Reactor-Grade and Weapons-Grade Plutonium in Nuclear Explosives

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Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives

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Virtually any combination of plutonium isotopes -- the different forms of an element having different numbers of neutrons in their nuclei -- can be used to make a nuclear weapon. Not all combinations, however, are equally convenient or efficient.

The most common isotope, **plutonium-239**, is produced when the most common isotope of uranium, **uranium-238**, absorbs a neutron and then quickly decays to plutonium. It is this plutonium isotope that is most useful in making nuclear weapons, and it is produced in varying quantities in virtually all operating nuclear reactors. As fuel in a reactor is exposed to longer and longer periods of neutron irradiation, higher isotopes of plutonium build up as some of the plutonium absorbs additional neutrons, creating **plutonium-240**, **plutonium-241**, and so on. **Plutonium-238** also builds up from a chain of neutron absorptions and radioactive decays starting from **uranium-235**.

These other isotopes create some difficulties for design and fabrication of nuclear weapons.

- First and most important, **plutonium-240** has a high rate of spontaneous fission, meaning that the plutonium in the device will continually produce many background neutrons, which have the potential to reduce weapon yield by starting the chain reaction prematurely.

- Second, the isotope **plutonium-238** decays relatively rapidly, thereby significantly increasing the rate of heat generation in the material.
- Third, the isotope **americium-241** (which results from the 14-year half-life decay of **plutonium-241** and hence builds up in reactor-grade plutonium over time) emits highly penetrating gamma rays, increasing the radioactive exposure of any personnel handling the material.

Because of the preference for relatively pure **plutonium-239** for weapons purposes, when a reactor is used specifically for creating weapons plutonium, the fuel rods are removed and the plutonium is separated from them after relatively brief irradiation (at low "burnup"). The resulting "weapons-grade" plutonium is typically about 93 percent **plutonium-239**.

Such brief irradiation is quite inefficient for power production, so in power reactors the fuel is left in the reactor much longer, resulting in a mix that includes more of the higher isotopes of plutonium. In the United States, plutonium containing between 80 and 93 percent **plutonium-239** is referred to as "fuel-grade" plutonium, while plutonium with less than 80 percent **plutonium-239** -- typical of plutonium in the spent fuel of light-water and CANDU reactors at normal irradiation -- is referred to as "reactor-grade" plutonium.

All of these grades of plutonium can be used to make nuclear weapons. The only isotopic mix of plutonium which cannot realistically be used for nuclear weapons is nearly pure **plutonium-238**, which generates so much heat that the weapon would not be stable. (International rules require equal levels of safeguards for all grades of plutonium except plutonium containing more than 80 percent **plutonium-238**, which need not be safeguarded.)

Designing and building an effective nuclear weapon using reactor-grade plutonium is less convenient than using weapon-grade plutonium, for several reasons.

Some nuclear weapons are typically designed so that a pulse of neutrons will start the nuclear chain reaction at the optimum moment for maximum yield; background neutrons from **plutonium-240** can set off the reaction prematurely, and with reactor-grade plutonium the probability of such "pre-initiation" is large. Pre-initiation can substantially reduce the explosive yield, since the weapon may blow itself apart and thereby cut short the chain reaction that releases the energy.

Nevertheless, even if pre-initiation occurs at the worst possible moment (when the material first becomes compressed enough to sustain a chain reaction) the explosive yield of even a relatively simple first-generation nuclear device would be of the order of one or a few kilotons. While this yield is referred to as the "fizzle yield," a one-kiloton bomb would still have a radius of destruction roughly one-third that of the Hiroshima weapon, making it a potentially fearsome explosive. Regardless of how high the concentration of troublesome isotopes is, the yield would not be less.

Dealing with the second problem with reactor-grade plutonium, the heat generated by **plutonium-238** and **plutonium-240**, requires careful management of the heat in the device. There are well developed means for addressing these problems and they are not considered a significant hurdle to the production of nuclear weapons, even for developing states or sub-national groups.

The radiation from **americium-241** means that more shielding and greater precautions to protect personnel might be necessary when building and handling nuclear explosives made from reactor-grade plutonium. But these difficulties are not prohibitive.

While reactor-grade plutonium has a slightly larger critical mass than weapon-grade plutonium (meaning that somewhat more material would be needed for a bomb), this would not be a major impediment for design of either crude or sophisticated nuclear weapons.

The degree to which these obstacles can be overcome depends on the sophistication of the state or group attempting to produce a nuclear weapon.

At the lowest level of sophistication, 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).

At the other end of the spectrum, 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.

The greater radioactivity would mean increased radiation doses to workers fabricating such weapons, and military personnel spending long periods of time in close proximity to them, and the greater heat and radiation generated from reactor-grade plutonium might result in a need to replace certain weapon components more frequently.

Proliferating states using designs of intermediate sophistication could produce weapons with assured yields substantially higher than the kiloton-range possible with a simple, first-generation nuclear device.

Every state which has built nuclear weapons from plutonium to date has chosen to produce weapons-grade plutonium for that purpose. States have been willing to make large investments in some cases to acquire weapon-grade rather than reactor-grade plutonium: the United States, for example, in the 1980s, considered spending billions of dollars on the Special Isotope Separation facility to enrich reactor-grade plutonium to weapon-grade.

The disadvantage of reactor-grade plutonium is not so much in the effectiveness of the nuclear weapons that can be made from it as in the increased complexity in designing, fabricating, and handling them. The possibility that either a state or a sub-national group would choose to use reactor-grade plutonium, should sufficient stocks of weapon-grade plutonium not be readily available, cannot be discounted.

In short, reactor-grade plutonium is weapons-usable, whether by unsophisticated proliferators or by advanced nuclear weapon states. Theft of separated plutonium, whether weapons-grade or reactor-grade, would pose a grave security risk.

The **plutonium-240** content even in weapons-grade plutonium is sufficiently large that very rapid assembly is necessary to prevent pre-initiation. Hence the simplest type of nuclear explosive, a "gun type," in which the optimum critical configuration is assembled more slowly than in an "implosion type" device, cannot be made with plutonium but only with highly enriched uranium, in which spontaneous fission is rare.

This makes HEU [Highly Enriched Uranium] an even more attractive material than plutonium for potential proliferators with limited access to sophisticated technology.

Either material can be used in an implosion device.

> **See W. G. Sutcliffe and T.J. Trapp. eds., Extraction and Utility of Reactor-Grade Plutonium for Weapons, Lawrence Livermore National Laboratory. UCRL-LR-I 15542, 1994 (S/RD).**
