Nonproliferation of Nuclear Weapons—recent work of the World Lab and the World Federation of Scientists

Presentation by Richard L. Garwin (www.fas.org/RLG/)
at the Pontifical Academy of Sciences
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Since the dawn of the age of nuclear weapons in 1945, the prospect of their further use has often been a matter of great concern. With the acquisition of nuclear weapons by the Soviet Union in 1949, followed by Britain, France, and China, the attention of the international community was turned toward an effort to keep the acquisition of nuclear weapons from being a routine matter to be pursued for national security of any country.

In particular, the scientists in the United States who built the first nuclear weapons at Los Alamos and Chicago were concerned with the consequences if nations as a matter of course acquired nuclear weapons. In many cases, neighbors have long-standing conflicts which might result in the use of nuclear weapons, one against the other. Some governments are unstable and subject to military coups; the weapons would fall into the hands of the military.

It was fortunate that the United States and the Soviet Union, despite their deeply felt and professed enmity did not have a common border. They did have surrogate borders in Europe, and a struggle abroad for sympathy and support not only for the nations but for their ideological position. Much effort on both sides was expended on preparations for nuclear war—both offense and defense—and ultimately on prevention of nuclear attack-- deterrence by assured nuclear retaliation that would have physically eliminated most of the population and industry of the two states, but would have caused a billion or more deaths in the rest of the world.

As this audience knows well, President Eisenhower took the lead in the 1950s in his advocacy of "Atoms for Peace," by which he instituted the complete sharing of nuclear knowledge for civil purposes, such as medicine, industrial applications, and nuclear power.

The 1970 Nonproliferation Treaty (NPT) made this explicit in dividing the world into nuclear weapon states (NWS) and non-nuclear weapon states (NNWS). Those states joining the treaty in the NNWS category would be entitled to information and support from the NWS to develop peaceful uses of nuclear energy and to share in what had already been developed.

Implementation of the NPT as a multi-lateral treaty signed by essentially all nations except Israel, India, and Pakistan was substantially aided by the creation of the International Atomic Energy Agency—IAEA—with the dual roles of supporting the transfer of peaceful nuclear technology and of monitoring peaceful nuclear technology to ensure that it was not diverted to military purposes.

The IAEA is not a police force. It reports to the member nations, who on occasion may take an adverse report to the Security Council for action. The key principle underlying the inspections by IAEA is that of "timely warning," so that in principle any abnormal action in the declared peaceful activity would be caught in time for the other member states and the United Nations counter the violation of a state's undertaking under the NPT before it could result in a substantial nuclear weapons capability.

All nuclear weapons include a fission bomb, in which the naturally occurring rare isotope of uranium (U-235) or the artificial material plutonium-239 (Pu-239) are used to propagate the neutron chain reaction.

A neutron that causes fission in a heavy nucleus such as U-235 or Pu-239 gives rise not only to two "fission fragments" the sum of whose masses almost equals that of the initial nucleus, but also to 2 or 3 neutrons. The explosive energy yield comes from the 150 million electron volts (MeV) or so of kinetic energy associated with the Coulomb repulsion of the fission fragments. With a small amount of fissionable material, it is unlikely that one of the fission neutrons will again cause fission before it leaves the mass, since the mean-free path of a neutron in uranium or plutonium metal is on the order of 7 cm.

But in a large enough quantity of fissionable material (that is, material in which a neutron of fission energy can cause the process), most of the neutrons will indeed collide before leaving.

The abundant (99.3%) isotope of natural uranium—U-238—is fissionable, but with hardly any probability below 1 MeV, and even though the mean energy of a fission neutron is about 2 MeV, it is not possible to make a nuclear explosive with pure U-238. The fission process competes with another process—inelastic scattering—that rapidly lowers the energy of the fission neutron below the threshold for fission.

But U-235 and Pu-239 are not only fissionable but also “fissile,” in that a neutron of the lowest energy (even thermal energy of 0.025 eV) will cause fission with high probability.

This was known from the earliest days of nuclear energy, and uranium highly enriched in U-235—HEU—was used for the bomb that destroyed Hiroshima with an energy output of about 13 kilotons (thousands of tons of high explosive equivalent). The bomb that destroyed Nagasaki contained about 6 kg of Pu-239 in an implosion system. So uncertain were these scientists at Los Alamos that they tested the Nagasaki weapon at the Trinity site in New Mexico three weeks before it was used against Nagasaki. The results were identical.

In their bomb-droppable form, the U-235 gun-assembly bomb and the Pu-239 implosion-assembly weapon each weighed about 4 tons.

Enormous plants at Oak Ridge, Tennessee, had been built to enrich uranium. And within two years after Fermi’s first nuclear chain reaction in a graphite "pile" with a steady power of about 2 watts at the University of Chicago, a reactor of a similar type, but with cooling from the Columbia River, was operating at Hanford in Washington State of the Pacific Northwest, at a level of about 250 megawatts of thermal power (MWt). Since such a reactor produces about one gram of Pu-239 per day per MWt, Hanford was producing some 6 kg of Pu-239 each month.

For a long time it was generally regarded that any state wishing to acquire nuclear weapons would need a program and an investment of comparable size. With the advent of nuclear power, however, both enrichment and plutonium generation became commonplace and almost unavoidable on an enormous scale. Plutonium separation, though, was optional.

Although that the Hanford reactor might have been used to produce a small amount of electricity, the large size of the reactor would have made this difficult, and there was no shortage of electric power in the state of Washington. The Soviets did use such reactors for the joint production of plutonium, electric power, such as those at Chernobyl, although they used slightly enriched uranium, on the order of 2% U-235 instead of the naturally occurring 0.7% material.

To this day, Canada makes and sells competitive heavy water reactors—CANDU—that use natural uranium, needing no enrichment in the fabrication of the fuel bars. But most of the world's 400+ power reactors are light-water reactors using fuel containing 4-5% of U-235. This is enough to compensate the absorption of neutrons by the protons in ordinary water, and to create a compact reactor that typically operates at about 3000 MWt, in producing 1000 megawatts of electricity (MWe).

The scale of the world's enterprise is staggering by comparison with the early efforts of the United States. Each full-size reactor consumes about one ton of U-235 per year, and the enrichment to 4.4% takes about 65% as much "separative work" as does the enrichment to 95% that would be ideal for nuclear weapons. Thus, the enrichment plants for the 300 tons per year of U-235 that goes into the world's nuclear energy production could, if diverted to HEU, produce about 195 tons of HEU annually. The Hiroshima gun-assembly bomb used about 60 kg of HEU, so the world's enrichment plants could provide about 3200 Hiroshima guns per year. A more efficient use of HEU, although more difficult to accomplish, is to use it in an implosion system, as did the Chinese with their earliest nuclear weapons. About 20 kg of HEU is taken to suffice for such an approach, so that the world enrichment capacity could produce about 10,000 implosion-type uranium weapons per year.

In the light-water power reactors, for reasons of efficiency, the fuel is left in the reactor typically for four years, and much of the Pu-239 that is formed from the U-238 in the reactor capturing a neutron is consumed because of the high thermal fission cross section of Pu-239. About 130 kg per year of Pu-239 is contained in the spent fuel of a light-water reactor, compared with the one ton of U-235 consumed to make it.

Comparing implosion weapons for the two materials, a single reactor consumes LEU from an enrichment facility that could have made HEU for about 32 nuclear weapons per year, and it produces Pu-239 that suffices to make about 130/6 = 22 nuclear weapons per year.

Most of the world's power plants do not process their spent fuel for separation of the Pu, but all of the 59 plants in France do so, and Japan has been committed to having spent fuel from its 54 reactors reprocessed so that the plutonium is separated and can be used again as fuel in these same reactors. This is mixed-oxide ceramic—MOX--made of the recycled plutonium, and some of the uranium left in the fuel when it is downloaded. Full utilization of the plutonium as MOX in LWRs would save about 20% of the uranium fuel of the once-through cycle.

HEU or for that matter the mildly enriched uranium—low-enriched uranium or LEU—is valuable, and there is a world price for HEU sold by Russia to the

United States in blended form to be used as 4-5% LEU in power reactors. The price is about $24,000 per kg.

In contrast, excess weapon plutonium from the surplus nuclear weapons in the United States or Russia calls forth no legitimate buyers for use in reactors. It simply is more costly to take free plutonium and to fabricate it with natural or depleted uranium into mixed-oxide ceramic fuel—MOX—than to use virgin uranium, paying the cost of mining, converting to uranium hexafluoride—UF6—for the enrichment process, and then fabricating it into the ceramic fuel. Over the decades, the energy intensive gaseous diffusion process used by the United States (and France) has been largely replaced by a gas centrifuge approach that uses only about 2% as much power. Furthermore, the centrifuges are far easier to make and operate, as is clear from the activity in Iran and the major proliferation effort impact of the Pakistani scientist A.Q. Khan, who working as an international civil servant stole the centrifuge design for his own country.

In general, the "secret of the bomb" has been greatly eroded because of the official and unofficial release of information and the transfer of technology such as by A.Q. Khan and also by governments in pursuit of commercial deals and political influence.

Details of the design and construction of bombs of the highest performance are still closely held, but unfortunately, even a Hiroshima or Nagasaki type bomb cause the same destruction as in 1945.

In limiting proliferation among states, the target audience was relatively small, and one knew where to find them. Furthermore, the nonproliferation problem, initially met by denial of access to information, transformed itself over the decades with the advent of the enormous nuclear power sector to the denial of access to the necessary fissile materials. But there was always a big loophole in the NPT. A state could join as an NNWS, acquire reactors, LEU, and the like, as well as a stockpile of spent fuel and even separated plutonium oxide (ostensibly to make MOX fuel), and then give three months notice to opt out of the NPT. This was entirely legitimate, and this approach has been chosen by North Korea, explicitly expelling the IAEA inspectors, opting out of the NPT, and apparently reprocessing spent fuel from its 25 MWt graphite reactor to acquire plutonium for perhaps 4-6 more implosion weapons than it had probably built by the mid-1990s. North Korea conducted its first nuclear explosion test underground in October, 2006.

Iran is potentially another similar case, but on a much larger scale. Iran insists that it has the right to the full civil nuclear power fuel cycle, and has a light-water power reactor at Bushehr, built by German firms and recently completed by Russian ones. In order to fuel this reactor Iran would have to provide about 200 tons of uranium per year, convert it into UF6, enrich it in centrifuges, reconvert the UF6 to oxide, and make precision fuel elements from the oxide ceramic material housed in stainless steel or zirconium alloy sheaths. For the enrichment, Iran has long planned a centrifuge hall at Natanz to house some 50,000 centrifuges that would just barely keep up with the needs of the Bushehr reactor. But as we have seen, such a facility that produces one ton per year of LEU could produce 650 kg of HEU—enough for 11 gun-type or 32 implosion-type uranium nuclear weapons.

Iran claims that its facilities are all for the civil sector, and the supreme religious leader proclaims that the possession of nuclear weapons is contrary to the Muslim faith. But others of the same faith do not seem to have similar reluctance.

The Ettore Majorana Foundation and Center for Scientific Culture, founded by Prof. Zichichi, and now the World Laboratory and the World Federation of Scientists, in 1981 began a major effort to reduce the hazard of use of nuclear weapons—initially by a series of summer sessions on prevention of nuclear war—especially that between the United States and the Soviet Union, holders of 99% of the world's nuclear weapons at that time. This effort convened scientists who had been major contributors to the nuclear weapons programs, including Edward Teller, Eugene Wigner and Paul Dirac, as well as current and recent directors of nuclear weapon laboratories and some who had spent many years in and out of government attempting to prevent the outbreak of nuclear war.

The sessions at Erice involved substantive and sometimes heated discussions, and with other activities that brought the two sides into contact helped to control the bilateral nuclear weapon threat until the Gorbachev era and the dissolution of the Soviet Union reduced the hazard of mutual annihilation. The nuclear-weapon professionals in the Russian government and military did an outstanding job in bringing to Russia all strategic and tactical nuclear warheads and bombs that had been deployed in other parts of the former Soviet Union, but it has not been a matter of highest priority to dismantle the enormous excess of nuclear weapons in Russia and in the United States, nor to consolidate and protect weapon-usable stores of plutonium and HEU.

Although the prospect of world-scale nuclear annihilation faded, the likelihood of use of a few nuclear weapons has probably risen, because of the new threat of nuclear terrorism. Thirty years ago, experts on terrorism would explain that the terrorists' purpose was not to kill people but to gain support for their political cause. There have always been assassinations of political leaders, sometimes by suicide bombers, but the advent of mass murder, with explosives the weapon of choice, is a recent phenomenon. And the availability of willing suicide bombers gives new flexibility and power to those who use such tools. Instead of seeking to gain attention and political support, "terrorists" can directly influence the actions of people and government by punishment, as is evident in Iraq.

In the context of nuclear terrorism, scientists at Erice in 2005 contributed the following document:

«ETTORE MAJORANA» FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

ERICE INTERNATIONAL SEMINARS ON PLANETARY EMERGENCIES

33rd Session

PERMANENT MONITORING PANEL ON TERRORISM (PMPT)
THIRD MEETING
Erice, 05-08 May 2005

FINAL REPORT

Recommendations of the Nuclear Aspects Group

The following recommendations assume that the needed economic support and incentives will be provided for their implementation. A serious analysis of the costs of nuclear material safeguards vs. the cost of blending down HEU must be conducted, together with the cost of an enhanced regime for international inspection and enforcement. Research and development programs should be undertaken to reduce such ongoing costs, at the same time that investments are made in current approaches. Weapon numbers must be reduced in order to prevent their use and to guard against theft, but the weapon-usable material must be consolidated in a few well-secured locations.

Our recommendations support and complement those of IAEA Director-General ElBaradei, presented to the 2005 NPT Review Conference.

R1. The civil nuclear power fuel cycle should be consolidated and placed under international monitoring conducted by the IAEA. Assured fuel supply and take back should be the norm.

R2. Accelerated blend-down of HEU should be undertaken, including the use of economic incentives to various parties to register, consolidate, and reduce stocks of weapon-usable HEU worldwide.

R3. IAEA inspection and enforcement mechanisms should be strengthened and supported financially

R4. States possessing nuclear weapons should commit themselves never to use nuclear weapons against states without nuclear weapons, and not to use nuclear weapons first

R5. Negotiations between Russia and the US should be re-initiated for early and serious reductions of nuclear weapon holdings—not just of "operationally deployed strategic weapons." The resulting treaty structure should be open to other states for the reduction of their weapon stocks, whether they are NWS Party to the NPT or not, with the overall objective of worldwide nuclear disarmament.

.R6. As regards relations between NWS and the non-NWS Party to the NPT, we call upon the five nuclear-weapon States Party to the NPT to meet their obligations under Articles IV and VI both

in letter and spirit. In addition we call on them to treat States Party that are in compliance with as much generosity as any non-signatory state, some of which are in evident non-compliance. We also recommend support of additional protocols to the treaty to expand the scope of the treaty in restricting activities that might lead to nuclear weapons, provided that they do not inhibit legitimate peaceful uses of nuclear energy by States Party to the NPT. The May 2005 proposals by the Director-General of the IAEA have these same objectives.

In addition there are difficult issues that need additional discussion:

1. *Multi-event scenarios and public and government reaction*
2. *Limiting access to nuclear technology and information long in the public domain*
3. *The establishment of links and procedures among national command authorities and at lower levels with real-time communications to mitigate the impact of an event as well as to prevent its occurrence*
4. *Agreed security standards for the registry and protection of radioactive sources and nuclear explosive materials*
5. *The application of advanced personnel reliability standards to all positions involving potential massive damage to society, including the extension of the "2-person rule" used in the nuclear-weapon field to ensure, for example, that no individual employee can destroy a nuclear reactor with resulting damage to the public*
6. *Expanded international standards for the transfer of sensitive nuclear material, technology and design information. This goes*

beyond the weapon-explosive materials themselves, to the technology and facilities for producing them

7. *International agreements precluding attack on nuclear power facilities, despite the fact that some of their power might be used to support military activities.*
8. *The magnitude of the deaths and societal damage that could be caused by a terrorist nuclear explosion or even the economic damage from a radiological dispersal device should, in principle, guide the allocation of resources for mitigation and prevention. It is necessary, however, to take into account not only the magnitude of the damage that might be prevented, and the estimated probability of the damage occurring, but also the potential effectiveness of the means proposed. A disaster potentially in the trillion-euro range and with an estimated probability of 1% per year should not automatically call forth multi-billion-euro annual expenditures unless there is some likelihood that the measures considered will be effective. Nevertheless, it is of primary importance for states to cooperate in making such estimates and investments for the common and individual good.*

Richard L. Garwin (USA) – chair
Pervez Hoodbhoy (Pakistan)
Vasily Krivokhizha (Russia)
Sally Leivesley (UK)
Alan Leigh Moore (USA)

More recently, in August 2006 we convened at Erice a number of world-class experts on nuclear power, to address the linked problems of energy and non-proliferation. Dr. Fulkerson, who is also here, was a co-leader of this effort to provide consensus that would permit expansion of the nuclear power sector without greatly increasing the hazard of proliferation of nuclear weapons. Here are the recommendations of the group:

RECOMMENDATIONS:

Nations should sign and ratify the amended Convention on Physical Protection of Nuclear Material (CPPNM):

States that have not already done so should complete Additional Protocols to their Full Scope Safeguards Agreements with the IAEA.

The option of dry-cask storage of spent fuel for up to 100 years should routinely be considered in the context of reprocessing and recycle or of direct disposal.

Nations should move urgently to develop a viable international regime for fuel leasing and take back under satisfactory nonproliferation and environmental standards.

Signed at Erice, August 22, 2006:

SPEAKERS IN THE GLOBAL NUCLEAR POWER FUTURE SESSION:

Jacques Bouchard, France	*/ Jacques Bouchard /*
Carmen Difiglio, USA	*/ Present in official capacity and thus unable to sign /*
Steve Fetter, USA	*/ Steve Fetter /*
Philip J. Finck, USA	*/ Philip J. Finck /*
William Fulkerson, USA	*/ William Fulkerson /*
Richard L. Garwin, USA	*/ Richard L. Garwin /*
Richard Hoskins, Austria	*/ Present in official capacity and thus unable to sign /*
Kazuaki Matsui, Japan	*/ Kanzuaki Matsui /*
Charles McCombie, Switzerland	*Charles McCombie /*

The Madrid and London bombings show the world scope of action of groups empowered by modern communications, groups that are not necessarily directed or controlled by any central organization.
Osama bin Laden's call for the death of 4 million Americans, increases the fear that terrorists may acquire or improvise nuclear weapons to begin to achieve these goals. Indeed, the use of disease-producing agents—biological weapons (BW)—is the only comparable and perhaps more powerful threat, accounting for our interest in Erice in preventing or mitigating such use.

Having shown you our recommendations of 2005 and 2006, I now explain briefly that the World Lab and the World Federation of Scientists cannot, of course, implement such recommendations. They need to continue to urge their implementation and to help to remove any impediments, but it seemed that the considerations involved with preventing the acquisition of nuclear weapons by terrorists had elements in common with preventing terrorist acquisition or use of biological weapons. In fact, the problems are not entirely parallel. Anthrax, for instance, is ubiquitous in the wild, and a terrorist group could take samples from a long-dead cow (of which there are many buried over the landscape in Texas, for instance) and with ordinary laboratory and production facilities such as those used in brewing beer, produce vast quantities of anthrax that could be used as a weapon. Barring access to anthrax is of limited use, but mitigation of the damage from anthrax use is possible.

Similarly, the world-wide calamity of the intentional introduction of smallpox, for which there has been no vaccination since the elimination of smallpox in the 1970s would be a disaster of cataclysmic proportions. Some terrorists belonging to a sect or a nation are perhaps deterred by the fact that in a worldwide smallpox epidemic, on the order of 30% or their own group might die as well, but not all people look beyond the immediate goal.

In looking again at what could be done to prevent or mitigate the use of biological weapons by terrorists, we found that we would need to discuss the many threats and the likelihood thereof, and protection against them—all of which has been done often over the decades. Because the world's attention was focused on highly lethal avian flu and a potential pandemic, it was decided that it would be productive to look at pandemic influenza (not necessarily derived from avian flu) as a model. We were not implying that avian flu would be used a terrorist weapon, but simply wanted to see what could be done to counter pandemic flu and to draw lessons from that in countering the use of biological weapons.

Here are some of the people who contributed to our May 2006 study on fighting pandemic flu[1] as members of the Sub-Group on Mitigation: Diego Buriot (FR), Dr. Kevin Clark (UK), Baruch Fischhoff (US), Richard Garwin (US), Pervez Hoodbhoy (PAK), Sally Leivesley (UK), Ron Manley (UK), Alan Leigh Moore (US), Richard Wilson (US).

Although some potential BW agents are contagious (passing from human to human efficiently as do smallpox and influenza) those that had attracted substantial military interest and investment were only infectious-- in that the initial germs infected humans and caused disease, but they did not pass directly from human to human. Among such are anthrax and tularemia.

Contagious agents can, of course, cause much more damage, because 100 initial ("index") cases might cause 300 in the next generation, 900 a few days later, and so on. By the same token, measures to prevent the spread of contagion can have spectacular results.

Epidemics are traditionally characterized by the reproduction factor R—the number of next-generation cases on the average per index case—and the serial interval I, which is the time between generations. For Sudden Acute Respiratory Syndrome—SARS—R is about 3 and I about 8 days. For

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[1] Final Report of the Permanent Monitoring Panel on Terrorism (PMPT), Fourth Meeting, Erice, 18-22 May 2006 (Ahmad Kamal, Chair).

smallpox, R is about 3 and I about 14 days. For influenza, though, R is about 2, and I about 4 days.

What is stunning, though, is the benefit that would be achieved if one could reduce the exposure of people in the population to the influenza germ by merely a factor 3. At first sight, it would seem that if 30 million people might die in an epidemic, reducing exposure by a factor 3 might limit the deaths to 10 million, but that is far from the benefit that would be achieved. One traveler infected with pandemic flu could in 4 days infect 2, in 8 days 4, in 12 days 8 more, in 16 days 16 more, and so on, so that at the end of the month 180 would have been infected and in two months a 32,400 and at the end of three months 5.8 million. The 30 million might die independent of the number of index cases, since the epidemic rages until the number of those still susceptible is too small to sustain the epidemic.

But if one could cut R for influenza by a factor 3 (from 2.0 to 0.67) then 100 index cases would make 67, would make 49 in the next generation, for a grand total of 100/(1-R) = 300 cases—not 30 million cases.

We made *recommendations* as to how one might reduce the transmission of influenza germs. And even if one knew what to do, that would not be enough. One needs to *package* the "How To" in materials that would be available on the uncertain day or week that pandemic flu broke out. And one would need to *deliver* those packages in a fashion that is all too disturbingly similar to an advertising blitz. The message is unsettling to a scientist: ideas are not enough—even correct ideas. A major effort in public health is required—in all languages and all societies.

The individuals involved in the work at Erice have moved with the concepts there developed. For instance, I helped to organize a workshop at Columbia University June 5-6, 2006 that convened about 40 people on the subject of non-pharmaceutical intervention to fight pandemic flu, and the US government has this week given a progress report on its efforts. A brief report from the conference, however, emphasizes the degree of ignorance about the basic facts:

PUBLIC HEALTH

Next Flu Pandemic: What to Do Until the Vaccine Arrives?

Most scientists consider another influenza pandemic inevitable, but there is little information on how best to protect the public before a vaccine can be made available.

Stephen S. Morse,[1*] Richard L. Garwin,[2] Paula J. Olsiewski[3]

(www.sciencemag.org SCIENCE VOL 314 10 NOVEMBER 2006)

In summary, the discussions at Erice play an important role in defending the world against major threats, but it is clear that additional efforts and mechanisms such as a vigorous web site (presence on the internet) are necessary to make the product continuously available worldwide to those who have the duty and power to implement the recommendations and to benefit from the insights of the experts convened at Erice.

(In the meantime, this presentation will appear on my own site: www.fas.org/RLG/)