Volume 2, Number 1
September 2002

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Pugwash
ISSUE BRIEF

Issued by the Council of the Pugwash Conferences on Science and World Affairs
Nobel Peace Prize 1995

Nuclear Terrorism: The Danger of Highly Enriched Uranium (HEU)

This *Pugwash Issue Brief* focuses on a danger of immediate and increasing concern to the international community – the prospect that a terrorist group could manufacture and explode a nuclear bomb in the heart of a major city, with horrifying consequences. The availability of open-source information on how to construct a nuclear device, and the relative ease with which a well-financed and technically competent group of individuals could in fact accomplish such an act, have been well known to the scientific and intelligence communities for many years now. As long ago as 1986, five distinguished physicists and former Los Alamos scientists, (Carson Mark, Theodore Taylor, Eugene Eyster, William Maraman, and Jacob Wechsler) issued such a warning, *"Can Terrorists Build Nuclear Weapons?"*, that was published by the Nuclear Control Institute of Washington, DC.

In the year since September 11, there have been many warnings about the risks of nuclear terrorism (including a Pugwash Council statement reprinted here), yet for too long there was too little concrete action by national governments and the international community to prevent such a catastrophe from occurring. In recent months, this has begun to change, most notably with the decision in June 2002 by the G8 countries to spend $20 billion over 10 years to eliminate large quantities of fissile material (and chemical weapons), especially in Russia (the so-called "10+10 over 10" program). Yet, as is argued in this *Pugwash Issue Brief*, more needs to be done, far more quickly.

The Pugwash Conferences will devote much of its efforts over the coming months and years to highlighting methods for decreasing the threat posed by terrorist use of nuclear weapons, and biological and chemical weapons as well, as part of its overall mission of working for the complete elimination of nuclear, biological and chemical weapons.

For more information on this and other issues of concern to the Pugwash Conferences, please visit the Pugwash website at www.pugwash.org.

> **"Against a great evil, a small remedy does not produce a small result, it produces no result at all."**
>
> —John Stuart Mill

This is the second of a new publication series, re-titled ***Pugwash Issue Briefs***, that will highlight important issues which lie at the intersection of science, technology and public policy.

Intended for wide circulation to policy makers and analysts, the media, NGOs, the academic and research communities, as well as the Pugwash community, ***Pugwash Issue Briefs*** will contain articles, commentaries and conclusions that emanate from the broad range of Pugwash workshops and conferences held each year.

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Nuclear Terrorism: The Danger of Highly Enriched Uranium (HEU)

by Jeffrey Boutwell, Francesco Calogero and Jack Harris

"It's not a matter of *if*; it's a matter of *when*."

Gen. Eugene E. Habiger
former commander
US Strategic Air Command

The horrifying September 2001 terror attacks in the United States that took the lives of more than 3,000 people have greatly increased the concern of the international community over the risks of a nuclear terrorist attack. The scale of the planning, resources and dedication to a cause that characterized the September 11 attacks on the World Trade Center and the Pentagon make clear that groups and individuals do exist who would not hesitate to use a nuclear explosive device in furtherance of their aims, whatever these may be.

We believe that the explosion in a major urban area of even a crude nuclear device, for the first time as a hostile act since Hiroshima and Nagasaki in 1945, would be an unparalleled disaster for the international community. Over and above the death, destruction and psychological trauma that such an explosion would cause, a nuclear threshold would have been crossed that could lead to great international tension and instability, and perhaps even the further use of nuclear weapons against humanity.

This is the risk that the world now faces. As explained below, we believe that it could be a relatively easy matter for a terrorist organization to assemble and then detonate a nuclear explosive device in one of the world's major cities. With access to the appropriate material, it is indeed easy to assemble a nuclear explosive device in a residence or workplace in the downtown section of a major city and then explode it with horrifying consequences.[1]

To be sure, there are many ways that terrorists can wreak death and destruction, including through the use of chemical and biological/ bacteriological agents, radiological materials, and the hijacking of airliners and using them as missiles to destroy skyscrapers, or perhaps civilian nuclear power plants. The question of which option may be "easier" than another is immaterial, as the answer will largely depend on the specific competencies and capabilities (including access to key materials) available to the terrorists, as well as their personal histories and contacts.

What does seem beyond doubt is that acquiring the capability to explode a nuclear device — the "absolute weapon" – must certainly be very appealing for any terrorist group seeking to cause major damage to society and the governmental and social institutions they oppose. Such a capability is likely to confer on its possessors a great feeling of power, not to mention its value as an effective instrument for blackmail or retaliation. And the scale of damage caused by exploding one or more nuclear devices — in terms of death, injury and suffering, of immediate physical destruction and lasting economic impact, and of psychological trauma – is certain to be horrendous.[2]

Assembling a nuclear device

Despite the fact that 30,000 nuclear weapons still remain in the arsenals of the major nuclear powers (more than 28,000 of these in the US and Russia alone), we believe it is unlikely that a subnational terrorist group will obtain an actual nuclear warhead. These instruments of mass destruction — wherever they exist — are

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Before taking early retirement, **Jack Harris** worked for 35 years in the UK's nuclear power industry and for this work was elected to Britain's National Academies of Science and of Engineering. He is the co-recipient of the Royal Society's 'Esso' Gold Medal for Energy Conservation, for studies leading to more efficient utilization of nuclear fuel. He is the former editor of *Interdisciplinary Science Reviews*, and the Vice Chair of British Pugwash.

by and large effectively protected against theft and diversion. By contrast, we believe it would be much easier for a terrorist group to obtain, and then smuggle to the target area, the key material necessary to manufacture, on site, a nuclear explosive device.

Most people assume that it is quite difficult to manufacture a nuclear explosive device. This may be true if the basic fissile material is plutonium, whose adaptation to a weapon was the main challenge of the nuclear weapons design effort at Los Alamos during World War II. Plutonium has made possible the construction of the compact nuclear weapons which dominate national nuclear arsenals. But if a sufficient quantity of Highly Enriched Uranium (HEU), the material used in the Hiroshima weapon, were available, a small group of terrorists might be able to manufacture a nuclear explosive device which would have a substantial probability of producing a nuclear explosion comparable to that which destroyed Hiroshima.

While many people around the world already possess the technical competence necessary for building such a nuclear explosive device, a terrorist group need not have access to such individuals, or even themselves be highly-trained scientists or engineers. A team of terrorists with sufficient knowledge of physics, explosives and machining could, having gathered information available in open and easily available sources, construct a crude nuclear bomb that would have a high probability of exploding with a sizable nuclear yield. Moreover, unlike plutonium, HEU poses no significant health hazards, other than accidental criticality, in the process of building such a device.[3]

By assembling a nuclear bomb in a residence, garage or workshop in the middle of a major city, possibly from components previously manufactured elsewhere, the terrorists would not have to worry about being detected trying to smuggle an entire device into the target country. After a period ranging from hours to months, the device would be ready. The terrorists could then detonate the nuclear bomb by remote control, or by a timer, allowing them ample time to get away.

PHOTO: MITSUGI KISHIDA

The ruins of Hiroshima smolder one day after the atomic bomb called "Little Boy" was dropped Aug. 6, 1945. The skeletal remains of a domed building, center, now called the Atomic Bomb Dome, have been preserved as a memorial.

Because of the likely crudeness of its design and construction, it might be difficult to provide any reliable a priori estimate of the final yield of such a device. Nonetheless, it is possible that its destructive power would be similar to that of the Hiroshima weapon (approximately 13 kilotons), and the number of fatalities (both short and long-term) could approach — or exceed — 100,000, especially if the bomb was exploded in a city with high population density like Hiroshima or the central urban area of a modern city.[4] Even if the terrorist bomb had an explosive yield only one-tenth that of Hiroshima, around one kiloton, the fatalities, casualties, and overall social, economic, and psychological impact of the blast would still dwarf any previous terrorist action.

Highly enriched uranium (HEU)

The biggest obstacle to manufacturing and detonating such a device is the difficulty of acquiring the basic "raw material" of such a bomb, weapons-grade Highly Enriched Uranium (HEU).

Uranium is an element that is widely present in nature, even as a tiny fraction of sea water. Yet natural uranium consists mainly of the isotope U-238 (some 99.3 percent), while the material needed to sustain the chain reaction of a nuclear bomb is the fissile isotope U-235, which only accounts for 0.7 percent of natural uranium. In order to produce weapons-grade HEU, the amount of U-235 in the uranium

"The unleashed power of the atom has changed everything save our modes of thinking and we thus drift towards unparalleled catastrophe."

Albert Einstein
24 May 1946

"Most people seem unaware that if separated U-235 is at hand it's a trivial job to set off a nuclear explosion, whereas if only plutonium is available, making it explode is the most difficult technical job I know."

Luis W. Alvarez, a key participant in the construction of the first US nuclear weapons and recipient of the Nobel Prize in Physics, 1987; see Luis W. Alvarez, *Adventures of a Physicist* (Basic Books, 1988), p. 125.

needs to be increased to 90 percent or above. However, any enrichment above 20 percent, the definition of highly-enriched uranium (HEU), is considered weapons-useable.[5]

The amount of highly-enriched uranium needed to make a bomb will depend, in the end, on the degree of enrichment and on the design of the explosive device itself (i.e., the skill of the manufacturer). For a primitive nuclear device, however, 100 kilograms of weapons-grade HEU would certainly be more than enough (we shall use this quantity as the notional unit in the discussion below, to also take account of possible losses in the process of construction).

Smuggling such an amount of weapons-grade uranium (especially in an oxide form, which, as a powder, is easier to both steal and transport) into the target city would likely be no more difficult than smuggling a similar amount of cocaine or heroin, as HEU can be hand-carried with no risk of radiation, and the 100 kilograms could be separated out into, say, half a dozen to a dozen one-liter cartons similar to those used for milk.

Enriching uranium for nuclear weapons is a difficult and expensive technological feat, which only a few states have mastered.[6] The Iraq of Saddam Hussein, for example, tried to produce HEU in the context of a clandestine program to acquire nuclear weapons (in violation of the nuclear Non-Proliferation Treaty to which Iraq was a Party), but after spending billions of dollars, it appears to have managed to produce only gram quantities of HEU.

It is important to note that, in addition to being used for nuclear weapons, weapons-grade uranium also serves as the fuel for the reactors of nuclear-propelled submarines and some Russian ice-breakers, as well as for various small scientific research reactors around the world. There are, however, plans for phasing out some of these uses of HEU (particularly in research reactors), although it is unlikely they will be fully implemented soon.

In terms of using uranium to produce electrical energy, nearly all the world's civilian nuclear power reactors use as fuel Low Enriched Uranium (LEU), in which the concentration of U-235 has been increased from 0.7 percent to around 3-5 percent. Even this modest enrichment of uranium, however, is difficult and expensive, and it is very important to understand that the cost of producing LEU containing a given quantity of U-235 is not that much less than the cost needed for producing HEU containing the same quantity of U-235, even though the proportions of U-235 present are vastly different (3-5 percent compared to 90 percent or more).[7] In short, the cost of producing LEU is a substantial fraction of the cost to produce HEU, and by the same token (also a point that will become important below), if one de-enriches HEU to LEU, only a minor fraction of the separative work gets wasted.

There is, of course, no free market in highly enriched uranium, and the sale and transfer of LEU is carefully safeguarded. But the quantity of HEU that exists in the world is exceedingly large due to the excessive accumulation of this strategic material during the Cold War, especially in the United States and the former Soviet Union; hence the high risk that some of it might be stolen or sold illegally on the black market.

Eliminating HEU

Of concern for several years now has been the very large quantity of HEU in the former Soviet Union (now mostly in Russia), which amounts to well over 1,000 metric tons (*one million* kilograms: enough for more than 10,000 easy to construct nuclear explosive devices). Given the economic difficulties affecting Russia and the Russian nuclear complex (operated by the Ministry of Atomic Energy, *MinAtom*), there are special concerns about this material being adequately secured against theft or diversion to third parties, be they states or subnational groups.

Beginning in the early 1990s, substantial efforts were initiated to improve the safeguarding of this fissile material, via the US-Russian Cooperative Threat Reduction Program. Since then, the US financial contributions have run into billions of dollars. The other G7 countries have made useful, though marginal, contributions to this endeavor. Recently, however, the

G7 (now G8, including Russia) countries have proposed additional contributions under a new program entitled "10+10 over 10".[8] This would involve the USA contributing $10 billion, to be matched by another $10 billion contribution from the remaining G7 countries, with all the funds being allocated over a ten year period. These decisions are to be welcomed, but the 10 year time scale is overly long. Were the $20 billion allocated instead to a crash program extending over just three years, this would be a more appropriate match to the scale and urgency of the problem. There are, moreover, additional fears that domestic politics and commercial considerations could delay the US Congress actually allocating the money. The complexity of the European Union decision-making process and its bureaucracy is another cause for concern.

The focus of the above programs is on strengthening the so-called *Material Protection, Control, and Accounting* (MPC&A) procedures at dozens of nuclear facilities throughout the former Soviet Union. An additional concern is preventing the outflow, or brain drain, of experts on nuclear weapons technology to states of concern suspected of seeking to acquire nuclear weapons.

Quantities of HEU also exist in other countries, especially in the states that possess nuclear weapons (certainly in the United States, United Kingdom, France, China, and Pakistan) or, in the case of South Africa, that once did. Most of these HEU stockpiles are small compared to those in Russia and the US (although still large in terms of the number of nuclear explosive devices that might be manufactured with them). In order to minimize the risk of theft or diversion of HEU from these countries, there must be constant monitoring and intelligence to ensure its safety, especially as HEU when being processed is less susceptible to precise accounting and easier to steal.

Clearly, an effective strategy for decreasing the risk of nuclear terrorism is to eliminate totally the basic raw material — HEU — needed for the easy manufacture of nuclear explosive devices. From a practical point of view, it is

UN PHOTO #149442

Hiroshima

enough to de-enrich HEU to less than 20 percent U-235, so that it cannot be used to produce a nuclear explosion. This is a straightforward task, the reversal of which is extremely difficult — in fact, for any terrorist group, quite impossible. Moreover, because both the US and Russia now have much more HEU than they can possibly use for their nuclear arsenals - which are fortunately in the process of being reduced — it has been politically possible to agree to move in this direction.

A 1993 HEU deal between the US and Russia called for Russia to de-enrich a substantial quantity of its weapons-grade uranium, 500 metric tons, and sell the resulting LEU to the US. This was an important achievement, but the mechanisms of its implementation were seriously flawed, inasmuch as they transformed a development motivated by well justified security concerns into a commercial deal, whose cumbersome implementation then undermined the initial security objectives. This evolution from security to commercial priorities began when the first Bush Administration announced that the deal would entail "no cost to the American

> **"The most urgent unmet national security threat to the United States today is the danger that weapons of mass destruction or weapons-usable material in Russia could be stolen and sold to terrorists or hostile nation states and used against American troops abroad and citizens at home."**
>
> Howard Baker and Lloyd Cutler, January 2001
> *See endnote 11*

taxpayer". Motivated no doubt by the need to sell the $12 billion program to an unsympathetic Congress, the Bush and then the Clinton administration proposed that Russia de-enrich its weapons-grade HEU to reactor-grade LEU, sell the LEU so obtained to the US, which then would re-sell it to electrical utilities as fuel for nuclear reactors, thereby recouping the funds paid to Russia.

Unfortunately, commercial considerations became so dominant in determining the specific terms of this agreement that its implementation was stretched out over a twenty year period (in order not to deflate the market price of LEU). This is an absurd time scale given the tremendous dangers associated with the presence of large quantities of inadequately guarded HEU in Russia.

Matters were then made much worse by assigning the implementation of the agreement to the United States Enrichment Corporation (USEC), an institution that clearly had no fundamental interest in importing enriched uranium from Russia's Ministry of Atomic Energy (a major market competitor), and which was moreover simultaneously transformed from a US government agency into a private company that, as such, would be more tempted to put profit motives above national and international security considerations. As a consequence, the HEU Deal (which the USEC trumpeted as "Megatons to Megawatts") was much hampered and its implementation delayed, especially given the pressures of a worldwide decline in demand for LEU. Not surprisingly, the deal has had to be rescued more than once by US government intervention, and almost ten years after the original agreement, the LEU transferred to the US corresponds to less than 150 tons of Russian HEU (less than 30 percent of the target amount of 500 tons, and only 10-20 percent of all the HEU in the former Soviet Union).[9]

It is clearly necessary and urgent that the HEU agreement be revisited by the Bush Administration, in the light of the much greater urgency in preventing the risk of nuclear terrorism that should prevail after September 11, 2001. But this will not be enough. Attention needs to be paid as well to the risk implicit in the existence of the enormous stocks of excess weapons-grade uranium in Russia (and also in the US), the size of which will increase in coming years because of additional reductions in US and Russian nuclear forces. The goal must be to eliminate this dangerous material as quickly as possible.

A supplementary strategy

In addition to the importance of accelerating the implementation of the US-Russia HEU deal described above (possibly by-passing the USEC altogether), serious consideration needs to be given to *supplementary initiatives* aimed at bringing about the elimination of as much HEU as possible, as quickly as possible.

One strategy for achieving this goal would be to subsidize its de-enrichment. The greater the financial inducement for Russia, and specifically *MinAtom* - the institution in Russia that is responsible for the oversized and now under-financed Russian nuclear complex (including both military and civilian installations) - the greater the incentive to proceed in this direction at the fastest possible rate to retrieve all available HEU. A secondary advantage of this approach would be to infuse funds into the *MinAtom* operation, funds which might contribute to preventing catastrophic developments resulting from the overall decay of this crucial institution.

The plan might be based on offering *MinAtom* an immediate cash payment for every quantity of HEU that is de-enriched, to say, below 20 percent (namely, low enough to exclude any possibility of explosive use). At a price of perhaps US $10 for each gram of high-grade HEU that is eliminated, $10 billion would be needed for the elimination of the approximately 1,000 tons of HEU remaining in Russia. (Of course, Russia would retain some HEU in its down-sized nuclear arsenal.) For the scheme to work, enough transparency should be provided by *MinAtom* to enable the outside world to verify, first of all, that the production of new HEU has definitely stopped, and secondly, that the de-enriched HEU is properly measured, accounted for and safeguarded (possibly by the International Atomic Energy Agency). Payments to *MinAtom* could be considered no-interest loans, to be repaid by Russia when material gets further de-enriched and treated to qualify as marketable LEU for sale to utilities worldwide for the production of electricity. (At current market prices, it is conceivable that Russia might earn twice as much money from the sale of LEU as it would have to repay for the no-interest loans obtained for the immediate de-enriching of HEU to below 20 percent, though such estimates must remain tentative given the uncertainty about future market prices for LEU.)

The main contributor to the plan would likely be the United States, though it is to be hoped that other industrial nations (the European Union countries, Japan, Canada, etc.) would contribute as well to reducing and ultimately eliminating the large excess stocks of HEU in Russia. Russia would certainly respond positively to such an offer, as would other former Soviet Union countries possessing much smaller stocks of excess HEU at nuclear research institutes.

In negotiating such a deal, conditions might be set for the way such funds are utilized by the countries receiving them. For example, Russia might use its funds, in part, for agreed measures of nuclear disarmament and/or the elimination of its enormous stocks of chemical weapons as called for by the Chemical Weapon Convention, a commitment Russia is having difficulty meeting because of its cost. All such conditions, however, should take a back seat with respect to the main goal of eliminating as much HEU as quickly as possible. It should be noted that allocating funds directly for the elimination of HEU is, in the long term, more cost-effective than devoting resources to upgrading its physical security, which of course requires continued additional investments over time.

Another strategy could be based on the principle of a "debt for security" swap, where creditor nations offer to transform Russian debts to non-interest-paying loans. Currently, Russia owes Germany over $26 billion, and Italy some $6 billion, out of a total debt of $71 billion.

Global stocks of nuclear weapons and nuclear materials

Country	Total nuclear weapons[3] (including those in reserve)	HEU (metric tonnes)[4]	Separated plutonium (metric tonnes)	
		Military[4] (1994)	Military[4] (1994)	Civilian[5] (2000)
US	~9,000	580–710	85	0
Russia	~20,000	735–1365	100–165	34
UK	<200	6–10[2]	7.6	78.1
France	~350	20–30	3.5–6.5	82.7
China	410	15–25	2–6	0
India	30–35[1]	0	~0.3	0
Pakistan	30–52[1]	0.6–0.8	0.001–0.01 (end 1999)	0
Israel	60–100	0	~0.4	0
South Africa	0	0.4	0	0
North Korea	0	0	~0.03	0
Germany	0	0	0	7.2
Japan	0	0	0	5.2
Other European	0	0	0	4.5
Total	30,085–30,152	1360–2140+ ~20 civilian	200–270	~200

[1] Estimates based on the amount of nuclear material these states are believed to possess.

[2] 21.9 tonnes as published in the *Strategic Defence Review* 1998

[3] Carnegie Endowment for International Peace: http://www.ceip.org/files/nonprolif/numbers/default.asp

[4] Federation of American Scientists. *Public Interest Report* Vol.54, No. 6.

[5] Based on national declarations to the International Atomic Energy Agency (Infcircs549 http://www.iaea.org/worldatom/Documents/Infcircs).

Source: Nuclear Terrorism, Parliamentary Office of Science and Technology, Number 179, July 2002

Both western countries and Russia might find it attractive to finance the elimination of HEU through this type of forgiveness of debt.[10]

Tragically, policymakers and the public have thus far demonstrated insufficient interest in, nor even awareness of, the very real dangers posed by the large quantities of HEU that might become available to terrorist organizations or others. Far greater political will and leadership will be necessary, particularly in the United States but also in Europe, Japan, Canada, and other countries, if we are to eliminate the tremendous risk of nuclear terrorism.

Plutonium

A few remarks are needed about plutonium, the (only) other raw material out of which nuclear bombs are now made.

The mushroom cloud formed by the "Mike" thermonuclear test on November 1, 1952.

While the availability of plutonium certainly poses a risk with respect to the possible acquisition of nuclear weapons by States, it does not pose a risk comparable to that of HEU for the possible clandestine manufacture of a nuclear explosive device by a subnational terrorist group. The reasons for this have to do with the far more demanding technological expertise required to manufacture a nuclear explosive device based on plutonium (including experimentation with very sophisticated conventional explosives and electronic equipment).

Moreover (albeit less importantly) handling plutonium entails much greater health hazards than does HEU, and transporting it clandestinely is more difficult (because of its more pronounced radiation signature). Hence, plutonium nuclear explosive devices are much less likely to fall within the competence of any subnational terrorist group, and in any case their yield is unlikely to be comparable to that of an HEU device.

The plutonium problem has received much more attention from analysts than the HEU issue because, from the technological point of view, what to do about plutonium is much more controversial. Despite the challenges posed by plutonium in terms of proliferation to states and safe and secure disposal,[11] it is Highly Enriched Uranium that presents the far greater nuclear terrorist threat, making it imperative that the world community devote immediate and substantial resources for strictly controlling HEU, with the goal of eliminating as much of this dangerous material, as quickly as possible.

Epilogue

The authors of a 1996 book, *Avoiding Nuclear Anarchy,* speculated on what would have happened had the terrorists in 1993 used a nuclear bomb at the World Trade Center instead of exploding several hundred kilograms of chemical explosives.[12] Basing their calculations on the detonation of about fifty kilograms of HEU - the size, incidentally, of a couple of grapefruits – they write that the result would have been a nuclear blast equivalent to the explosion of between 10,000 and 20,000 tons of TNT (about the yield of the Hiroshima bomb). This would have devastated a three-square-mile area covering the southern portion of Manhattan, including all of Wall Street reaching up to Gramercy Park. Depending on the timing of the attack, more than one hundred thousand people might die, with at least that many, if not more, seriously injured. Indeed, other estimates put the casualties even higher.[13]

Similar assessments most likely have been made, or could be made, for the effects of a comparable nuclear detonation in London, Delhi, Beijing or Moscow. If detonated near the Kremlin in Moscow, or the Forbidden City in Beijing, or the Indian Parliament in Delhi, or Westminster and Buckingham Palace in London,[14] the resulting deaths and injuries, not to mention the psychological trauma, would be a shock to the international system and could well destabilize relations among the nuclear powers.

The destructive potential described above is within the reach of small, determined groups of people. We cannot know what groups might attempt to inflict such horrendous suffering, for what purpose, or against which city or nation. What we do know is that the need to prevent such horrific acts exists now. And it is clear what can and should be done now, before it is too late.

Notes

[1] See, for instance, the following by Francesco Calogero: "Fast-track the uranium deal", *Bulletin of Atomic Scientists,* November/December 1997, pp. 20-21; reply to letter, *Bulletin of Atomic Scientists,* January/February 1998, p. 66; "The risk of Highly Enriched Uranium (HEU) for terrorism", paper co-authored with Giancarlo Tenaglia and presented at the 1999 Annual Pugwash Conference, Rustenburg, South Africa, 8-13 September, 1999, and at the 1999 Amaldi Conference, Mainz, Germany, 6-10 October, 1999 and published in the Proceedings of these meetings; "The risk of terrorist uses of nuclear explosions", Section 3.8 of Issues in Arms Control, Lectures given in the Academic Training Program of CERN, February 12-16, 2001, *CERN Report 2001-004*, ISBN 92-9083-187-1; "Nuclear terrorism", Proceedings of the Nobel Peace Prize Centennial Symposium, Oslo, December 6-8, 2001 (in press); "Memo on nuclear terrorism", proffered paper, Amaldi Conference 2002, Pontignano near Sienna, Italy, April 27-29, 2002; "Nuclear terrorism", letter in *Bulletin of Atomic Scientists,* May/June 2002, p. 5.

[2] Depending of course on the final yield of such a nuclear explosion, the scale of the damage is likely to be much larger than that achievable by any other means — with the possible exception of the widespread diffusion of a lethal and highly infectious pandemic disease such as might be caused by a particularly virulent strain of smallpox.

[3] See Al Narath, "The Technical Opportunities for a Sub-National Group to Acquire Nuclear Weapons", presented at the XIV Amaldi Conference on Problems of Global Security, Pontignano, Italy, April 2002; see the Accademia Nazionale dei Lincei website. Narath is a former Director of Sandia National Laboratory in New Mexico, the main laboratory in the US where nuclear weapon designs are finalized.

[4] See the paper by Richard L. Garwin, "Nuclear and Biological Megaterrorism," paper given at the 27th Session of the International Seminars on Planetary Emergencies, 21 August 2002, at www.fas.org/rlg/020821-terrorism.htm; a shorter version of the paper was published as "The Technology of Megaterror," *Technology Review,* September 2002.

[5] While both very expensive and technically demanding, the enrichment process is essentially accomplished by separating out the required quantity of U-238 so that the proportion of U-235 in the remaining uranium increases accordingly.

[6] See Frank von Hippel, "Recommendations for preventing nuclear terrorism," *FAS Public Interest Report,* vol. 54, no. 6 (Washington, DC: Federation of American Scientists, November/December 2001).

[7] It is easy to explain this apparent paradox. Every 1,000 atoms of natural uranium contain 7 atoms of U-235, and 993 atoms of U-238. To transform this material into LEU (enriched, say, to 3.5 percent) one must shed 800 atoms of U-238, so that one is left with 200 atoms, 7 of which are U-235, and 193 of U-238. Subsequently, in the next stage of separation, it will be sufficient to shed less than 200 atoms of U-238 to get HEU. Roughly speaking (the percentages are not exact), only an additional 20 percent of effort and cost is needed to produce HEU from LEU, from what was needed to move from natural uranium to LEU.

[8] The "10+10 over 10" initiative was agreed to during the G8 Summit, held 25-27 June 2002 in Kananaskis, Alberta, in Canada. Leaders of the G8 (Canada, the US, UK, France, Italy, Germany, Japan and Russia), adopted the "G8 Global Partnership Against the Spread of Weapons and Materials of Mass Destruction, and pledged to commit $20 billion over ten years to support projects, most initially in Russia, aimed at disposing of fissile material, destroying chemical weapons, dismantling decommissioned nuclear submarines, and securing employment for former weapons scientists. See the website of the Government of Canada; www.g8.gc.ca.

[9] For more on the failings of USEC, see Robert Civiak, "The need for speed," *Bulletin of the Atomic Scientists,* July/August 2002. In the same issue, see also Oleg Bukharin, "Making fuel less tempting", for information on less well-guarded HEU at Russian research reactors.

[10] This type of "debt for security" swap is being investigated and promoted by Maurizio Martellini of the Landau Center – Centro Volta, of Como, Italy.

[11] For recent analyses of the risks associated with the availability of nuclear-weapon materials, see: Matthew Bunn, John Holdren, and Anthony Weir, "Securing Nuclear Weapons and Materials: Seven Steps for Immediate Action" (Cambridge, Mass.; Belfer Center for Science and International Affairs, Harvard University, May 2002), and Howard Baker and Lloyd Cutler (Co-Chairs, Russia Task Force, U. S. Secretary of Energy Advisory Board), A report card on the Department of Energy's nonproliferation programs with Russia, final draft of 10 January, 2001, available at www.hq.doe.gov/seav.

[12] Graham Allison, Owen Cote, Richard Falkenrath, and Steven Miller, *Avoiding Nuclear Anarchy* (Cambridge, Mass.: MIT Press, 1996).

[13] See Garwin, "Nuclear and Biological Megaterrorism."

[14] J.E. Harris, "The threat of Nuclear Terrorism," Editorial, *Interdisciplinary Science Reviews,* vol. 24, no. 2, 1999, p. 81.

Statement of the Pugwash Council

Monday, 12 November 2001, London, UK

The Dangers of Nuclear Terrorism

"War does not determine who is right—only who is left."

—Bertrand Russell

The horrific nature of the September 11 attacks has demonstrated the ability of international terrorist networks to carry out well-planned and complex operations that can kill thousands of innocent civilians. The potential for biological, chemical, and/or nuclear terrorism has greatly increased.

While there has long been concern about nuclear material being acquired by non-state groups, reports in the past few days indicate that nuclear weapons may now, or soon will be, available to terrorist groups. The challenges facing the international community from terrorism have been greatly compounded by the world's failure to reduce and eliminate nuclear weapons.

Most immediately, the members of the United Nations must adopt and effectively implement the proposed international conventions on international terrorism and on nuclear terrorism.

More generally, the large quantities of highly-enriched uranium (HEU) that are poorly controlled and otherwise unaccounted for in the former Soviet Union and dozens of other countries demand immediate attention and action by the world community.

HEU poses the danger that it is far easier to manufacture into a nuclear weapon than is plutonium, so much so that even sub-national terrorist groups could accomplish the challenge. European and Asian governments especially need to join the United States in providing aid to the Russian government in controlling and destroying this fissile material (enough to build 20,000 nuclear bombs) through greatly accelerated funding and commitment to such programs as the Cooperative Threat Reduction Program (Nunn-Lugar). In addition, the international convention on the physical protection of nuclear materials must be strengthened and expanded, and greater efforts made to safeguard fissile materials in civilian use.

HEU can, however, be readily diluted with natural uranium to a low-enriched level where it has high commercial value as a proliferation-proof fuel for civil nuclear reactors. Here again, an important opportunity exists for Europe and Japan to work with the United States in purchasing such fuel from Russia and greatly reducing available supplies of weapons-grade uranium.

Much work will be needed on a broad range of fronts, from recognizing and addressing the root causes that facilitate the growth of terrorist networks, to bringing to justice those who commit mass murder and crimes against humanity.

In order to safeguard global peace and security, it is essential that national governments and the world community recognize that the twin dangers of international terrorism and nuclear proliferation pose entirely new threats that demand immediate and sustained attention.

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PUGWASH CONFERENCES ON SCIENCE AND WORLD AFFAIRS

Nobel Peace Prize 1995

In 1995, the Pugwash Conferences and one of its co-founders, the physicist Sir Joseph Rotblat, shared the Nobel Peace Prize in recognition of their decades-long work to reduce the threat of nuclear war and ultimately abolish nuclear and other weapons of mass destruction. Beginning with its first international conference in Pugwash, Nova Scotia in 1957, the Pugwash Conferences have brought together influential scientists, scholars and public figures concerned with reducing the danger of armed conflict and seeking cooperative solutions for global problems.

Today, there are more than 40 national Pugwash groups around the world, and four offices in Rome, London, Geneva, and Washington, DC. The current President of Pugwash is Prof. M.S. Swaminathan of India; the Secretary General is Prof. Paolo Cotta-Ramusino of Italy; the Executive Director is Dr. Jeffrey Boutwell of the US; and the Chair of the Pugwash Council is Prof. Marie Muller of South Africa.

Inspired by the Russell-Einstein Manifesto of 1955, and founded on the principle of the individual responsibility of scientists for their work, the Pugwash Conferences have worked for the past 45 years toward the twin goals of abolishing nuclear weapons and the peaceful settlement of international disputes. The emerging challenges in science, technology and international politics of the 21st century make those principles and goals more relevant than ever.

Pugwash

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