

Tape Transcription

Dr. Richard Garwin
Drell Lecture

U.S. NUCLEAR WEAPONS AND NUCLEAR EXPLOSION TESTING

Tuesday, March 9, 2004

[With "[SLIDE x]" references to accompany file USNW_Slides.pdf]

CHAIR: [Welcome on behalf of the Center for International Security and Cooperation within the Stanford Institute for International Studies.] My name is Christopher Chyba, and with Scott Sagan I co-direct CISAC, the Center for International Security and Cooperation. The Drell Lecture was established by Bud and Cecily Wheelon who are with us here this evening, in 1994, and then named in honor of Professor Sidney Drell upon his retirement at Stanford. Bud Wheelon has had a remarkable career as Deputy Director of the CIA and been CEO of Hughes Aircraft, and he and Sid Drell both played a remarkable role in intelligence gathering and the resulting possibilities for arms control during the Cold War. You can read about those roles in Philip Taubman's book Secret Empire. Sidney Drell was also here at Stanford, one of the founding co-directors of CISAC as well as Deputy Director of the Stanford Linear Accelerator facility.

We could hardly have a better speaker to be this year's Drell Lecture than tonight's speaker Dr. Richard Garwin. Dr. Garwin received his Ph.D. in Physics from the University of Chicago in 1949. He is now Philip D. Reed Senior Fellow for Science and Technology at the Council on Foreign Relations and also IBM Fellow Emeritus as well as previous Director of the IBM Thomas J. Watson Research Center. He was a member of the President's Science Advisory Committee and is currently a member of the National Academy of Sciences, the Institute of Medicine and the National Academy of Engineering as well as the Council on Foreign Relations. Most recently he is the 2002 National Medal of Science winner. His most recent book with Georges Charpak is Megawatts and Megatons: The Future of Nuclear Power and Nuclear Weapons.

Tonight he's going to speak to us on United States nuclear weapons and nuclear explosive testing, and then there will be time after his talk for questions from the floor. There are microphones on both sides. Dr. Garwin will moderate questions and I'll bring the evening to a close in a little under an hour and a half from now. Thanks very much for coming. Please join me in welcoming Dr. Richard Garwin. APPLAUSE.

DR. RICHARD GARWIN: Thank you, Chris, and welcome. I'm going to talk about nuclear weapons and nuclear explosion testing, why nuclear weapons are a threat to us as well as a tool, and what we ought to do about them. [SLIDE 1] In more detail, I'm going to tell you how nuclear weapons are made, why they're tested, whether one can have a nuclear weapons stockpile without continually testing them, look at two new type weapons that are being proposed, one for destroying deep underground hardened facilities and the other supposedly for destroying chemical or biological agents in shallow underground facilities without scattering them to the atmosphere. And after that, on the basis of some

of the conclusions that I draw, I will discuss further the means for reducing the proliferation of nuclear weapons and for reducing the threat from excess nuclear weapons, mostly in Russia and the United States, and from nuclear weapon materials-- highly enriched uranium and plutonium-- and reducing nuclear weapon stockpiles. [SLIDE 2].

First I'm going to tell you about nuclear weapons. Probably most people here don't know very much about them, but you can and now will. They all start with fissile material. That is, a material such that a neutron striking a nucleus of one of these materials, usually uranium 235 or plutonium 239, causes fission, and the essential point is that each fission gives rise to more than one neutron-- two and a half in the case of uranium 235, three and a half in the case of plutonium-- and if you have enough fissile material so that not too many neutrons escape, then in the time required to go from one nucleus to the next, that is not the next one over but the next one that interacts, a distance of about five centimeters and at the speed of neutrons 2×10^9 centimeters per second, in just a few billionths of a second a neutron population doubles. The magic of compound interest is such that in less than a microsecond one neutron can lead to fission of the entire mass of material.

The only equation I'll discuss here and I won't show it to you is Einstein's relation between mass and energy. If you use that, you can show that one kilogram, 2.2 pounds, of uranium 235 or plutonium when it is fissioned gives the equivalent of 17,000 tons of high explosive. Not one ton in a truck bomb but 17,000 tons of high explosives. One of those bombs-- 13,000 tons, 13 kilotons-- destroyed the city of Hiroshima. Another one, slightly more powerful, destroyed the city of Nagasaki in 1945.

Uranium 235 occurs in nature, probably fortunately for us. It's only seven-tenths percent of normal uranium, and it's a complicated and energy-intensive process to get it out. In fact, it may be the most inefficient process we know. It should take about less than one volt unit of energy to separate a uranium 235 atom from the 140 uranium 238's that accompany it. Instead, we pay five million electron volts for that. It's so inefficient that this bomb sketched here [SLIDE 3] from the Cox Report, Congressional Report of 1999, had more energy put into it from the power plants at Oak Ridge, Tennessee, than it liberated in destroying Hiroshima. It was just a big storage battery. Be that as it may, it's four tons of bomb dropped from an airplane which had the explosive power of 13,000 tons of TNT.

Nuclear energy has a beneficial side. Seventeen percent of U.S. electricity comes from nuclear power plants. There are a hundred of them here, and 300 full-size plants in the world altogether, giving approximately that same fraction of the world's electrical power. Nuclear power has its own problems associated with the benefits-- those of cost, catastrophic accidents, and of radioactive waste disposal. In general, I'm in favor of nuclear power. It does have two particular problems that you see now in the newspapers, and I'm glad that there's more attention being paid to them. First is the link of nuclear energy to proliferation of nuclear weapons. It doesn't have to be so, but often states that desire to be closer to nuclear weapons will make choices in their nuclear power line of reactors and

fuel cycles that allow them to get their hands on enriched uranium or separated plutonium. This is very much in the news. In fact, on February 12, 2004, President Bush spoke at the National Defense University about his proliferation security initiative, in which he proposes that most countries not have the full fuel cycle. They should operate reactors to produce electrical power or maybe even heat, and they should forego the enrichment plants and the reprocessing plants to obtain the plutonium.

Just to be complete, I talked about the uranium 235 as a component of a nuclear weapon, and plutonium 239 works even better. It takes 60 kilograms of pure uranium 235 metal to make a bare critical mass that will have an exponentially growing chain reaction. It takes only 10 kilograms of plutonium 239. On the other hand, here is how the first bomb used on Japan was built, approximately. It had one mass of uranium 235, another mass-- three rings of it actually-- and propellant behind this one shot it into the other one. No particular speed is required except for one reason: if a neutron gets there too soon, then the chain reaction will start at a very low rate and things will expand and disperse almost harmlessly.

In 1944, a difficulty was encountered at Los Alamos as they were planning to use the plutonium coming from the Hanford reactors where it is produced from uranium 238, as happens also in almost all nuclear power plants. That plutonium emitted neutrons spontaneously at too high a rate, and it was a fundamental matter of plutonium 240 impurity that could not be separated chemically. So the idea of launching a plutonium projectile, because we didn't have enough uranium for all the bombs we thought we might have to build, was out the window. It would be sure to pre-detonate with a negligible yield. Another approach was taken in which more rapid assembly was possible—high explosive rather than propellant, and a solid sphere of plutonium was then chosen as the simplest way to make a supercritical mass.

Nuclear explosives are really interesting. I'll show you my book that Chris referred to which tells you a lot more than I have time to discuss here. If you have less than a critical mass, how do you make it more than a critical mass without adding more plutonium? Well, by squeezing it. A balloon that's been hanging around the house gets much darker as it gets smaller because the dirt on the surface gets closer together. That's what happens in an implosion: a squeezed ball of plutonium becomes darker to neutrons and, initially safe in its compressed state, it will give a nuclear explosion.

Well, over the years, we learned how to do this better, and unfortunately other people did too, so the Cox Report has this sketch of a modern nuclear weapon-- a thermonuclear weapon. This is a sketch of the most modern one in the U.S. inventory, and over here it contains a plain ordinary fission weapon of the kind we just discussed. The implosion bomb dropped on Nagasaki in 1945 also weighed four tons and had a yield of 20,000 tons, 20 kilotons. Here it weighs only a hundred pounds or less. Instead of a plutonium ball it has a plutonium shell. It is a boosted weapon, in that before the weapon is imploded to make it super critical, some grams of deuterium and tritium gas-- hydrogen isotopes--

are put into the hollow in the pit. And then it is imploded, becomes critical. At the appropriate time neutrons are injected and one has the kiloton-class explosion.

In 1952 we demonstrated the first hydrogen bomb, of which this is an example, by the principle of radiation implosion. It had a yield of 11 megatons. Over here [SLIDE 4] is a secondary and it is squeezed not necessarily to make it critical but to speed the reaction of the thermonuclear fuel. It can be pure deuterium, a fusion fuel in which the energy is released not by having the heavy atom split into two lighter ones, but by having light nuclei, heavy hydrogen form helium 4. The Soviet Union made some of these for peaceful purposes—peaceful nuclear explosions (PNE). The secondary in one of these Soviet PNE devices was 30 kilotons and had no uranium, no fission in it at all, but often hydrogen bombs have a good deal of fission—typically providing 50-70% of the total energy release. This modern weapon weighs about 800 pounds. It has an explosion yield of 300 kilotons, 300,000 tons of TNT, which is about 20 times of the Hiroshima or Nagasaki bomb. It's about my height. It weighs somewhat more but I'm getting there, and it's got a pointier head.

Now, to paraphrase Senator Everett Dirksen, with these weapons of a thousand times the yield of the fission weapons of 1945 and tens of thousands of times as many, pretty soon you're talking about real destructive power. In fact, it was rather unexpected. The hydrogen bomb was originally conceived as a way to get a very much more powerful weapon, and they have been detonated up to 60 megatons in explosion yield. They could be made with yields of a hundred or a thousand megatons. We had a lot of multi-megaton weapons in the U.S. inventory and the Soviets did too, but weapons now are mostly half a megaton or a third of a megaton or 40 kilotons because they are more useful. A very big weapon just destroyed more than there was to destroy and it was better to divide up the payload of the bomber or of the missile into smaller and more accurate nuclear weapons.

We had tens of thousands of weapons, atomic demolition munitions, depth charges, air-to-air missiles, nuclear armed interceptors to destroy ballistic missiles, to the point that people got tired of having so many weapons and of having to find targets for them all.

Levity aside, this is why we're talking about nuclear weapons. The first nuclear weapon used against Japan destroyed the city of Hiroshima and killed about 150,000 people. You may say, well, there are buildings still standing and a nuclear weapon is not so bad, but that's because it was detonated to cause the maximum total damage, not the greatest damage at the epicenter under the explosion. Had it been detonated at ground level, there would be a big crater there and nothing left. With the "air burst," the blast damage extended farther than if it had been detonated at ground level.

Nuclear explosion testing initially took place in July 1945 on a 100-ft tower in New Mexico. You probably can't read the slide, [SLIDE 6] but there were 216 U.S., 213 Soviet, France 45, China and Great Britain 21 each, and one "unknown"

claimed on the Swiss web site. To my understanding that was not a nuclear explosion in the South Atlantic; it was a malfunction of the detection system, but we could argue about that. It's not relevant.

In 1951 the United States conducted the first underground test [SLIDE 7] and we have had 818 of them, Soviets 500, France 153, China and Great Britain each exactly 24, India 3, the first in 1974, and Pakistan 2. Some of these events were multiple nuclear explosions at the same time.

On this slide are the purposes of nuclear testing [SLIDE 10]. There are atmospheric tests, the underwater tests, underground tests, and space environments. Some of the purposes of testing are related to nuclear weapons-- to explore principles-- for instance, of boosting that I mentioned, or of radiation implosion-- or development tests of a stockpile weapon. After you've built the weapon and turn it over to the factory to make hundreds or thousands, then a prudent person would want to verify that the production weapons really work—production verification. Stockpile verification, absence of aging effects.

If you would say that we've never done stockpile verification, you wouldn't be far wrong. We've had a couple of stockpile verification tests-- not because they were felt by the weapon laboratories to be necessary but because they were politically desirable. And then there are weapon effects tests, on military and civil targets, the production of electromagnetic pulses by nuclear explosions in space or on the ground.

Some basic research has been done. Production of super-heavy nuclei, neutrinos, equation of state, and then the category of peaceful nuclear explosions where we had dozens of tests and the Soviets many more. We never used a peaceful nuclear explosion-- our Plowshare Program-- productively, but the Soviets did for the stimulation of oil and gas to create storage cavities, to crush rock, and they used dozens of these explosions for seismic sounding-- underground explosives that would produce enormous signals that could be detected at great distances.

Finally, one can use nuclear explosives testing to provide ground truth for weapon designers and to maintain skill in testing. Each of these purposes was intended to be of benefit to somebody, in addition to the lab and contractors conducting the tests.

Here is a partial list of the peaceful nuclear explosions carried [SLIDE 8] out by the Soviet Union, some of them under the Oil Production Ministry, some the Geology Ministry and so on, mostly in the kiloton range.

In order to protect the environment and to minimize the development of new nuclear weapons, there has long been an interest in a total ban on nuclear testing. I first worked on this in 1958, with Professor Pief Panofsky, in negotiations with the Russians. In 1963 we achieved a limited test ban treaty that banned all except underground nuclear explosions, and in 1996, a comprehensive test ban treaty was signed first by the United States and by France, and then by many other

countries. The United States has not ratified the CTBT because when it was finally submitted by the Clinton administration to the Senate for ratification in the Fall of 1999, the Senate declined to do so. There was as I recall 19 hours of debate (or one hour of debate repeated 19 times), and three partially technical issues were discussed which I will get to in a minute.

Before the treaty was opened for signature, the United States of course evaluated our national security interests in having a comprehensive test ban treaty that banned all nuclear test explosions, of whatever yield in whatever medium. General John Shalikashvili, who was chairman of the Joint Chiefs of Staff, signed off for the military that this would be in the U.S. national security interest. About the time that it was presented to the Senate, President Clinton appointed General Shalikashvili, who had retired by then, as a person to marshal analyses, to understand the arguments that had been raised in the Senate debate. And General Shalikashvili asked The National Academies to study three topics [SLIDE 11]—whether U.S. nuclear weapons could be maintained safe and reliable under a comprehensive test ban treaty because many in the Senate debate doubted that; whether the international monitoring system, part of the CTBT, supplemented by U.S. national technical means could detect significant tests by others, say those above one kiloton; and whether activities harmful to U.S. security could be conducted by nuclear test explosions below the detectable level.

Now it's absolutely clear that there are levels of testing that would be undetectable by any of these cooperative measures that are now deployed under the comprehensive test ban treaty. For instance, we have had nuclear explosions, and others could also have a nuclear explosion of just a few pounds energy release. Such a test could be done in a contained facility; it would have no seismic shock; it would be underground; but the point is what military benefit could be obtained from that other than saying, "well, I did it and I got away with it," which would of course spoil the whole thing because then they wouldn't have gotten away with it.

Our Academy committee in this case was chaired by John Holdren of Harvard and besides Panofsky and myself, its membership included three former directors of U.S. nuclear weapon laboratories—Harold Agnew from Los Alamos, Al Narath from Sandia which makes the arming, firing and fusing aspects of nuclear weapons, and Al Trivelpiece from Oak Ridge which makes the highly enriched uranium and with the lithium deuteride components. We studied the available evidence and we judged that as for the first question (which is the only one I'm going to discuss here) [SLIDE 12] that the U.S. has the technical capability to maintain confidence in safety and reliability of the nuclear weapon stockpile provided that we have resources (and we are spending about \$6 billion a year on this), and that we focus them adequately on this task. Whether we do that or not is a matter of debate.

Then we took head-on the assertion that "confidence will inevitably degrade over time," and our judgment was that this "underestimates our current capabilities, further underestimates the future capabilities, and overestimates the

role that nuclear testing has ever played or would ever be likely to play in assuring stockpile reliability.”

The question wasn't put to the committee members as to whether they wished the comprehensive test ban treaty had been signed, but only the technical issues. President Eisenhower stated that the failure to achieve a comprehensive test ban treaty was the greatest failure of his administration and perhaps of any administration. I personally wish with President Eisenhower that the CTBT had been signed and ratified by the U.S.

Why are we worried about nuclear weapons? [SLIDE 5] The Bush administration proclaims, (which is true) that the Soviet Union no longer exists and the people of the half of it that constitutes Russia and has all the nuclear weapons are now not our enemy, in fact, they are our friends. We have some difficulties with those particular friends, but who doesn't have difficulties with some friends? However, nobody believes that Russia is going intentionally to launch nuclear weapons against the United States, or that we will launch ours against them. Nevertheless, we maintain thousands of nuclear weapons ready to launch at a moment's notice, simply because the other side has the capability to launch nuclear weapons. Our nuclear weapons (if you do a detailed analysis) can in principle destroy all of the Russian nuclear weapons so that they would be unable to retaliate, and therefore Russia judges that we are not deterred from such a strike. The fact that we have no interest in such a strike doesn't cut any ice in this calculus.

Worse; besides the six thousand or more nuclear weapons ready for use and another six or ten thousand nuclear weapons in reserve, there is enough uranium 235 and plutonium in Russia to build tens of thousands more nuclear weapons, and much of this material is not properly safeguarded. It's spread over dozens of sites. We have a program for the last ten years—the Cooperative Threat Reduction Program initiated by Senator Richard Lugar and now former Senator Sam Nunn—which spends almost a billion dollars a year to try to reduce the threat by cooperative means. This is largely spent through our Department of Defense. But it is not largely spent in Russia, and so the Russians are not motivated, they can't buy people to do the work. The United States economy is well used to providing motivation other than altruism—in this case for Russians to improve the national security of the rest of the world by securing their materials.

Here's what one low-yield nuclear weapon would do in Manhattan. [SLIDE 13] If you go to the website www.fas.org/RLG you will find my August 2002 paper, "Nuclear and Biological Megaterrorism." It's a lot easier to make an improvised nuclear explosive weapon than to make one like in the first slide that could be dropped from an aircraft and would explode at a preset altitude. It's a lot easier because it can be on a tabletop or built on the floor. It can be much larger. Uranium 235 is a particular hazard in this way.

It shouldn't be imagined that a nuclear weapon made by terrorists, maybe with some advice from others and using highly enriched uranium metal, would have

a low yield. It could perfectly well have a full yield of 10,000 tons, “10 kilotons,” 10,000 tons of high explosive. It would kill people up to a radius of 600 meters, 2,000 feet from air blast. It would kill them from the thermal pulse out to almost two kilometers and from prompt radiation from the explosion to more than a kilometer. Even a one-kiloton weapon would kill hundreds of thousands of people if detonated at ground level in Manhattan at a time when the population density was highest.

I promised I would talk to you about the nuclear weapons that the Department of Energy wants to design. They have no commitment to build them, they explain, but they are enthusiastic about analyzing them, in part to maintain the skills in the nuclear weapon laboratories and in part because of congressional pressure. The two that are most in the news are the so-called “bunker buster” nuclear explosion and the “agent defeat” weapon. Now, the bunker buster is intended to destroy hardened facilities buried at depths of hundreds of meters. We've had such a weapon in our inventory for a long time. It's the B-53 nine-megaton nuclear bomb, but nine megatons exploded on the surface creates lethal fallout over hundreds of thousands of square kilometers, and especially if the other side has put the hardened facility under a city, you would destroy the entire city. And who knows what that facility was doing or worth in the first place?

So there is a call for less powerful weapons to do the same job. One approach is this observation that was made years ago that if you bury a nuclear weapon_ even very shallowly_ you can't read [SLIDE 9] this but for a kiloton of yield, this is the scale depth so burying at a meter will increase the effective yield (for creating ground shock) by a factor of 20, from what it is if detonated right at the surface. That's because the energy from the explosion is first in the form of x-rays and it goes out, heats the earth around it, rather than escaping into the air. You only need to bury it a third of a meter, and this scale is like the one-third power of the yield, so if I were talking a hundred kilotons, then this third of a meter would only go up to about 1.7 meters; burial at two-meters depth would produce a ground shock like that from a 2-megaton surface burst. We modified one of the aircraft delivered bombs, the B-61, to the Mod-11. It will penetrate a good many meters into earth. But people who build hardened facilities don't want nuclear weapons to destroy them and so they're likely to put a hard cap of granite or concrete, reinforced concrete over it, and so there's a call for more robust nuclear weapons, a robust earth penetrator.

.Anyhow, something which will penetrate a cap, go down to a few meters and explode there. The technician in me says, well, you may want to do this, but that's not the way to do it. We have long had a better approach. Even during the Vietnam War we had many small weapons in our inventory, not nuclear, just a few pounds of explosive, to destroy runways, not by cratering them—it's too easy to fix; but this was a shaped charge which poked a hole through the runway, several feet of concrete. Then a small conventional explosive, two pounds or so, went through the hole, exploded under the runway, and buckled it, so no airplane could take off.

The combat engineers would first have to come out, destroy their own runway, and then rebuild it. The same thing can be done here writ large. You can have a 2,000-pound shaped charge. Just to give you the scale, 15 pounds of high explosive in an appropriate shaped charge configuration, according to the Army Field Manual will blow a hole three meters deep and a third of a meter in diameter. Two thousand pounds will blow a hole deep enough and big enough for any nuclear weapon that we have. So the weapon doesn't need to be hardened. This combination of conventional and nuclear will get it down to the point where one gets the full factor 20 enhancement of the yield. So if that's our purpose, we shouldn't be monkeying around designing new nuclear weapons. We ought to be putting into the inventory these shaped charges and having that capability now rather than five or ten years from now.

Let's not confuse this robust earth penetrator with the "agent-defeat" weapon

The agent-defeat weapon, another reason sometimes argued for testing, also has to go down through the ground, but its purpose is to explode so close to an underground facility that has biological weapons—anthrax is easier to say—or chemical weapons—sarin—that the radiation from the nuclear explosion will sterilize the anthrax or the heat from the explosion will denature either the biological or chemical warfare agent.

Good idea.

Then it is argued that by this means we may be able to destroy these agents totally without distributing them to the atmosphere. Bad estimate, because the radiation from a nuclear explosion goes only less than a meter in earth. The heat of course does not propagate very far but the strong shock has heating behind it which can denature material. Unfortunately, the shock that is that strong is also plenty strong enough to make a crater and throw out the material, much of it undisturbed, into the atmosphere. I've seen no calculation that shows any promise of doing what is advertised, namely destroying the BW or CW material without scattering undestroyed material into the atmosphere. (If such calculations are made, one still has the problem of getting a nuclear weapon within meters of the desired point underground, and of countering agents deployed not within a large spherical chamber but in a series of tunnels.)

I've discussed the comprehensive test ban treaty, that bans all nuclear test explosions. I have discussed the two weapon designs that are most touted as perhaps requiring testing, and also the lack of necessity of testing in order to maintain the U.S. nuclear weapon stockpile of existing type weapons. And I've shown you the devastating effect a small nuclear weapon has on one poor city.

Now what to do about these things? Well, we really should be able to do something about underground control centers, or factories, and Admiral Mies, recent head of the U.S. Strategic Command, has emphasized that we are not powerless. If we know the exits and entrances to such facilities, we can use non-nuclear weapons to destroy those and continue to keep them destroyed so that the facility, whatever it is, will lose its effectiveness.

So although the arguments in this country are how bad for us a comprehensive test ban treaty is, really the discussion should be that other people's nuclear weapons are bad for us, and in the spirit of the Cooperative Threat Reduction Program, even if we reduce our nuclear weapons some, our security would improve if we could thereby reduce other people's nuclear weapons and improve the command and control over them, and reduce the hair-trigger alert on which Russian nuclear weapons are maintained.

President Bush had good words in his speech of February 12, 2004, on the "Proliferation Security Initiative" but there's no money, and therefore nothing is likely to get done. I mentioned the restriction of the fuel cycle, and I alluded to U.S. power reactors for which we do not reprocess the fuel. The fuel goes once through the reactor for three or four years. It is then stored in swimming pools at the reactor site until some of the decay heat dies away, and then is put into steel casks and will eventually go into the Yucca Mountain Repository in Nevada to be entombed for geologic time. But other countries, notably France and Britain, do reprocess fuel, and Germany and Japan who don't reprocess have had laws at times requiring them to have their fuel reprocessed—the plutonium separated—and there are thus now many hundreds of tons of plutonium. Every ton will give at least 100 nuclear weapons, so there are tens of thousands of nascent nuclear weapons in this reactor grade plutonium.

There used to be a myth in the nuclear industry, still believed by many who haven't looked into the facts, that you couldn't make an effective nuclear weapon from reactor-grade plutonium. In a 1994 volume from the National Academy of Sciences we asserted that one could. We referred both to estimates and to a study classified Secret done for us that the problem with reactor-grade plutonium is largely the large neutron emission rate; no matter how large that is, an ordinary plutonium bomb would give an explosion yield of at least one or two kilotons, one or two thousand tons of high explosion yield, and people who know what they're doing can get a full yield from reactor-grade plutonium.

So what needs to be done with this plutonium, the stuff that in the French sites and in Britain are reasonably well secured? As for the plutonium and the uranium in Russia (as I have indicated and I'll show you a reference where you can read to your heart's dismay about this), some 40 percent of the sites have had no security upgrades under the Nunn-Lugar program.

One needs really to consolidate the plutonium and the highly enriched uranium at fewer sites. If I have \$100 billion in gold spread around the country at a thousand sites each with a \$100 million, the probability of theft of a million here, a million there would be much higher than if I have all of that gold in one place. And it's just that way with plutonium and enriched uranium. It's even worse with these fissionable materials because the plutonium is no longer valuable, it's no longer to be kept from the principal adversary; it goes against one's interests to spend money and effort guarding something one wishes one didn't have. Plutonium is a toxic waste, but a dangerous toxic waste that can be fashioned into powerful nuclear explosives. [SLIDE 14].

We need rapidly to provide security for this consolidated material_ with sufficient mechanisms enforced to prevent robbery, not by a few people who are amateurs but by teams equipped with powerful weapons and some of whom are willing to die, as is the case with terrorists these days.

We're not going to do this perfectly. There will be terrorist nuclear explosions in cities in the next few years. But we can reduce the numbers, we can delay the time.

We have to expand the systems for detecting smuggled highly enriched uranium and plutonium. This is not an easy task, because plutonium, although highly radioactive, is an alpha emitter; it does not emit much penetrating radiation and so it's hard to detect.

We need also to improve our intelligence systems, ranging from infiltrating terrorist groups to better techniques for detecting these materials in the shipping containers as they are transferred. We need to spend a lot more money. Compare the billion dollars a year for the Nunn-Lugar Cooperative Threat Reduction with the \$87 billion dollars appropriation a few months ago for a year of war in Iraq, which was impelled by the possibility of weapons of mass destruction. But these are real weapons of mass destruction that we're talking about here, and they're much more threatening to us than the ones that actually didn't exist in Iraq.

And finally, because we have to motivate the rest of the world to do a lot of things that are in their interests but they don't recognize it, and in our interest and we haven't recognized it very much, we need to make what will look to them like sacrifices but in fact are really in our national security interest. It will reduce our expenses, it will reduce the nuclear threat if we cut our U.S. nuclear weapon inventory from the 10,000 or so we have now (plus a lot more in the form of weapon-ready material), to a total of 2,000, and then sometime in the next few years to a thousand.

The Treaty of Moscow signed by the Bush administration with President Putin's administration, promises to reduce the operationally deployed strategic nuclear weapons by the year 2012 to about 2,000. That is the range from 1,700 to 2,200, and it is likely that ours will be reduced to 2,199_ an example of the hard-won experience that in arms control a ceiling becomes a floor.

So why would we be doing this? And how would we do this? We would do it by disassembling and committing the highly enriched uranium to some future use as low-enriched uranium, useless for nuclear weapons, for reactor fuel. We can't do that immediately. In 1992, we initiated a program to buy 500 tons of weapon uranium from Russia over 20 years for \$12 billion. That's profitable to us and the Russians make money out of it too, because even though some investment has been lost by blending down this highly enriched uranium, it still has a big value for use in reactors.

Plutonium cannot be blended down. It can be used to fuel reactors, but it costs more to make nuclear fuel for reactors from free plutonium than it does to pay somebody to find uranium, dig it out, purify it, enrich it and make fuel from it. So plutonium is a dead loss and the question is how we can minimize the cost of disposing of it and maximize the rate. We spent a lot of time and a lot of effort in discussion with the Russians about how we do this, but we need to have money and a coherent program to do this as rapidly as possible. The two best options are to provide the necessary subsidy to use the excess plutonium in power reactors at a rate of 0.3 tons or even one ton per year in suitable reactors, or to dispose of the excess plutonium by mixing it with the fission product waste created when separating the plutonium.

I hate to think that these measures to improve security will have higher priority after the first terrorist nuclear explosion in our city or a Russian city, but that would certainly have that impact.

I'll just comment that in order to demilitarize, we can quite readily render nuclear weapons useless as nuclear weapons, and we have been looking at how one can verify that nuclear weapons on the other side and the nuclear materials are all accounted for. This does not mean that they could not then be seized by the government and used again to make nuclear weapons, but one can introduce delays by distorting the material, separating it and keeping it under accounting control as well as some security control.

So there you are. The problem is to avoid Hiroshimas, to avoid cities being subject to nuclear attack in an era when it is totally incomprehensible that the Russians with their 18,000 nuclear weapons would use them intentionally against us or we against them. There is a bigger probability that a few nuclear weapons will be used without restraint, not for what we would regard as valid political or security goals but simply because some people want to kill other people in this world.

Thank you.

APPLAUSE.

CHAIR: . . . step up to the mike. INAUDIBLE.

QUESTION: You made mention of the Moscow Treaty, and I'm just wondering how valid you consider the treaty considering that it makes no mention of tactical weapons and that the terms of the Treaty enter into force on the day that the treaty expires.

GARWIN: The Treaty is in force now, but it doesn't have any requirement for reductions until December 31 of that year. You're absolutely right. It controls only operationally deployed strategic weapons. If you have more strategic weapons that you want to use sometime, well you operationally undeploy them, or you deploy them and state that they're nonoperational. I think it gives treaties and arms control a bad name, but the people who negotiated it on behalf of the

United States don't believe in arms control anyhow, did not want a treaty and state that they called it a treaty only because the Russians insisted on calling it a treaty. So it really has no impact.

Probably Russia, which cannot afford to maintain vast numbers of nuclear weapons, will choose means that are less are in our security interests and their own in order to make up the allowed number. They will put multiple reentry vehicles on their missiles, whereas our agreements thus far were to eliminate multiple warheads. It's a step backward and there's plenty of time to do something about it, by 2012. Even though the treaty expires after that, reason may prevail.

CHAIR: Dick, I have a question while others I hope come up to the mikes. You made a comment about a study that stated with reference to a classified document that reactor-grade plutonium could be used for a warhead, and I wonder if you could talk about the broader question which is something that comes up for us at CISAC regularly. I would say almost weekly it comes up in one discussion or another, which is how do you decide what to publish or what to say and what not to say? How do you decide where to draw the line between warning the public or the Congress about what's possible and that we need to protect ourselves against, versus providing hints or suggestions, if you will, to terrorists. And I know this is a topic you've been deeply embroiled in.

GARWIN: Well, first of all you have to follow the law so you can't reveal classified information. But also you have to make the judgment yourself, that things that are totally unclassified should not give people with destructive intent tools that they don't already have. You need to be reasonable, especially now with globalization of information, with the availability of the Internet, with a lot of people who may not be terrorists doing their work for them in providing information and suggestions. The bottom line is that you shouldn't keep from our Congress, our administration and the American people things that these other folks can readily find.

That's the distinction for me. If something is already knowable to ordinary people who search for it, then it's fair game for discussion if it serves a purpose of identifying a problem for which there is a solution.

Here [SLIDE 16] is the National Academy Comprehensive Test Ban Technical Issues volume from the summer of 2002 and here is the latest version of our Megawatts and Megatons: The Future of Nuclear Power and Nuclear Weapons—(it's the same book as 2001, this is the 2003 paperback)—by George Charpak and myself. The Academy report can be found and even downloaded in pdf format from www.nap.edu in a couple of clicks and then you can search it, read it, print it. My book you have to buy.

And here are other things that you can see helping to decide what one can say about nuclear weapons. [SLIDE 15] First, there is this volume available on the web, RDD-7, the seventh in a series Restricted Data: Declassification Decisions to show very specific times when a particular fact relating to nuclear weapons has

been declassified. And here are works by local talent, Mike May and Zachary Haldeman and by Jim Goodby and Sid Drell.

I mentioned to you the work at Harvard, Managing the Atom, and on the Nuclear Threat Initiative website which I didn't give here. It's www.nti.org. There's a document Preventing Nuclear Terrorism that tells you where we are in securing highly enriched uranium and plutonium.

I'm sorry. I didn't see Dean over there.

DEAN WILKENING: Dick, on one of your charts you showed reducing U.S. and Russian nuclear stockpiles, first to two thousand, then to one thousand down from current levels. I'm wondering if you could give us your thoughts on both political and technical prerequisites for going lower, and under what circumstances could we go lower than a thousand and how far would you recommend going? What would be the various stopping points, including possibly going all the way down the zero?

GARWIN: You can get pretty wide agreement that a thousand nuclear weapons in the U.S. inventory would be enough for any conceivable purpose. That is, to destroy all the cities on the other side, and to destroy a lot of weapons on the other side. We've had of course on alert many more than that, almost ten thousand nuclear weapons. I was for a time on the Advisory Group to the Joint Strategic Planning Staff, and although I don't know which weapons were assigned to which targets, I do know that many were assigned to leadership, down very far in the Soviet government. Lee Butler who was head of the Strategic Command and head of the Strategic Air Command before that, noted that not only would their offices be targeted but their homes, their dachas, and whatnot.

Other retired officers who had been the vice directors of the Joint Strategic Planning Staff that actually determines the targeting for the weapons, have said that their captains and majors did yeoman work finding targets for all of these new weapons as they were deployed. It wasn't easy but they found them, because there is always something less valuable to destroy.

I would ask, "why are you targeting missile silos on the other side? By the time our weapons could get there, those missiles would already have been launched." But they would say that you can't be sure that they would already have launched them, there's some possibility, and so we need enough weapons to destroy those sites.

In an earlier report, our National Academy group looked at the future of the U.S. and Soviet nuclear weapon forces, and we looked at more reasonable targeting. If you're destroying silos, well, we would plan to send two or sometimes three weapons against them to compensate for unreliability, but most of the unreliability is in the launch phase and you know within a couple of minutes that the weapon did not go to its target. So instead of sending two or three in every case, you could send one, and then if it didn't launch properly, send a

second. That would reduce the force requirement by a factor of 2 or so. So in that way, get down to a thousand without much controversy.

Another argument for large numbers is that the other people have fewer and that if we reduce to a thousand, maybe the French or the British or the Chinese would have three hundred and we would be in their league again, instead of having a hundred times as many as they.

But it isn't the large numbers ratio of our weapons to their weapons that contributes to our security. It's the small numbers of their weapons, and so reducing our useless large numbers would be valuable if we can get other States to reduce their numbers and take better care of them. So we would need to have agreement with the Russians and with the other countries who for the most part are already reducing their numbers. The British have only their submarine-based weapons left, and the French as well. It is not clear how many weapons the Chinese have, but it's certainly not a thousand. Then you have Israeli undeclared weapons, you have dozens of weapons in India and Pakistan, and I don't think they want large numbers of weapons either; but they need to have a model, there needs to be a convergence.

I can't see getting rid of all nuclear weapons. I can see ultimately having some nuclear weapons that are passed around so that they clearly don't benefit just U.S. security but other folks' security, or with less levity are jointly managed.

I don't need to worry about that yet. I want to get rid of most of the hazard by going to much lower numbers.

QUESTION: The national labs right now-- Los Alamos and Livermore-- are working on modifications to the B-61 and B-83 under the Robust Nuclear Penetrator Program. You talked about large precursor shaped charges as one of the answers for the bunker problem. Do you see that as being part of that program or do you envision some other program?

GARWIN: It's not part of that program. It's a non-nuclear adjunct. The interaction with nuclear weapons would be that as this package goes down together, you would want to make sure that the nuclear weapon itself is not disabled by the high explosion going off in its neighborhood. But that doesn't require a nuclear test. You start with inert nuclear weapons and you perfect your technique there, and then eventually you'll use a real nuclear weapon, but it doesn't have to be tested, just needs to be disassembled afterwards.

I didn't mention the role of nuclear testing in ensuring reliability. Suppose you test a nuclear weapon. First of all, you are testing it underground, and there's a significant difference between underground testing and atmospheric testing. Furthermore, you test it with other facilities than those in the deployed weapon. You often don't use the neutron source that you have in the weapon itself, you don't use the arming and fusing.

After you've tested it, even if it were precisely the same as the other nuclear weapons in the inventory, all you know is that particular one worked. You don't know that the other ones will work. So you have to have a lot of non-nuclear knowledge of comparison to know that the one you tested was either representative or it was less likely to work, and the evidence that it worked, that means that the others are more likely to work. So nuclear explosion testing really tells you very little that you don't learn from the non-nuclear inspection and remanufacture if necessary.

So, no, this is not in that program. There ought to be an alternative program. It could be done at Sandia. It's one of those things that doesn't fit very well in the system.

QUESTION: Do you care to make any comments about how our thinking might change with the revelations about A. Q. Kahn and developments in North Korea?

GARWIN: Well, in 1998, I spent six months of time as a member of the nine-person Rumsfeld Commission to Assess the Ballistic Missile Threat to the United States (you can find the unclassified executive summary on my website). We judged first that any of the three so-called rogue states—Iraq, Iran or North Korea—could, if they had enough money and foreign help and put the priority high enough, develop and deploy a few inaccurate, unreliable, long-range missiles that could carry a biological weapon payload, and if they had a light enough nuclear weapon, could carry a nuclear payload against the United States.

But we also judged, and this was in line with our charter, we also judged that any of those states could much sooner, more reliably and accurately, deliver any of those payloads, even heavier ones, from short-range missiles, either ballistic missiles or cruise missiles, from ships or aircraft near U.S. shores.

There is a big difference between the U.S.-Soviet confrontation where in the Reagan era, Secretary of Defense Casper Weinberger in commenting on the national security strategy, said that our security depended upon our ability to have fewer Soviet citizens surviving than Americans. We discussed whether five Americans survived and only two Soviets, whether we would have won, and yes, according to that criteria. There are now other threats and we judged also that these proliferant countries were pretty much self-sufficient, even in 1998, that North Korea was supplying missiles to Pakistan, who tested their Ghauri missile of 1300-kilometer range, which was a North Korean No-Dong missile with a new coat of paint. North Korea was a supplier of missiles not only to Pakistan but also to the rest of the world, to anybody who would pay, and North Korea has been very frank that that's the only way they can earn money abroad. They would probably sell plutonium too if there were a market for it and they could get away with it.

What Pakistan used to pay for these missiles is not clear. They may have used money. They may have used nuclear expertise. But it was quite shocking to learn from Libya in December that A. Q. Kahn who had stolen the European

centrifuge design when he was working in Europe and brought it back to Pakistan, was personally (according to the Pakistani government at least) a one-man proliferation show, and that he had shipped centrifuges, centrifuge designs and nuclear weapon designs to Libya. Now why would he do that to Libya and not in his 18 visits to North Korea have done the same to North Korea? So there a lot of information which I hope is being obtained by private conversations with Dr. Kahn who has confessed doing these things but has given no details publicly, and there's a lot that could be done if we would have the details from him.

So it is a problem, a bigger problem, though, even than one rogue person.

SIDE THREE:

Even easier than an indigenous enrichment program is to use highly enriched uranium metal from stockpiles in Russia.

QUESTION: Do you think a terrorist small nuclear attack on an American city would result in a chain reaction, a major nuclear war?

GARWIN: Well, that's a terrible problem, and it could. There was discussion over the years of "catalytic war," that is of two sides, the United States and the Soviet Union, armed with thousands of nuclear weapons and one might go off and be misattributed and then another would be launched-- not the entire force, why would you do that? But then it would certainly be a U.S. weapon landing in the Soviet Union, and what they would do as a result was not at all clear. You would hope they would do nothing—that they would communicate quickly-- but people are not always like that.

Now, if it were in India and Pakistan, until a few months ago they had armed conflict and who knows what would have happened there. You need to develop the kind of "wisdom" that we had with our nuclear weapons. Proliferant countries might have difficulty arriving at that state of wisdom; but of course I'm being sardonic about this. It was a low kind of wisdom, a tactical kind of wisdom which did not extend to limiting greatly the numbers of nuclear weapons that we acquired, and to reducing the apparent threat to the Soviet Union so as to reduce the real threat to us posed by their hair-trigger posture of launch on warning.

QUESTION: Good evening. What do you believe must happen, either in the world or in the U.S., before we will make a strong commitment to a comprehensive test ban treaty? What needs to change in the political dynamics and what do you think could bring about this change?

GARWIN: Well, you can do a lot by just thinking, and if we could get people to think of their own security interests, I believe we would have a comprehensive test ban treaty. But there are many clever people who are debaters or lawyers who will espouse a cause and do their best for it, rather than try their best to ask what are the benefits on both sides and to make a judgment. It would help if our Congress had more time for its work rather than running for reelection, if

they took seriously the job of running the country. The job is very difficult, even if you would spend full time at it with the best people. Administrations, too, need to have good people in their positions. They need to identify the big problems rather than work on the fringes. So I don't have a lot of confidence that this will change.

A good many of us have been trying our best for 40 years or more to help solve these problems, and at times people are more aware of the problems. You can't solve the problems unless people are aware. Sometimes they are more aware of them, sometimes they take destructive responses. It's like an alcoholic to whom the answer to any problem is another drink, and in this case, the answer to any security problem for years, even in administrations that were rather friendly to arms control, was to build more nuclear weapons—as if it couldn't hurt.

QUESTION: I'd like to, if you will, talk just a little bit more about the Nunn-Lugar particular legislation, and clearly you made the point that probably one of the largest risks, maybe the greatest risk right now, is the fact that there are literally hundreds, maybe thousands or more, ten thousands of these weapons scattered in many different locales and not particularly secure and therefore subject, at least to the possibility of terrorists having access to them. Why is that not so well understood, as you've explained it-- I'm sure many of you have explained it-- at highest level of policy in the U.S. government, but that is not receiving a higher priority and greater amount of financial support, because that does seem to me to be the possibility of leading toward what you mentioned, a possibility of a nuclear explosion in an American city.

GARWIN: Politicians don't like to identify problems without solutions. It isn't good for votes and they can't see any benefit in scaring people. This problem has no immediate solution. You're absolutely right. General John Shalikashvili's name is on the door of the office next to my temporary office in CISAC here, and he's a person who really understands this problem, has worked on it during his years of active duty and afterwards, and has a good deal of entree and influence. A few years ago there was a commission which looked at the problem and said we should be spending \$5 billion, \$30 billion, \$50 billion over a number of years to address this problem. Specifically, the "Russia Task Force", co-chaired by Howard Baker and Lloyd Cutler, "A Report Card on the Department of Energy's Nonproliferation Programs with Russia" of January 10, 2001, recommended an expenditure of about \$30 billion over eight to ten years.

But it is really hard, first to get people to understand how serious the problem is. Then if you don't promise to solve it absolutely, relatively few people understand that it's worth a partial solution. That is, if we have a million people, ten million people dying each year on the average from this threat, how much better it would be to have 100,000 people only dying. Reducing the threat, making things better doesn't get a lot of support, even though it may be all we can do in this regard.

We may need, as I say, one of these disasters, which would not be the end of the world unless we make it so, and we could.

Suppose 100,000 people were killed in a terrorist nuclear explosion. Well, we have 300 million people. That's one in 3,000 people; from the point of view of the economy and even among friends, few of us would know one of those. But the response is likely to be, to suddenly recognize the problem, which should have been recognized before, to shut down the system of international trade, to introduce martial law not only here but elsewhere, and it's not clear how the country would recover from such self-generated wounds in response to such a stimulus.

QUESTION: Just a very quick follow-up. It seems to me when you consider the enormous trauma that this country went through when 3,000 people died in the World Trade Center and you're talking about maybe requiring a hundred thousand to be sacrificed in order to have this become a central issue, that's kind of a very pessimistic outlook.

GARWIN: You're right.

QUESTION: Dr. Garwin, I was wondering what your thoughts were on how we could secure our national laboratories like Los Alamos in general and specifically from elements such as espionage like that, which prompted the Cox Report, and the best way to do so while maintaining scientific integrity?

GARWIN: Well, I'm not in favor of people spying against us, but a fact of life is that spying goes on, and the United States is quite good at it. I wish we were better at it. But you cannot on the one hand say that the United States should spy either by the usual underhanded means, trying to get citizens of other countries to give us information that they've sworn not to give us, or to penetrate their systems technically, and throw up your hands to say it's immoral for other people to spy on us. We should do our best to catch them.

On the other hand, you have to maintain some proper judgment as to what would be lost, and there are different amounts of value associated with information. Spying for the most part is getting information. And in my opinion, Wen Ho Lee did very bad things, whether as a spy or not or just foolish, I don't know. But if the Chinese had all that information from our weapon laboratories, it would not have changed the Chinese nuclear capability very much. They have perfectly good nuclear weapons. It might have helped them. Not the actual designs-- I doubt that they could build those designs-- but it might have helped them to have some principles that they could use for their future generation of nuclear weapons. I haven't noticed a lack of brains among our Chinese friends, and I think they probably have enough of these ideas of their own.

As for countering spying, do things that are reasonable to keep it from happening, but don't destroy the laboratories and keep them from working in order to preserve information that is available to the other side already, or that won't help them very much.

The problem (of hobbling our own efforts) is not only in the weapon laboratories. I worked for IBM for 40 years and there are many restrictions that the government imposes routinely on participation at scientific meetings, letting people into the country here, allowing foreign graduate students in our universities to attend certain meetings or classes, even though these sessions are totally unclassified. This sort of thing keeps information from getting to our industry without significantly limiting its availability to foreign countries. There are big problems and lots more to be said about it, but not here.

QUESTION: What's your opinion of peaceful nuclear explosions, perhaps elaborating the different kinds and what you think their uses and uselessnesses might be?

GARWIN: Well, we've studied peaceful nuclear explosions and we don't have the last word. People may have new ideas. I participated in a 1974 study for the Arms Control Agency and looked at all of the U.S. program. Some of it was stimulation of natural gas production. The problem is that the gas then has tritium in it and that reduces its value.

I looked at Project Pacer, an idea to supplant nuclear power plants. Instead of using a reactor with its finely machined components to produce heat, you could explode two 100-kiloton bombs each day in a large underground cavity filled with steam. The cavity would have to be reused for 10 years, so that's an awful lot of bombs, 7,000 explosions. You can imagine doing the quality control on that; but it turns out if you align the cost of the plant side by side, it doesn't have any potential benefit over building a reactor and getting the heat out.

The Russians, for instance-- Soviets in those days-- built an almost totally thermonuclear explosive, which had modular secondaries. You could add as many thirty-kiloton units as you wanted and the fission yield was only, as I recall, about 300 tons. So almost free of fission products. They were going to use that for breaking rock in a very clever fashion.

Seismic sounding was an application they used, but we do it differently. This is something that they missed, that you can use signal processing and coherent thumping on the ground over a long time, months, in order to have the equivalent of a nuclear explosion for deep seismic sounding.

We haven't found anything which would repay the effort in peaceful nuclear explosions. Earth moving is another approach, and in fact, in 1994, 1995, the Chinese were ready to sign the comprehensive test ban treaty if there were an exemption for peaceful nuclear explosions. The treaty as it actually is signed, says that PNEs can be brought back in ten years, really by unanimity. If the world's population judged that (or the population of the United Nations judged) that this were desirable, we could have peaceful nuclear explosions.

The United States had Project Orion, some of my best friends worked on that, in which hundreds of small thermonuclear explosions would drive a rocket, not from the surface of the earth but from space. It would propel the rocket by the

impulse of the material against the pusher plate. A lot of wonderful things can be imagined, but when you have all those nuclear explosions, it's just too easy to have any one of them go astray.

If one used two 100-kiloton nuclear explosives a day to replace each existing U.S. nuclear power plant, that would be 200 a day so 70,000 a year in the United States. Any one of those would destroy a city. Do we really want that when there seems to be no economic benefit?

QUESTION: Well, there's the asteroid possibility. Deflecting asteroids.

GARWIN: Deflecting asteroids. Well, that kind of thing can be brought back by popular demand.

QUESTION: Well, I suppose the demand would be rather popular, but you wouldn't have studied it in advance, which might be desirable if you want to actually be sure.

GARWIN: It is possible that a nuclear explosion could deflect an asteroid. It's probably going to shatter it, which may or may not be good. It's not something where you would do a specific test because the asteroids are different, one from the other, and so it really depends on analysis, and yes, we can and should analyze that. We might have a year or a few years of warning, but we could be ready to do that. That would not be a PNE; that would be a concerted effort on the part of the world, and I think you could probably get agreement in the Security Council to do it, despite the existence of a treaty.

QUESTION: Well, is agreement in the Security Council all that would be required?

GARWIN: No, you need to have the technical ability to do it, and it's not only the nuclear explosive. It's the rocket capability.

QUESTION: Yes, I take it from your talk that you think that if a nuclear weapon goes off in the United States, it's much more likely to be the result of terrorism or some other covert form of delivery, rather than an ICBM being lobbed over from someplace like North Korea. And if that's true, I wonder what you think the future of national missile defense is, and what your opinion on that might be. Thank you.

GARWIN: Yes, you can go to this site, www.fas.org/RLG, here and you will find many of my papers on national missile defense. In short, first the Rumsfeld Commission that looked at the ballistic missile threat did not have a word to say about defense. It was misquoted in the news, misrepresented in the newspapers. We didn't discuss defense. We didn't say anything about defense. When Mr. Rumsfeld and I appeared July 15, 1998 on the Lehrer program, or maybe the McNeill-Lehrer program, after hearing our views on the missile threat, of course they wanted to know what that meant for missile defense, and Don Rumsfeld said, well, he hadn't studied it but he would have to get his mind

around it the way he had the missile threat. I said I'd studied it and what was being proposed for deployment wouldn't work because it was mid-course defense where putting the warhead in a spherical balloon and having balloon decoys would defeat that system predictably. So I proposed in 1999 and since then, boost-phase intercept using ground-based interceptors which would work against North Korea, and with difficulty against Iran because Iran is such a big country.

I still believe that the Missile Defense Agency should have run with that. An American Physical Society report of summer 2003, assumed that it would take ten years to have such a boost-phase defense. We ought to do what we could in four years. That would have both some effectiveness and also a deterrent capability that might even keep North Korea from building long-range missiles, which are going to be destroyed before they're launched anyhow, so it's not a good thing for them to do. So I don't worry about attack on the United States by ballistic missiles from other states. I believe they can be deterred. We have to make it clear to them that we're not just going to stand by and destroy those missiles in flight we can shoot down without attacking both the missiles before they are launched and the countries afterwards.

CHAIR: Dick, I believe we have three individuals still waiting to ask questions. I'd like to ask all three of them to ask very brief succinct questions and then you can pick which you'd like to reply to.

QUESTION: Your talks and/or all of the questions so far have been about the weapons side. The first word in the title of your book, "megawatts", and a theme in another book that I just received from a friend called Out of Gas talks about running out of energy domestically and the likelihood of the return of nuclear as a much larger share of domestic energy supply. My very brief question I hope would be your answer would be do you personally, is it possible in the next ten or twenty years that we might develop technology for cleaning up the radiation of nuclear energy production so that it might become a more reasonable part of domestic supply?

QUESTION: Could you explain what the significance of the CTBT for the nonproliferation regime given that it's still possible to develop nuclear weapons without testing them?

QUESTION: My question is would you expand however briefly you wish on the technical feasibility of terrorists actually detonating a nuclear device, having to get the material, handle the material, deliver the material and actually exploding it without themselves being the victims. Thank you.

GARWIN: I'll take the last one first. I'll take all of those. Many terrorists don't care any more whether they get away. That's the big problem. Furthermore, there is a global economy. It isn't as if I need to go to Russia, make myself up like a Russian, steal some stuff, bring it out through the borders, transport it over here, assemble it and detonate it. No. There's money, and the money lubricates the theft or maybe even the person in charge of a facility to provide the material.

Then there are middle people, they help to transport it elsewhere. The person who has to detonate it and maybe blow themselves up because a timer might be unreliable, isn't the same one who provides the instructions for how to do it. And unfortunately, highly enriched uranium with a gun-type assembly that does not need to be dropped from an airplane is all too easy to do.

Now, in answer to can we clean up the radiation, no. One can with great difficulty burn up some of the radioactive materials but you have other radioactive materials. I'm in favor of nuclear power and can conceive of ten thousand nuclear reactors in the United States, but we will get rid of the waste by putting it back in the ground. Eventually it's no more radioactive than the uranium from which we fuel the reactors-- eventually, a hundred thousand years or so. That's not a long time on a geologic scale and what you put under does not come up every place. It may come up one place, so that's good enough.

There has to be a liberalization of the treatment of radioactive waste. It should to be certified by the International Atomic Energy Agency, there should be competitive, mined geologic repositories where people make money by accepting waste from others, but those have to satisfy standards too. And there should be international security backups to the local commercial teams so that if some bandit wants to set up a mining operation to ship off all this stuff for reprocessing, it's not just the contractor who opposes them.

And finally, "what will CTBT do for nonproliferation because you can build nuclear weapons without testing?" Well, absolutely you can. I talked about the gun type; also knowing that the implosion weapon that we used on Nagasaki worked, you certainly don't need nuclear testing to make a similar one. It would be pretty big, but it could be made smaller even without testing. Nevertheless, a comprehensive test ban treaty has a totally different purpose: Nonproliferation. Not because it keeps people from knowing how to build primitive weapons but because it keeps people in the nonproliferation treaty, where they agree-- and they instruct their citizens and their industry-- not to build weapons because it's a commitment on the part of the nation.

How does that work? It works because of the bargain that the nuclear weapon powers are supposed to limit and reduce (and eventually eliminate but that can take a long time) their own nuclear weapon stocks and to give access to peaceful nuclear technology, not nuclear weapons, for industry, medicine, and whatnot, to those who are signatories to the nonproliferation treaty without nuclear weapons. It's really important to keep people in the NPT. If they are members in good standing and truly complying with the nonproliferation treaty, the comprehensive test ban treaty doesn't add anything. It adds restraints only to those people who are nuclear weapons states, and it adds a moral position for people to take action against those nonmembers of the NPT who test. The United States needs to be a member in good faith of the Nonproliferation Treaty, even if we have nuclear weapons, in order that these other folks see it in their interest and don't generate resentment.

As part of my talk I intended to explain that in 1974 and 1975 NASA launched two satellites for the French and Germans, the Symphonie satellites, because the Europeans were having troubles with their launchers. But NASA put a condition that the satellites not be used for commercial purposes because they would then compete with the commercial launches that NASA had already conducted. This made the Europeans so angry that they went on to develop the European Space Launch Organization and the Ariane boosters which compete with U.S. launches in the commercial field, and are very good technically and very good commercial competitors.

It's said that nations don't have friends, they just have interests. But they also have resentments, just like people. It's better not to stimulate those resentments. Thank you.

APPLAUSE.

CHAIR: I'd like to thank Dick Garwin not only for this evening's fascinating lecture and all of this time in discussion, but also for spending several days with us here at CISAC. He's already spent time with one of our undergraduate classes and will spend more time in the coming days with undergraduates and graduate students, so Dick, thank you very much. That's very much in keeping with the purpose of the Drell Lecture. Thank you for joining us.

GARWIN: It's a pleasure.

APPLAUSE.