The Risk of a Nuclear Catastrophe

Francesco Calogero

Physics Department, University of Rome I "La Sapienza"

1. Introduction: various types of nuclear catastrophes

Nuclear catastrophes may be of different types. A rough taxonomy lists, in a rough order of decreasing impact: (1) a major nuclear war involving a large number (hundredths, thousands) of nuclear explosions; (2) a military conflict in which few (say, a one-digit number of) nuclear explosions take place, mainly against civilian targets (cities); (3) the military (so-called "surgical") employment of few nuclear explosions against specific targets, such as deeply-buried bunkers housing key installations, trying to minimize "collateral damage" to civilians; (4) the destruction of a city by a nuclear explosion produced by a terrorist commando; (5) the deliberate radioactive contamination on a significant scale of an inhabited area (so-called "dirty nuclear bomb" or, more properly, "radioactive dispersion device"); (6) the accidental explosion of a nuclear weapon, or other accidents involving nuclear weapons; (7) a serious accident in a civilian nuclear installation, typically in an electricity-producing nuclear reactor. I review below quite tersely these 7 types of events. I then focus on item (4), the treatment of which constitutes the main topic of this contribution. And I then complete this presentation with a terse mention of the risk of nuclear-weapon proliferation, a topic that should never be forgotten given its impact on the future of our civilization inasmuch as it largely influences the likelihood that some of the catastrophes listed above shall eventually happen; and with the opposite prospect of progress towards the achievement of a nuclear-weapon free world.

1.1. A major nuclear war

During the Cold War enormous nuclear arsenals have been built and deployed, mainly by the USA and the Soviet Union, now Russia. They comprised several tens of thousands nuclear warheads, most of them having explosive yields hundreds of times larger than those of the two bombs that destroyed Hiroshima and Nagasaki (6 and 9 August 1945; themselves with yields of 10-20 kilotons, namely equivalent to the explosive energy released by 10-20 million kilograms of high explosives such as TNT). Given the size of these arsenals, and the enormous effects of nuclear explosions -- including, in addition to blast and heat (killing people and causing large-scale fires), immediate nuclear radiation and delayed radioactivity (fallout) -- the possibility of an all-out nuclear war involving the two major nuclear-weapon countries entailed the prospect of an abrupt end of our civilization, possibly even the extinction of *homo sapiens*. The present arsenals have been somewhat -- but not yet drastically -- reduced with respect to those of the Cold War time. The prospect of a major nuclear war involving the two nuclear superpowers has instead decreased

substantially -- although many nuclear-armed missiles with intercontinental ranges are still kept on quick-reaction alert entailing the capability that their launch be decided and executed within minutes. A worrisome recent development is the return -- by the current leaderships in the United States and in Russia (Bush and Putin) -- to antagonistic postures playing up to nationalistic feelings and based on unilateral rather than cooperative attitudes to national and international security.

1.2. Few nuclear explosions in the context of a military conflict

A military conflict in which very few nuclear explosions take place, mainly against civilian targets (cities), would entail the immediate death of millions of people, the delayed death – after weeks and months of suffering – of many more, and of course major economic losses. It might typically occur in the context of confrontations among countries with nuclear weapons, such as the conflict over Kashmir pitting India and Pakistan against each other, or a military development in the Middle East leading to the employment of nuclear weapons, presumably in a situation in which the leadership of Israel -- the only country in that region having now an operational nuclear arsenal -- feels the very survival of their country at risk. Clearly any prospect of additional nuclear-weapon proliferation in the extended Middle East region will increase the risk of nuclear catastrophes in that region, while on the contrary the establishment and implementation of a nuclear-weapon-free zone agreement covering that region -- or a weapons-of-mass-destruction-free zone agreement, also encompassing chemical and biological weapons -- would essentially eliminate that danger, especially if it were achieved in the context of a transition from the present conflictual circumstances to a universally accepted settlement of existing controversies, including the mutual recognition of all States in the region (including Israel and a Palestinian State).

1.3. Few nuclear explosions pinpointed on specific military targets

This scenario has been contemplated relatively recently, mainly in the context of envisaged attempts to destroy underground bunkers containing installations considered of crucial strategic relevance, such as those producing materials essential for eventual or ongoing nuclear-weapon proliferation: for instance, centrifuges enriching uranium -- say, in Iran -- or nuclear reactors producing plutonium -- say, in North Korea. The effectiveness of such actions is moot, as well as the illusion that they might be achieved with relatively minor “collateral damage”. It is moreover -- hopefully -- widely understood that any military employment of nuclear weapons -- breaking a taboo that prevailed for over six decades (Hiroshima and Nagasaki, August 6 and 9, 1945, were the only instances of the use of nuclear weapons “in anger”) -- would represent a major blunder, certainly with very bad repercussions -- for instance in terms of nuclear-weapon proliferation. Fortunately it appears that the possibility of undertaking such initiatives is somewhat less talked about now than it was in the recent past. In any case it is useful to remind any decision-maker contemplating the responsibility of ordering such actions that whoever were to do so would be considered a “war criminal” in terms of international law as currently

interpreted by the International Court of Justice: a judgement likely to affect the rest of the life of that person, and likely to go down in history.

1.4. Destruction of a city by a nuclear explosion produced by a terrorist commando

It has been and is my assessment that the likelihood that such a catastrophe occur is significant -- and can be significantly affected by some countermeasures that might and should be taken, while it is only marginally influenced by other, rather useless, types of countermeasures now being contemplated and undertaken. The bulk of this presentation will be devoted to this topic. Clearly to make such an assessment, and to evaluate the more adequate countermeasures, it is necessary to understand and discuss the easiest route, for the possible perpetrators, to achieve the goal of destroying a city via a nuclear explosion. The risk that by doing so one might provide useful hints to them, turning concern into self-fulfilling prophesy, should not be neglected: this suggests caution in treating these matters, both in terms of the information provided and the kind of media used to advertise these possibilities. But excessive self-restraint carries the opposite danger of forswearing the responsibility to issue warnings that, if heeded, might instigate initiatives likely to decrease significantly the probability that such a terrible disaster occur.

Another component of this issue -- that will be ignored below, since I do not feel competent to provide in this direction any nontrivial information -- deals with the reasons and sentiments motivating the possible perpetrators of such a hideous act, aimed at killing in a flash millions of civilians and other millions after weeks and months of suffering. Suffice here to state that the argument often used in the past -- according to which terrorists, being politically motivated, would never use such tactics, likely to alienate the sympathies of most people -- are now considered to be invalid by most competent observers.

1.5. Radioactive-dispersion device

This refers to the possibility of the deliberate dispersal, “in anger” (i. e., with the specific purpose to harm people), of radioactive materials. It seems to me that this threat has been given more play than it really deserves. Indeed the likelihood that many (say, thousands) of people would die within weeks due to the radioactive contamination caused by such an event is moot, mainly because of the difficulty of getting hold, handling and properly dispersing a quantity of radioactivity likely to produce such results. It is undoubtedly possible to achieve in this manner a major media impact, and as well a very significant economic impact if such an event will occur on a significant scale in a major city, and also quite a few casualties resulting from the panic that might ensue – also due to the widespread fear of radioactivity, compounded by the inability of humans to feel its presence (although simple and cheap instruments to detect and measure it exist). The countermeasures to be adopted are quite obvious, and should be in any case undertaken independently of the terrorist threat: monitor and protect carefully all radioactive sources, educate the public to

understand (quantitatively!) what radioactivity is, what the dangers associated with it are, and how it can be measured (also making widely available simple instruments to do so).

1.6. Accidents involving nuclear weapons

Of course, due to the existence of nuclear weapons, a nuclear catastrophe could occur accidentally rather than being intentionally caused. Two scenarios are relevant with respect to this risk.

The first and most dramatic -- as it might trigger a nuclear war -- might be caused by the accidental launch of a nuclear-armed delivery vehicle -- typically a long-range missile carrying nuclear warheads. Careful procedures -- including the psychological screening of the men who are in charge of these missiles -- have of course been envisaged to minimize this risk. But some such danger of course lingers, especially in the context of nuclear postures -- such as those still prevailing in the USA and Russia -- maintaining the option to decide and execute the launch of some intercontinental nuclear-armed missiles within minutes. The reasonableness to maintain such postures should be questioned by public opinions and by political leaders.

An additional worrisome element possibly entailing malign interventions rather that inadvertent mistakes is the possibility that the computer network controlling the launches of missiles -- as well as the influx and assessment of the information determining the eventual decision to launch -- be penetrated and tampered with by insiders and/or by outside hackers, with catastrophic consequences. Clearly such possibilities cannot be completely ruled out as long as nuclear weapons exist, and in particular as long as some of them are deployed on long-range delivery vehicles such as missiles (unstoppable once launched) in a quick-response alert mode.

The second type of risk is the accidental explosion of a nuclear weapon due to a mishap. Serious accidents involving nuclear weapons -- but none of them causing an actual nuclear explosion -- occurred during the height of the Cold War, when nuclear weapons were routinely flown on bombers, some of which were always kept in the air.

Finally, no discussion of accidents involving nuclear weapons can omit at least a mention of the submarines carrying nuclear-tipped missiles, that constitute an important component (due to its “invulnerable” character) of nuclear arsenals. The dramatic loss of such submarines with their entire crew is unfortunately a possibility that has indeed materialized.

1.7. A serious accident in a civilian nuclear installation

Minor accidents occur routinely in nuclear installations: some of them might entail the release of minute quantities of radioactivity. Given the idiosyncratic fear of public opinions with respect to radioactivity the management of nuclear installations tries occasionally to hide such events, rather than dealing with them with complete transparency. Such a tendency tends of course to increase rather than to decrease the concern of public opinions. Occasionally (rarely) an important accident occurs: the

major instance was Chernobyl, mainly due to a quite irresponsible behaviour of the managers of that nuclear installation. However, even in that case, no nuclear explosion occurred. In fact the probability that a nuclear explosion occur in a nuclear reactor is extremely tiny, for all practical purposes it can be considered an impossibility: even as a consequence of deliberate sabotage, the occurrence of a real nuclear explosion in a nuclear reactor (with effects comparable to those produced by a nuclear-explosive device) is extremely unlikely, perhaps just impossible. But electricity-producing nuclear reactors, after they have been operating for quite some time, contain very large quantities of highly radioactive material, and the release of even part of it -- due to an accident (now rather unlikely) or to sabotage -- would certainly constitute a major disaster. This is what happened in Chernobyl: accidentally, but due to such an irresponsible behaviour of the management of the reactor that the event could even be categorized as unintentional sabotage…

But the enormous, qualitative difference should be emphasized among the consequences, on one side, of a nuclear explosion in an inhabited area such as a city (deliberately produced with the intent to harm) and, on the other side, of the release of radioactivity due to even a major accident -- some kind of (non nuclear) explosion -- in a nuclear reactor or in an installation where radioactive spent fuel elements of a nuclear reactor are stored.

2. Nuclear terrorism

This second section focuses on the risk that a small subnational group acquire the technical capability to destroy large part of a large city with a nuclear explosion, causing an enormous human catastrophe, probably worst than what happened on August 6, 1945, in Hiroshima and three days later in Nagasaki. If and when a terroristic commando will demonstrate such a capability, such an event -- a nuclear explosion in a city -- and the prospect that such a catastrophe be repeated -- will put into question the very survival of our civilization.

What could and should be done to lessen this risk is then tersely outlined.

2.1. The most likely procedure for a terrorist commando to destroy a city

A small subnational commando -- provided it acquires a sufficient quantity of (weapon grade, i. e. uncontaminated and containing, say, at least 90% U-235) Highly Enriched Uranium (HEU) -- is quite likely to be able to manufacture a primitive nuclear explosive device, itself quite likely to destroy large part of a large city, killing promptly very many people (at least several tens of thousands, but more likely hundreds of thousands or even millions), leaving in its wake as many or even more who will suffer for days weeks months before dying, and causing an immense economic damage. To reach this conclusion – which has the nature of a scientific/technological truth – one must realize that a primitive nuclear explosive device is much easier to manufacture than a nuclear weapon produced for employment in a military context by a State: the nuclear explosive device need not be

transportable nor sturdy (most likely, it will be clandestinely manufactured in a rented locale in the target city), it need not be reliable (most likely, its yield will be *a priori* unpredictable, but with a significant probability to be of the order of that of the Hiroshima bomb), it need not have any security/safety gadgets (but given the low radioactivity of Uranium it can be manufactured without any health risks), and most likely it will be exploded via a timer allowing ample time for an easy getaway. The ease to manufacture such a device is implied by the fact that a nuclear explosion is produced whenever a supercritical mass of HEU is assembled sufficiently fast (namely in a time of the order of, say, a millisecond), possibly with a tamper around it in order to reduce the critical mass and to facilitate the supercritical mass remaining assembled for a sufficiently long time so as to guarantee that a cosmic ray neutron, or an internally produced neutron, start the chain reaction and that the chain reaction involves a sufficiently large number of nuclei before it gets stopped by the explosive disassembly of the device.

All the additional materials besides HEU needed to manufacture such a device are easily available in the open market (except possibly for some conventional explosives, easily available in the black market if they are indeed needed). And no previous expertise in the manufacture of nuclear weapons is needed (although it would of course facilitate the task), nor any knowledge of nuclear or material sciences beyond what an intelligent bricoleur may easily get from the open literature (available in books and via internet). This explains why this task can presumably be performed by a small commando of individuals, who need not muster any exceptional skills. While this is not the place to go into additional details, I suggest to any reader who doubts that this assessment is scientifically or technologically correct, to consult experts on the manufacture of nuclear weaponry -- but make sure that the question being asked is the proper one, namely not the difficulty to build a *nuclear weapon*, but the difficulty to manufacture a *nuclear explosive device* of the type likely to be realized by terrorists in order to destroy a city. And I invite those of you who are interested but sceptic to read the appropriate literature. Let me just quote here a sentence from a paper entitled “The technical opportunities for a sub-national group to acquire nuclear weapons”, written by a former director of the Sandia Laboratory in the United States, where the US nuclear weapons are manufactured:

“While not entirely straightforward, designing and fabricating a nuclear explosive device of the type described here is unlikely to confront a sub-national group with insurmountable difficulties”.

And I should add that in his paper this author is actually discussing a somewhat more reliable nuclear explosive device than the gadget I mentioned above – as being one the yield of which would be *a priori* unpredictable, but with a significant probability to be in the kiloton or multi-kiloton range (the yield of the Hiroshima bomb was about 13 kilotons, produced by the fission of about one kilogram of HEU; about 60 kilograms of HEU were contained in that bomb).

Fortunately there is a barrier to be overcome before a subnational terrorist group acquire the capability to destroy large part of a large city via a nuclear explosion, namely the difficulty to get hold of the required quantity of HEU. This

explains why a nuclear catastrophe has not yet happened. But complacency in this respect is, in my opinion, unwise. I have however become convinced that the scepticism about the likelihood of a catastrophe of new type happening is so widespread and overwhelming, that the threat of a nuclear explosion in a city caused by a subnational commando is unlikely to be taken adequately seriously before a catastrophic instance of it happen. Indeed the main rejoinder I hear by individuals who try to downplay this risk is: if you say it is so easy to do, why it did not yet happen?

Let me repeat: I believe the reason why it did not yet happen is because it is difficult for a subnational group to get hold of the sufficient quantity of (weapon-grade uncontaminated) HEU. And I do not pretend to be able to provide any reliable expertise on this aspect of the problem, which has to do mainly with intelligence. But it seems to me the following facts motivate serious concern.

One hundred kilograms of weapon-grade HEU are more than enough to manufacture easily a primitive nuclear explosive device. Once this amount of HEU is acquired by a terrorist commando, smuggling it anywhere is a trivial task, facilitated by its small volume (less than ten litres) and marginal radioactive signature. On the other hand I do not believe that HEU can be manufactured by a terrorist commando, indeed few States have the capability to produce it; and I discount the likelihood that any state provide a terrorist group with a large enough quantity of such material -- hoping not to be overly optimistic in this respect. But this amount of HEU -- less than *one hundred* kilograms -- must be compared with the existing stocks of this material, which in Russia alone probably still exceed *one million* kilograms, dispersed over many sites (perhaps up to one hundred?).

Of course these considerations do not apply only to Russia, which is however the country where there is the largest stock of HEU.

2.2. Preventive countermeasures

Obviously the first priority to prevent the acquisition by terrorists of the capability to manufacture a nuclear explosive device is to impede that they acquire a sufficient quantity of HEU.

Some steps to improve the accounting and physical security of this material have been taken, mainly in the context of cooperative activities among the United States and Russia (and some of the other New Independent States formed after the disappearance of the Soviet Union), funded by the United States under the Nunn-Lugar legislation; but many experts believe that much less than enough has been and is being done.

Some progress has also been made in eliminating HEU: indeed the oversized stocks of HEU left over after the end of the Cold War make the elimination of large quantities of it -- hundreds of metric tons -- insignificant from a military-strategic point of view (except as regards the risk of its use by terrorists!); while the down-blending transformation of HEU into LEU (Low Enriched Uranium) containing, say, 3-5% U-235, which is the standard fuel for most commercial nuclear reactors, can be performed easily hence cheaply. (LEU cannot be used to manufacture nuclear

explosive devices, and transforming LEU back to HEU is a task beyond the capabilities of most States, let alone a terrorist group). The most important development of this kind is the so-called "HEU Deal", agreed at the beginning of the 1990's, that regulates the down-blending to LEU in Russia of 500 metric tons (half a million kilograms) of Russian HEU and the sale of this LEU to American utilities via the United States Enrichment Corporation (USEC), a previously federally-owned institution that was privatized just when this deal was initiated. This arrangement is meant to entail that this entire operation be conducted "at no cost to the American taxpayer". But this caused the security motivations to eliminate *as much HEU as possible as quickly as possible* acquiring secondary importance with respect to the commercial aspects of this deal. Indeed, mainly for commercial reasons (namely, not to affect adversely the market price of LEU), the implementation of this deal has been spread over a quite long time period (20 years) -- hardly consistently with a proper appreciation of the danger entailed by the prospects of nuclear terrorism based on the availability of HEU. Moreover, again just due to controversies about financial aspects, this program suffered various delays.

Anyway so far the HEU Deal caused the elimination by down-blending of over 300 metric tons of Russian HEU (estimated by USEC to correspond to the elimination of over *twelve thousand* nuclear warheads), and it seems to proceed now at a steady rate entailing the elimination of 30 metric tons of HEU per year. This is a positive result, although much more could and should be done, indeed a faster rate of elimination (by as much as a factor of five) would have been feasible -- certainly technologically and also in terms of Russian willingness -- if adequate funds were made available (even on a temporary basis) to support an acceleration of the elimination of the 500 metric tons of HEU declared by Russia to be in excess of their military needs. An extension of the project so as to eliminate additional quantities of Russian HEU can/should now be envisaged, perhaps via a different sort of financial arrangement. Unfortunately -- and in my opinion most unwisely -- the USA and other affluent countries do not seem as committed to address this question as it should be implied by the lip service paid to the risk of nuclear terrorism, for instance at the meeting of the G8 group of nations (or G7+1: Canada, France, Germany, Italy, Japan, UK, USA + Russia) held at Kananaskis in 2002, where the formula 10+10/10 (ten plus ten over ten) was advertised, meaning an agreement "in principle" to devote 10 billion US dollars by the USA, plus 10 billion US dollars by the other countries, over the next 10 years, to promote various developments meant to alleviate the risk of the use by terrorists of means of mass destruction. But these commitments have not been and are not being fully implemented.

A study advocating faster progress in the elimination of HEU and suggesting political and financial arrangements to this end was completed some years ago. It originated in the Pugwash context -- then was commissioned by the Swedish government and performed by an international expert group. [G. Arbman, F. Calogero, Paolo Cotta-Ramusino, Lars van Dassen, M. Martellini, M. Bremer Maerli, A. Nikitin, J. Prawitz, L. Wredberg, "Eliminating Stockpiles of Highly Enriched Uranium: Options for an Action Agenda in Co-operation with the Russian

Federation", Report submitted to the Swedish Ministry for Foreign Affairs, SKI Report 2004: 15, ISSN 1104-1374, available on www.ski.se] The main idea of that study is to offer financial incentives – possibly in the form of loans without interest -- to Russia (and possibly to other countries of the former Soviet Union; but most of the HEU is in Russia) in order to promote additional elimination of HEU besides that already agreed with the USA. The hope was that other affluent countries (Europe, Japan, Australia, Canada,...), besides the USA, become involved in this enterprise; but, for various reasons, this has not (yet) happened. Perhaps some developments in this direction -- at least in the bilateral USA-Russia context -- are now in progress. However, the foundation of the HEU Deal was a Russian decision -- taken at the beginning of the 1990s and sanctioned by the Duma -- to declare 500 metric tons of HEU redundant to any military employment. But -- in spite of the obvious military irrelevance of most of the remaining stock of HEU still possessed by Russia-- it seems now unlikely that Russia will agree to additional elimination of its HEU, due to the changed geopolitical setting: much improved financial circumstances of Russia mainly thanks to the raise in the price of oil and gas, deteriorated strategic relations among Russia and Western countries (*in primis* the USA), resurgent nationalism in Russia with the standard associated tendency to ignore rational considerations.

Less than fully reasonable is – in my opinion -- also the attitude of the USA, where -- while 217 metric tons of HEU have been declared unnecessary for national security needs, and about half of them have been already down-blended to LEU -- an enormous quantity of HEU has instead been set aside to guarantee the availability of fuel for nuclear-powered submarines into the remote future.

Also in this connection it should be mentioned that much useful work has been done by professor Frank von Hippel of Princeton University and by others, towards the eventual total elimination of the use of HEU from non-weapon activities worldwide, namely from all research reactors and from all the reactors used for naval propulsion (icebreakers and submarines). Indeed technological developments -- including in particular the development of much more compact LEU fuel elements -- make such a development possible. Clearly the eventual, complete phasing out of HEU from all human activities will be a must for the survival of our civilization, that is incompatible with the availability of a material allowing to a small group of individuals the capability to destroy a city. But let me emphasize that the total elimination of weapon-grade HEU does by no means entail a renunciation to peaceful nuclear activities, including the utilization of nuclear energy to produce electricity, a task which does not require any use of HEU.

Finally let me note that more attention has been and is devoted, rather than to the elimination of HEU, to the elimination of Plutonium, the (only) other material suitable for the construction of a nuclear explosive device. This is due to certain industrial and commercial interests which stand to gain (especially in Europe) from investments made in this direction rather than towards the elimination of HEU, and as well because this problem is technically more challenging (hence intellectually more interesting) than the elimination of HEU. But this misplaced focus is unfortunate, not only because there is still more HEU around than Plutonium, but especially because it

is so much more difficult to build a nuclear explosive device with Plutonium than with HEU that the likelihood that a Plutonium device be manufactured by a sub-state terrorist commando is moot. («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, key physicist in the Manhattan project, and subsequently Nobel laureate in physics, in his memoirs published in 1987, one year before his death).

2.3. Defensive countermeasures

Enormous investments (totalling hundreds of billions of dollars) have been and are being spent by the USA to build a defensive shield against (nuclear-armed) missile attacks. The declared rationale for this investment is the need to defend against the embryonic nuclear-weapon capabilities of "rogue States". It is indeed recognized and advertised by the USA that such a shield will never be effective against an adversary possessing a nuclear-weapon arsenal as large and advanced as that deployed by Russia. But some in Russia nevertheless perceive it as an attempt to eliminate the retaliatory capability of Russia hence to make the threat of an American first-strike against Russia more likely or at least more credible. The response by Russia is to modernize its nuclear-weapon complex, and to be less disposed to reductions in its nuclear weaponry, namely to progress in nuclear disarmament. This pattern is becoming more and more an impediment to that transition from confrontation to cooperation of the USA and NATO with Russia (and also with China), that should have been the natural consequence of the end of the Cold War. There are indeed ugly symptoms of a return towards a Cold War climate in the relations among these two sides, mainly due to developments interpreted in this context as "provocative" by Russia – such as the planned deployment of radar and "defensive" missile bases in Eastern Europe. This is not the place for any further elaboration of these topics. The only point to be made here is that the defensive shield – irrespective of whether it will ever provide any reliable protection against nuclear-armed missiles – is obviously totally irrelevant against the nuclear threat by terrorists. As recently stated (Testimony to Congress, July 2007) by William Perry, a former (from 1994 to 1997) U. S. Secretary of Defence: "The centrepiece of our government's strategy for dealing with a nuclear attack is the National Missile Defence system…But the greatest danger today is that a terror group will detonate a nuclear bomb in one of our cities. Terrorists will not use a ballistic missile to deliver their bomb…".

More relevant to our topic here are defensive measures specifically meant against terrorism, being earmarked to impede the entry of weapons and dangerous materials into a country. A major effort in this direction is made by the USA, involving expenditures totalling billions of dollars. The idea is to install instrumentations and personnel at airports and all ports of entry, capable to monitor hence impede that any dangerous item enter the USA. While an investment in this direction has no negative implications (from the security point of view; it might have some negative economic impact, due to the delays it is likely to entail), it seems to me to be relevant rather as a Keynesian intervention to stimulate employment even if

consisting of quite useless actions (like, as Keynes suggested, employing a work force firstly to dig holes in the ground and then to fill them), than in terms of its effectiveness -- at least with respect to the goal of impeding, to a terrorist commando who had acquired enough HEU to manufacture a nuclear explosive device, to transfer it to the target city and set up shop there to perpetrate their hideous deed. I believe it is possible -- indeed easy -- to block such a commando if by intelligence it has been identified -- before or after it enters the country. I consider instead pie in the sky the hope to create an impenetrable shield making it impossible -- or even quite difficult -- to introduce in a major American city a quantity of HEU sufficient to manufacture easily there a nuclear explosive device capable to destroy it. The motivation of this opinion of mine comes from the very small volume of such material (of the order of ten litres) and its quite marginal radioactive signature -- to be compared with the enormous amount of goods that enter daily, by an extremely large number of legal ports of entries, in the USA -- not to mention the significant quantity of materials, for instance tons of forbidden drugs, that enter every year via illegal routes.

Finally, it should be noted that there begins to be serious consideration in the USA of the measures to be taken if a city is hit by a nuclear explosion (in particular, one caused by terrorists): see, in particular, the report entitled “The Day After: the action in the 24 hours following a nuclear blast”, the text of which is available on the web (http://cisac.stanford.edu/publications/day_after_the_action_in_the_24_hours_following_a_nuclear_blast/).

2.4. How likely is it that this catastrophe will happen?

The title of this section is the natural question that is evoked by any discussion of this unpleasant and scary subject. The only contribution I can usefully provide to this question is to outline -- as I tried to do above -- the technical facts that underlie this issue. This treatment is I believe useful inasmuch as it identifies some fundamental realities, and it also serves to identify measures that should certainly be taken: devote resources and efforts primarily towards the elimination of HEU -- *as much of it as possible as quickly as possible* -- and as long as HEU exists, as stop-gap measure, also devote efforts and resources to improve its physical security. But I do not know if there is anybody who can provide a reliable reply to the question stated above. My hunch -- based on the technical data I know, as reported above -- is that the probability is significant; hence it motivates a quite serious concern. So, I am quite concerned, and I expect a catastrophe to occur any day. But a more specific assessment of the relevant probability requires an expertise on the precise workings of the terrorist archipelago including an insight -- mainly based on intelligence -- that I do not muster. However, it appears that my concern is shared by the authors of the report mentioned at the end of the preceding section, who are presumably much better informed than me on these matters given their previous jobs in government.

3. Nuclear-weapon proliferation

In this section I will tersely review the main facts relevant to the current regime concerning the so-called “horizontal” proliferation of nuclear weaponry (the “vertical” nuclear-weapon proliferation refers mainly to the nuclear arms race involving the two so-called nuclear superpowers, the USA and the Soviet Union, now Russia). This terse review is meant for readers who are unfamiliar with these topics and wish to get a brief survey of the main relevant facts. As already mentioned above the motivation to present it here is because clearly a collapse of the nuclear non-proliferation regime -- entailing the emergence of programs for the acquisition of nuclear weapons in many new countries -- would make the occurrence of nuclear catastrophes much more likely, indeed essentially inevitable: a bleak future for humankind.

I will then end by tersely outlining the prospects that humankind achieve an alternative future, a world without nuclear weapons and without the raw materials to produce them; focussing in particular on some, hopeful, recent developments.

3.1. The nonproliferation regime

The main pillar of the nuclear-weapon nonproliferation regime is the Non Proliferation Treaty (NPT). It entered into force in 1970, and it was made into a permanent treaty – with no time limit – in 1995. The NPT identifies five nuclear-weapon countries: USA, Soviet Union (now Russia), United Kingdom, France, China. Their commitments under the treaty are not to transfer nuclear weaponry to other countries or help other countries to acquire such weapons, and to get eventually rid of their own nuclear arsenals – although no specific time limit is set by the treaty for this achievement. All other countries are identified as non-nuclear-weapon countries, and their commitment is not to acquire nuclear weaponry. The right by all countries to have access to peaceful nuclear technology is moreover affirmed by the treaty, and non-nuclear-weapon countries are committed to accept a verification regime administered by the International Atomic Energy Agency, based in Vienna, to certify that their peaceful nuclear activities are not diverted towards the acquisition of a nuclear-weapon capability.

All countries but three (or maybe four, including North Korea) are now party to the NPT: the three exceptions are India, Pakistan and Israel. The first two have recently acquired a nuclear-weapon capability, and they have demonstrated it by performing experimental nuclear explosions -- underground, in order not to violate the Treaty that prohibits all nuclear explosions not taking place underground, to which these two countries, as most others, are parties. Israel has a deliberate policy of opacity concerning its nuclear-weapon capabilities, but it is certain that it has acquired a nuclear arsenal, presumably meant to be used -- or threatened to be used -- only in exceptional circumstances, when the very survival of that country is perceived to be at risk.

Other important components of the international nuclear-weapon nonproliferation regime are several nuclear-weapon-free zones, covering a large portion of the globe. Generally the nuclear-weapon-free zones exclude altogether the presence of nuclear weapons in the countries that are parties to them, while the NPT

is generally interpreted to allow the presence of nuclear weapons (belonging to a nuclear-weapon country) in a non-nuclear-weapon country provided the hosting country cannot decide by itself to use such weapons. At present the only country that deploys its nuclear weapons in the territory of other countries is the USA. A few hundred American nuclear bombs, to be eventually delivered by aircraft, are now deployed -- in the context of the Atlantic Alliance (NATO) -- in six European countries: United Kingdom, Belgium, the Netherlands, Germany, Italy and Turkey. At the peak of the Cold War, many different types of American nuclear weapons were deployed in Europe, including mines and artillery shells, and several types of missiles besides bombs for aircraft; their total number reached a peak exceeding seven thousands warheads. The American nuclear weapons now present in Europe are meant to have a purely political (symbolic) significance: some NATO documents state that any decision to use them would take months to be implemented. The idea that the negative impact of such a symbol -- in the context of the worldwide nuclear weapon non-proliferation regime -- outweigh now its positive implications seems to be gaining ground on both sides of the Atlantic.

The nuclear non-proliferation regime based on the NPT has had a remarkable success in containing the spread of nuclear weapons. Indeed, at the end of the 1960' it appeared that many countries would acquire nuclear weapons: several countries already had more or less embryonic nuclear-weapon programs, which were terminated when these countries became parties to the NPT; and many more countries would have been forced to start such programs once their competitors and neighbours acquired such capabilities. Moreover the NPT provided the appropriate framework for the complete elimination of the nuclear weaponry of countries that became parties to this treaty *after* having acquired such arsenals: this was in particular the case of South Africa after the political transition to majority rule, and of Kazakhstan, Ukraine and Belarus after the dissolution of the Soviet Union (each of the arsenals of strategic nuclear weapons that fell under the control of the first two of these three countries when the Soviet Union disappeared were much larger than the combined arsenals of the three "lesser" nuclear-weapon countries, United Kingdom, France and China).

But unfortunately there is now an impending risk that the nuclear-weapon nonproliferation regime collapse.

3.2. Viability of the nonproliferation regime

The main symptoms of stress of the nuclear-weapon nonproliferation regime have been the open acquisitions of nuclear weaponry by India and Pakistan, greeted in both countries by signs of broad popular support. Another gloomy indication have been the developments in East Asia, where North Korea has acquired (and demonstrated) a nuclear-weapon capability in clear violation of its commitments under the NPT of which this country was a party, although at one point it declared the intention to abandon that treaty. This has opened the prospect that other countries in that part of the world – in particular Japan and South Korea -- could opt out of the NPT and acquire a nuclear-weapon capability. This would be particularly easy, from

a technological point of view, for Japan, a country that could quickly manufacture a significant nuclear-weapon arsenal if it decided to do so. Fortunately a strong opposition to nuclear weaponry – underscored by its Constitution -- has characterized Japan as a consequence of the Hiroshima and Nagasaki traumas. But it could be overcome by the fear of a nuclear-armed North Korea. Hopefully, however, recent developments justify some hope that the crisis with North Korea be overcome in the context of the six-country negotiations involving North and South Korea, China, Japan, Russia and the USA, entailing a compete and verified renunciation by North Korea of any nuclear-weapon ambition and the consequential re-entry of this country as "normal" member of the international community.

Yet another worrisome development concerns the acquisition by Iran of a large-scale capability to enrich uranium, a technology that Iran claims to be developing for peaceful purposes but that in fact also has a clear nuclear-weapon potential ---as explained above (once such a capability has been acquired, it can be used to produce LEU for peaceful uses as well as HEU for nuclear weapons; justifying the concern that once such a capability has been acquired Iran might walk out of the NPT and acquire nuclear weapons. In spite of contrary statements by Iran, this concern finds some foundation in aggressive pronouncements of certain components of the Iranian political leadership, including its President, and also on dubious aspects of its past activities that have motivated doubts in the context of the verification activities by the IAEA. The future unfolding of this crisis is for the moment unclear.

But it is in any case rather evident that the fundamental underlying reason of the risk that the international nuclear-weapon non-proliferation regime collapse is the unwillingness of the nuclear-weapon countries – *in primis*, the two nuclear-weapon superpowers, USA and Russia – to make serious progress towards fulfilling their part of the NPT bargain, namely the eventual elimination of their nuclear-weapon arsenals. It is in fact obvious that only in the context of a nuclear-weapon-free world -- in which no country reserves the privilege to possess its own nuclear arsenal -- the arguments for acquiring nuclear weapons that demagogues raise and public opinion now eagerly listen to in various geopolitical contexts -- based on the powerful rejoinder: "why should we exercise restraint if others do not?" -- could be effectively countered. To bolster the nuclear non-proliferation regime an overall global consensus must be internationally established, founded on a universally shared norm and entailing a cooperative framework based on a common interest: to prevent any country, and any subnational group -- if necessary by force, with the backing of the entire international community -- from acquiring nuclear weaponry and/or the capability to manufacture nuclear-explosive devices.

3.3. A nuclear-weapon free world: Desirable? Feasible?

This is not the place for a detailed analysis of this issue. Suffice here to note that -- while many influential individuals, especially in or near the leadership of the nuclear-weapon countries (and in particular the most influential of these countries, namely the USA), still believe that the prospect of a nuclear-weapon-free world is utopian,

hence that any policy motivated by this goal is naïve hence misguided -- the recognition of the obvious truth that the achievement of this goal is in fact the only alternative to eventual widespread nuclear-weapon proliferation with catastrophic consequences has been steadily making progress and is now understood and internalized by more and more people, including individuals who played key roles in the development of nuclear weapons, who shaped the thinking about their political and military roles and who served in positions of high responsibility in supervising their management.

Past milestones in this thinking were: two collective books produced in the context of the Pugwash Conferences on Science and World Affairs [*A nuclear-weapon free world: Desirable? Feasible?*, edited by J. Rotblat, J. Steinberger and B. Udgaonkar, Westview Press, 1993 (also translated in many languages including Russian, Japanese, Spanish, Arabic, Korean,…and published in as many countries); *Nuclear Weapons: the Road to Zero*, edited by J. Rotblat, Westview Press, 1998]; two documents issued respectively by the Canberra Commission and by the Committee on International Security and Arms Control (CISAC) of the U. S. National Academy of Sciences ["Report of the Canberra Commission", August 1966; "The Future of U. S. Nuclear Weapons Policy", National Academy Press, Washington, D. C., 1997].

Important examples (all easily googable) of recent developments are: two articles by a bi-partisan quartet composed by two former US Secretaries of State, a former US Secretary of Defence and a former US Senator [George P. Shultz, William J. Perry, Henry A. Kissinger and Sam Nunn, "A World Free of Nuclear Weapons", *The Wall Street Journal*, January 4, 2007 and January 17, 2008]; the reply to the first of these two articles by Mikhail Gorbachev ["The Nuclear Threat", *The Wall Street Journal*, January 31, 2007]; the remarkable remarks by Arnold Schwarzenegger, Governor of California (October 10, 2007); the support that these developments have evoked by most of the former U. S. Secretaries of State, Secretaries of Defence and Special Assistants to the President for National Security; and various significant recent developments along these lines in other countries, including: the specific proposal ("Laying the Foundations for Multilateral Disarmament", February 5, 2008) presented at the Disarmament Conference in Geneva by the British Minister of Defence Des Browne, offering the UK's Atomic Weapons Establishment at Aldermaston to host a technical study of the verification of the elimination of nuclear weapons, to be performed jointly by experts of the 5 official Nuclear-Weapon Countries; and the decision by the Australian government to establish a new Canberra Commission. Pronouncements supporting progress towards the total elimination of nuclear weaponry can also be found in the following developments (to mention just a few): the very recent French White Paper on Defence; several recent interventions by leading British politicians, including the Prime Minister; and a bipartisan group of four eminent statesmen including a former Secretary General of NATO (article in *The Times* of London); an analogous intervention in Italy (an article in the major Italian newspaper signed by four top politicians from both sides of the political spectrum and by myself as token representative of the scientific community: *Il*

Corriere della Sera, July 24, 2008); the electoral platforms issued by both candidates to the November 2008 presidential elections in the USA; and several statements issued by NGOs worldwide, such as, for instance, that issued by the Executive Committee of the Pugwash Conferences on Science and World Affairs and that promulgated by the Luxembourg Forum, an international group of experts based in Moscow -- taking its name, just as the Pugwash Conferences do, from the location of its first meeting -- who convened an international conference recently (June 2008) in Rome.

Collectively, these developments suggest that the prospect of the transition to a Nuclear-Weapon-Free World is graduating from desirable utopia to practical politics. Clearly in this respect a crucial role will be played by the new American Presidency.