Presentation of Professor Frank von Hippel before the UN Secretary-General's Advisory Board on Disarmament Affairs on February 24, 2005 on The Nuclear Fuel Cycle: Fissile Material Control

Ambassador Vicente Berasategui, Chair of the Advisory Board: First we will hear the presentation of Professor Frank von Hippel, of Princeton University.

Frank von Hippel. Thank you very much, Ambassador Berasategui. I would like to describe what fissile materials are, and the quantities we have in the world and then finally I will get to the question of the verification of a Fissile Material Cut-Off Treaty, which is currently a salient issue.

For arms-control purposes, fissile materials are materials which can be used to make a fission nuclear explosion, like the ones that destroyed Hiroshima and Nagasaki. The explosives that destroyed Hiroshima was made out of highly enriched uranium (High Enriched U-235) and the one that destroyed Nagasaki was made out of plutonium. There are some other fissile materials that one should be aware of, including some that are not usually talked about, but they are not available in very large quantities.

- High-enriched uranium (more than 20% U-235 or 12% U233)
- Plutonium containing less than 80% Pu-238
- Np-237, Am-241

Potential fission-explosive materials

Material	Halflife (years)	Bare Critical Mass (kg)*	Fraction of transuranics in 53 MWd/kgU spent fuel
^{233}U	**1.6×10^5**	**16.2**	-
Weapon-grade U (94% ^{235}U)	7.0×10^8	49.1	-
20%-enriched U (boundary between HEU and LEU)	"	780	-
^{237}Np	2.1×10^7	57.	0.066
^{238}Pu (heat source)	87.7	9.7	Made by n + ^{237}Np
Weapon-grade Pu(94% ^{239}Pu)	**2.4×10^4**	**10.7**	
Reactor-grade Pu (67% ^{239}Pu)	"	**14.4**	0.824
^{241}Am	432.	60.0	0.089 (20 yrs after discharge)

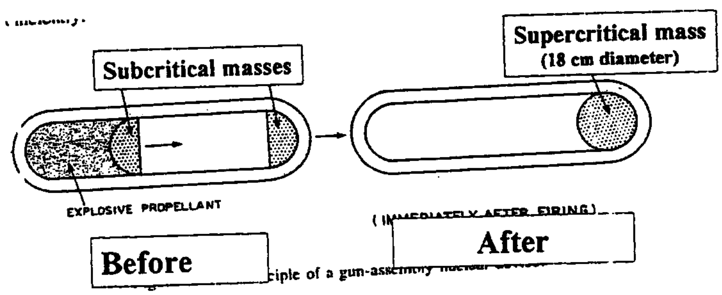
* x(≈ 1/2) if surrounded by "neutron-reflector"

I highlight the critical mass of weapons grade uranium, which is about 50 kilograms, and the critical mass of 20 percent enriched uranium, which is about 800 kilograms, so about twenty times larger. I show those because there is a global effort going on to convert research reactors. There are more than an hundred around the world fueled with weapon's grade uranium. There is a global effort to convert them to lower enriched uranium. The boundary between low enriched uranium and high enriched uranium is this 20% level. At that level, a long time ago, we tried to find out exactly by what process it was decided that below 20% the critical mass became so large and it would be impractical to make a nuclear weapon out of that material.

The Hiroshima bomb is unfortunately a very easy bomb to replicate, including by terrorists if they should be able to acquire highly enriched uranium. So this is a special reason for trying to minimize the stockpiles and use of highly enriched uranium in the world. Basically the way it works: it assemblies a supercritical mass out of two sub-critical masses.

HEU Gun-type design easy for terrorists

(Hiroshima bomb contained about 60 kg HEU ~80% ^{235}U, South African devices about 55 kg of 94% HEU, implosion time about 5×10^{-4} sec.)



Doesn't work with plutonium.

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Now this design did not work with plutonium and the Nagasaki design was an implosion design. The gun-type design did not work for plutonium because plutonium spontaneously produces neutrons and the chain reaction would start while it was still assembling and the explosion would be small.

With regard to fuel cycle issues, the major issue is that even though power reactor plutonium is not called weapons grade, it is weapon usable. Even with this first design, it could in fact produce at least five hundred tons of high explosive equivalent energy release, which, in New York terms, would destroy about sixty blocks. It would be a huge explosion.

Pu Implosion (Nagasaki) design more difficult
(6 kg Pu; implosion time ≈ 10^{-5} sec.)

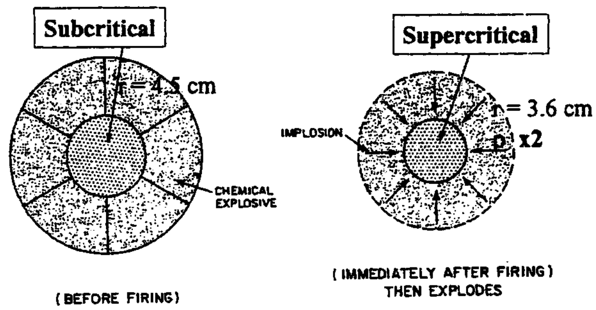

Figure 1.53. Principle of an implosion-type nuclear device.

Power-reactor Pu (>20% ^{240}Pu) would give >500 tons
(about 60 blocks destroyed)
[Carson Mark, *Science & Global Security*, 1993)

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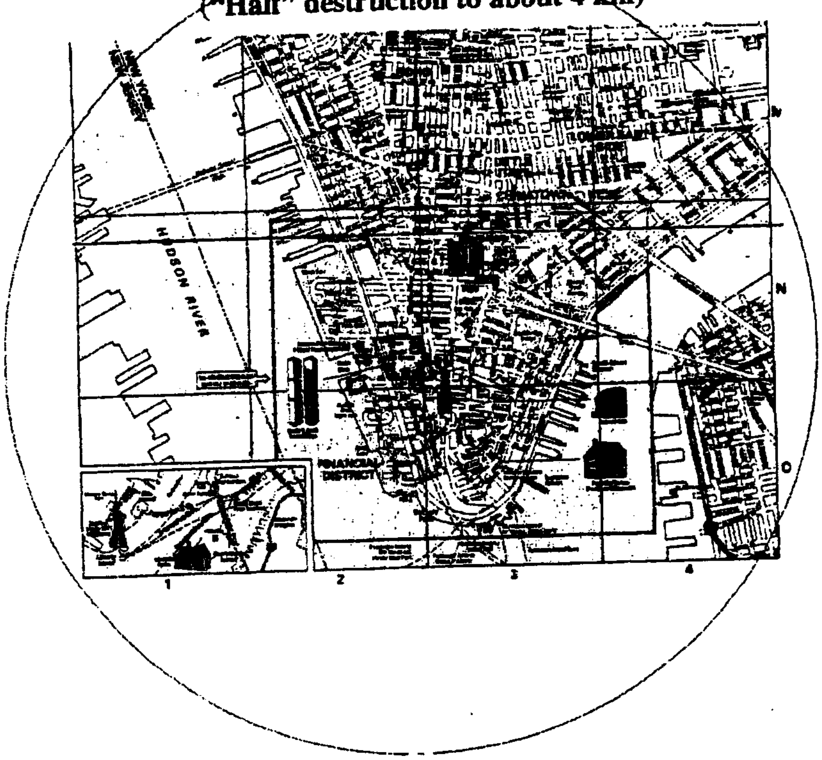
This shows actually the area superimposed on New York around the World Trade Center, the area that was completely destroyed by the Hiroshima bomb, which as I said could be easily produced by terrorists if they were able to acquire the 50 or so kilograms of highly enriched uranium that would be required.

Radius of total destruction at Hiroshima was 2 kilometers
("Half" destruction to about 4 km)



≈200x
area of
World
Trade
Center
(600 blocks)

2. **Global stockpiles of fissile material** (tonnes)

(not including weapon materials declared excess)

	Weapon U* (93% ^{235}U equiv)	**Weapon Pu***	Civil Pu-2003 In-country (own)	Civil HEU (including in spent fuel)
Russia	600 ± 300	120 ± 25	38	?(10's)
USA	525 ± 70+	47	9 (2002)	?
China	25 ± 6	3.5±1.5	-	?
France	25 ± 8	5 ± 1.4	79 (48)	6.5
U.K.	8 ± 2	3.1	96 (73)	1.6
Japan	-	-	5 (41)	?
Germany	-	-	11(2002)(29)	1
TOTAL	**1200 ±350**	**180 ±25**	**250**	**≈50?**

+U.S. has stockpiled about 200 tons for naval reactors

Total: 1300 - 2000 tons fissile material (≈20% civilian)

[*Weapons material from Albright, Berkhout & Walker, 1996; civil Pu/HEU from IAEA]

There is a lot a fissile material in the world. The table shows that there is in total about 2000 tons or 2 million kilograms of fissile material, most of it produced for weapons This is weapons grade uranium and weapons plutonium. But also, there is a lot now of the civilian plutonium that has been separated out as a result of civilian reprocessing programs, 250 tons. I mentioned already the use of highly enriched uranium in research reactors. This number has not been well estimated but I would guess about 50 tons of that material.

Stockpiles of fissile material (weapon equiv.)

(not including weapon materials declared excess)

	Weapon U (25 kg/weapon) ← same	**Weapon Pu** (4 kg/weapon) weapons →	**Civil Pu** (8kg/weapon, in country)	**Civil HEU** (50 kg/weapon)
Russia	24,000±12,000	30,000 ±6,000	5,000	hundreds
USA	21,000 ± 3,000	12,000	1,000	?
China	1,000 ± 240	900±400	-	?
France	1,000 ± 320	1250 ± 350	10,000	130
U.K.	320 ± 80	800	12,000	32
Japan	-	-	600	?
Germany	-		1400	20
TOTALS	**50,000±13,000**	**45,000±7,000**	**30,000**	**≈1000**

The weapons material that is estimated in the table does not include material which has been declared excess.

Weapon material declared excess (disposed as of 6/30/04)

	HEU 25 kg units (90% ^{235}U)		Plutonium (4 kg units)	
	tons	WH equiv.	tons	WH equiv
Russia	500 (225)	20,000 (9000)	34(0)	8500 (0)
U.S.	125 (30)	5,000 (1200)	34(0)	8500 (0)
U.K.	0	0	0.4 (0)	100 (0)
Total	**625 (255)**	**27,000 (10,000)**	**68.4 (0)**	**17,000(0)**

700 tons declared excess (≈1/3 of weapon stocks)

The table also shows a conversion of those numbers into weapons equivalence. Weapons equivalences for weapons states, where I gave the conversion, and then, using the IAEA conversion for the civilian plutonium and the Hiroshima quantity for the highly enriched uranium. You see that there is a huge amount of fissile material here and that the numbers of warhead equivalence in the weapons arsenals is far in excess of what the U.S. and Russia actually have in weapons. All of these numbers could be greatly reduced.

In fact, in 1991, as a result of an initiative by the first President Bush and Gorbachev, about one third of the total stockpile of weapons fissile material was declared excess. The table shows the quantities and the warhead equivalence. You see how much is actually being eliminated. I show in parentheses how much has actually been eliminated. You see that the elimination of weapons grade uranium is proceeding, but the elimination of the plutonium has not yet begun.

Here is a scenario which I think should be quite feasible, to reduce the total fissile material weapons usable material in the world from about 2000 tons today to about a hundred tons. I show this as an intermediate stage to the elimination of the weapons entirely. I show here that even after this hundred fold reduction the U.S. and Russia could still have 2000 warheads each, which is approximately the number of their numbers of strategic deployed warheads in 2012 under the Strategic Offensive Reduction Treaty. I would advocate that in fact, because there is no economic need to separate civilian plutonium that the separation of plutonium should be phased out until there is a need some time in the unknown future and that these stocks should be consumed in fuel.

Similarly, and here I imagine and hope that all of the world's research reactors can be converted from weapons-grade uranium to low-enriched uranium successfully.

Can we go from 2000 to 100 tons?

	Weapon U (25 kg/weapon) ← same	Weapon Pu (4 kg/weapon) weapons →	Civil Pu (8kg/weapon, in country)	Civil HEU (50 kg/weapon)
Russia	24,000->2,000*	30,000 ->2000	5,000	hundreds
USA	21,000->2,000*	12,000-->2000	1,000	?
China	1,000 -> 300	900--> 300	-	?
France	1,000 -> 300	1250--> 300	10,000	130
U.K.	320 -> 300*	800--> 300	12,000	32
India/Pak/ Israel	? -> 100*	-> 200	600	?
Tot. WHs	50,000->3,000	45,000->3,000	30,000-->0	≈1000-->0
Tonnes	**1250--> 75**	**180--> 12**	**250-->0**	**50-->0**

***Naval reactors would have to convert to LEU.**

I note that Russia, the US and the UK all use highly enriched uranium, uranium enriched with more than 20 %, in their naval reactors. Russia also uses it in its icebreaker reactors. For these reductions to be achieved those reactors would have to be converted to low enriched uranium as would the research reactors. I think that is feasible and I have written articles on it.

Finally, with regard to the verification of the Fissile Material Cut-Off Treaty, I quote here the objections that the U.S. raised in the Conference on Disarmament to verification, saying that "effective verification of an FMCT would require an inspection regime so extensive that it could compromise key signatories' core national security interests" (which presumably means US) "and so costly that many countries will be hesitant to accept it. Even with extensive verification measures, we will not have high confidence in our ability to monitor compliance with an FMCT."

My interpretation of this statement is that the U.S. is concerned about the intrusiveness of Additional Protocol-type inspections at its nuclear weapons facilities. There are complications there that are not present in the non-weapon states and so my proposal would be to start with an FMCT that verifies that known reprocessing and enrichment plants are not producing unsafeguarded highly enriched uranium or plutonium, and then deal later with this issue of the extension of these additional protocol type inspections to nuclear-weapons facilities. Thank you.

Biographical information: Frankl von Hippel is a theoretical physicist, a Professor of Public and International Affairs at Princeton University and co-principal investigator of Princeton's research Program on Science and Global Security. From September 1993 through 1994, while Assistant Director for National Security in the White House Office of Science and Technology Policy, he played a major role in developing U.S.-Russian cooperative programs to increase the security of Russian nuclear-weapons materials. He is the elected chairman of the American Physical Society's Panel on Public Affairs, chairman of the editorial board of *Science & Global Security*, and a member of the editorial board of the *Bulletin of Atomic Scientists*.

Since the early 1980's von Hippel's research has focused on developing the analytical basis for deep cuts in the U.S. and Soviet/Russian nuclear stockpiles; removal of their ballistic missiles from launch-on-warning alert; verified nuclear-warhead elimination; a comprehensive nuclear-warhead test ban; and ending production, minimizing use and disposing of excess weapons-useable fissile materials.

In 1977, von Hippel shared with Joel Primack the American Physical Society's Forum Award for Promoting the Understanding of the Relationship of Physics and Society in their book, *Advice and Dissent: Scientists in the Political Arena*. In 1989, he was awarded the Federation of American Scientists' Public Service Award for serving as a "role model for the public interest scientist." In 1991, the American Institute of Physics published a collection of his articles under the title, *Citizen Scientists*, in its "Masters of Physics" series. In 1993 he was awarded a 5-year MacArthur Prize Fellowship. In 1994 he received the American Association for the Advancement of Sciences' Hilliard Roderick Prize for Science, Arms Control and International Security. In 2004, he was awarded the first George F. Kennan Distinguished Peace Leadership Award.