Nuclear Terrorism

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I am here on behalf of the Pugwash Conferences on Science and World Affairs, co-recipient (with Joseph Rotblat) of the 1995 Nobel Peace Prize; but, according to Pugwash tradition, I speak here in my personal capacity, since this text has not been approved by the Pugwash Council. The Pugwash Council did however issue recently (Sunday, 11 November, 2001) a Statement on "The Dangers of Nuclear Terrorism", and Pugwash is in the process of producing an *Issue Brief* with a more detailed analysis of this important subject; and what I write below is much in consonance with these interventions.

In this contribution I focus on a single issue, namely the risk that a subnational terrorist group manufacture clandestinely a nuclear explosive device in an apartment or a garage downtown in one or more cities, and I outline what should in my opinion be done to minimize this danger. I tried rather unsuccessfully to advertise this issue over the past few years.[1] Perhaps after the events of September 11, 2001, more attention will be devoted to this problem.

Obviously, there also exist many other options a terrorist commando might adopt to wreak destruction and sufferings on civil society, exploiting instruments of mass damage (including chemical or biological/bacteriological agents, or radioactive materials) or other means (such as those used in New York on September 11, 2001). The question of which one of these options is "easier" to realize is moot, as it largely depends on the specific competencies and capabilities (including access to key materials) available to the terrorists, which themselves depend on unpredictable parameters related to the previous life history of these individuals and the personal contacts available to them.

The acquisition of the capability to explode a nuclear device -- the "absolute weapon" -- is certainly very appealing for any terrorist group who is bent on causing major damage to civilian society. Such a capability is likely to confer on its possessors a great feeling of power, and indeed it might also be used as an effective instrument for blackmail or retaliation. The scale of damage -- both in terms of deaths and sufferings, and of immediate destruction and lasting economic impact -- 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 effectively dispersed, say, in a major airport.

But I believe it is unlikely a subnational terrorist group might get hold of a nuclear weapon, because these instruments of mass destruction -- wherever they exist -- are effectively protected against theft and diversion. It is much easier to get hold of, and to smuggle to the target area, the key material (see below) necessary to manufacture there a nuclear explosive device. This is the topic on which I focus in this contribution.

Most people believe that it is quite difficult to manufacture a nuclear explosive device. They are mistaken. If the key material (see below) were available, a very small group of terrorists -- possibly even a single person -- might manufacture in an apartment or a garage a device which would then have a substantial probability to produce a nuclear explosion comparable to that which destroyed Hiroshima.

The number of individuals who master the key knowledge to implement successfully such a project is vast; indeed, it seems to me the individual(s) involved in this enterprise need not have any knowledge of nuclear physics or of engineering that could not be acquired in a few weeks by an intelligent technically educated person from completely open, and easily available, sources (such as encyclopedias); nor would skills be needed beyond those of a competent bricoleur; nor would any significant health hazards be encountered.

Such a nuclear explosive device might be assembled in the downtown area of one or more large cities; it would not be transportable, and its explosive yield might be hard to predict with any precision in advance. But it is likely that, once set off -- by remote control, or by a delayed timer allowing ample time for getaway -- each such explosion would cause a sudden catastrophe much much worse than any previous terrorist act, to an extent that is hard to envisage.

What fortunately stands in the way of the realization of such a project is the difficulty to acquire the basic "raw material" to manufacture such a device, namely weapon-grade Highly Enriched Uranium (HEU).

Uranium is an element that is widely present in nature (even as a tiny fraction of sea water); but natural uranium is mainly made of an isotope -- U-238 -- which is not easily exploitable as a source of nuclear energy (and not at all in its explosive variant); while the isotope U-235, which is instead capable to sustain a nuclear chain reaction and therefore to allow the explosive release of macroscopic quantities of nuclear energy, is only a tiny fraction -- 0.7% -- of natural uranium.

The majority of nuclear reactors for the production of electricity use as fuel Low Enriched Uranium (LEU), in which the concentration of U-235 has been increased from 0.7% to, say, 3-4% . To manufacture easily a nuclear explosive device one needs HEU, which contains, say, more than 90% U-235. The quantity needed to manufacture one such device depends on the degree of enrichment (how much beyond 90%) and on details of the design, hence on the skill of the manufacturer; 50 kilograms are probably sufficient even to an unsophisticated practitioner, 100 kilograms are certainly more than enough (we shall use hereafter this quantity as notional unit).

The enrichment of uranium is a difficult and costly technological feat, which only few States master. For instance Saddam Hussein's Iraq 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 managed to produce only gram quantities of HEU.

Hence LEU and HEU are costly commodities. The latter is mainly used for nuclear weapons, and for the reactors of nuclear-propelled submarines which, due to the requirements of compactness, tend to use HEU rather than LEU. Moreover, some small research reactors are fueled by HEU, but few such reactors are still operational, and there is a worldwide policy to phase them out and not to build any one any more.

Although the concentration of U-235 in LEU is only of the order of 3-4%, hence much less than that in HEU (over 90%), the separative work (hence the cost) of producing LEU (from a given quantity of natural uranium) is a substantial fraction of that needed to produce HEU (from the same quantity of natural uranium). It is easy to understand the basis of this apparently paradoxical fact: 1,000 atoms of natural uranium contain 7 atoms of U-235 and 993 of U-238; to transform this into LEU (enriched, say, to 3.5%) one must shed 800 atoms of U-238, so that one is left with 200 atoms, 7 of which are U-235; and clearly it is subsequently sufficient to shed less than 200 atoms of U-238 to get HEU. The separative work needed is roughly proportional to the amount of U-238 separated out in the enrichment process. The cost of the operation is approximately proportional to the amount of separative work, since this is an extremely energy-consuming operation; during the peak of the Cold War the amount of electrical energy used in the Oak Ridge enrichment plant in Tennessee was comparable to the entire energy consumption of France. Hence the cost of producing LEU is a substantial proportion of the cost to produce HEU; conversely, if one de-enriches HEU to LEU, only a minor fraction of the separative work gets wasted.

There is of course no free market of HEU, and also the sale of LEU is carefully safeguarded. But the quantity of HEU that exists in the world is exceedingly large due to the exaggerated accumulation of this strategic material during the Cold War, especially in the United States and in the Soviet Union; hence the high risk that some of it be stolen or hijacked.

Of particular concern is 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 -- more than enough to manufacture *ten thousand* nuclear explosive devices). The concern is motivated by the economic difficulties affecting the former Soviet Union including Russia and the Russian nuclear complex (MinAtom), entailing that not all this material is adequately secured against theft or diversion.

Much has been done to improve the safeguarding of this material, via Cooperative Threat Reduction and other programs to which the USA contributes quite substantially (Nunn-Lugar funds, approximately $400 million per year over the last few years). Much more, however, should be done. Other countries (Japan, Europe) have also contributed to this endeavor, but only by marginal amounts.

These programs focus - in addition to nuclear disarmament -- on strengthening Material Protection, Control, and Accounting (MPC&A) at dozens of sites throughout the former Soviet Union, and also at preventing the brain drain towards countries of concern of experts on nuclear weapon technology.

But clearly the most effective way to decrease the risk of nuclear terrorism is to eliminate altogether the basic raw material -- HEU -- needed for the easy manufacture of nuclear explosive devices. From a technological point of view it is quite obvious how to achieve this goal: it is enough to de-enrich HEU to, say, less than 20%, so that it cannot be used any more to produce a nuclear explosion. This is a straightforward task, and one which is extremely difficult -- in fact, for any terrorist group, quite impossible -- to reverse. Moreover, because both the USA and Russia have now much more HEU than they can possibly use for their nuclear arsenals - which are fortunately in the process of being reduced -- it is also politically possible indeed easy to agree and proceed in this direction.

In fact an agreement was reached for the de-enrichment by Russia of a substantial quantity of its HEU -- 500 metric tons -- and the sale of the LEU so produced to the USA. This was an important achievement, but the modalities of its implementation were seriously flawed, inasmuch as they transformed a development motivated by well justified security concerns into a commercial deal, the logic of which turned out to be quite contradictory to the security concerns that motivated this deal to begin with. The origin of this transformation can be traced to the announcement by the Clinton Administration that the deal would be effected "at no cost to the American taxpayer" -- probably motivated by the need to sell such a deal, entailing an overall payment to Russia of some $12 billion, to an unsympathetic Congress dominated by the Republican Party. Indeed the idea is that Russia de-enriches its weapon-grade HEU to reactor-grade LEU, sells the LEU so obtained to the USA, who then sell it to electrical utilities as fuel for nuclear reactors, thereby recuperating the funds paid to Russia.

But unfortunately commercial considerations became so uppermost in determining the specific terms of the agreement, that its implementation was staggered over a twenty year period, mainly in order not to affect excessively the market price of LEU -- an absurd time scale in the context of the tremendous dangers associated with the presence of large quantities of insufficiently guarded HEU in Russia. Matters were made much worse by assigning the implementation of the agreement to the United States Enrichment Corporation, an institution that clearly had no interest to begin with in importing enriched uranium from Russia, and which was moreover simultaneously transformed from an agency fully owned by the Federal Government into a private company, that could of course not be expected to lose money because of national and international security considerations. As a consequence the HEU Deal -- to which USEC assigned the public relation name "Megatons to Megawatts" -- was, in a context of worldwide declining demand for LEU, much hampered and its implementation delayed, so that it had to be rescued more than once by interventions of the Federal Government and, after almost ten years from the date of the original agreement (1993), the LEU transferred to the USA corresponds to only little more than 100 tons of Russian HEU.

It is clearly necessary and urgent that the HEU Deal be revisited by the USA 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 is not enough: some thought should be urgently focussed on ways and means to address the risk implicit in the existence of the enormous stocks of excess HEU in Russia (and also in the USA), the size of which will be increased by the progress in nuclear disarmament that has been very recently agreed to by Presidents George W. Bush and V. Putin (although the time scale -- 20 years -- of this welcome development also appears excessively drawn out). The goal should of course be to eliminate this dangerous material as quickly as possible. Let me quote from my CERN Lectures1 an approach to achieve this goal.

"An obvious scheme -- to the extent concern focuses on the HEU in the former Soviet Union, most of which is in Russia -- is to subsidize its de-enrichment. Indeed, it would be wise to provide such a substantial financial inducement that Russia -- and specifically MinAtom, the institution in Russia that is responsible for the oversized and now underfinanced Russian nuclear complex (including both military and civilian installations) -- proceed in this direction at the fastest possible rate, carefully striving to retrieve all available HEU. A secondary advantage of this approach would be to infuse funds in the MinAtom operation, funds which might contribute to prevent catastrophic developments resulting from the overall decay of this crucial institution. But let me emphasize that this positive aspect is secondary. Even if it were not to emerge because the funds take other directions, nevertheless the main goal -- elimination of the dangerous material (HEU) -- would be achieved by the scheme outlined below.

It seems to me that a reasonable scheme to implement this approach will be to offer MinAtom an immediate cash award for every quantity of HEU that is de-enriched -- perhaps a reasonable amount would be US$ 10 for each gram of high-grade HEU that is eliminated, but of course the exact amount should be negotiated and mutually agreed. Clearly for the scheme to work enough transparency should be provided by MinAtom to guarantee first of all that the production of new HEU is definitely stopped, and secondly that the de-enriched HEU is properly measured, accounted for and safeguarded (possibly by the International Atomic Energy Agency). The award could be considered as a loan without interest, to be given back by Russia when the LEU gets sold, over time, to utilities worldwide, for the production of electricity. (The order of magnitude of the expected revenue might be twice the cash value of the award mentioned above, although such an estimate is quite tentative as the future market price of LEU is hard to predict.) The main lender might be the USA, but other affluent partners (European Union countries, Japan, Canada, etc.), which certainly also have a stake in preventing the tremendous risk entailed by the large available stocks of HEU, should also be willing to pitch in. There is no doubt in my mind (also on the basis of explorations I have made with relevant individuals) that the offer of such a scheme -- or variants of it, all having the goal to promote the elimination of HEU at the fastest possible rate -- would evoke a positive reply by Russia, and probably as well from all other countries possessing (certainly much smaller) stocks of HEU, to which similar offers should also be made. The exceptions would be the more affluent countries, *in primis* the USA, which should be expected to dispose of their own stocks of HEU without external help."

Finally, a few words about Plutonium, which is the (only) other indispensable raw material -- additional, or alternative, to HEU -- out of which nuclear bombs are now made.

Indeed, the disposition of Plutonium in ways that minimize the possible adverse effects of its wide availability as regards nuclear-weapon proliferation has been much more at the center of attention[2] than the analogous problem for HEU -- in spite of the fact that the quantities of HEU now available are larger, perhaps by an order of magnitude, than those of Plutonium. The main reason of this fact is that, while -- as explained above -- the technological route to eliminate HEU is quite obvious, the way to dispose of Plutonium so that it will no more pose a nuclear-weapon proliferation risk is a much more complicated issue, both technologically and politically -- for reason which shall not be detailed here.

But while the availability of Plutonium certainly poses a risk with respect to the possible acquisition of nuclear weapons by States, it does not really pose -- in my opinion -- a significant risk for the possible clandestine manufacture of a nuclear explosive device by a subnational terrorist group. Indeed the technological expertise required to manufacture a nuclear explosive device based on Plutonium (including experimentation with very sophisticated conventional explosives and electronic equipment, and the fact that handling Plutonium entails much greater health hazards than it is the case for HEU) is so much greater than in the case of HEU, to most likely exceed that available to any subnational terrorist commando.

It is for this reason that, to lessen the tremendous threat of nuclear terrorism, it is in my opinion justified -- indeed, necessary and urgent -- to focus primarily (although, of course, not exclusively) on HEU, with the goal to eliminate as much of this dangerous material as possible, as quickly as possible.

FOOTNOTES

1. See, for instance: "Fast-track the uranium deal", Bull. Atomic Scientists, November/December 1997, pp. 20-21; reply to letter, Bull. 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.

2. For a recent overview of the risks associated with the availability of nuclear-weapon materials see: M. Bunn, "The next wave: urgently needed new steps to control warheads and fissile materials," April 2000, available at http://ksgnotes1.harvard.edu/BCSIA/Library.nsf/pubs/Nextwave, and the literature quoted there, including in particular: H. Baker and L. 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.