The Evolving Nuclear Weapon Threat To Society

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/, www.garwin.us

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Abstract Vast reductions in deployed nuclear weapons have taken place, and the international consensus against nuclear weapon proliferation is strong. However, world security is threatened by emergent nuclear powers and especially by the growing threat of non-state deliberate unauthorized use of state-owned nuclear weapons and by the threat of improvised nuclear explosives fashioned from stocks of weapon-usable fissionable materials—highly-enriched uranium or plutonium

I. The nature and number of nuclear weapons.

I begin by reminding you of the destructiveness of nuclear weapons, and their current numbers around the world. Then I discuss a bit what it takes to build and detonate a nuclear weapon and the change in perception of the nuclear weapon threat over the decades since the two used in war at Hiroshima and Nagasaki August, 1945. SLIDE 1

Slide 1 Hiroshima, October 1945

Since then, almost 1000 nuclear weapons have been exploded in tests in the atmosphere, mostly by the United States and the former Soviet Union. U.S., Soviet, and U.K. atmospheric testing was brought to an end by the Limited Test Ban Treaty of 1963. Since 1992, the United States has not tested a nuclear weapon underground, and similarly with Russia.

The bombs used in 1945 are shown in SLIDE 2;

Slide 2 Little Boy and Fat Man – Hiroshima and Nagasaki bombs ~13 and 20 kilotons explosive yield, ~ 4 tons weight.

They weighed more than 8000 lbs and had yields of 13 and 20 kt respectively. In contrast the 3 W-78/Mk-12A warheads on the U.S. Minuteman III missile, SLIDE 3, each weighs about 700-800 lbs and has a yield of 335 kt. The warhead is 71 inches long and 21 inches in base diameter. It was placed into service in late 1979.

Slide 3 Three multiple independently targeted reentry vehicles for the Minuteman III.

The Comprehensive Test Ban Treaty was opened for signature in 1996, and since then there have been nuclear tests underground only by India and Pakistan in 1998 and by North Korea in 2006 and 2009.
All nuclear weapons begin with the assembly of a supercritical mass of fissile material that will support an exponentially growing neutron chain reaction with a generation time of 10-20 nanoseconds. A single fission is nothing; it would kill a few cells in the body. But a microsecond's worth of chain reaction in the case of the Nagasaki bomb fissions a kilogram of plutonium and liberates energy within the bomb equivalent to 17,000 tons of high explosive. This produces an enormous fireball, and the heated air rises to create the typical "mushroom cloud." SLIDE 4,

Slide 4 15-kiloton surface burst. Nevada Test Site, 25 May 1953

Nuclear weapons are again in the news. Their control and even potential elimination is a priority with the Obama Administration and with President Obama himself. Following President Obama's speech in Prague April 5, 2009, we have had the signature in Prague April 8, 2010, by Presidents Obama and Medvedev of the "New START" Treaty to replace the 1991 Strategic Arms Reduction Treaty—START—that expired December 5, 2009. Furthermore, on April 6, 2010 the U.S. government issued the Nuclear Posture Review report—NPR[1], a totally unclassified document with the purpose to specify what the U.S. intends to do about its nuclear weapons over the next five to ten years, and how it views nuclear weapons in the world, On April 12-13, President Obama presided in Washington over the Nuclear Security Summit, concentrating on rendering more secure the material that might be used to make nuclear weapons, transforming the administration goal of securing all weapon-usable material within four years to a global goal to do the same thing.

By "weapon usable material" is meant highly enriched uranium (by IAEA definition >20% U-235 in U-238, but in reality probably >80% U-235). The other major material for building nuclear weapons is plutonium, of which the Pu-239 isotope is most useful. However, even the plutonium separated from power reactor fuel in some countries for recycle into power reactors as Mixed OXide fuel (MOX) can be used by knowledgeable weapon builders to make a nuclear weapon without yield penalty or, by relative novices, with no less than a 1-2 kiloton yield (i.e., the content of 1000 trucks loaded with 2 tons of HE). Even a 1 kiloton nuclear explosion could kill many tens of thousands of people in a city within days by exposure to radiation fallout.

For an excellent account, see "The Making of the Atomic Bomb" by Richard Rhodes. The wartime Manhattan Project to develop and produce the nuclear weapons cost the United States some $2 billion, and for many years that cost of "a billion dollars per bomb" and a feeling of American superiority persuaded many that only America could possess the superweapon. By 1949, though, the Soviet Union detonated its first nuclear weapon—a copy of the plutonium design tested July 16, 1945 near Alamogordo, New Mexico. The plutonium was created in production reactors fueled by natural uranium; the necessary 6 kg of Pu required 6000 megawatt-days of reactor power—in the case of the 200 MW(thermal) Hanford reactor, this was 30 full-power days. For a modern power reactor of one-million kWe (3000 MWt) 2 days of operation would suffice.

The Hiroshima gun-type weapon used about 60 kg of HEU, produced by a particularly inefficient "gaseous diffusion" isotopic separation process from the 0.71% U-235 content in natural uranium. Now most of the world uses the gas centrifuge in an extremely clever design that consumes only about 2% of the energy needed by gaseous diffusion for the same product. The common "light water" power reactor, of which the United States operates 104 at present, each produces about a million kWe of

[1] http://www.defense.gov/npr/docs/2010%20nuclear%20posture%20review%20report.pdf

electrical power and consumes annually about 25 tons of low-enriched uranium fuel, fissioning a ton per year of U-235. The 25 tons of spent fuel downloaded annually contains about 150 kg of Pu-239 and almost 100 kg of Pu-240 and heavier Pu isotopes.

Most of the “separative work” required to produce a ton of HEU is already invested in the ton of LEU (4% U-235) fed annually to each power reactor. Each “unit of separative work” (SWU) costs on the world market about $100; 151 SWU are invested in each kg of U-235 in 4.4% fuel, so the SWU content of 1 kg of U-235 content costs about $15,100 and the SWUs in the ton of U-235 annual feed represents about $15.1 million in enrichment cost.

At 60 kg of HEU per gun-type weapon and a SWU content of 232 SWU/kg, the SWU cost per kg is $23,200 and the enrichment cost of a weapon is $1.39 million. Naturally, a centrifuge plant that is built to make a few weapons will have higher cost than one that is amortized over 10 years of commercial fuel production, but the cost is negligible for a state of any size.

And unfortunately, with the passage of time and the availability of the internet, the original “secrets” of the atomic bomb have become relatively common knowledge. Among useful books to help understand both nuclear weapons and nuclear power is “Megawatts and Megatons,” by Richard L. Garwin and Georges Charpak (2001).

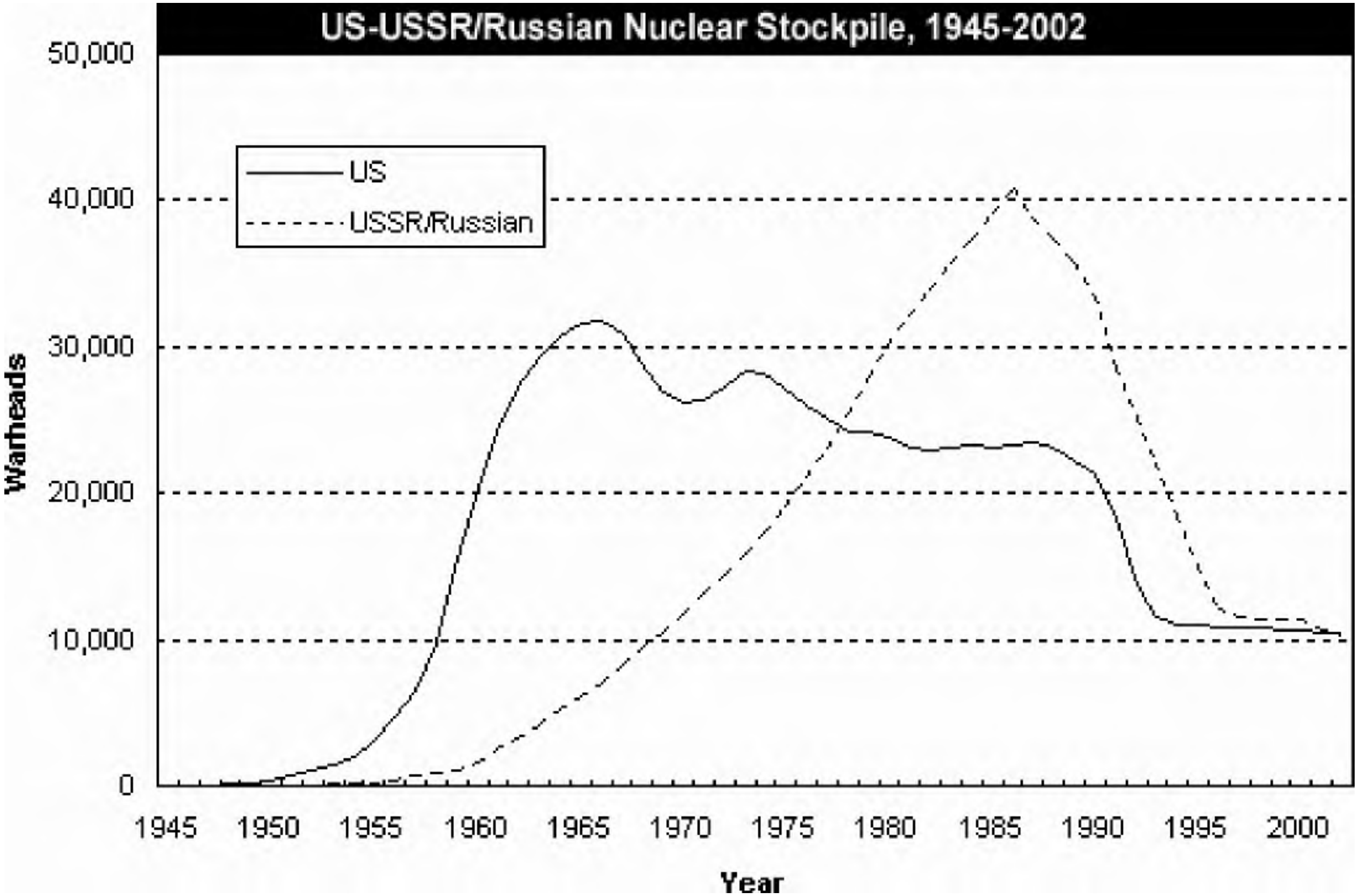
On January 4, 2007 four U.S. leaders in the security field—George P. Shultz, Sam Nunn, Henry A. Kissinger, and William J. Perry, following a well-prepared meeting at Stanford University, published an Op-Ed in the Wall Street Journal to proclaim their goal of the elimination of nuclear weapons and, in the nearer term, massive reductions in nuclear weaponry. President Obama has adopted this goal, and the April, 2010, NPR details some of the early conditions that must be met in order that a world without nuclear weapons might come about.

Although the Department of Defense was responsible for the NPR, the Department of Energy, the State Department and the National Security Council (NSC) all contributed heavily, and it the NPR is a policy document that guides the entire government. Fortunately the NPR is entirely unclassified, although, naturally, some of the implementation directives will inevitably be secret. The Department of Energy’s National Nuclear Security Administration (NNSA), responsible for designing and creating U.S. nuclear weapons, receives its guidance consistent with the NPR, as do the military departments responsible for raising, equipping, and training the military personnel.

It is clear to all, even those who believe that the elimination of nuclear weapons is infeasible or undesirable, that the 35,000 nuclear warheads the United States had at its peak in 1967 and the 45,000 Soviet nuclear warheads in 1982 are far in excess of a potential need for nuclear weaponry in the 21st century. These were built and maintained, together with their delivery means and the command and control system to make it absolutely clear that an attempt the Soviet Union to destroy the United States (or vice versa) would lead to the destruction of the attacking country itself.

Secretary of Defense Robert McNamara in 1964 established a criterion for "assured destruction", assumed to be the foundation of nuclear deterrence, as 400 equivalent 1-megaton warheads arriving at their targets in the Soviet Union. From that time on, the enormous numbers of strategic nuclear weapons were supported (largely after the fact) by the assumption of large-scale potential destruction of these weapons before they could be launched and by an assumed relatively effective ballistic missile defense system and air defense system that could intercept the nuclear weapons before they reached their targets. Despite secrecy about the numbers of warheads in every country, knowledgeable estimates were published that were not far from the mark. SLIDE 5

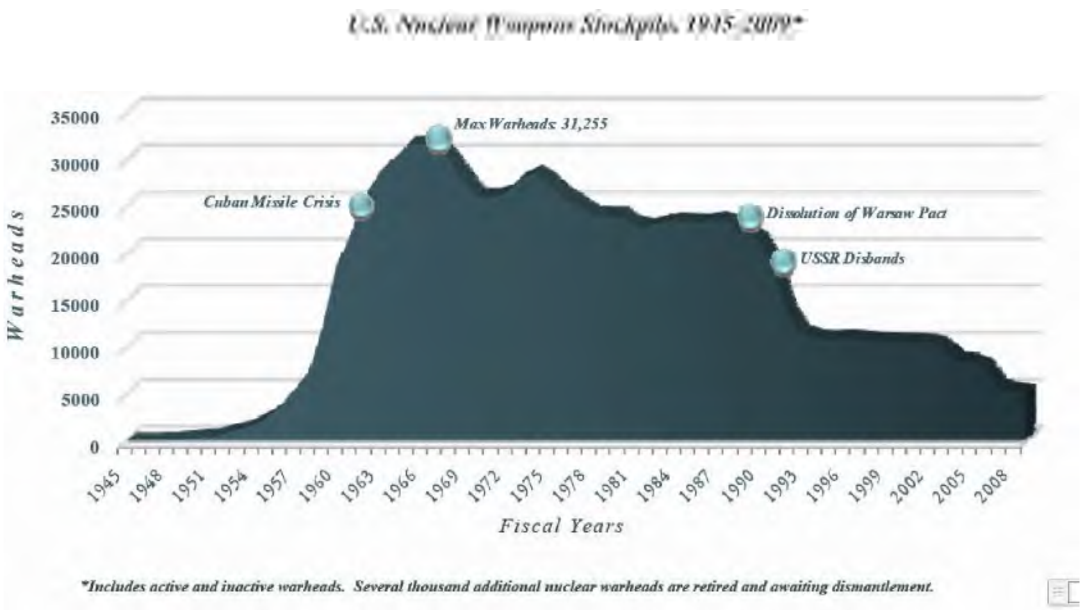
NRDC estimates



Slide 5 Natural Resources Defense Council (NRDC) graph

Today the threat of world-wide communism that could succeed only by the elimination of the United States is no longer credible, and with the enormous openness in the world in recent decades, together with the collapse of the Soviet Union, it is clear also that the United States is not planning the destruction of Russia or any other of the five nuclear states under the 1970 Nonproliferation Treaty-- NPT.

But there are reasons other than excess cost to move to greatly reduce the numbers of nuclear weapons and to secure weapon usable-material. In May 2010, the United Nations in New York was held the Eighth Review Conference on the NPT, which in 1995 was converted from an agreement renewable for five year terms to one of indefinite duration. Much in discussion is the “grand bargain” of the NPT, by which almost all the nations of the world signed up as non-nuclear-weapon states—NNWS—while those that had detonated nuclear explosives by January 1, 1967 signed as nuclear weapon states with obligations to provide information and support for peaceful use of nuclear technology to the NNWS. In her speech at the NPT Conference May 3, Secretary of State Hillary Clinton presented official data on deployed U.S. nuclear warheads and those that are held in reserve. As of September 20, 2009, the United States possessed 5113 nuclear warheads and bombs of all types. An additional “some thousands” of warheads are not maintained ready for use and are scheduled to be dismantled. SLIDE 6 shows the progression of U.S. warhead numbers, as revealed by the U.S. government in May, 2010.



Slide 6 U.S. Government Fact Sheet May 2010

Do these thousands of nuclear weapons ensure world security, or even U.S. security? The 2010 NPR gives five U.S. objectives related to nuclear weapons

#1: Preventing nuclear proliferation and nuclear terrorism:

#2: Reducing the role of nuclear weapons:

#3: Maintaining strategic deterrence and stability at reduced nuclear force levels:

#4: Strengthening regional deterrence and reassurance of U.S. allies and partners:

#5: Sustaining a safe, secure, and effective nuclear arsenal:

First, there is the hazard of ***proliferation*** of nuclear weapons to additional states, as has occurred with North Korea and which, it seems to many, is the goal of Iran's nuclear program, despite protestations that Iran's enrichment of uranium from the natural abundance of 0.71% U-235 to 5% and more recently to almost 20% U-235 is for the production of nuclear-electric power in Iran and not for the acquisition of nuclear weapons. Iran concealed from the International Atomic Energy Agency (IAEA) for 18 years enrichment activities that under the 1970 nonproliferation treaty (NPT) it was committed to report in a timely fashion. Paradoxically, what indicates a bomb-oriented program is that the enrichment facilities are much too small to provide fuel for even the one large power reactor that has been built at Bushehr by Germany and completed and initial fuel supplied now by Russia.

An even greater threat, according to most analysts and world leaders, is the acquisition of nuclear weapons by terrorist groups such as Al Qaeda, which has vowed to use a nuclear weapon against the United States if they can acquire it.

The sheer magnitude of the problem is apparent from experience with the highly successful 1992 "megatons to megawatts" program under which the United States has been buying 500 tons of Russian highly enriched uranium (HEU) from their nuclear weapon stockpile. This HEU is blended in Russia with some of the depleted uranium left from the initial enrichment process to the 4% U-235 range and then fabricated in the United States into fuel rods for the 104 large U.S. nuclear power reactors; about half of the U.S. nuclear electricity is thus fueled by uranium from Soviet nuclear weapons.

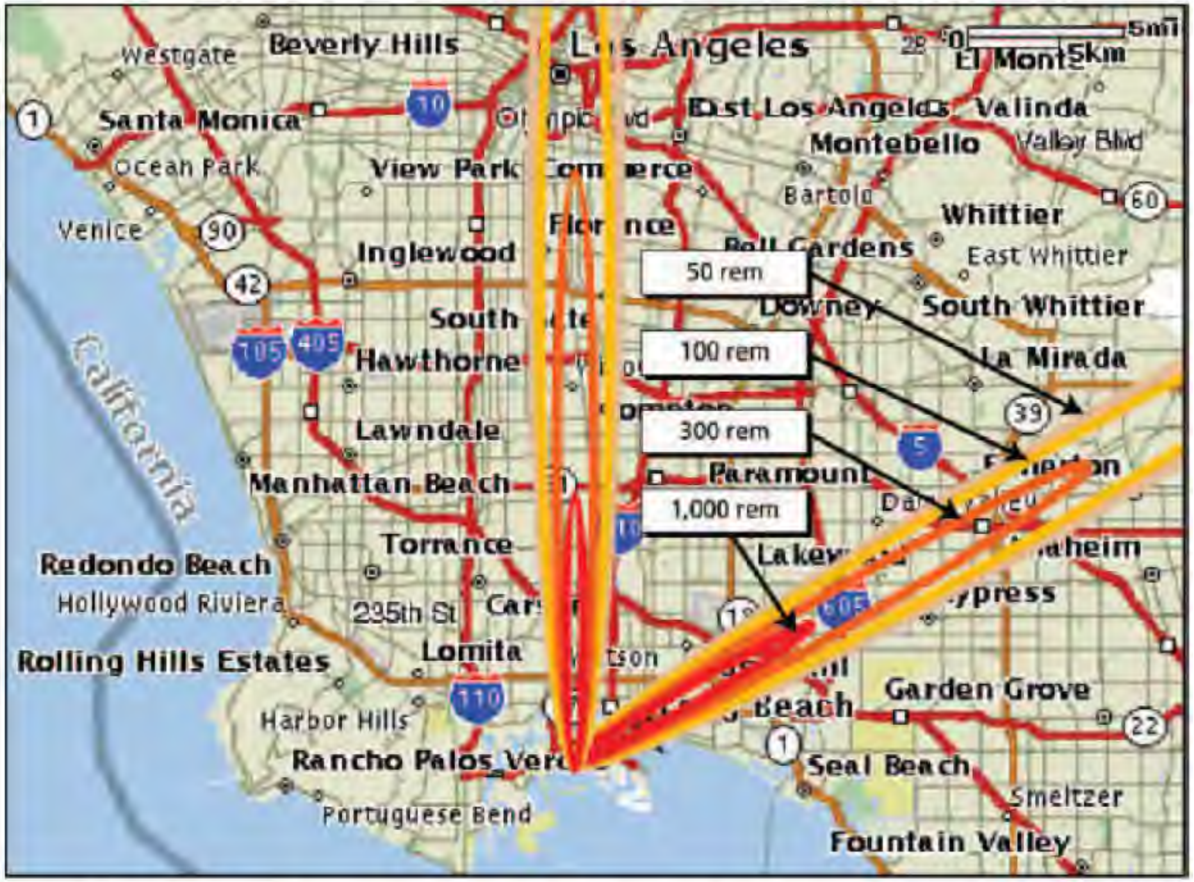
An understanding of what 500 tons of HEU means in terms of fabricating simple nuclear weapons is available from the International Atomic Energy Agency (IAEA) long-time establishment of "significant quantity" (SQ) for HEU and for plutonium. One SQ is 25 kg of HEU or 10 kg of plutonium, although weapons can evidently be made with less, since the average in the U.S. weapon stockpile is about 4 kg of Pu per weapon.

The Hiroshima gun-type that did not compress the bomb fuel, so about 60 kg of HEU was required to produce some 13 kt of yield. The "implosion" method of assembly using high explosive is the only practical one for plutonium, for which an SQ is 10 kg. China's first nuclear weapons were implosion-assembled HEU, and they have formed the mainstay of Pakistan's nuclear forces. Here the SQ is 25 kg. Although the Hiroshima bomb weighed some 8000 lbs to produce a yield of 13 kt, later gun type weapons were much smaller and lighter—among them 6 such weapons secretly built by South Africa and later destroyed without having been tested. In 1957 the United States began the deployment of more than 1200 army artillery shells—the W33—that was tested in Nevada with a yield of 1 kt, but that had other selectable yields up to 40 kt (probably enhanced with fusion "boosting.") The W33 weighed 243 lbs, and was 8-inches in diameter and 37 in long.

The 500 tons of Russian HEU blended down to 4% U-235 for use in civil power reactors could, instead, have made 20,000 nuclear weapons. And there remains at least an equivalent amount of HEU still in Russia. Terrorists might steal or be given a nuclear weapon from the armory of Russia or Pakistan or even North Korea. Alternatively, they could probably more readily obtain HEU and fashion it into an Improvised Nuclear Explosive (INE) that could be detonated in a city.

Here I draw on my article on a terrorist nuclear detonation in a city that appeared in the June 2010 *The Bridge*, a publication of the National Academy of Engineering. Because this is a detonation at ground level (presumably in a basement or a lower floor of a building, the consequences are quite different from a similar yield of 10 kt air-burst, as was the case in Hiroshima and Nagasaki. In particular, there may be fewer direct burns from the fireball, which will be on the ground, but there will be a crater some 56-ft deep and 245 ft in diameter, which will mix with the radioactive fission products from the bomb and largely fall out in the local area and in a relatively narrow plume that will extend for ten miles or more from the point of detonation. Had the failed truck bomb in Times Square been an improvised nuclear explosive of 10-kt yield, some 300,000 people might have been killed, and a good many more depending on the prevailing winds and the track of the fallout. An example of a simplistic predicted fallout plume from an attack on Long Beach, California, is shown in SLIDE 7.

Figure A.7
Alternative Estimates of Fallout After First Day



SOURCE: Map and content © 2006 by MapQuest, Inc. Used with permission.

Slide 7 Charles Meade and Roger Molander (2006)

Naturally, the best approach to preventing such a terrorist nuclear explosion is to eliminate or to lock up all nuclear weapons and weapon-usable materials, and to enforce strict personnel security practices among those who have "legitimate" access to such items. Useful also would be to reduce the number of individuals who wish to carry out such an act. And other means are important to consider on the "supply side" of the terrorist nuclear explosive threat.

Since 1962, many U.S. nuclear weapons have been equipped with increasingly competent "permissive action links" (PAL) so that physical possession of a weapon does not convey the ability to obtain a nuclear explosion. In the United States, increasingly greater demands are being imposed on the security of nuclear weapons—with the ideal that in the wrong hands a weapon would be totally inert[2]. Many safety features on U.S. weapons also contribute to security—e.g., measures that ensure that a lightning strike cannot detonate the weapons, the requirement that the weapons be "one-point safe" so that it produces no damaging nuclear yield if its explosive (used to implode the plutonium "pit") is detonated at any one point, and the secure transport system that is used to move the nuclear weapons. Although attention is often focused on "intrinsic" surety features most readily provided in weapons of new design, much progress can be made with improvements in the weapon environment, and in procedures for handling, storing, and transporting nuclear weapons. I hope that presentations such as this will increase the demand among the public and the political leaders of those states possessing nuclear weapons to ensure that these weapons are not only safe against accident but also secure against theft of a weapon and even secure against acts by those authorized to maintain nuclear weaponry.

But beyond that, public officials have the obligation to mitigate (i.e., reduce but not eliminate) the effects of terrorism or accident, and in that regard there are actions that can be taken at relatively low cost. It is unclear whether political leaders will accept the political/electoral cost of explaining this risk.

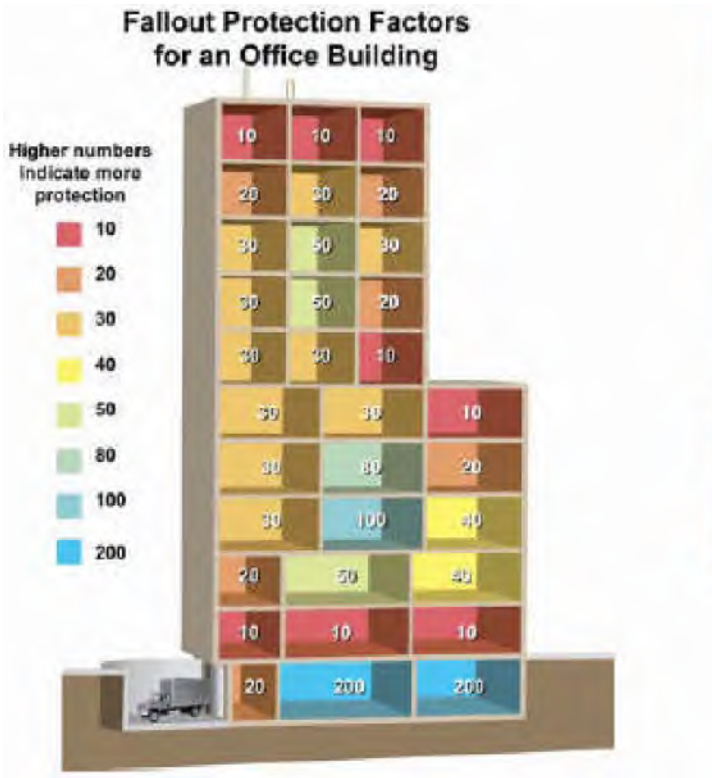
Education and communication are among these actions, and it should be possible to inform people that there is a remote hazard of a terrorist nuclear explosion in their city, corresponding to a significant possibility in a city in general, and that "if you see something, say something" in this regard as well as others. Not much can be done for medical care of people injured in the

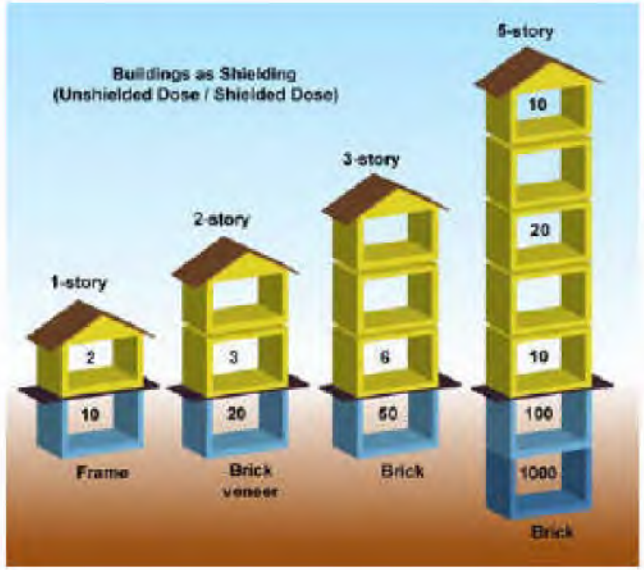
[2] In a speech of January 31, 2008, US STRATCOM Commander General Kevin P. Chilton expressed the need for a nuclear weapon so secure that in terrorist possession "it would be a doorstop."

nuclear explosion, because the local resources for healthcare are microscopic compared with the need. It will be self-help, if anything, for the first day or so. In the United States, there is considerable discussion of the federal role in such an attack, in view of the fact that the rest of the country would be undamaged. If 300,000 people are lost, this is 0.1% of the total U.S. population, and a primary (strategic) federal role is to ensure that no single explosion, or even two could destroy the entire society as a consequence of undue concentration of records or talents in a particular fairly small region of a city. An important federal role is to analyze thoroughly the potential consequence of such a terrorist nuclear explosion and to assess the impact of the possible responses, sharing this with the public and local and state authorities. The federal government would need to work with cities to create and practice the management of the vast effort that would be required to bring external supplies and support to a stricken city.

What can be done in the immediate aftermath of a nuclear detonation is to reinforce discipline that people should get indoors and stay there until they are told that they can move. Within a couple of minutes it should be possible to obtain from the NARAC (National Atmospheric Release Advisory Center) a prediction of the fallout map, and within an hour, a local map of actual fallout could be obtained from aircraft at sufficient altitude to be flown even by pilots. At that time, people in the fallout pattern might be advised urgently to walk half a mile to either side, which could be the difference for them between life and death, although most will be safe by remaining indoors.

And if they don't move, they could, without measuring radiation levels themselves, do a good deal to reduce their hazard by moving to a different location within the building as exemplified by the shielding factors on the following SLIDE 8.





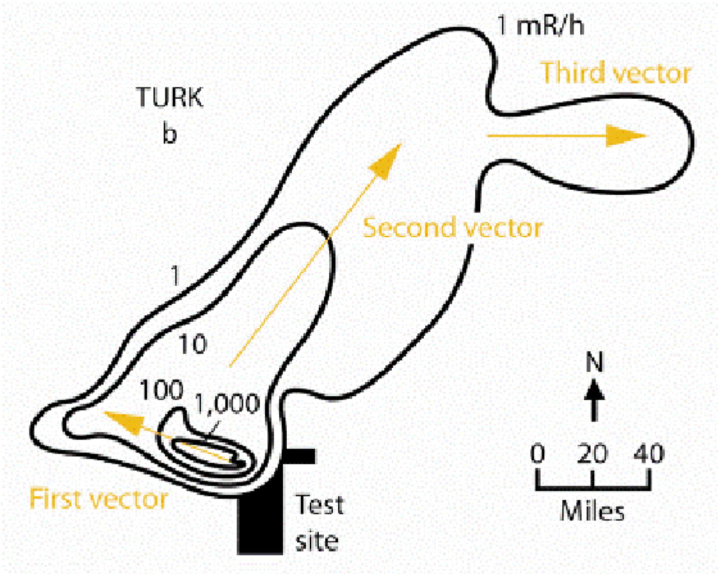
Slide 8a Building as shielding: numbers represent a dose reduction factor. A dose reduction factor of 10 indicates that a person in that area would receive 1/10 th of the dose of a person in the open.

Slide 8b Building as shielding: numbers represent a dose reduction factor. A dose reduction factor of 200 indicates that a person in that area would receive 1/200 th of the dose of a person out in the open.

With the new perception of danger from an improvised or stolen nuclear explosive detonated in a city, the U.S. Congress in 2007 required the Department of Homeland Security (DHS) to undertake a quantification of the hazard and what interventions might minimize that hazard.. I had addressed this in my presentation in April 2007 to a high-level meeting in Washington convened by the "Preventive Defense Project" of Ashton B. Carter and William J. Perry.

A window on the work that has been done under the mandate to DHS on urban nuclear explosions is an excellent paper by Brooke Buddemeier.[3] Here are a couple of illustrations from that paper.

SLIDE 9 is an example of the complex nature of the fallout, given actual winds aloft at various levels.



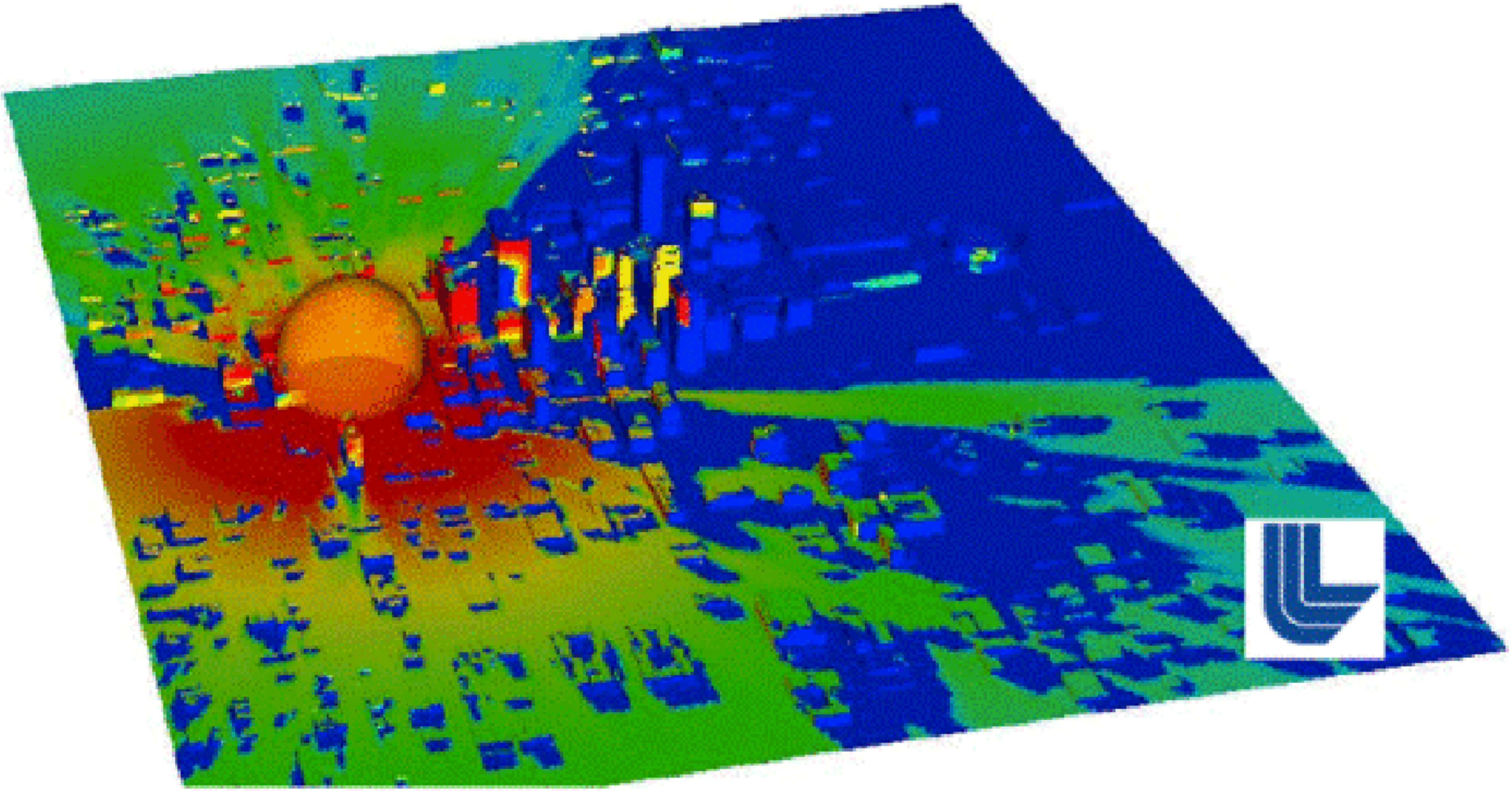
Slide 9 Early fallout dose-rate contours from the TURK test at the Nevada Test Site. SOURCE: Lawrence Livermore National Laboratory.(from B. Buddemeier, June 2010, by permission.

[3] "Reducing the Consequences of a Nuclear Detonation: Recent Research," by Brooke Buddemeier, *The Bridge*, Summer 2010, pp. 28-38, To be found at http://www.nae.edu/File.aspx?id=19815 .

Buddemeier provides estimates of the radiation dose from fallout as influenced by delay time to evacuation and makes the point that to stay for delayed evacuation in a portion of a building with a reasonable protection factor (PF) substantially reduces the dose and the potential damage from radiation exposure—a point we have been making in our Permanent Monitoring Panel in Erice for several years. Naturally, the evacuation route also influences the dose, not only because the fallout itself is non-uniform, but because the time spent along different evacuation routes varies with capacity and congestion.

Of course, choosing a route and an estimated speed is only a tiny part of what needs to be done in planning for the aftermath of a nuclear explosion, where police and military supervision need to be organized for a situation in which hundreds of thousands of people may already have died and the survivors are in great peril.

Paradoxically, the greatest psychological problems in working in this field arise from discussions of how best to save lives and preserve health among the survivors. Other interesting aspects of the problem, such as that illustrated in SLIDE 10 for the beneficial shadowing effects of buildings against the thermal radiation from the fireball are easier to contemplate.



Slide 10 Integrated thermal flux from a 10-kiloton ground-level nuclear detonation in a small U.S. city. SOURCE: Lawrence Livermore National Laboratory. For more information contact brooke2@llnl.gov . (From Buddemeier, June 2010, by permission)

PROLIFERATION brings to mind North Korea but also Iran. The possibility that Iran will obtain nuclear weapons is encouraging similar thoughts in the Middle East and elsewhere, as Arab states face the possibility that a fellow Muslim (but not Arab) country acquires what has long been called “the ultimate weapon.”

It may be that some of these countries are simply hedging their energy bets, believing that the era of oil is drawing near its end, and that they should begin to make a transition to nuclear power. In fact, just before the overthrow of the Shah of Iran of 1979, the United States government was proposing to Iran the acquisition of 20 nuclear power plants, and the full fuel cycle for supplying them. As you know from the news, Iran has had a very active program for mining uranium, converting in into UF_6 gas, and enriching that gas in U-235.

Both for Iran and for the rest of the world, it would be cheaper and safer for individual countries to buy enriched uranium fuel or enriched uranium material on an assured market rather than to build and operate enrichment plants themselves. If they don’t trust the reliability of supply, they could buy fuel as long as ten years in advance, because the fuel cost for a nuclear reactor—unlike for a coal or gas-powered plant—is a tiny fraction of the overall cost of electrical energy.

Similarly, rather than directly entomb the highly radioactive spent fuel (or the separated fission products) within the country that generates it, as is the legal requirement now, nations ought to encourage the development of regional mined geologic repositories so that only the reactor itself would be on national territory.

CONCLUSION

Although the possibility of destruction of the United States by an onslaught of hundreds or thousands of Russian warheads is much reduced, there is a growing probability of the detonation of a stolen or improvised nuclear weapon in a large city—especially in a U.S. city-- which might kill directly 300,000 people—mostly within a few weeks by exposure to radioactive fallout within first hour or day after the explosion. Although the loss of 0.1% of the U.S. or European population need not destroy the entire society, without analysis and planning at great cost, it might do so. Hence the recognition that nuclear weapons anywhere are a great threat to our society.

I believe that such an urban nuclear explosion is probable over the next ten years, and that probability can be greatly influenced by a collaborative effort, world over, to protect stores of weapon-usable plutonium and HEU, to reduce holdings of nuclear weaponry and to improve greatly the security of nuclear weapons. Most important is to recognize that this is a problem on which progress can be made both in prevention and mitigation.

The final SLIDE 11 reminds us of the consequences of failure in this mission.

As a remedy to security problems, nuclear weapons have potentially lethal side effects.

Slide 11 WHICH COUNTRY? WHICH CITY? OCTOBER 2010?