241		12
Pu-242	~	100
U -235		52

Nuclear Reactivity - continued

- There is misunderstanding in the technical community about the utility of the Pu-240 in nuclear explosives

- Pu-240 has negligible fission with slow neutrons

- Slow neutrons drive all power reactors

  The build up of Pu-240 in reactors therefore reduces the reactivity of material in reactors

- Pu-240, however, is a good fissile material with fast neutrons – fast neutrons drive nuclear explosives

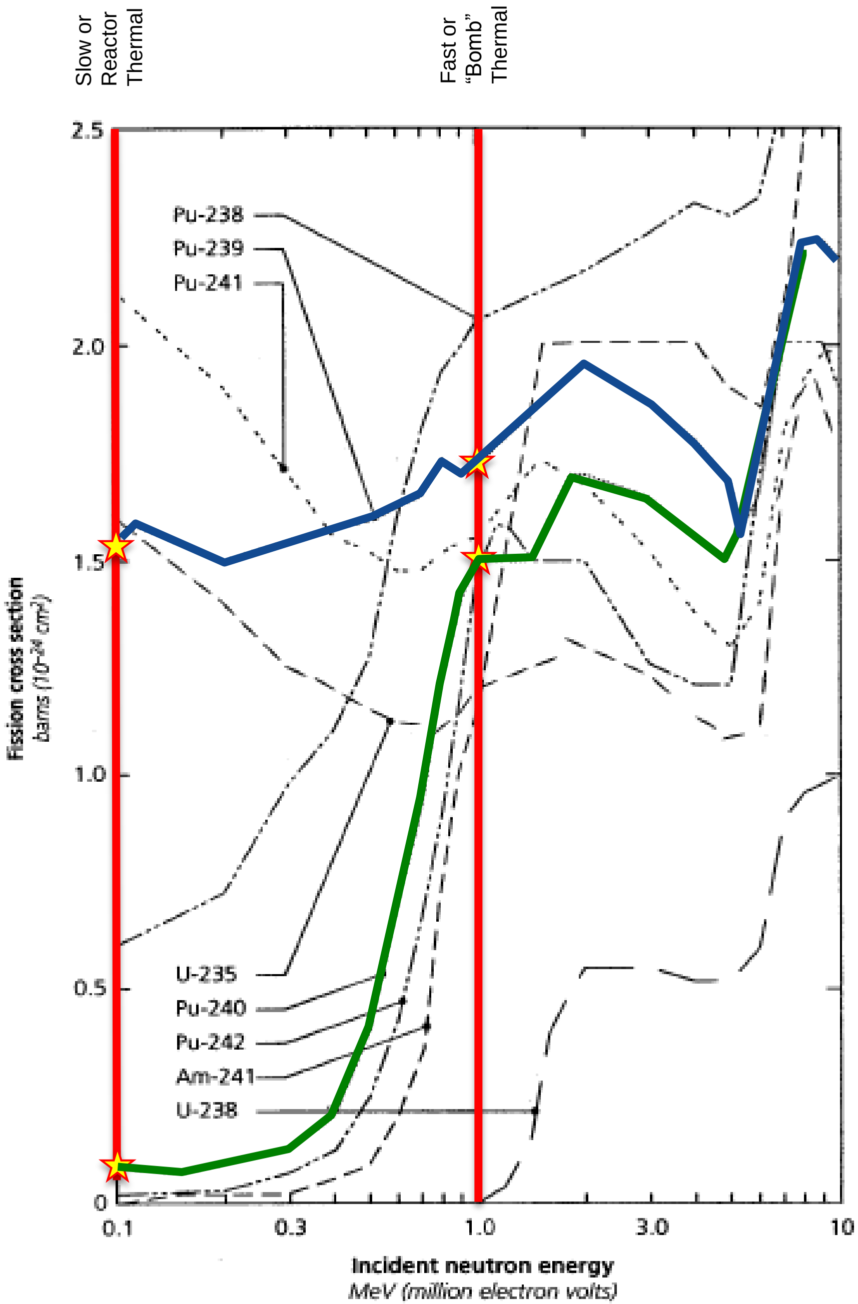

Figure 2: The neutron cross-section for fission of the principal plutonium and uranium isotopes (and americium-241, a decay product of Pu-241) against neutron energy.

Handling

- All Pu isotopes are radioactive and so require radiation handling mitigations
- The half life (time for half of the material to decay) is a good way to show the relative radiation hazard

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

The longer the half life,

the lower the radioactivity hazard

Handling - continued

- **Now compare reactor grade Pu with weapons grade**

	Weapons grade	Reactor grade
Radioactivity (curies/gm)	3	10
Heat (watts/kg)	3	10
Neutrons emitted (n/sec/gm)	100	500

- **Radioactivity differences of several factors of ten would be needed to seriously inhibit handling**

- **In newly built facilities, handling reactor grade is essentially the same as handling weapons grade Pu**

Neutron Background

- Neutron background is important in a nuclear explosion because it can influence when the explosive chain reaction is initiated

- A condition 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 neutron initiation in order to explain the differences between reactor and weapons plutonium in a nuclear explosive

Neutron Background - continued

- To get the desired explosive yield, super-criticality must be high enough so that the desired number of fissions occur before heat expands the fissioning material, stopping criticality, thereby shutting off the chain reaction

There is a race between the fission chain reaction producing explosive energy and the heat expansion shutting off that chain reaction

- A chain reaction that leads to an explosion can only happen with fast neutrons. Slow neutrons in a reactor ***cannot produce a nuclear explosion*** ...

…heat expansion always wins

Neutron Background - continued

- **Pre-initiation occurs when neutrons enter a fissile mass during assembly, but before it reaches the needed level of super-criticality. This starts the chain reaction too soon, and allows the heat expansion to stop fission explosive energy prematurely**
- **The chance that pre-initiation happens depends on the number of neutrons present during the time between when the implosion first becomes critical and the needed level of super-criticality for a given explosive yield**
- **Pre-initiation results in a statistical distribution in yield between a predictable, fixed lowest yield and higher yields**
- **The number of neutrons present depends upon the type of fissile material and comes from random, spontaneous fission**

Neutron Output (n/sec/gm): 100(wpns) 500(reactor)

Neutron Background - continued

- The time between first critical and the needed level of super-criticality also depends on the implosion speed of the fissile material

- A low velocity assembly in a high neutron background will result in very low fission yield (expansion wins)

- However, high implosion velocity enables fissile material to produce significant yield

Conclusion

- A militarily useful first generation nuclear explosive using reactor grade plutonium can be designed to produce nuclear yield in the multi-kiloton range.
- A first generation nuclear explosive is very large, unsophisticated, and would use weapons grade plutonium
- A nominal explosion yield would be ~ 20 kilotons
- With reactor grade plutonium, the yield would be more than 1 kiloton
- This would have a destructive radius greater than 1/3 that of the Hiroshima explosion

Summary

- **All plutonium isotopes can be used directly in nuclear explosives**

  In fact, in 1962, the US tested a nuclear explosive made with reactor grade plutonium

- **"Denatured" plutonium (that is, Pu which is unsuitable for nuclear explosives) *does not exist!***

- **High Pu-240 isotope content in a nuclear weapon is an engineering complication, *not an impediment***

What this means

- "A potential proliferating state or subnational group using designs and technologies no more sophisticated than those used in first-generation nuclear weapons could build a nuclear weapon from reactor grade plutonium that would have an assured, reliable yield of one or a few kilotons (and a probable yield significantly higher than that)" *

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