Nuclear Explosives

Abstract The history of the development of the first nuclear devices in the US are discussed from the standpoint of both the science and the politics behind this decision to move towards developing such devices. The Hiroshima and Nagasaki weapons were developed through completely different processes–one with uranium and one with plutonium. The different paths are compared and contrasted. The basic physics of nuclear weapons is discussed from the vantage point of the now-declassified Los Alamos Primer. The development of fusion-boosted weapons is also described, along with the historical backdrop of the Cold War and the arms race in the 1960s and beyond. The impact of the dismemberment of the Soviet Union on the availability of weapons-usable nuclear material is outlined, and the classification of nuclear material is described from the viewpoint of various national and international regulatory bodies.

1 History

1.1 The Dawn of the Atomic Age

The Atomic Age officially started with the test and subsequent deployment of fission-based nuclear explosives by the United States in 1945. The first nuclear attack came on the largely civilian population of Hiroshima, Japan on August 6, 1945. The death toll is uncertain, with estimates of 70,000 killed immediately by the blast and at least 20,000 more dead from burns and radiation sickness over the next few months. On August 9, 1945, a second nuclear explosive was deployed at Nagasaki, Japan, resulting in a cumulative death toll of between 60,000 and 80,000. While these numbers are small compared to the total deaths in World War II ($\sim$60 million), this demonstration of nuclear explosives as the most terrifying and lethal weapons in mankind's history has changed the world permanently.

The possibility of a weapon based on nuclear fission had occurred to many physicists after the discovery of nuclear fission. An experiment in Germany by Hahn and Strassman in 1938 showed that bombardment of uranium with neutrons created enormous energy release compared to other known reactions and created reaction

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products such as barium. By 1939, Lise Meitner and Otto Frisch gave a theoretical explanation for this process as the breakup of the heavy uranium nucleus due to the its large coulombic forces, and the production of two lighter nuclei as a result. An experiment by Enrico Fermi and Leo Szilard at Columbia University in the United States showed that more than one neutron was produced per neutron-induced fission, thus paving the way for a nuclear chain reaction. Szilard and Eugene Wigner then approached Albert Einstein and asked if Einstein would sign a letter addressed to then-President Franklin Roosevelt, advising him to develop uranium resources and technology for development of a nuclear explosive. The letter was sent on August 2, 1939. Roosevelt asked Lyman Briggs of the National Bureau of Standards to chair a committee (the "Advisory Committee on Uranium") to examine the possibility for a nuclear explosive. In November of that year, the committee reported back to Roosevelt that the fission concept was very likely to yield a bomb of immense explosive power. Meanwhile, parallel efforts were going on in England, and Frisch and Rudolf Peierls had calculated the critical mass for a ^{235}U device to be about 10 kg, much smaller than other prevailing estimates of the day. While this result was ignored in the United States, an Australian physicist, Mark Oliphant, working in Birmingham, England at the time, visited Berkeley, California in 1941 and communicated this result to Ernest Lawrence, who then became a believer in the prospects of a fission explosive. Lawrence then persuaded several key scientists in the government to start a large-scale program, and Roosevelt approved what would become known as the Manhattan Project in October 1941. By the summer of 1942, large numbers of physicists gathered at the University of Chicago and at Berkeley to discuss theoretical aspects of nuclear fission. In order to preserve secrecy about the project, most participants were relocated to Los Alamos, New Mexico starting in late 1942, in a new secret laboratory under the direction of J. Robert Oppenheimer from Berkeley. Overall direction of the Manhattan project was done by Leslie Groves of the U. S. Army.

Another important development had occurred in 1941 in Berkeley. Nuclear chemist Glenn Seaborg and his group had isolated a new element, plutonium. It was produced by exposing ^{238}U nuclei to neutrons. It quickly became apparent that this new element also had a high probability of fissioning under exposure to neutrons, similar to ^{235}U. This made it clear that there would be two paths to developing the critical material for an atomic bomb: either by enriching uranium to obtain a product containing mostly ^{235}U or by producing plutonium in a fission reactor. By late 1942, Fermi and Szilard had demonstrated the first nuclear reactor at the University of Chicago. By early 1943, a site at Hanford, Washington was commissioned to build plutonium production reactors.

An initial approach to uranium isotope production was developed at Berkeley using a method based on ion mass spectrometry and called the Calutron. Large-scale versions of these machines were built at Oak Ridge, Tennessee and known as the Y-12 plant. The magnet coils for these machines were made with pure silver conductors, representing about 395 million troy ounces in silver (worth roughly $ 10 billion in today's market) on loan from the repository at West Point, New York.

(After the war, the silver was returned to West Point, and gaseous diffusion replaced electromagnetic separation.)

The difficulty of producing adequate quantities of weapon-grade uranium resulted in the decision not to test the uranium weapon, which was ultimately used at Hiroshima and called Little Boy. However, the design of Little Boy was not sophisticated, and relied upon the combination of two subcritical components by firing an explosive behind one of the components, causing it to mate with the other with a linear trajectory. This "gun-type" design was very heavy (almost five tons), required a great deal of enriched uranium (64 kg of 80 % enriched U), and was inefficient (its nuclear yield was around sixteen kilotons TNT equivalent, or a little over one percent burnup of its nuclear fuel).

The Nagasaki weapon, known as Fat Man, was a very different device. It was made with plutonium produced mostly in reactors at Hanford. It also used a more sophisticated system of implosion of the subcritical components in a symmetrical way. The timing of the shock waves had to be carefully controlled, and the design of the explosive lens had to be carefully worked out. However, there were significant advantages to the Fat Man design. Firstly, it used a much smaller amount of fissile material (only about 6.2 kg, less than a tenth of Little Boy), secondly, that material could be plutonium, which was easier to obtain at the time, and thirdly, the device would only detonate if all of the chemical explosives worked together, so that an accidental criticality during handling was very unlikely. Enough plutonium was available at the time to perform a test before the actual deployment in Japan, and this test (of a device called "Gadget") was performed at the White Sands test site near Alamogordo, New Mexico on July 16, 1945. The code name for this test was Project Trinity. The test was successful, and produced about 20 kilotons of TNT equivalent energy. Preparations began immediately following this test to deploy both Little Boy and Fat Man in Japan, and both devices were used three weeks later.

At this point it is interesting to consider the resources that were available for this endeavor. On the one hand, financing for this project was practically unlimited. Almost $2 billion (equivalent to about $25 billion today) was spent on the Manhattan Project from its start until August 1945, an unprecedented amount for a government-supported research and development program at that time. The human capital for the project was also impressive, representing some of the brightest physicists, chemists, mathematicians, and engineers on the planet. But compared to today's technology, one can see some great disadvantages. "Computers" were not computers in the modern sense, but were humans using mechanical calculators, and only late in the project were there mechanical calculators using punched cards. Implosion calculations took months at a time. The transistor was not invented until 1948, and electronic systems in 1945 used vacuum tubes, gas-filled switch tubes, and mechanical relays. Gamma-ray spectroscopy was in its infancy (The Manhattan Project resulted in the invention of the scintillation detector in 1944, by Samuel Curran at Berkeley), and solid-state germanium detectors came along much later. High-speed photography was also developed out of necessity for the project, and high-speed radiography did

not exist. Conjectures about the difficulty for small countries or terrorist organizations to stand up a nuclear weapon development program, seventy years later, should consider these changes.

1.2 The Cold War and the Arms Race

While American nuclear experts knew that the Soviet Union would be trying to develop nuclear explosives, it came as a surprise that the first successful Soviet test would happen as soon as 1949, when on August 29 the Soviets detonated a device they referred to as "First Lightning"(nicknamed "Joe-1" in the West, after Joseph Stalin). The test was performed at Semipalatinsk in what is now Kazakhstan. The design was an implosion-type plutonium device with a 22 kiloton yield and was almost identical to Gadget and Fat Man. In retrospect this was not so surprising once the extent of espionage at Los Alamos became known. This test also demonstrated the beginning of airborne radioactivity monitoring to detect nuclear testing, as the United States used a specially fitted B-29 aircraft with radioactivity-sensing equipment, which picked up a plume of radioactivity about a week later when the plume appeared east of the Kamchatka peninsula.

The race was then on to develop a large arsenal of nuclear weapons, and to develop more powerful and more easily deployable designs. Starting with early meetings in Berkeley in 1942, Edward Teller had argued for the development of the "Super", which would exploit nuclear fusion reactions

$$ {}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow \mathrm{n} + {}^{3}_{2}\mathrm{He} $$

$$ {}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow \mathrm{p} + {}^{3}_{1}\mathrm{H} $$

$$ {}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow \mathrm{n} + \alpha $$

The last reaction makes 17.6 MeV of energy, much less than the 200 MeV released in a fission event, but with three times the yield per gram of material, and is a net producer of fast neutrons, which can in turn be used to trigger more fission reactions. The two isotopes of hydrogen used, ^{2}H and ^{3}H, known as deuterium and tritium, are easily obtainable: deuterium exists as a minority isotope in ordinary water (fully deuterated water is called heavy water), and tritium can be manufactured in a nuclear reactor by neutron absorption on lithium. (Or the tritium can be created at the time of detonation by introducing lithium deuteride into the device.) While Oppenheimer at Los Alamos did not encourage the development of the Super, renewed interest came after the detonation of Joe-1. After some failed attempts at testing some fusion-boosted designs, a successful (deuterium-only) test was done on November 1, 1952 at the Eniwetok Atoll in the South Pacific. The test, code-named Ivy Mike, produced a little over ten megatons of yield. However, this test involved a device that was far too massive (82 tons) to be used as a weapon.

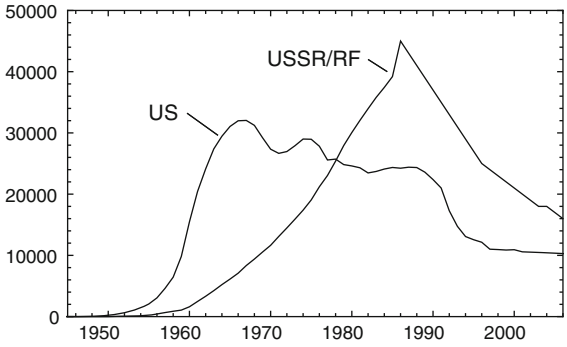

Fig. 1 Stockpile size per year for the United States and Soviet Union/Russian Federation, 1945–2006. Data from [6]

Soviet tests progressed along similar lines, culminating in the first detonation in the megaton range by November 22, 1955. By 1961, the Soviets had assembled a device nicknamed "Tsar Bomba", which was detonated on the remote Arctic island of Novaya Zemlya on October 30, with a yield of 58 megatons.

Meanwhile, the buildup of field-usable nuclear weapons began to grow and become more sophisticated. A typical example was the W-7 device developed in the United States in 1952, which weighed only 400 kg and could be placed on a small short-range missile. As shown in Fig. 1, inventories grew exponentially in the 1950s in the US, with a slower but similar rise in the Soviet Union, continuing upward until the mid-1980s.

Other members were added to the "nuclear club". Great Britain, a partner along with Canada in the U.S. nuclear program during World War II, developed its own arsenal of nuclear weapons starting in 1953. France made its first nuclear test in 1960, and had a nuclear weapon by 1964. China tested in 1964 and started weapon production within the year. While not openly disclosing any details, Israel is believed to have developed nuclear capability, starting in 1967 [10]. In 1974 India tested ("Smiling Buddha") [8] and began putting weapons into stockpile after that time. Pakistan probably started a program shortly after that, and under the leadership of Abdul Qadeer Khan by 1981, and performed cold tests in about 1983. They tested for the first time on 28 May 1998 [1]. A nuclear program was started and later abandoned in South Africa [7]. More recently North Korea has developed a nuclear program, with a low-yield test in 2006 but with substantially higher-yield tests in 2009 and 2013 [2].

1.3 The Fall of the Soviet Union

In 1985, The General Secretary of the Soviet Politburo, Mikhail Gorbachev, announced that the Soviet economic system was not sustainable and called for vast reforms of the Soviet system. Ultimately this led to the breakup of the Soviet Union starting in 1989, followed by complete dissolution of the Soviet Union in 1991. Some

of the former Soviet countries possessed nuclear weapons at that time. Of particular interest were Ukraine and Kazakhstan, which had approximately 5000 and 1400 devices respectively in 1991 at the time of the dissolution. All of these weapons were returned to Russia by 1997. However, questions remain about weapons-usable nuclear materials stored (by a DOE estimate in 1998) at over 150 facilities at 53 sites, in Russia and former Soviet republics. Of continuing interest is the former Soviet test site of Semipalatinsk in Kazakhstan, which covers 7000 square miles. The lack of recordkeeping and the lack of site security over this vast area form a risky combination of factors.

2 Device Physics

The treatments given here closely follow the now-unclassified document known as the Los Alamos Primer, distributed at Los Alamos in 1943 as part of an indoctrination course for scientists working on the Manhattan Project [9].

2.1 Critical Mass

The smallest size for a fission explosive is given by neutron transport theory. For a complete derivation of the theory, consult a standard textbook such as Lamarsh [4].

We assume that we have a spherical assembly of pure ^{235}U with radius a. The equation concerning the rate of growth of the fast neutron population is given by:

$$\dot{\mathrm{n}} = \mathrm{D}\Delta\mathrm{n} + \left(\frac{\nu - 1}{\tau}\right)\mathrm{n}. \tag{1}$$

Here n is the number density of neutrons in the assembly, D is the diffusion coefficient and is equal to $(1/3)\lambda_{\mathrm{tr}}\mathrm{v}$, where λ_{tr} is the mean free path for the neutrons, and v is the average speed of the neutrons. The mean free path is given by the number density in the fuel material $\mathrm{n_f}$ and the total cross section $\Sigma_t = \mathrm{n_f}\sigma_{\mathrm{t}}$ as

$$\lambda_{\mathrm{tr}} = \frac{1}{\Sigma_{\mathrm{t}}} = \frac{1}{\mathrm{n_f}\sigma_{\mathrm{t}}} \tag{2}$$

and the quantity ν is the average number of neutrons produced per fission event. The quantity τ is the average time for a neutron to cause another fission event with a fuel nucleus after production and is given by

$$\tau = \frac{1}{\Sigma_{\mathrm{f}}\mathrm{v}}. \tag{3}$$

Here $\Sigma_f = n_f \sigma_f$, with σ_f as the fast fission cross section in the material. The operator Δ is the laplacian operator, sometimes written as ∇^2. We can separate the variables in this equation so that

$$n(\mathbf{r}, t) = T(t)R(r) \tag{4}$$

where we assume spherical symmetry. The time dependence is then given by

$$T(t) = \exp\left(\frac{\nu' t}{\tau}\right) \tag{5}$$

with

$$\Delta R(r) + \frac{-\nu' + \nu - 1}{D\tau} R(r) = 0 \tag{6}$$

If we solve this equation with a boundary condition $n(a) = 0$, we find that the lowest order solution is given by

$$R(r) = n_0 \frac{\sin(\pi r/a)}{\pi r/a}$$

and then the operator Δ is replaced by $-(\pi/a)^2$. However, the choice of boundary condition $n(a) = 0$ isn't quite correct; the actual boundary condition requires a correction to account for the free streaming of neutrons at the boundary, with no returning flux. A simple way to handle this is to add an "extrapolation length" to the actual radius, giving an effective radius as

$$a' = a + \delta \tag{7}$$

for planar geometries, $\delta \approx 0.71 \lambda_{tr}$, and we assume that this is approximately correct for the spherical problem. The critical size (for which $\nu' = 0$) is given by

$$(a + \delta)^2 = \frac{\pi^2}{3\Sigma_f \Sigma_t (\nu - 1)} \tag{8}$$

and then the critical mass $M_c = (4/3)\pi\rho a^3$.

We can now calculate the critical mass for ^{235}U as an example. Using modern values for ^{235}U for fast neutrons, $\nu = 2.70$, $\Sigma_f = 0.06192$ cm^{-1}, $\Sigma_t = 0.2160$ cm^{-1}, and $\rho = 18.7$ g cm^{-3} gives

$$M_c = 52 \text{ kg}$$

(The original Los Alamos number was 60 kg, quite close considering the error bars on the data at that time.)

A similar calculation for ^{239}Pu ($\nu = 3.10$, $\Sigma_f = 0.0936$ cm^{-1}, $\Sigma_t = 0.2208$ cm^{-1}, $\rho = 15.92$ g cm^{-3}) gives an much smaller value of $M_c = 11.0$ kg. Note that in general, the critical mass scales as

$$M_c \propto \frac{1}{\rho^2[\sigma_t \sigma_f (1-\nu)]^{3/2}} \tag{9}$$

Note especially the $1/\rho^2$ dependence, showing that significantly less material is required for an implosion-type device.

The above calculations assume that only one species is present. The crude one-speed diffusion theory shown here works fairly well for these examples because the fission cross section is roughly constant over the fast neutron energy spectrum, and the details of more complex scattering physics, such as angular dependence of the scattering and inelastic scattering, are less important. For the case of ^{235}U and ^{238}U at arbitrary enrichment, this is no longer the case, because the neutron-induced fission of ^{238}U is a threshold process with a minimum energy required of about 1 MeV, which is inside the range of energies of neutrons produced in fission. (The neutron energy spectrum from fission is a roughly maxwellian spectrum with a "temperature" of about 1.3 MeV.) Inelastic scattering can lower the fission-produced neutron energy to below the fission energy threshold for ^{238}U in one collision.

For this type of neutronics problem, one is better served by using a Monte Carlo computer code such as MCNP to calculate the critical mass. An example of such a calculation, for uranium spheres at various enrichment levels, is shown as Fig. 2. This calculation shows that the critical mass required goes to very impractical values for enrichments below 15 %, and that no fast assembly (i.e. a bomb) can be made with material at standard power plant nuclear fuel enrichments of 3–4%.

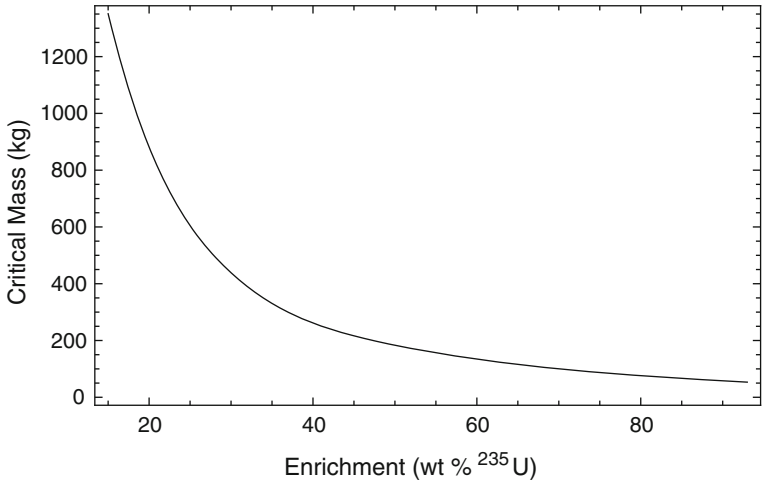

Fig. 2 Critical mass versus enrichment for bare uranium spheres. Data from [3]

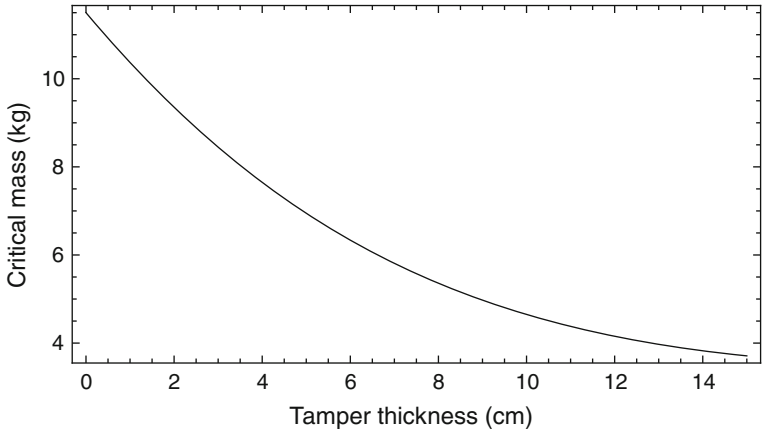

Fig. 3 Critical mass versus Be tamper thickness for weapon-grade Pu. Data from [3]

One further detail of weapon construction needs to be considered as part of a discussion about criticality, however. That is the possibility that a second non-fissile zone may be added to the outside of the fissile material. This is called a "tamper" and it serves two purposes. Firstly, neutrons leaving the fissile zone into the tamper will be scattered and thus some of them will re-enter the fissile zone, or be "reflected" back into the fissile zone. Secondly, by its mere inertia, the tamper slows the expansion of the fissile zone when it is supercritical, thus prolonging the time of exponential growth and increasing the yield. Tamper criticality calculations are also more complex than can be derived accurately with one-speed diffusion theory, but again, Monte Carlo calculations can assist in getting an accurate picture of how the tamper can lower the critical mass required. Figure 3 shows the effect of adding a beryllium tamper to a sphere of weapon-grade plutonium.

2.2 Heat Generation. Neutron Background and Predetonation

Several other details concerning the physics of nuclear weapons must be considered in order to appreciate the risk potential of various fissionable actinide isotopes. The first and simplest topic is the radioactivity of the isotopes involved and their propensity to generate heat. Excessive heat may cause thermal distortions of parts of the device and lead to degradation of the chemical explosive in the device. Table 1 lists the specific heat generation rates for various isotopes of interest. This shows, for example, that while ^{233}U is a usable weapon material, the material must be produced with very tight limits on the presence of ^{232}U, because of its high heat generation rate; the same applies to ^{238}Pu in ^{239}Pu-based assemblies. Also, some of these isotopes generate

Table 1 Properties of various isotopes of interest in fission-based nuclear explosive assemblies

Nuclide	Half-life	Specific activity	Heat Gen.	Spont. fission rate
U-232	6.89E+01 y	8.25E+11 Bq g^{-1}	7.14E-01 W g^{-1}	n/a
U-233	1.59E+05 y	3.57E+08 Bq g^{-1}	2.76E-04 W g^{-1}	2.1E-04 $g^{-1}s^{-1}$
U-234	2.46E+05 y	2.30E+08 Bq g^{-1}	1.79E-04 W g^{-1}	3.98E-03 $g^{-1}s^{-1}$
U-235	7.04E+08 y	8.00E+04 Bq g^{-1}	5.99E-08 W g^{-1}	5.60E-06 $g^{-1}s^{-1}$
U-236	2.34E+07 y	2.39E+06 Bq g^{-1}	1.75E-06 W g^{-1}	2.30E-03 $g^{-1}s^{-1}$
U-238	4.47E+09 y	1.24E+04 Bq g^{-1}	8.50E-09 W g^{-1}	6.78E-03 $g^{-1}s^{-1}$
Np-237	2.14E+06 y	2.61E+07 Bq g^{-1}	2.06E-05 W g^{-1}	5.22E-05 $g^{-1}s^{-1}$
Pu-238	8.78E+01 y	6.34E+11 Bq g^{-1}	5.67E-01 W g^{-1}	1.20E+03 $g^{-1}s^{-1}$
Pu-239	2.41E+04 y	2.30E+09 Bq g^{-1}	1.93E-03 W g^{-1}	7.11E-03 $g^{-1}s^{-1}$
Pu-240	6.57E+03 y	8.39E+09 Bq g^{-1}	7.06E-03 W g^{-1}	4.78E+02 $g^{-1}s^{-1}$
Pu-241	1.44E+01 y	3.82E+12 Bq g^{-1}	3.28E-03 W g^{-1}	9.18E-04 $g^{-1}s^{-1}$
Pu-242	3.74E+05 y	1.46E+08 Bq g^{-1}	1.17E-04 W g^{-1}	8.04E+02 $g^{-1}s^{-1}$
Am-241	4.32E+02 y	1.27E+11 Bq g^{-1}	1.14E-01 W g^{-1}	5.47E-01 $g^{-1}s^{-1}$

Data from [5]

energetic gamma rays in their decay sequence, and the presence of these may make it difficult for workers to assemble these devices or to be near them after they are made.

Also of interest is the rate of neutron emission from these materials. Neutrons can be produced in fissile materials by spontaneous fission. In order for a device to perform with substantial yield, the device must be sufficiently supercritical before neutrons induce a fission chain reaction, which in turn produces enough energy to start the dis-assembly of the device. A predetonation caused by the spurious presence of early neutrons is called a "fizzle". For the relatively slow assembly afforded by a gun-type process such as used in the Little Boy design, with velocities around 1000 meters per second and distance traveled between exact criticality and supercriticality on the scale of ten centimeters or so, the period when a fizzle is possible by premature neutron-induced fission is on the order of 10^{-4} s. Plutonium, on the other hand, typically gets manufactured in a nuclear reactor by absorption of neutrons on ^{238}U. Further nuclear reactions will turn some of this plutonium into ^{240}Pu, and at least a few percent concentration of ^{240}Pu is unavoidable. This isotope has a high rate of spontaneous fission.

For this reason, even though ^{235}U is a less desirable material than Pu for constructing a nuclear weapon for large programs such as the US and Russian programs, ^{235}U can be considered a greater terrorism/rogue nation threat because the technological barrier is much less for developing a usable weapon, given that sufficient quantity of material is available. On the other hand, kilogram quantities of weapon-grade Pu (usually taken to be $<7\,\%$ ^{240}Pu) is a credible threat in the hands of a somewhat more sophisticated adversary.

The foregoing analysis also points to the types of nuclear reactors that are more of a threat to the production of weapon-usable plutonium. A large power reactor,

say an 1100 MWe (3300 MWth) reactor (such as most of the reactors online in the US) typically has very high burnup rates for the fuel, and the fuel elements are in the reactor for years at a time. The plutonium in the spent fuel from these reactors typically has more ^{240}Pu than ^{239}Pu, and is extremely difficult to be used in a nuclear weapon. Small research reactors in the 15–30 MWth class pose more of a risk, as these are more open, accessible systems with lower typical fuel irradiation. CANDU-type reactors, with their ability to be fuel-swapped while they are running, are also more difficult to control from a safeguarding viewpoint.

3 Special Nuclear Material

The purpose of this section is to define the terms that are used to describe materials connected to the development of nuclear weapons.

Special Nuclear Material, or SNM, is a term used by the U. S. Nuclear Regulatory Commission (NRC) to mean uranium enriched in ^{235}U or ^{233}U, ^{233}U, and plutonium of any isotope. This definition is given in Title I of the Atomic Energy Act of 1954. The NRC has the authority to add other materials to the list of SNM materials, but it never has done so.

The NRC has also broken down SNM into three Safeguard Categories of risk. Category I is defined as Strategic Special Nuclear Material, or SSNM, and is defined as material containing:

- 2 kg or more of plutonium; or
- 5 kg or more of U-235 (contained in uranium enriched to 20 % or more in the U-235 isotope); or
- 2 kg or more of U-233; or
- 5 kg or more in any combination computed by the equation grams = (grams contained U-235) + 2.5 (grams U-233 + grams plutonium).

Category II, “Special nuclear material of moderate strategic significance” is defined as

- Less than a formula quantity of strategic special nuclear material but more than 1,000 grams of uranium-235 (contained in uranium enriched to 20 % or more in the U-235 isotope) or more than 500 grams of uranium-233 or plutonium, or in a combined quantity of more than 1,000 grams when computed by the equation grams = (grams contained U-235) + 2 (grams U-233 + grams plutonium); or
- 10,000 grams or more of uranium-235 (contained in uranium enriched to 10 % or more but less than 20 % in the U-235 isotope).

Category III, “Special nuclear material of low strategic significance” is defined as

- Less than an amount of special nuclear material of moderate strategic significance (see category II above) but more than 15 grams of uranium-235 (contained in uranium enriched to 20 % or more in U-235 isotope) or 15 grams of uranium-233

or 15 grams of plutonium or the combination of 15 grams when computed by the equation grams = (grams contained U-235) + (grams plutonium) + (grams U-233); or

- Less than 10,000 grams but more than 1,000 grams of uranium-235 (contained in uranium enriched to 10 % or more but less than 20 % in the U-235 isotope); or
- 10,000 grams or more of uranium-235 (contained in uranium enriched above natural but less than 10 % in the U-235 isotope).

Enriched Uranium means any uranium containing more that 0.71 % ^{235}U. *Highly Enriched Uranium, or HEU*, is defined by the U. S. Department of Energy (DOE) as uranium containing more that 20 % ^{235}U. This is considered the lowest enrichment for which a nuclear explosive is possible. In 1996, the DOE had about 740 metric tons in this category. (Since that time, the inventory has been reduced by downblending and disposal.) The DOE also separates out its inventory of >90.0 % enriched uranium, which might be considered "weapon grade", although DOE does not use that terminology specifically, nor does it report its total inventory in that category.

The term *Significant Quantity* is used by the International Atomic Energy Agency (IAEA) to denote "the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded." The significant quantities are 8 kg of Pu(<80 % ^{238}Pu), 8 kg ^{233}U, 25 kg HEU, 75 kg enriched U(<20 % enriched), 10 metric tons natural U, 20 metric tons depleted U, or 20 tons Th. These quantities are used as the trigger points for further action following their detection during inspections.

One can notice some decoupling of these definitions from the actual threat. It is interesting to note that ^{237}Np is not SNM under U.S. guidelines, although it is generally known as a nuclear weapon-usable material. Also, the IAEA would not consider the quantity of plutonium used in the Fat Man Nagasaki weapon to be "significant"!

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