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The Amount of Plutonium and Highly-Enriched Uranium Needed for Pure Fission Nuclear Weapons

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A. The North Korean Situation

On 27 July 1994, Kang Myong Do, a defector who identified himself as the son-in-law of North Korea's prime minister, said at a news conference that a high ranking North Korean official told him that the country had built five nuclear warheads.[1] In response to this claim, U.S. Secretary of Defense William Perry is quoted at a news conference as having said, "we do take . . . seriously" [the defector's claim]. "If they had a very advanced technology, they could make five bombs out of the amount of plutonium we estimate they have."[2]

The United States intelligence estimate of the amount of plutonium separated by North Korea to date is about 8-9 kilograms (kg). In 1986 North Korea began operating a gas-cooled graphite-moderated reactor at the nuclear complex at Yongbyon.[3] In 1989, after an average fuel burnup of just under 200 megawatt-days per metric tonne (MWd/MT), the reactor was shut down for about 100 days, while some or all of the fuel was discharged, and the plutonium chemically separated from the spent fuel and fission products. The North Korean government admits that some plutonium was separated, but claims only 89 leaking fuel elements were removed and reprocessed; in which case only about 100 grams of weapon-grade plutonium (WGPu) would have been recovered.

Inspections by the International Atomic Energy Agency (IAEA) in 1992 revealed that North Korea was not being truthful about how much fuel had been processed and how much plutonium recovered. Based on circumstantial evidence, the United States intelligence community believes the entire core was removed in 1989 and subsequently reprocessed, in which case North Korea has separated on the order of 8-9 kg of WGPu (~1.4 percent Pu-240).

On 14 May 1994 North Korea announced that it had started to remove fuel rods from the 25 MWt Yongbyon reactor. This was confirmed by the IAEA inspectors on 18 May.[4] By 1 June according, to an IAEA official, some 5000 of the 8000 fuel rods had been replaced. A week later the refueling had been virtually completed.[5] North Korea continues to maintain that this was the first and only refueling, other than the removal of the 89 defective fuel rods.

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[1] Lee Keumhyun, "N. Korea Has 5 Nuclear Warheads, No Delivery System, Defector says," *Washington Post*, 28 July 1994, p. A25.

[2] Ibid.

[3] The size of this reactor, measured in terms of its capacity to produce heat is 25 megawatt-thermal (MWt), and it is designed to produce 5 MW of electricity (MWe). A second reactor--250 MWt, or ten times larger than the first--is under construction at Yongbyon. It is expected to be completed in 1995. The first reactor core contains about 50 metric tonnes (MT) of natural uranium fuel in some 8000 fuel rods, or elements, distributed among some 812 fuel channels.

[4] R. Jeffrey Smith, "N. Korea Defies Atomic Energy Agency," *Washington Post*, 15 May 1994, p. A30; R. Jeffrey Smith, "New Defiance by North Korea Found," *Washington Post*, 19 May 1994, p. A36.

[5] "Pyongyang 'Virtually Finished' Removing Yongbyon Fuel Rods," Tokyo Kyodo, 8 June 1994, in JPRS-TND-94-014, 13 July 1994, p. 16.

If the U.S. intelligence estimate is correct, then the 1994 refueling represents the *second* core discharged. In any event, no one disputes that at a burnup of 600 MWd/MT, there is an inventory of about 28 kg of WGPu (~4 percent Pu-240) in the spent reactor fuel which has not yet been reprocessed. Whether this spent fuel will be chemically separated by North Korea is the subject of ongoing negotiations between North Korea and the IAEA, and separate negotiations between the North Korea and the United States.

Following the discovery that North Korea was giving false information about its plutonium separation efforts, the *New York Times* reported in December 1993 that the Central Intelligence Agency (CIA) had told President Clinton that there was a better than even chance that North Korea had developed one or two nuclear bombs.[6] At the time of the May-June 1994 refueling the U.S. government claimed -- based on an estimate that 28 kg WGPu remained in the spent fuel -- that North Korea could have an additional four or five nuclear weapons if the spent fuel was reprocessed.[7]

Secretary Perry's remarks indicate that the U.S. intelligence community's estimates are based on the assumption that North Korea would most likely build weapons of a low-technology design, similar to the implosion design--*Fat Man*--developed by the United States. *Fat Man* was first tested at the *Trinity* site in New Mexico on July 16, 1945, and dropped on Nagasaki on August 9, 1945. This atomic bomb reportedly used 6.1 kg of WGPu.

As Secretary Perry has now revealed, assuming a mastery of more sophisticated designs, North Korea could have made five nuclear weapons from the 8 to 9 kg of WGPu. According to our estimates, such medium to high technology weapons would have nuclear yields in the range of one to eight kilotons (kt) of TNT equivalent and would meet the volume and weight constraints for clandestine emplacement or delivery by intermediate or long range ballistic and cruise missiles.

B. IAEA Safeguards.

In 1953 the United States proposed the establishment of the International Atomic Energy Agency (IAEA) to provide a means of verifying that nuclear materials and equipment provided for peaceful purposes would not be used for explosive or military purposes. After three years of debate the IAEA was established in 1957. To carry out the safeguards obligations subsequently assigned to the IAEA under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), and other multinational and bilateral agreements, the IAEA has devised a

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[6] Stephen Engelberg with Michael Gordon, "Intelligence Study Says North Korea Has Nuclear Bomb," *New York Times*, 26 December 1993, p. 1.

[7] Michael R. Gordon, "North Korea Said to Have A-Bomb Fuel," *New York Times*, 8 June 1994, p. A1.

system of safeguards, one objective of which is to assure the detection of -- and thereby deter -- the diversion of safeguarded nuclear materials to the production of nuclear explosives.[8]

The principal safeguards documents of the IAEA, both of which have been revised over the years, are "Information Circulars" INFCIRC/66 and INFCIRC/153. Nuclear materials and nuclear facilities in all non-weapon NPT member states, and other states accepting IAEA safeguards, are covered under either INFCIRC/66 and INFCIRC/153. The main difference between INFCIRC/66 and INFCIRC/153 is the "full-scope" intent of the latter -- it applies to all nuclear material in all peaceful nuclear activities of the non-nuclear weapon state. The technical objective of safeguards, made explicit in paragraph 28 of INFCIRC/153, is "the timely detection of the diversion of **significant quantities of nuclear material** from peaceful nuclear activities to the manufacture of nuclear weapons or other explosive devices or for purposes unknown and deterrence of such diversion by risk of early detection."[9]

For safeguards purposes the IAEA defines a "significant quantity" (SQ) of nuclear material as "the approximate quantity of nuclear material in respect of which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded."[10] Significant quantity values currently in use by the IAEA are given in Table 1.[11]

The SQ values were recommended to the IAEA by a group of experts, namely, the IAEA's Standing Advisory Group for Safeguards Implementation (SAGSI), and "relate to the potential acquisition of a first nuclear explosive by a non-nuclear weapon state."[12]

The direct-use values in Table 1, that is, 8 kg of plutonium, 8 kg of uranium-233, and 25 kg of HEU, are also referred to by the IAEA as "threshold amounts," defined as "the approximate quantity of special fissionable material required for a single nuclear device."[13] The IAEA cites as a source for these threshold amounts a 1967 United Nations document.[14]

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[8] *IAEA Safeguards: An Introduction*, IAEA, IAEA/SG/INF/3, 1981, p. 12.

[9] Ibid., p. 14.

[10] *IAEA Safeguards Glossary, 1987 Edition*, IAEA, IAEA/SG/INF/1 (Rev. 1), 1987, p. 23.

[11] Ibid., p. 24.

[12] Thomas Shea, "On the Application of IAEA Safeguards to Plutonium and Highly Enriched Uranium from Military Inventories," IAEA, (June 1992, with additions: December 1992).

[13] Ibid., p. 23.

[14] *Effects of the Possible Use of Nuclear Weapons ...*, United Nations, A/6858, 6 October 1967.

The IAEA states,

> These threshold amounts include the material that will unavoidably be lost in manufacturing a nuclear explosive device. They should not be confused with the minimum critical mass needed for an explosive chain reaction, which is smaller.[34]
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> [34] Using highly sophisticated techniques available to NW States, the critical mass and the corresponding threshold amount can also be significantly reduced, but these are special cases that need not be considered here.

As seen below, the direct-use SQ or threshold values currently used by the IAEA are technically indefensible. The IAEA is making false claims as to the minimum quantity of nuclear material needed for a nuclear weapon, even for a low-technology first nuclear explosive by a non-nuclear weapon state, including consideration of unavoidable losses.

C. NRDC's Estimate of a Quantity of Safeguards Significance

For single-stage pure fission weapons, a spherically symmetric implosion design requires the least amount of fissile material to achieve a given explosive yield, relative to other possible designs. For this type of device the amount of fissile material required depends primarily upon the type of fissile material used, e.g., plutonium, U-233, or highly-enriched uranium (HEU), the desired explosive yield of the device, and the degree to which the fissile material is compressed at the time disassembly of the fissile material begins due to the release of energy from the rapid nuclear chain reaction.

The degree of compression achieved depends on the sophistication of the design and degree of symmetry achieved by the imploding shock wave. There are, of course, other factors -- such as the timing of the initiation of the chain reaction and the type of neutron reflector used -- but we will assume that the proliferant state or subnational group already has acquired the necessary skills so that these factors are of secondary importance.

In Figures 1 and 2 we plot the explosive yield of a pure fission weapon as a function of the quantity of fissile material (WGPu in Figure 1 and HEU in Figure 2) for three degrees of compression. In the figures the degree of compression is labeled according to our judgement as to the sophistication of the design; that is, whether it represents low, medium or high technology. As seen from Figure 1, the Nagasaki bomb, *Fat Man*, which produced a 20 kt explosion with 6.1 kg of WGPu, falls on the "low technology" curve. However, only three kilograms of WGPu compressed the same amount would still have produced a 1 kt explosion. Thus it is abundantly clear that the IAEA SQ values are badly flawed. A 1 kt yield is still a very damaging explosion with the potential to kill tens of thousands of people, depending on the population density and physical characteristics of the targeted area. Many tactical nuclear weapons that were in the U.S. nuclear arsenal had yields in the kiloton, and even sub-kiloton range.

But the bad news does not stop there. A non-nuclear weapons state today can take advantage of the wealth of nuclear weapons design information that has been made public over the past 50 years, and do even better. As seen from Figure 1, to achieve an explosive yield of 1 kt, we estimate that from 1 to 3 kg of WGPu is required, depending upon the sophistication of the design. And from Figure 2, we estimate that some 2 to 7 kg of HEU is required to achieve an explosive energy release of 1 kt. Table 2 presents some of the results of our calculations in a different form. We estimate, for example, that as little as 2 kilograms of plutonium -- a fourfold reduction from the current international threshold quantity -- or about 4 kilograms of HEU -- a sixfold reduction from the current standard -- are required to produce a yield of 10 kilotons.

D. Conclusion.

The IAEA "threshold amounts" and "significant quantities" are not technically valid. If one took the same *Fat Man* design, first tested at the *Trinity* site in New Mexico and dropped on Nagasaki in 1945, and substituted a three kilogram plutonium core for the 6.1 kilogram core that was used in 1945, the yield of this device would be on the order of one kiloton, a very respectable atomic bomb. Thus, the IAEA is in error to assert that "highly sophisticated techniques available to NW States" are needed to make nuclear weapons with "significantly reduced" quantities of materials. Also, the so-called "highly sophisticated techniques available to NW States" were known to U.S. weapons designers in the late-1940s and early 1950s, and nuclear devices using very small quantities of plutonium and HEU -- so-called "fractional crit" weapons -- with yields on the order of one kiloton were tested during the Ranger series in 1951. Furthermore, a well advised safeguards program for a given country or group of countries would set the "significant quantity" levels at values less than the minimum amount needed for a weapon, in recognition of the fact that materials can be diverted from more than one source. The practice of setting higher levels to account for manufacturing losses is imprudent, particularly in view of the fact that a significant fraction of these "losses" are technically recoverable.

In sum, safeguards apply to all non-weapons countries, irrespective of their technological sophistication. Many countries, such as Japan, Germany, Israel, India and Pakistan, have highly developed nuclear infrastructures, and must be considered technologically sophisticated. Even for countries that are in general not highly sophisticated technologically, the key technical information needed to establish a program for achieving a high degree of compression by implosion techniques is now available in the unclassified literature. The quantities defining safeguards significance, therefore, must be based an the assumption that the proliferator has access to advanced technology. As a consequence, NRDC believes the IAEA's significant quantities should be lowered 8-fold to the values in Table 3.

Figure 1. Yield vs. Pu Mass
(As a Function of Technical Capability)

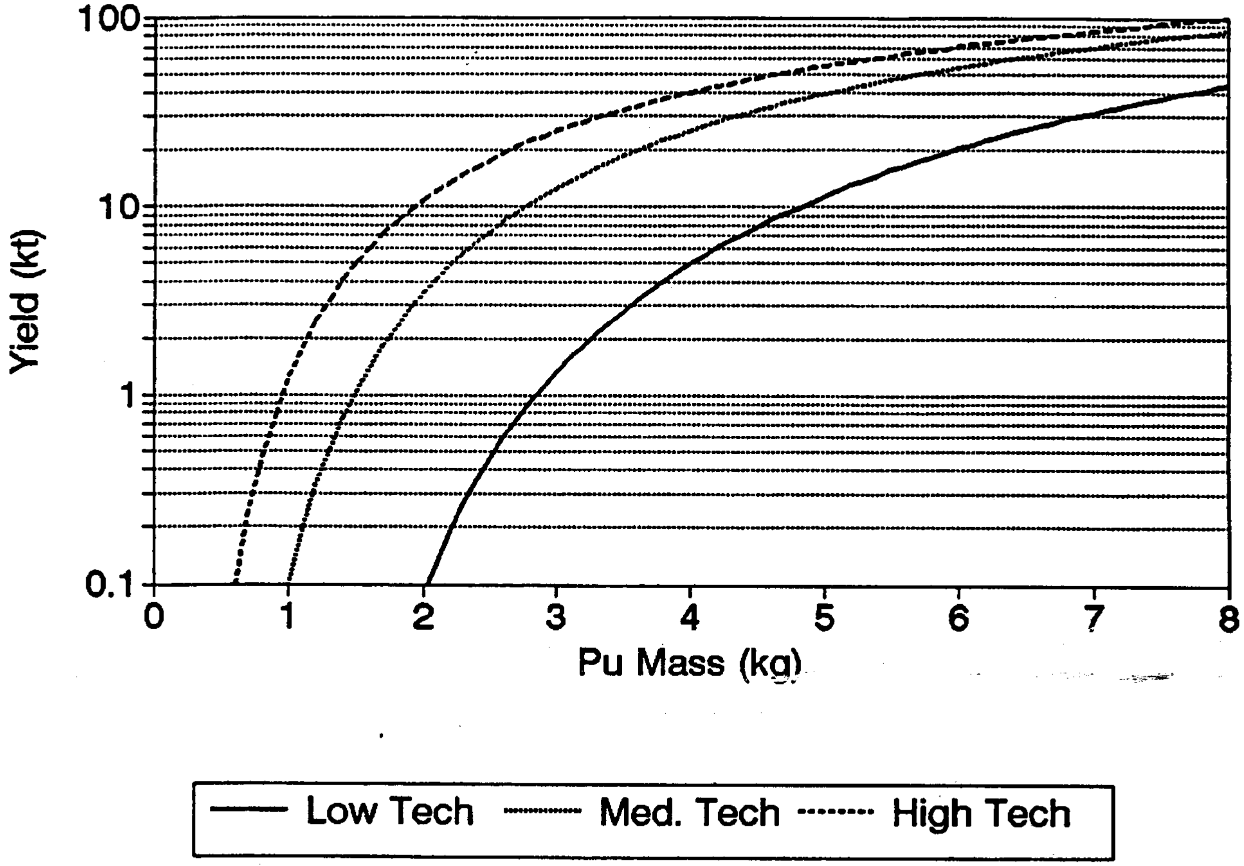

Figure 2. Yield vs. HEU Mass
(As a Function of Technical Capability)

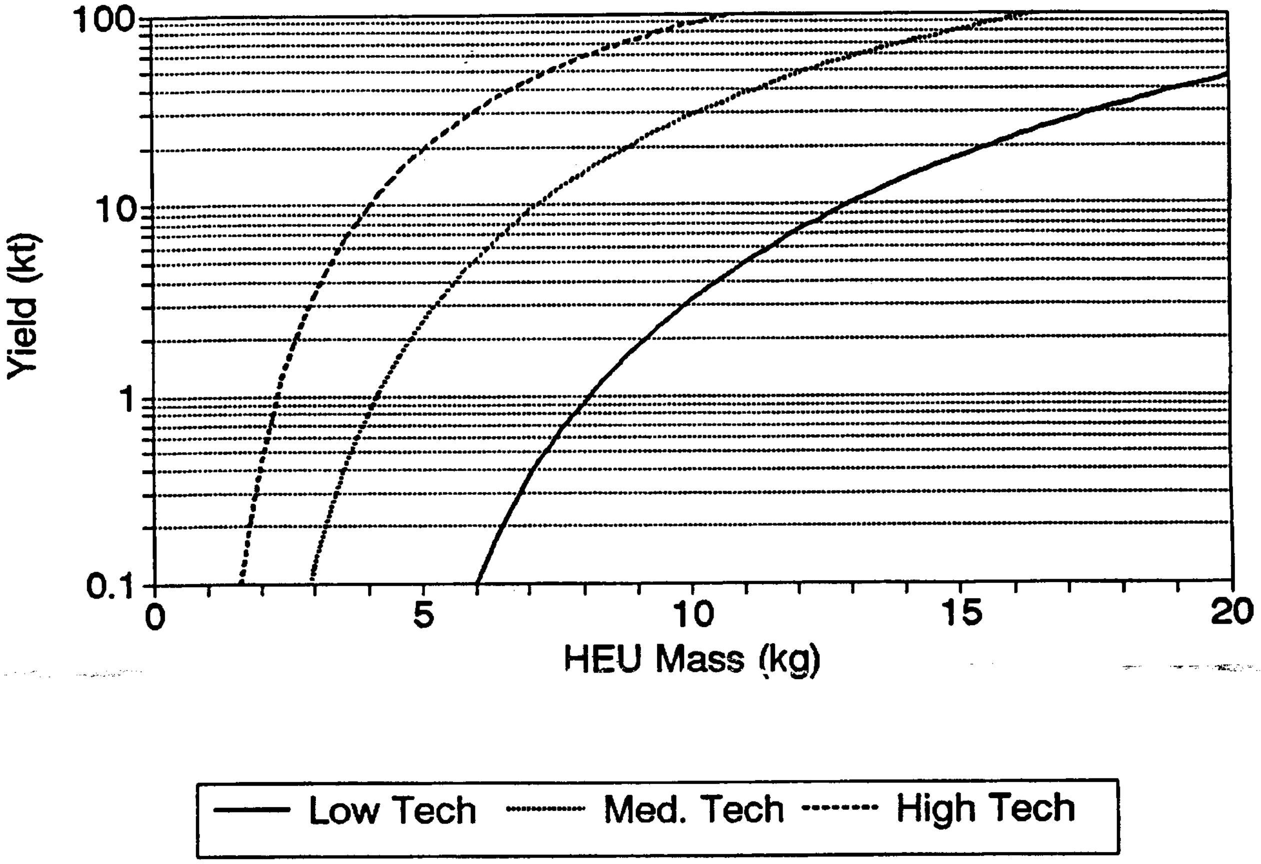

Table 1. IAEA Significant Quantities.

Material	Quantity of Safeguards Significance	Safeguards Apply to:
Direct-use nuclear material		
Plutonium (<80% Pu-238)	8 kg	Total element
Uranium-233	8 kg	Total isotope
Uranium enriched to 20% or more	25 kg	U-235 isotope
Indirect-use nuclear material		
Uranium (<20% U-235)	75 kg	U-235 isotope
Thorium	20 t	Total element

Table 2. Approximate Fissile Material Requirements for Pure Fission Nuclear Weapons.

	WEAPON-GRADE PLUTONIUM (kg)			HIGHLY-ENRICHED URANIUM (kg)		
Yield	Technical Capability			Technical Capability		
(kt)	Low	Medium	High	Low	Medium	High
1	3	1.5	1	8	4	2.5
5	4	2.5	1.5	11	6	3.5
10	5	3	2	13	7	4
20	6	3.5	3	16	9	5

Values rounded to nearest 0.5 kilograms.

Table 3. NRDC's Proposed Significant Quantities.

Material	Quantity of Safeguards Significance	Safeguards Apply to:
Direct-use nuclear material		
Plutonium (<80% Pu-238)	1 kg	Total Element
Uranium-233	1 kg	Total isotope
Uranium enriched to 20% or more	3 kg	U-235 isotope