Volume 87 Number 859 September 2005

INTERNATIONAL
REVIEW
of the Red Cross

Use of nuclear and radiological weapons by terrorists?

Christoph Wirz and Emmanuel Egger
Christoph Wirz (Dr. phil. nat.) and Emmanuel Egger (Dr. rer. nat.) are senior physicists in charge of nuclear issues at the Spiez Laboratory, the Swiss Nuclear, Biological and Chemical Defence Establishment.

Abstract
There is great concern that terrorists could obtain nuclear or radiological weapons and detonate them in a large city. The authors analyse the technical requirements for and obstacles to obtaining such weapons. What difficulties would have to be surmounted? Could these problems be solved by a terrorist organization without direct support from a State possessing nuclear weapons? The authors conclude that nuclear weapons are most likely out of reach for terrorists. However, radiological weapons may well be used by terrorists in the future. The possible consequences of such an attack are discussed.

Introduction

Fortunately there have not been any acts of nuclear or radiological terrorism so far. But the attack with the chemical warfare agent Sarin in Tokyo (1995), the anthrax cases in the USA (2001) and the smuggling of radioactive material are causing concern. Furthermore, the attacks of 11 September 2001 clearly showed that there are groups with considerable financial and human resources as well as the will to inflict the highest possible damage.

Does the fact that there have not been any acts of nuclear terrorism mean that this is unlikely at present and not very probable in the future? What is easy will be done, what is difficult is less likely to happen. With this in mind, a study was conducted to consider the technical difficulties involved, the materials needed and the problems a terrorist group wanting to secretly implement such a project would face.[1] That comprehensive study has been used as a basis for this less technical article.

The first part concentrates on the feasibility of nuclear terrorism. It will demonstrate that the use of nuclear weapons by terrorists is very unlikely. Conversely, radiological weapons may well be within terrorists' capabilities. Possible consequences of the use of radiological weapons will therefore be discussed in detail.

Use of nuclear weapons by terrorists?

There are two imaginable ways for terrorists to get nuclear explosives. They could try to build a so-called improvised nuclear device (IND) or they could seek to steal or buy a nuclear weapon. Before discussing these two cases, we would like to give some information on the working principle of the simplest nuclear weapons.

The working principle of a nuclear weapon

In a nuclear weapon there is enough fissile material for the formation of several critical masses, but prior to detonation it is kept in a subcritical state. In other words, the fissile material is arranged in such a way that spontaneous neutrons cannot start chain reactions or only very short ones, which quickly die out.

To initiate the nuclear explosion, the fissile material is brought as quickly as possible into the state of maximum supercriticality. At the optimum moment, the chain reaction is started by an injection of neutrons from a neutron source, thereby starting a kind of race between two processes: on the one hand, in a supercritical configuration the number of neutrons and with them the amount of energy released rises exponentially; on the other hand, this energy released by the fission events causes an expansion, which tends to make the configuration subcritical again.

If the chain reaction starts before the system is near the maximum reachable overcritical state, the rise in the neutron number is less steep and the energy yield will be only a fraction of the maximum possible one. Because of spontaneous fission, new neutrons are constantly being released and the presence of neutrons that can induce such a pre-ignition cannot be ruled out.

Depending on how the initially subcritical mass is made supercritical, one can distinguish between two main types of explosive configurations: the gun-type and the implosion-type.

Gun-type
Before the explosion the fissile material is kept in a number of separate pieces, each below the critical size. Using conventional explosives, the pieces are then joined together to form a single geometrically favourable (spherical would be

1 Bernard Anet, Ernst Schmid, Christoph Wirz: "Nuclear terrorism: A threat to Switzerland?", Spiez Laboratory Internal Report, LS2000-03, 2000.

best) supercritical mass. The density of the fissile material does not change, or changes only insignificantly.

As this method is very slow, pre-ignition can drastically reduce the yield from the design yield of, say, 13 kT down to a few tons.[2] To have a good chance of reaching the design yield, only fissile material with a very low spontaneous fission rate is used, i.e. uranium with a high U235 content.

The nuclear weapon dropped over Hiroshima was based on the gun-type. A cylindrical plug of uranium with a diameter of approximately 10 cm and a length of approximately 16 cm was fired into a hollow cylinder of uranium. The joint weight of the two masses was 64 kg and they consisted of 80% of U235 on average. South Africa also built six gun-type bombs which each used 55 kg of 80% U235 and later dismantled them.

Implosion-type

A subcritical spherical mass of fissile material is symmetrically squeezed so that the configuration becomes supercritical. Because the critical mass is inversely proportional to the square of the density, a twofold compression turns an object of half a critical mass into one with two critical masses. Such compression can be achieved with spherical convergent shockwaves. For that purpose "lenses" of explosives with widely different velocities of detonation waves are used. The lenses must be arranged around the sphere which is to be compressed, so that the whole surface is covered.

Although this method is quick, pre-ignition can still reduce the yield from the design yield of, say, 20 kT down to 1 kT or less. Yet the chance of reaching the design yield is good, even with fissile material with a not very low spontaneous fission rate. Highly enriched uranium and plutonium (preferably with a low Pu240 content) may be used.

The bomb dropped over Nagasaki was of the implosion-type. The core of this nuclear weapon consisted of 6.2 kg plutonium (approx. 0.9% Pu240).

Can terrorists build an improvised nuclear device (IND)?

Requirements to obtain a plan

To make a working IND an accurate blueprint is required and not only a sketch of the principles. Although it is amazing how much interesting and correct information is publicly available on nuclear weapons physics and technology, especially from the Internet, this does not mean by far that the said information would be sufficient for making a nuclear explosive device. It shows on the contrary what extreme difficulties in terms of technical skills and engineering knowledge would have to be overcome.

There was talk of a Chinese bomb design sold by the Khan network (22 kT uranium implosion device) to Libya. Apart from this example, we have not heard of any blueprints being out of governmental control.

2 Yield: energy released, usually expressed in kilotons of TNT equivalent (kT); 1 kT corresponds to 10^{12} calories or 4.19×10^{12} joules.

But even if a terrorist group could get hold of such a blueprint, they would most certainly be forced to redesign. It is very unlikely that they would have the same fissile material and the same types of explosives China used 40 years ago. To adapt a plan they have to understand it, they need to know why some decisions have been taken — basically the same knowledge and expertise is required as for a completely new design. How much effort is needed to get this knowledge?

The so-called N-th Country experiment conducted by the United States government between 1964 and 1967 might give some indication. Three post-doctorate physicists with no access to classified information were given the task of developing a viable fission weapon design. They were able to use the extensive library of the Lawrence Radiation Laboratory and go to congresses on explosives. To simulate the help of an experimenter team they could describe an experiment in great detail, and then a team of experienced bomb designers would calculate and pass the result of the experiment back to them. After expending three years of manpower over two and a half calendar years, they had a design of an implosion-type weapon which they were later told was viable. Now what does viable mean? Would this bomb yield 1 kT or 20 kT? It was never built and never tested.

A terrorist group could doubtless pay physicists to do such a job. But as certain information cannot be found in the relevant literature, a few crucial experiments would have to be done. This requires access to materials that are difficult to obtain and gives rise to secrecy problems.

The difficulty of obtaining fissile material

Experts seem to agree that the most difficult challenge for a terrorist organization wanting to construct an IND would be to obtain the necessary fissile material. For a gun-type weapon, about a bare critical mass of very highly enriched uranium (see Table 1 below) is needed. For an implosion-type approximately half a bare critical mass of highly enriched uranium or of plutonium is needed.

Both the enrichment of uranium and the production of plutonium in a nuclear reactor are surely out of the question for a terrorist group; the efforts required would be much too big. Certainly, such projects could not be kept secret. So this possibility can be ruled out. Nonetheless, the option of stealing or buying stolen fissile material remains.

Most nuclear power plants worldwide use low enriched uranium (LEU). This fuel is of no use for building a bomb. There are, however, civilian research reactors, test reactors and submarine propulsion reactors which use highly enriched uranium (HEU), i.e. uranium with a U235 content higher than 20%. Moreover, part of the used civilian spent fuel is recycled, i.e. the plutonium which built up during the time in the reactor is taken out and re-used in new fuel rods. Although such civilian fissile material is not optimally suited for making a nuclear bomb and no nuclear-weapon State would ever use it, it might be used by terrorists.

To prevent the use of civilian fissile material for military purposes, the International Atomic Energy Agency (IAEA) inspects all nuclear facilities and every storage facility in the non-nuclear-weapon States which are parties to the Treaty on the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty

- NPT). The IAEA prescribes to the operators and owners of such facilities how the fissile material must be safeguarded, and by its bookkeeping it also knows where what quantities of fissile material exist. The frequency of the inspections depends on the danger that could be caused by the material if stolen.

Information on smuggling activities may serve as a measure of the efficiency and comprehensiveness of fissile material control. The IAEA "List of confirmed incidents involving HEU or Pu" shows a peak of incidents in 1994. All the material on this list combined would be well below the amount necessary for a nuclear weapon. Although this is comforting, the percentage of smugglers caught is not known, nor whether the drop since 1994 is real. Maybe the smugglers have learned and are now more sophisticated.

The difficulty of manufacturing the IND

Even if fissile material and blueprints exist, the making of an IND would still be a demanding technical project. Above all because of the large quantities of fissile material, it is a life-threatening undertaking for the potential manufacturers.

Although the obstacles to manufacturing a gun-type IND are clearly smaller than those for an implosion-type, they must not be neglected. To make the uranium parts of the IND, metallurgical experts and equipment are required. The following are some of the practical obstacles they would have to overcome:

- uranium ignites spontaneously in the air at 150-175° C;
- uranium is chemically toxic and radioactive. Highly enriched uranium exhibits more than 100 times as many disintegrations per time unit as natural uranium;
- when cooling down from its melting point (at 1132.2° C) to room temperature, uranium undergoes two phase transitions. The density thereby increases by more than 8.5%. A change of 8.5% in density results in a change of approximately 18% in the critical mass;
- it is not possible to check whether or not the two subcritical masses fit together;
- reflector materials and isostatic presses suitable to form reflectors are subject to export controls.

The following example may serve to demonstrate the difficulties of compression and consequently those of building an implosion-type improvised nuclear device. In order to squeeze one litre of water into a volume of half a litre or less, huge pressure would be needed and the slightest asymmetry would cause a jet, not compression. As the binding forces between the atoms of a solid are small compared to the forces required, solids (e.g. uranium or plutonium) in this pressure region behave like liquids and thus according to the laws of hydrodynamics.

The difficulty of acquiring the necessary expertise, the technical requirements (which in several fields verge on the unfeasible), the lack of available materials and the lack of experience in working with these materials are the reasons why the making of an implosion-type IND with relevant compression could hardly be accomplished by a subnational group.

To sum up, it takes much more than knowledge of the workings of nuclear weapons and access to fissile material to successfully manufacture a usable weapon.

Can terrorists acquire a nuclear weapon by stealing (or buying a stolen) one?

Clearly, international security depends on the seriousness with which the States with nuclear weapons take their responsibilities. Nuclear weapons are located at well protected and guarded weapons emplacements or in nuclear weapons storage facilities. A theft would involve many risks and great efforts in terms of personnel, finances and organization. Without the support of insiders and local knowledge, such a theft is inconceivable. Up to now there have not been any confirmed or even credible reports of such a theft.

Several different types of safety and security systems exist, ensuring that under no circumstances can an unwanted nuclear explosion take place. These are some of them:

- inertial switches and acceleration sensors allow priming only after a threshold level has been reached;
- certain types require a high energy electrical impulse;
- environmental sensing devices monitor the trajectory and switch on only at a distinct ratio of the longitudinal to lateral acceleration;
- a barometric switch activates the electric circuit only at a distinct height above ground;
- a so-called permissive-action link (PAL) is needed, consisting for instance of several number codes with up to 12 digits and allowing a limited number of tries. The code has to be entered by more than one person, i.e. each person concerned knows only part of the entire code.

It is also known that since the 1970s, security systems for nuclear weapons exist in the USA that will destroy critical components or render them useless if someone handles the weapon improperly or tries to open it. Similar safety and security systems are also incorporated in Russian nuclear weapons. If the nuclear weapon is not completely destroyed when it is opened, and the fissile material can be removed, the quantity will not be sufficient for a primitive design; to obtain enough, several weapons would have to be stolen.

These safety and security systems also ensure that the successful use of a stolen weapon would be very unlikely.

Use of radiological weapons by terrorists?

Definition: What is a radiological weapon?

A radiological weapon (or radiological dispersion device, RDD) is any device that is designed to spread radioactive material into the environment, either to kill, or to deny the use of an area. Sometimes, when high explosives are used

INTERNATIONAL REVIEW of the Red Cross

to disperse the radioactive material, radiological weapons are called "dirty bombs."

A radiological weapon is not a nuclear weapon. Even if uranium or plutonium is spread by a radiological bomb, the blast effect is due only to the high explosive; no nuclear fission occurs, as it would in a nuclear bomb. The blast effect of a radiological bomb is therefore the same as the blast effect of a conventional bomb using the same amount of explosive.

Radiation effects on humans

The "dose" is the term used to describe the amount of radiation a person receives. The dose rate is measured in units of thousands of a Sievert (Sv), called the milliSievert (abbreviated mSv).[3]

Basically we can distinguish between acute effects with the symptoms of radiation sickness and possible death shortly after the irradiation, and long-term radiation effects with an increased probability of cancer mortality many years after the irradiation. The threshold value for the appearance of acute radiation damage is around a whole-body dose of 1,000 mSv. For a population of all ages and both genders, the number of cancer deaths resulting from a chronic irradiation is estimated at 5% to 6% per Sv.[4] For this effect, no threshold value is known.

How difficult is it to build a radiological weapon?

To build a radiological weapon, terrorists would need to have access to a sufficient quantity of radioactive material. Radioactive sources are used in medical, industrial, agricultural and research applications. They can be found in hospitals, medical and industrial irradiation facilities, universities and even homes. However, not all of these sources would be suitable for use in an RDD. Most are far too weak to cause extensive damage. Furthermore, many radioactive sources are in metallic form and would not be dispersed very effectively by high explosives. Nonetheless, we cannot completely rule out that terrorists could get their hands on the appropriate material and in sufficient quantities to contaminate a large area.

Safely manipulating a strong radioactive source requires knowledge of radioactive materials and radiation protection. For terrorists or "suicide bombers" we may assume that safety considerations and long-term cancer risks are not their primary concern.

With regard to technical feasibility, we must therefore conclude that the construction of a radiological weapon is quite possible. In all cases it requires advanced know-how and planning, a very targeted approach and considerable

3 1 mSv is the same as 100 mrem.

4 "Report of the United Nations Scientific Committee on the effects of atomic radiation to the General Assembly," generally referred as UNSCEAR 2000 Report.

expenditure. Nevertheless, there is no fundamental obstacle to hinder terrorists from building a radiological weapon.

In order to prevent the use of radioactive sources in radiological weapons, the International Conference on Security of Radioactive Sources, held in Vienna, Austria, in 2003, addressed these concerns and called for international initiatives. As a direct result the IAEA "Code of Conduct on the Safety and Security of Radioactive Sources" was revised in 2003, its supporting "Guidance on the Import and Export of Radioactive Sources" was developed and approved in 2004 and the "Safety Guide on Categorization of Radioactive Sources" was completed recently. More than 70 countries have already expressed their intention to follow the guidance given in the "Code of Conduct on the Safety and Security of Radioactive Sources".

The G-8 at its meeting in Evian in 2003 expressed its full political support for the IAEA actions and for the Code of Conduct and encouraged all States working to increase the safety and security of radioactive sources. At Sea Island in 2004, the G-8 gave its support to the "Guidance on the Import and Export of High-Risk Radioactive Sources," which was developed under the auspices of the IAEA and was subsequently endorsed by the General Conference in September 2004. UN Security Council Resolution 1540, in its preamble, recognized that most States have taken effective preventive measures in accordance with the recommendations given in the Code of Conduct. These measures at the international level aim at ensuring the security of radioactive sources and reduce the probability of one falling into the hands of terrorists.

Possible scenarios for the use of a radiological weapon

Enclosed radiation source

A gamma-emitting source generates a locally limited radiation field with rapidly decreasing intensity as distance from the source increases. A strong gamma-emitting source could be hidden in high-profile areas, such as highly populous urban sites or government facilities, which could expose a large number of people to intense radioactivity over a short period of time. It is unlikely that people exposed to such a source would suffer an acute radiation syndrome. However, on discovery panic reactions are to be expected among all persons who have spent time close to it. In the long term, persons irradiated by it could be subject to a very small, probably statistically non-detectable increased risk of cancer. Once discovered, the source can be shielded and removed relatively easily.

An alternative option would be the use of such a source to irradiate a limited number of people over a long period of time. In this case, those persons could suffer from acute radiation syndrome and could even die as a consequence of the irradiation. However, the number of victims of such an attack would be very limited.

Contamination of food

Food or beverages could be contaminated by adding radioactive substances, for example in production plants, during transport or at the retail shop. The main danger in this case is an internal contamination of the consumer. Even a selective and weak contamination of only a small number of items would have a considerable effect on the public and cause great economic damage.

Contamination of drinking water
Because of their high dilution in the huge amount of water, the addition of soluble radioactive substances, even in large quantities, to drinking water in water supply and distribution systems is not expected to result in a contamination that would be dangerous for the consumer. However, the low tolerance values for drinking water may be exceeded and require costly mitigation measures.

Explosive device with radioactive material
The detonation of an explosive device to which radioactive substances have been added produces both local and extensive contamination. Such a device is generally called a "dirty bomb". The local contamination is caused by ejected radioactive material. The large area of contamination results from the propagation and deposition of aerosols produced by the explosion. The inhalation of radioactive aerosols results in internal irradiation of the people concerned. Injured people may be contaminated. It is very probable that contaminated casualties will be transferred to hospitals, hence contaminating them too. In this case decontamination may be difficult, time-consuming and expensive.

Air contamination by means of aerosols
With suitable technical equipment, an easily respirable aerosol is produced. The spraying of a solution of radionuclides in a major public building would result in the breathing of contaminated air by the people there. In addition, the deposition of aerosols would cause a surface contamination both of the people and of the floor of the building. Such an attack may give rise to fears of cancer for the persons concerned and lead to closure of the building for the time required for decontamination, subsequent economic loss and high decontamination costs.

Consequences of the use of a radiological weapon

After the use of a radiological weapon a certain area will be contaminated with radioactive substances, especially in the last two scenarios mentioned above. The size of this area will depend on the means used to disperse the radioactive material, the quantity of radioactive material, the weather conditions and much more.

Typically, radioactive contamination in an affected area decreases with the distance from ground zero. Contamination also decreases with time. First, weather conditions continuously remove radioactivity from the contaminated area, and second, there is also the natural decay of the radionuclides.

Mathematical models have shown that in the event of a dirty bomb attack we could expect a maximum dose rate of about 10 mSv/h at the explosion site. This value depends, of course, on the hypothetical parameters, such as activity, meteorological conditions and the amount of explosives. A person would have to spend one hundred hours in this core area to have a 5% likelihood of developing symptoms of acute radiation sickness. This makes it practically impossible for the affected inhabitants, services or passers-by to accumulate a radiation dose high enough for them to suffer radiation sickness or death.

The radioactivity emitted by a radiological weapon is therefore unlikely to present a serious or acute health hazard. But measures to avert or reduce long-term radiation-induced damage of the affected population (a possible rise in cancer and leukaemia risks) might prove to be necessary. The International Commission on Radiological Protection (ICRP) recommends that measures be taken if the expected dose resulting from all known sources of radiation to the concerned population exceeds 10 mSv/year.[5]

In principle, depending on the degree of contamination, the following measures may be ordered to protect the population:

- recommendation to all persons who were outside during the attack to shower and change their clothes;
- temporary limits on time spent outside;
- temporary stays in a basement or shelter;
- limits on the consumption of certain agricultural products;
- ban on harvesting, putting livestock out to pasture, hunting and fishing;
- temporary evacuation, or
- definitive relocation of the affected population.

Staying inside a house offers a safety factor of approximately 10, i.e. when the ambient dose rate measured outside is 1 mSv/h, it is 0.1 mSv/h inside. Evacuation can be ordered for a short period of time only, to allow the civil protection organizations to survey and decontaminate the affected area undisturbed. Evacuation is also a possibility when a building provides inadequate protection or conditions in it are too restrictive to be tolerable.

If it should prove impossible or too costly to decontaminate an area, the relocation of the population and the closing of the area may be considered. In the event of radioactive contamination these measures may diminish or even totally eliminate health hazards. The risk of radiation-induced cancer could be reduced to such a degree that no demonstrable rise in cancer incidence would be expected. From the point of view of health hazards alone, the necessary measures could be launched without undue haste, since a delay of several days would make hardly any difference. Possibly contamination would be so weak as to make all measures superfluous.

In the event of high-level contamination it might be necessary to decontaminate the affected persons, buildings and streets, i.e. clean them of radioactive material. A change of clothes and a thorough shower are usually sufficient to decontaminate a person. Decontaminating streets, squares and buildings is considerably more complicated; they must be sprayed with plenty of water and scrubbed, sometimes even vacuumed. Depending on the type

5 *Protection of the Public in Situations of Prolonged Radiation Exposures*, ICRP Publication 82, 2000.

of contamination and the surface, this procedure eliminates 10% to 90% of the radioactivity — several repeat operations may be required to have any significant effect. Certain radioactive substances may combine with asphalt or concrete, thus rendering the above procedure ineffective. In these cases it may be necessary to remove cladding from buildings or street surfaces and dispose of it as radioactive waste. For areas that cannot be decontaminated — such as gardens or parks — the topsoil has to be removed to a depth of 20–30 cm, requiring the disposal of great amounts of radioactive waste.

The army, the protection and support units and private companies would probably be deployed to cope with such a large-scale task. After successful decontamination the population could return home after a few days or months. A failed effort might require demolition and reconstruction of affected buildings and/or the relocation of the population.

The trust of the population that the authorities are doing the right things will be undermined by the large number of — partly contradictory — recommendations and laws on radiation protection. A United States survey shows that about 40% of the people would not follow official instructions, and would in any case attempt to flee the site as fast as possible.[6] In the USA, in the year 2004, six laws setting different dose limits could apply to RDD clean-up.[7] Whilst experts and politicians debate on unresolved arguments, public confidence will further be undermined. This will delay remediation, thus increasing the RDD impact and costs, and will eventually lead to unnecessary expensive remedial actions undertaken only to regain public confidence.

In a densely populated area, thorough decontamination of even a relatively small zone would be likely to generate immense costs. Local companies would probably have to temporarily shut down; many inhabitants might move out. Apart from these more or less direct costs, the uncertainty and shock suffered by large parts of the population would give rise to considerable general costs. Although the health risk might be marginal, the affected town or even region would lose much of its attraction for inhabitants, companies and tourists. In the worst case, this could result in costs of several hundred billion US$.

Conclusions

The hurdles for terrorists to get a nuclear weapon are extremely high. The probability of terrorist use of such a weapon is therefore extremely low. To build nuclear weapons is a difficult task, even for countries. Iraq tried it 15 years ago with a project on the scale of US$ 10 billion and 7,000 employees, and did not succeed. Moreover, the Non-Proliferation Treaty, the main pillar of nuclear non-

6 Roz D. Lasker: *Redefining Readiness: Terrorism Planning through the Eyes of the Public*, Center for the Advancement of Collaborative Strategies in Health, New York Academy of Medicine, 14 September 2004.

7 D. Elcock, G.A. Klemic, A.L. Taboas: "Establishing remediation levels in response to a radiological dispersal event" (or 'dirty bomb'), *Environ. Sci. & Technol.*, Vol. 38, No. 9, pp. 2505–2512.

proliferation, has been strengthened and safeguards have been improved since. For NPT members it would now be very difficult to develop nuclear weapons without causing suspicion, especially for those countries with the International Atomic Energy Agency (IAEA) 1997 Additional Safeguards Protocol in force. The secret development of a nuclear weapon by a sub-state group is even more unlikely.

The usual tools against nuclear proliferation impede nuclear terrorism. Consequently a stronger commitment to strengthening the NPT, the reduction of warheads and the reduction of critical fissile material would further reduce the risk of nuclear terrorism.

In contrast to the nuclear weapon case, we conclude from our study that there are in principle no insurmountable obstacles to the acquisition and use of radiological weapons by a well-organized terrorist group, even though such an action remains high-tech and thus very difficult. Experts estimate the probability of such an attack occurring within the next 10 years at 40%.[8] Most countries do not have comprehensive programmes for the management of an RDD attack. These would include public education, first responder preparedness and standards defining the levels of contamination we can live with if that attack were to occur. Should the experts' estimate be correct, contingency action is urgently needed to prevent panic and mitigate the possible consequences of such an event.

8 Richard G. Lugar: *The Lugar Survey on Proliferation: Threats and Responses*, June 2005, available at <http://lugar.senate.gov/reports/NPSurvey.pdf> (visited on 12 September 2005).

INTERNATIONAL REVIEW of the Red Cross

Annex — Some Basic Terms of Nuclear Physics

The most important terms required for an understanding of the principles and mechanisms of nuclear and radiological weapons are explained below.

Isotopes

Atomic nuclei consist of protons and neutrons. The number of protons determines the element concerned. A nucleus of uranium, for instance, consists of 92 protons and a nucleus of plutonium consists of 94. The nuclei of an element can have different numbers of neutrons; one then speaks of different isotopes of this element.

Radioactivity, half-life

Radioactive atomic nuclei have the property to emit, without any external influence, a particle; in this way they are converted into a different nucleus. In the event of an alpha-decay, the atomic nucleus emits an alpha-particle, consisting of two protons and two neutrons; the nucleus thus loses the corresponding amount of mass. In the event of a beta-decay, the nucleus emits an electron, a so-called beta-particle; its mass, however, remains almost constant. Both alpha- and beta-decays can be accompanied by so-called gamma-radiation, which is a high energetic electromagnetic radiation. A sheet of paper or several cubic metres of air will stop alpha-radiation. Beta-radiation will be stopped by a thin book, whereas gamma-rays will even go through walls.

The temporal behaviour of radioactive decay is characterized by the half-life, which is the time needed to reduce the amount of radioactive material by a factor of 2.

Spontaneous fission

Spontaneous fission is understood as the radioactive decay in which an atomic nucleus splits, without any external influence, into two or very seldom three fragments. At the same time, some neutrons, gamma-radiation and energy (in the form of kinetic energy of the particles) are released.

Induced fission/chain reaction

Neutrons may hit nuclei and thereby be captured. But the neutrons captured by certain heavy isotopes may also cause the nuclei to split; this is induced fission.

With each fission, neutrons which can induce further fission events are released. A so-called chain reaction builds up. Fissile material is composed of isotopes that can be split by neutrons of any energy and can sustain a fission chain reaction.

Critical mass

The critical mass of an assembly of fissile material is the amount needed for a sustained nuclear chain reaction. In a larger assembly, the reaction increases at an exponential rate; this is termed supercritical.

The critical mass is not a constant. The smallest critical mass results for fissile material in the form of a sphere, since its ratio of surface to volume is minimal. The critical mass can be reduced if the neutrons escaping from the fissile material are reflected back. Furthermore, the critical mass is inversely proportional to the square of the density. Table 1 gives critical masses for the plutonium-239 isotope and different mixtures of uranium isotopes.

		Critical mass (kg)
Pu^{239} (densest phase)		~ 10
U^{235}		~ 48
U^{235} (94%)	U^{238} (6%)	~ 52
U^{235} (80%)	U^{238} (20%)	~ 70
U^{235} (50%)	U^{238} (50%)	~ 160
U^{235} (20%)	U^{238} (80%)	~ 800

Table 1: Bare critical masses (no reflector) of different fissile material spheres