What the U.S. Can Do Now To Reduce the Hazard of Nuclear Weapons

by

Richard L. Garwin
IBM Fellow Emeritus
IBM Thomas J. Watson Research Center
P.O. Box 218, Yorktown Heights, NY 10598
RLG2@us.ibm.com, www.fas.org/RLG/
October 30, 2008

Talk at Qingdao University Symposium
Qingdao, Shangdong Province, China
29 October 2008

Outline

What is a nuclear weapon?

What does it do?

How many nuclear weapons have there been and are there now?

How much does a nuclear weapon cost?

What is the prospect for defense against nuclear explosions?

Nuclear deterrence as protection against nuclear weapons held by another state.

The prospect of nuclear terrorism.

Securing nuclear weapons and weapon-usable materials against theft and terrorist use.

An agenda for action by the United States.

What other countries can do to improve their own security (not addressed in this talk).

On August 6, 1945, the industrial city of Hiroshima, Japan, was destroyed by a single bomb that exploded at a height of 576 m above the city. The energy yield of 13,000 tons of high explosive equivalent gave rise to a blast that destroyed buildings out to several km distance, and set fire to wood, paper, and clothing. Because it was a nuclear explosion, a small fraction of the people died from the effects of nuclear radiation, but the greatest sources of death and destruction were blast and fire.

On August 9, the city of Nagasaki was destroyed by a second nuclear explosion of a different type. The Hiroshima bomb, “Little Boy” weighting about 4,000 kg, was a “uranium gun” containing about 60 kg of U-235, separated from the 99.3% abundant U-238 by the processes of gaseous diffusion and electromagnetic separation.

The Nagasaki bomb, of explosive yield 20,000 tons equivalent of high explosive, had at its core 6 kg of plutonium (Pu) produced from natural uranium via a nuclear reactor at Hanford in the northwest state of Washington. This reactor of thermal power output 200 megawatts produced about 0.2 kg of Pu per day, so was capable of making about one Nagasaki bomb per month.

The energy of the bomb was about 7 million times as much as that available from the same mass of plutonium if it were high explosive. It derived ultimately from the fact that U-235 or Pu-239 undergo fission with high probability when they capture a neutron. Other reactions with slow neutrons were discovered in 1934, but the world's most eminent experimenters, having caused fission with their weak laboratory neutron sources, missed the unique pulses of ionization 30 times as large as any natural radiation decay, because they had used a thin film of aluminum foil in their ionization chambers in order to avoid the much more frequent signal from the natural alpha-particle radioactivity of uranium.

As imagined by Leo Szilard when the neutron was discovered by James Chadwick in 1932, the fission reaction itself gave rise to enough neutrons to carry on an exponentially growing chain reaction-- about 2.5 neutrons in the case of U-235 and about 3.5 neutrons on the average in the case of Pu-239. Hence in a sufficiently large mass of pure U-235 or Pu-239, there will be a fast-neutron chain reaction, in which a single fission provokes 2 fissions, which in turn provoke 4,8,16,32, and so on, The time between "generations" of fission is simply the time for a neutron of energy on the order of 1 MeV (they are liberated in fission with an energy of about 2 MeV) to collide with another U-235 or Pu-239 and cause fission. This time is of the order of 10 nanoseconds, so a microsecond is long enough, in principle, for most of the nuclei in the kilograms of uranium or plutonium to have undergone fission in this exponentially growing chain reaction.

But just because a large amount of energy is liberated in the fission process, in which the heavy “compound nucleus” of 92 protons and 235+1 total nucleons in the case of U-235 (so 144 neutrons) breaks up not into two nuclei of charge about 46 and mass about 116, but into one light fission fragment and one heavy fission fragment, because that is the most favorable mode of decay. The original heavy nucleus is proton-poor (neutron-rich), so that the resulting fission fragments are fiercely radioactive, as their excess neutrons decay into protons and electrons (and neutrinos).

A simpler way of estimating the energy released in fission, now that you know it happens, is simply to ask for the electrostatic potential energy of a light fission fragment in contact with a heavy fission fragment as they begin to speed away from the “compound nucleus” that was formed by neutron capture in the fissionable nucleus. This amounts not to the fraction of an MeV typical of two hydrogen nuclei (protons) in contact, but to about 150 MeV, in view of the 45-fold larger charge and the nuclear radius that grows as the cube root of the number of nucleons.

The energy of the first few generations of fissions does nothing to the kilograms of mass, but by the time one-millionth of the mass is fissioned, it is as if the material had been inspired with the energy of high explosive, and it begins the process of disassembly. That process is terminated when the material moves within a neutron generation time to be “sub-critical.”

The problems that were solved at the Los Alamos National Laboratory during the years from March 1943 to August 1945 included:

- maintaining the material sub-critical until bomb had been dropped and reached the required altitude;
- assembling the fissile material into a highly super critical state so that the generation time would be short;

- doing that quickly enough so that the chain reaction was not initiated by a stray cosmic ray neutron or one from spontaneous nuclear decay of the material;
- and injecting neutrons at the appropriate time.

The uranium gun maintained the material sub-critical by having the approximately 60 kg of U-235 in two separate pieces, one of which was a central cylindrical core in a short gun barrel. The other half was a set of U-235 rings. Gunpowder was used to propel one of the pieces so that it would assemble in a time short compared with the time between stray neutrons. Because the U-235 was purified of light materials such as traces of lithium or beryllium, there was an acceptably low neutron generation rate from the alpha-n reaction widely used in the form of radium-beryllium (or radon-beryllium) sources of laboratory neutrons.

If the engineers had been confident of being able to stop the metal rings and so to maintain the super-critical assembly, no neutron source would have been needed. A cosmic ray neutron in a few seconds would have initiated the nuclear reaction. Instead, a “switchable” alpha-n reaction was used in the form of many curies of Po-210 separated from beryllium metal by a thin metal layer that was disrupted when the projectile contacted the neutron initiator,

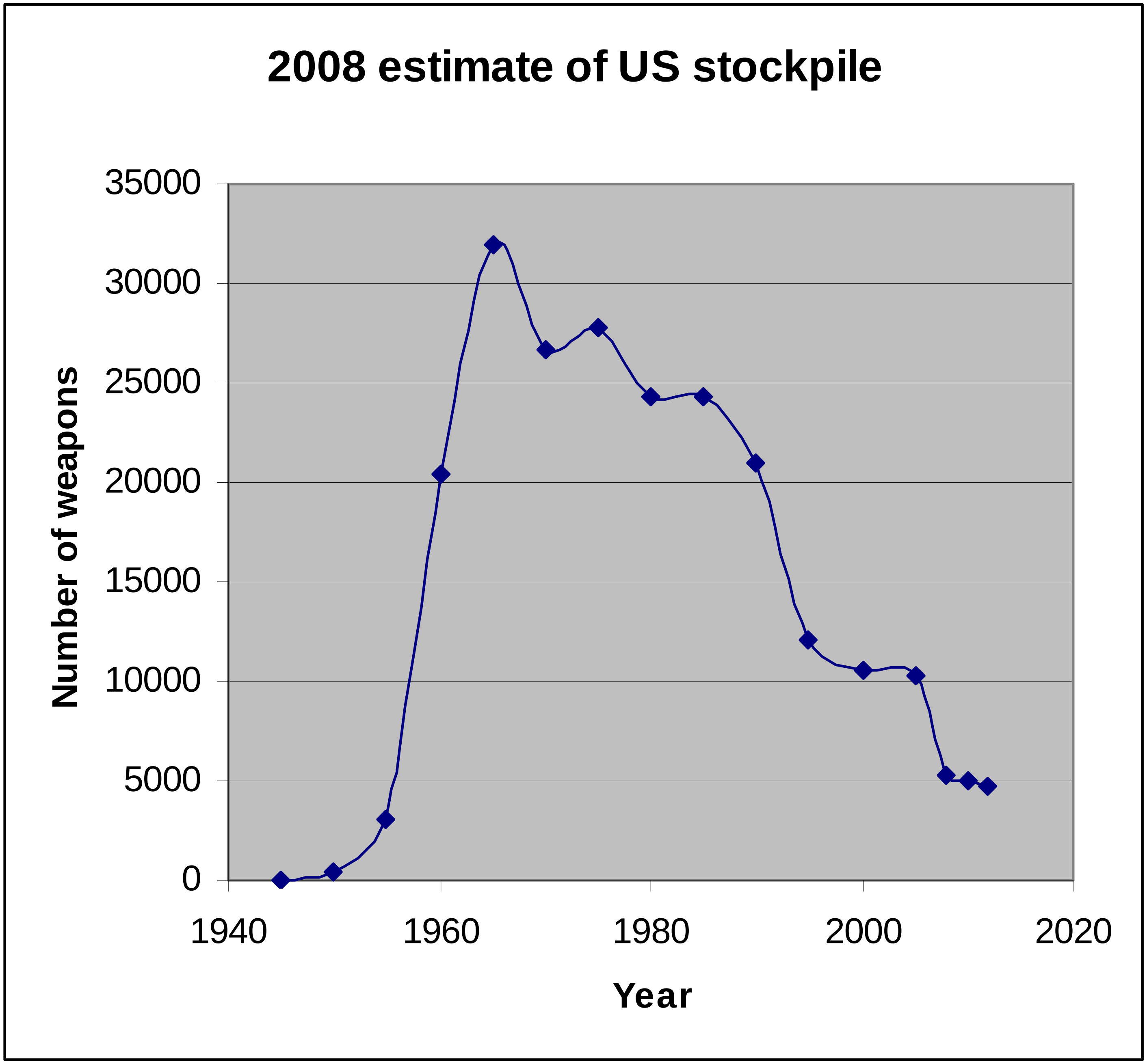
For the Nagasaki bomb, made of Pu-239 because there was a very limited supply of U-235, a plutonium gun was initially envisaged, which would have been simpler in view of the fact that only about 10 kg of Pu would have been needed, in view of the larger reaction cross section and larger neutron number per fission for Pu compared with U-235. When the first Pu was delivered from Hanford to Los Alamos, however, its neutron generation rate was carefully measured and found to be unacceptably high for gun assembly. Accordingly, the laboratory worked out a much faster means of assembly in which instead of the one-sided propulsion by gunpowder, high explosive itself was used to compress a solid Pu sphere uniformly from all sides. The Nagasaki bomb, “Fat Man,” was in fact a 4-ton sphere of high explosive containing the 6-kg Pu core surrounded by a natural uranium reflector (and tamper). The Pu sphere was barely sub-critical, and when its density was increased and radius reduced by the implosion, it became supercritical. The mass required for criticality goes down like one over the second power of the density.

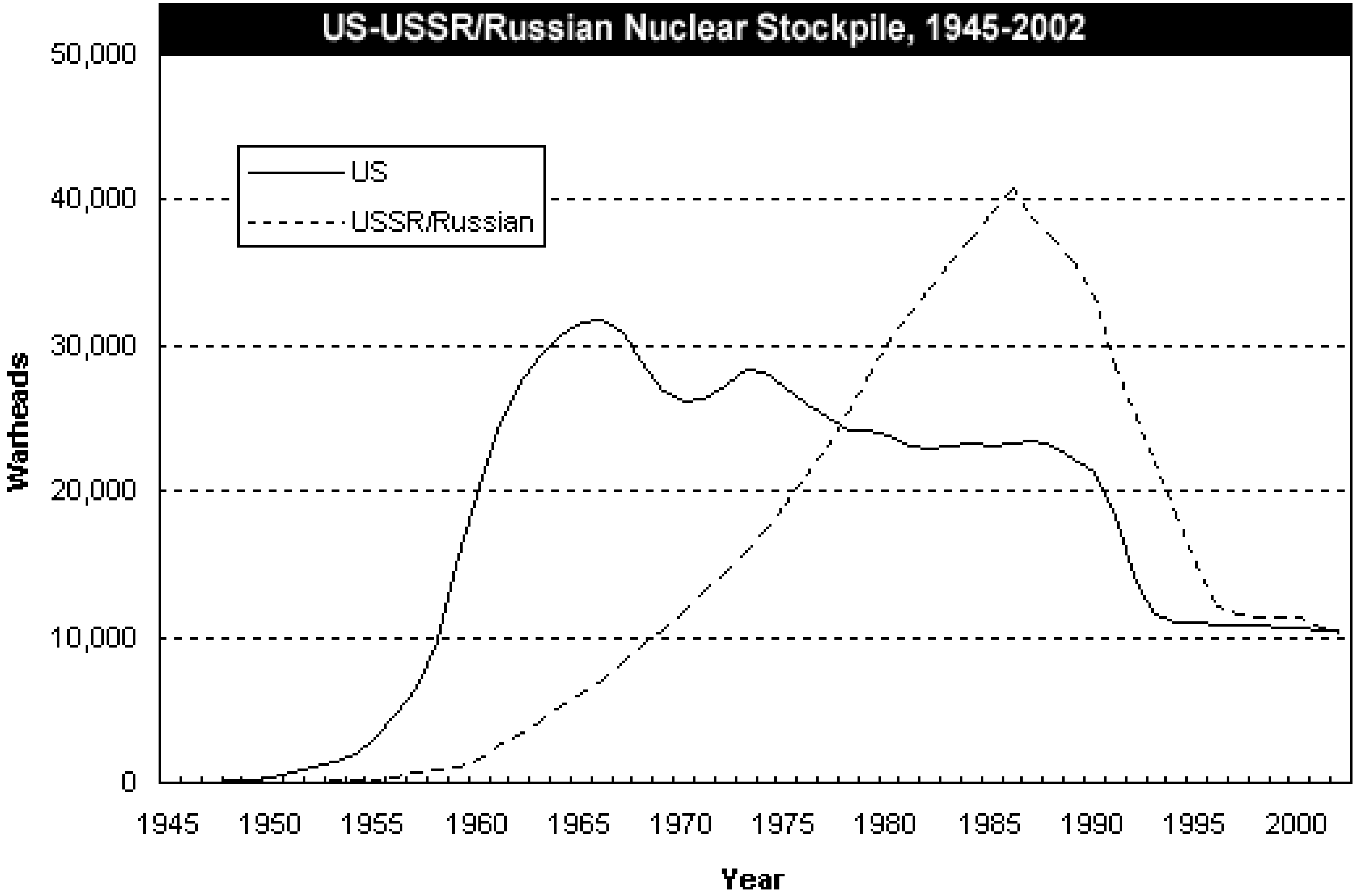
The plutonium implosion weapon was initiated by a Po-Be initiator in a spherical cavity at the center of the Pu ball, operating on the same principle as in Little Boy.

Although it was only a matter of time before Japan was conquered or surrendered because its cities were being destroyed by thousands of tons of fire bombs each day, an invasion was planned, and the Soviet Union was about to enter the war, the destruction of Hiroshima and Nagasaki by nuclear weapons gave the emperor of Japan a reason to be involved and to encourage or insist that the military accept the U.S. terms of unconditional surrender.

Once the nuclear weapon material began arriving from Oak Ridge, Tennessee, in the form of U-235, and from Hanford, Washington, in the form of Pu-239, the system built additional weapons, so that at the end of 1945 there were six. A recent tabulation from the Natural Resources

Defense Council (NRDC) and the Federation of American Scientists (FAS) shows the number of U.S. nuclear weapons vs. year.


2008 estimate of US stockpile
Number of weapons
35000
30000
25000
20000
15000
10000
5000
0
1940
1960
1980
2000
2020
Year



Possibly discouraging other nations from acquiring nuclear weapons, the United States emphasized for many years that the cost of the Manhattan Project (the code name for the 1941-45 effort to produce the nuclear weapon) was $2 billion in then-year dollars, so that each of the bombs might be said to have cost $1 billion. In fact, a much lower estimate of the material production cost is suitable for the present day, because of the wide use of the centrifuge approach to enrichment, perfected over the decades not only for the production of enriched uranium for nuclear weapons, but for slightly enriching U-235 from the natural 0.7% to a typical 4.4% enrichment for use in the common light-water reactors that produce some 17% of the world's electrical energy.

You can easily determine that the Hiroshima bomb, in which only about 2% of the material fissioned, liberated less energy when it exploded than the electrical energy that had been required to separate the U-235, which is about 5 MeV per atom, compared with the 150 MeV x 1% = 1.5 MeV of explosive energy per atom of U-235 present in the bomb.

The U.S. nuclear weapon test of the plutonium implosion bomb on July 16, 1945, and the two bombs used against Japan were followed by the first Soviet test explosion in 1949, that of Great Britain in 1952, France in 1960, and China in 1964. India tested a nuclear explosive in 1974 and again in 1978 followed within two weeks by Pakistan. It is widely believed that Israel has more than 100 nuclear weapons, and North Korea tested a plutonium bomb of a few hundred tons yield in 2006.

I have published many papers on nuclear weapons and nuclear weapon proliferation, most of which can be found at my website as indicated above—www.fas.org/RLG/. One, "Post-Cold War World and Nuclear Weapons Proliferation" is at www.fas.org/rlg/v095pcwp.htm. ** Needs to be small "rlg" **

Now I am going to tell you a great secret, and that is how to learn what I have published on a given topic without even going to my website:

A good way to see what I have written about such matters and posted on my website at *www.fas.org/RLG/* is to use a "focused search" by putting in the Google search box:

site:fas.org/RLG/ "nuclear weapon" Hiroshima altitude

The search gives 6 "hits." To see what I have said about the North Korean bomb explosion simply modify the search so that the Google search box now reads

site:fas.org/RLG/ "nuclear weapon" "North Korea" explosion test 2006

Now there are only 8 hits. But it turns out that I have neglected to post on my web site a paper with Frank von Hippel, analyzing the results of the test, to be found at *www.armscontrol.org/act/2006_11/tech*

The number of nuclear weapons in the world, in the inventory of each country, as estimated by NRDC is shown in the next two graphs. **RLG will find them.**

Obviously these weapons did not cost $1 billion each! In fact, if one assumes a uranium implosion weapon that uses the IAEA's "significant quantity"—SQ—of U-235 (25 kg), and from my other papers understands that a kg of 95% U-235 contains about 221 separative work units (221 SWU) and that a SWU on the commercial market costs about $100, one sees that if one had a centrifuge plant that ran for long enough to repay its initial cost, the investment in U-235 for each implosion weapon would be on the order of 221 x 25 = 5525 SWU or about $552,000. Assuming that one could buy or steal adequate centrifuges, and build up an armory only over two years instead of perhaps the 10-year economic life of a centrifuge, the cost of enrichment of U-235 per weapon would not exceed on the order of $2.6 million, to which would need to be added the cost of 200 kg of natural uranium per kg of U-235 produced; at $50/kg of natural uranium, this would be another 25 x 200 x $50 = $250,000 per SQ of U-235.

It is of interest that in a public speech in November 1945,
J. Robert Oppenheimer, the head of the Los Alamos Laboratory that built Little Boy and Fat Man, stated that if war broke out between two powers armed with nuclear weapons, they would be used by the thousands or by the tens of thousands.

In contrast, Hans Bethe, the Nobel-Prize Physicist who led the theoretical effort at Los Alamos during the war said late in life "No one at Los Alamos expected that more than a few hundred of these weapons would be made."

In 1951, two scientists at Los Alamos invented the concept of "radiation implosion" by which a nuclear explosive would greatly compress fuel for nuclear fusion (deuterium or perhaps lithium deuteride) contained in a heavy metal capsule, all within a "radiation case" that would serve temporarily to contain the x-rays from the nuclear explosion, to which almost all of the energy is converted in the early stages. This "two-stage thermonuclear bomb" was first tested by the U.S. November 1, 1952 (the

MIKE test) with a secondary capsule containing liquid deuterium and was tested in 1954 in a solid-fuel version that could be carried on bomber aircraft. The Soviet Union followed with its two-stage radiation implosion system in 1955.

I did the preliminary design of the MIKE test and before it was successfully demonstrated designed also flyable liquid-deuterium hydrogen bombs of which about 6 were built by the U.S. and deployed without ever having been tested.

Although the Soviet Union tested the two-stage concept at 50 megatons (which would have been 100 megatons had the lead capsule been replaced by uranium), most nuclear weapons now are in the range of 0.1-5 MT, simply because individual nuclear weapons against individual targets, made possible with improved delivery accuracy, is more effective.

The main virtue of the radiation implosion is thus not to obtain enormous yield (MIKE had almost 1000 times the yield of the Hiroshima bomb) but to obtain it with the use of less fissionable material, which at one time was rare and costly. In books published by the U.S. National of Sciences Committee on International Security and Arms Control (CISAC), we were permitted to say that the average nuclear weapon dismantled from the U.S. stockpile contains about 4 kg of Pu.

Of course, nuclear weapons have gotten a lot less massive, as well. For instance, in discussions of possible warheads for North Korean or Iranian missiles, a warhead mass of 500 or 1000 kg is commonly discussed. Nuclear weapons have been built with mass below 50 kg.

Because of the destructive power of nuclear weapons, although enormous sums were spent on air defense and on defense against ballistic missiles, the conventional protection against nuclear weapons launched by another state is to ensure that they are never launched. That is done by "deterrence," for the most part, the commitment to strike back with nuclear weapons against those responsible for launching an attack with nuclear weapons.

The logic of deterrence then impels a country to have either a secure “second-strike” force that cannot be destroyed by the adversary in a first disarming strike, OR to have a reliable warning system that would allow the deterrent nuclear weapon force to be fired before it was destroyed. This requirement led to the replacement of liquid-fuel ICBMs in the United States by solid-fuel missiles, just in order that they be ready to launch on a few-minutes notice. The early ICBMs took an hour or more to fuel, and so could in principle have been destroyed in an attack. A secure second-strike force needs to be emplaced in hardened silos or hidden in the oceans on submarines, while a launch-on-warning deterrent force needs no such costly protection. But an LOW force carries its own hazards, more apparent if the one who relies on LOW is one’s opponent. Thus, the United States worries that Russia is relying on obsolete and inadequate systems of warning satellites and radars, and many in the Unites States believe that it is a matter of extremely high priority to take measures so that Russia will not feel that it needs to maintain its force ready to be launched. Many feel the same way in the United States about the U.S. force, capable of launch-on-warning.

The other novelty in the world in the last 10 or 20 years is the recognition that terrorists are now likely to prefer suicide missions to those that require the meticulous plotting of an attack so that the attacker can get away unscathed. Furthermore, especially with the advent of the Internet, terrorists groups have shown themselves adept in separating inspiration and even command and control from the foot soldiers who carry out attacks. The nightmare concern is that a nuclear weapon or weapon-usable material might be stolen and delivered to the heart of a city for assembly by a suicide terrorist team. Unlike military nuclear explosives, these improvised nuclear explosives need not survive a truck ride, much less airplane carriage and ballistic fall to the desired point of detonation.

One solution, of course, is to interfere with the terrorist process, but states are already doing that. Another approach is to lock up and otherwise protect and consolidate nuclear weapons and weapon-usable materials. It is recognized that this should be done with much greater urgency than has been the case since 1992, the start of the Nunn-Lugar program (named after Senator Richard Lugar and former Senator Sam Nunn). So here is what the United States in its new administration should be doing. All of this should have been done years ago.

The Non-Proliferation Treaty that entered into force in 1970 permits the five states that had tested nuclear weapons before 1964 to retain those nuclear weapons, but in Article VI requires

Article VI
Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a Treaty on general and complete disarmament under strict and effective international control.

Many in the United States regard a terrorist nuclear attack on a U.S. or allied city as disturbingly probable—on the order of 5 or even 10% per year—and argue that massive consolidation and improved protection of weapons and weapon usable material is a matter of extreme urgency. In order to motivate the world to carry this out, the United States must do far more to fulfill its commitments under Article VI of the NPT.

And this must be done while fulfilling also the commitment under Article IV,

Article IV

1. Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with articles I and II of this Treaty.

2. All the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear-

weapon States Party to the Treaty, with due consideration for the needs of the developing areas of the world.

The latter involves restrictions on the fuel cycle of nuclear power plants, because both the enrichment process and the retreatment process (if any) for the fuel that has been in the nuclear reactor for four years can produce weapon-usable materials. The hazard of enrichment can be reduced by multi-national facilities and by continuous and effective inspection by the International Atomic Energy Authority (IAEA). Fortunately, the spent fuel from light-water reactors need not be treated and recycled to light-water reactors when it can save no more than 20% of the uranium otherwise needed, at a cost per kg of uranium saved on the order of $700. This compares with traditional uranium costs of $30/kg or more recently $100/kg and has a hazard of providing plutonium that can be used to make powerful nuclear weapons.

The United States is not immune from laxity in guarding its nuclear weapons, as shown by the event of August 29-30, 2007, in which six nuclear-armed advanced cruise missiles were flown on the wing of a bomber from Minot Air Force base to Barksdale and were not even missed for 36 hours. They sat unguarded on the runway at Barksdale. U.S. Secretary of Defense Robert Gates dismissed both the Secretary of the Air Force and the chief military officer, the Air Force Chief of Staff over this incident.

The U.S. long advocated and negotiated for a Comprehensive test Ban Treaty and was first to sign that Treaty in 1996. China has also signed, but neither state has ratified the Treaty. The United States is in a very weak position to urge others not to test or acquire nuclear weapons, without its having ratified the CTBT.

So in a new administration, the United States should lay out to the U.S. Senate the arguments for improving U.S. security by ratifying and helping to bring into force the CTBT.

It should also immediately renew the Strategic Arms Reduction Treaty (START 1) with Russia, which otherwise expires at the end of 2009, primarily in order to have a framework of verification and other rules on which to lay the edifice of a new system that will guide major reductions from the high thousands of nuclear warheads in each of the U.S. and Russian inventories to a level slightly below 1000 on each side. This can be done without negotiation, presumably after some preliminary discussions, just as President George H.W. Bush in 1991 unilaterally brought back from abroad and from shipboard almost all the thousands of tactical nuclear weapons—an act that was met by similar reductions by Russian leader Mikhail Gorbachev. The United States actually destroyed about 3000 of these weapons in the 1991 Presidential Nuclear Initiatives (PNIs)[1].

According to the proposal "Toward True Security," of which I was a coauthor[2], the next U.S. president should take 10 unilateral steps to bring U.S. nuclear weapons policy into line with today's political and strategic realities:

1. Declare that the sole purpose of U.S. nuclear weapons is to deter and, if necessary, respond to the use of nuclear weapons by another country .

---

[1] "The Presidential Nuclear Initiatives (PNIs) on Tactical Nuclear Weapons At a Glance," Arms Control Association Fact Sheet, March 2006 (at http://www.armscontrol.org/factsheets/pniglance)

[2] "Toward True Security," February 2008 (at http://www.ucsusa.org/assets/documents/nwgs/toward-true-security.pdf)

2. Reject rapid-launch options by changing its deployment practices to allow the launch of nuclear forces in days rather than minutes .
3. Eliminate preset targeting plans, and replace them with the capability to promptly develop a response tailored to the situation if nuclear weapons are used against the United States, its armed forces, or its allies .
4. Promptly and unilaterally reduce the U.S. nuclear arsenal to no more than 1,000 warheads, including deployed and reserve warheads .
The United States would declare all warheads above this level to be in excess of its military needs, move them into storage, begin dismantling them in a manner transparent to the international community, and begin disposing— under international safeguards—of all plutonium and highly enriched uranium beyond that required to maintain these 1,000 warheads. By making the end point of this dismantlement process dependent on Russia’s response, the United States would encourage Russia to reciprocate .
5. Halt all programs for developing and deploying new nuclear weapons, including the proposed Reliable Replacement Warhead .

6. Promptly and unilaterally retire all U.S. nonstrategic nuclear weapons, dismantling them in a transparent manner, and take steps to induce Russia to do the same .

7. Announce a U.S. commitment to reducing its number of nuclear weapons further, on a negotiated and verified bilateral or multilateral basis.

8. Commit to not resume nuclear testing, and work with the Senate to ratify the Comprehensive Test Ban Treaty .

9. Halt further deployment of the Ground-Based Missile Defense system, and drop any plans for space-based missile defense. The deployment of a U.S. missile defense system that Russia or China believed could intercept a significant portion of its survivable long-range missile forces would be an obstacle to deep nuclear cuts. A U.S. missile defense system could also trigger reactions by these nations that would result in a net decrease in U.S. security .

10. Reaffirm the U.S. commitment to pursue nuclear disarmament, and present a specific plan for moving toward that goal, in recognition of the fact that a universal and verifiable prohibition on nuclear weapons would enhance both national and international security .