REACTOR-GRADE AND WEAPONS-GRADEPLUTONIUM IN NUCLEAR EXPLOSIVES

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, Pu-239, is produced when the most common isotope of uranium, U-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 Pu-240, Pu-241, and so on. Pu-238 also builds up from a chain of neutron absorptions and radioactive decays starting from U-235.[1] Because of the preference for relatively pure Pu-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 Pu-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 ("reactor-grade" plutonium).

Use of reactor-grade plutonium complicates bomb design for several reasons. First and most important, Pu-240 has a high rate of spontaneous fission, meaning that the plutonium in the device will continually produce many background neutrons. Second, the isotope Pu-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 Pu-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.

In a nuclear explosive using plutonium, the plutonium core is initially "subcritical," meaning that it cannot sustain a chain reaction. Chemical high explosives are used to compress the plutonium to higher than normal density (so that the neutrons released in each fission have a higher probability of hitting other atoms and causing more fissions). In a well-designed nuclear explosive using weapons-grade plutonium, a pulse of neutrons is released to start this chain reaction at the optimal moment, but there is some chance that a background neutron from spontaneous fission of Pu-240

will set off the reaction prematurely. With reactor-grade plutonium, the probability of such "pre-initiation" is very 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. Calculations demonstrate, however, that 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 device similar to the Nagasaki bomb would be of the order of one or a few kilotons. While this yield is referred to as the "fizzle yield," a 1-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. With a more sophisticated design, weapons could be built with reactor-grade plutonium that would be assured of having higher yields.[2]

Dealing with the second problem with reactor-grade plutonium, the heat generated by Pu-238 and Pu-240, requires careful management of the heat in the device. Means to address this problem include providing channels to conduct the heat from the plutonium through the insulating explosive surrounding the core, or delaying assembly of the device until a few minutes before it is to be used.

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.

In short, it would be quite possible for a potential proliferator to make a nuclear explosive from reactor-grade plutonium using a simple design that would be assured of having a yield in the range of one to a few kilotons, and more using an advanced design. Theft of separated plutonium whether weapons-grade or reactor-grade, would pose a grave security risk.

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[1] For a useful figure showing the buildup of these isotopes as a function of irradiation time, see J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," *Science and Global Security*, Vol. 4, no. 1, 1993, pp. 111-128.

[2] See W. G. Sutcliffe and T.J. Trapp, eds., *Extraction and Utilityof Reactor-Grade Plutonium for Weapons*, Lawrence Livermore National Laboratory, UCRL-LR-115542, 1994 (S/RD). For unclassified discussions, see J. Carson Mark, op. cit.

The Pu-240 content even in weapons-grade plutonium is sufficiently large that very rapid assembly is necessary to prevent preinitiation. 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. The makes HEU 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.