Dirty Bombs and Primitive Nuclear Weapons

Dr. Frank Barnaby
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Both Prime Minister Tony Blair and US President George W. Bush have warned us that nuclear terrorism is a, if not the, major threat facing the international community today. A number of other analysts and commentators have recently issued similar warnings.

One of the main concerns is that terrorists will acquire radioactive material and then use conventional explosives to spread it far and wide. Such a device is called a radiological dispersal device or a 'dirty bomb'. Another concern is that terrorists will get hold of fissile material, fabricate a primitive nuclear weapon and explode it.

The public has the right to know the risks they face from nuclear terrorism and the consequences of a terrorist attack. Against this backdrop, this paper provides information about the dirty bomb, the simplest and, therefore, the most likely weapon to be used by terrorists. Also described is a primitive nuclear explosive that could be constructed by a terrorist group. Some international safeguard measures to counter nuclear terrorism are then discussed.

This paper portrays the real danger that faces us today, underlining the need to develop effective peaceful ways to counter the threat of nuclear terrorism and promote global security.

Executive Summary

There are a number of types of nuclear terrorist attacks that a terrorist group may undertake. This briefing will examine two types: making and detonating a dirty bomb and the fabrication and use of a primitive nuclear weapon.

A dirty bomb

The simplest and most primitive terrorist nuclear device is a radiological weapon, commonly called a dirty bomb. A dirty bomb would consist of a conventional high explosive and a quantity of a radioactive material such as caesium-137. There are literally millions of radioactive sources used worldwide in medicine, industry and agriculture; many of them could be used to fabricate a dirty bomb. They are often not kept securely. Terrorists should be able to acquire radioactive material.

Deaths and injuries caused by the blast effects of the conventional explosives and long-term cancers from radiation exposure would likely be minimal. The true impact of a dirty bomb would be the enormous social, psychological and economic disruption caused by radioactive contamination. It would cause considerable fear, panic and social disruption, exactly the effects terrorists wish to achieve.

The explosion of a dirty bomb could result in the radioactive contamination of tens of square kilometres of a city requiring the area to be evacuated and decontaminated. This is likely to be very costly, perhaps 100s of millions of pounds, and take weeks or, most likely, many months to complete.

A primitive nuclear weapon

After the recent terrorist attacks on 11 September 2001 in New York and Washington the next rung on the terrorist ladder of escalation of violence may well be the fabrication and use of a nuclear weapon. A major concern is that as plutonium from civil nuclear programmes becomes more available worldwide, it is becoming increasingly possible for a terrorist group to steal, or otherwise illegally acquire, civil plutonium that could be used to fabricate a nuclear explosive device.

The size of the nuclear explosion from such a crude device is impossible to predict. But even if it were only equivalent to the explosion of a few tens of tonnes of TNT it would completely devastate the centre of a large city.

Even if the device, when detonated, did not produce a significant nuclear explosion, the explosion of the chemical high explosives would disperse the plutonium widely. This could render a large part of the city uninhabitable until decontaminated, a procedure which could take many months or years.

What can be done?

A number of recent events have clearly shown that nuclear materials and technology are becoming increasingly available to terrorists as well as states. Certain international measures to reduce the risk that terrorists will acquire dirty bombs and nuclear weapons could and should be taken.

- Improve the international safeguards system applied by the International Atomic Energy Agency (IAEA).
- Negotiate a treaty banning the further production of fissile materials for use in nuclear weapons.
- Stop reprocessing plutonium and manufacturing mixed-oxide (MOX) nuclear fuel.
- Fund research to find alternatives to radioactive materials for functions such as food sterilization and smoke detection.
- Expand the use of radiation detection systems.

To effectively counter nuclear terrorism it is important to prevent terrorists from acquiring fissile materials, plutonium and highly enriched uranium, to fabricate a primitive nuclear explosive and from acquiring significant quantities of radioisotopes, particularly caesium-137, strontium-90, cobalt-60 and plutonium, to build a dirty bomb. The protection of these radioactive materials is clearly of the utmost importance.

Introduction

Mass killing by weapons of mass destruction may fit well into the Armageddon and apocalyptic visions of some religious terrorist groups, Christian and Islamic, some of which believe that they are under divine instruction to maximise killing and destruction. There is, therefore, clearly a danger, some would say inevitability, that terrorists will acquire, or develop and fabricate, and use weapons of mass destruction – biological, chemical, or nuclear.

Recent experience – for example, the use of nerve agents by the AUM group in Tokyo in 1995 and the use of anthrax in the USA in 2002-03 – shows that terrorist biological and chemical weapons are unpredictable and difficult to use effectively, in a way that causes a very large number of casualties. Effective dispersal of both biological and chemical weapons is difficult. This suggests that chemical and biological weapons will not best serve the purposes of future fundamentalist terrorists planning an attack that will maximise the number of fatalities. To fulfil their aims, therefore, future fundamentalist terrorists are likely to make nuclear attacks rather than biological or chemical ones.There are a number of types of nuclear terrorist attacks that a terrorist group may undertake: attacking a nuclear facility, such as a nuclear-power station to release radioactivity in the core of a nuclear-power reactor or the high-level radioactive waste tanks at a reprocessing plant, like the ones at Sellafield, to spread the radioactivity contained in them; attacking, sabotaging or hijacking a transporter of nuclear weapons; attacking a transporter carrying nuclear materials or radioactive waste and releasing radioactivity into the environment; stealing or otherwise acquiring a nuclear weapon from the arsenal of a nuclear-weapon power and detonating it; stealing or otherwise acquiring fissile material – highly enriched uranium or plutonium – and fabricating and detonating a primitive nuclear explosive; and making and detonating a radiological weapon, commonly called a dirty bomb, to spread radioactive material.

This briefing will examine the last two types of nuclear terrorist attacks – making and detonating a dirty bomb and the fabrication and use of a primitive nuclear weapon. The construction and use of a dirty bomb is the simplest type of nuclear terrorism, and, therefore, the most likely to occur, at least in the short term. The detonation of a nuclear explosive could cause a large number of fatalities and a great deal of destruction and would, therefore, be attractive to fundamentalist terrorists because of its Armageddon nature.

Two previous ORG reports address other aspects of WMD terrorism. *The New Terrorism: A 21st Chemical, Biological and Nuclear Threat* examines these three forms of WMD terrorism, the nature of international terrorist groups and counter-terrorism. Current Decision Report 27, *Nuclear Terrorism in Britain: Risks and Realities,* brings together papers from experts on all aspects of nuclear terrorism, including the risks of an attack against Sellafield and the psychology of mass casualty terrorism. Further details are available at www.oxfordresearchgroup.org.uk.

I. The terrorist use of a dirty bomb

It is 12.45pm on Tuesday, 23 December 2004. Oxford Street, London is teeming with Christmas shoppers and office workers going to lunch. A post office van, later found to have been stolen, pulls up at the kerb. People ignore the van as the driver walks off. Soon the van explodes in a fireball.

Police and ambulances arrive quickly. Five people are killed and about 30 injured, 10 seriously burnt. The injured are taken to the Middlesex hospital in nearby Wigmore Street. A mushroom cloud of dust and light debris rises to an altitude of 150 metres or so and is blown west by a 20 kilometre per hour wind.

At 7pm on the same day, Joan Underwood, a hospital physicist at the Middlesex is walking through the ward where medical staff is treating the seriously burnt victims. She has just been monitoring a neighbouring ward where patients have been given a drink of radioactive liquid for diagnostic purposes. She had not yet turned her Geiger counter off.

To her great surprise, the counter ticks madly. She soon discovers that most of the injured people are radioactive, some very radioactive. Rapid analysis on the hospital's gamma-ray spectrometer identifies the radioactive material to be the radioisotope caesium-137, a material commonly used for medical, industrial and agricultural purposes.

The anti-terrorist police first assume that the explosion in Oxford Street was a usual terrorist bomb, probably exploded by the real IRA. It is now clear that it was, in fact, a radiological dispersal device, commonly called a dirty bomb, the most primitive terrorist nuclear device. Forensic scientists soon found that Semtex and thermite, an incendiary material, surrounded the radioactive material.

A health physics team, sent from the National Radiological Protection Board at Didcot in Berkshire, discovers that a roughly elliptical downwind area stretching to Chiswick is contaminated with radioactivity.

People in and around Oxford Street when the bomb went off pick up radioactivity on their clothes and bodies and carry it home with them, contaminating public transport on their way. Vehicles travelling away for the scene also pick up radioactivity and spread it.

The authorities decide that a very large area will have to be evacuated and decontaminated. This operation will cost many millions of pounds and take months to achieve. The social disruption and economic cost resulting from the dirty bomb is exactly the point of the terrorist attack.

The simplest and most primitive terrorist nuclear device is a radiological weapon or radiological dispersal device, commonly called a dirty bomb. A dirty bomb would consist of a conventional high explosive (for example, semtex, dynamite or TNT), some incendiary material (like thermite) surrounding the conventional explosive, and a quantity of a radioisotope, probably placed at the centre of the explosive.

When the conventional high explosive is detonated, the radioactive material would be vaporised. The fire ignited by the incendiary material would carry the radioactivity up into the atmosphere. It would then be blown downwind, spreading radioactivity. A dirty bomb is not the same as a nuclear weapon in the normal sense of the phrase since it does not involve a nuclear explosion.

Many types of radioisotopes (radioactive isotopes) could be used in a dirty bomb. The most likely to be used is one that is that is relatively easily available, has a relatively long half-life, and emits energetic radiation. Suitable examples include caesium-137, cobalt-60, and iridium-192. Strontium-90, which is concentrated in bone, is also a possible candidate. The use of plutonium in a dirty bomb would cause the greatest threat to human health, because of its very high inhalation toxicity, and the most extensive contamination. If plutonium is inhaled into the lung this intense ionisation is likely to produce cancer. However, terrorists would find it difficult to acquire significant amounts of plutonium.

The detonation of a dirty bomb is likely to result in some deaths but would not result in the hundreds of thousands of fatalities that could be caused by the explosion in a city of a crude nuclear weapon. Generally, the explosion of the conventional explosive would be the most likely cause of any immediate deaths or serious injuries. The radioactive material in the bomb would be dispersed into the air but would be soon diluted to relatively low concentrations.

If the bomb is exploded in a city, as it almost certainly would be, some people are likely to be exposed to a dose of radiation, but the dose is, in most cases, likely to be relatively small. In the longer term, any exposure to ionising radiation can cause fatal cancers. The number of fatalities in a group of people will be proportional to the total radiation dose received by the group. The effects on the health of people exposed to the radioactivity released by a dirty bomb will depend on how long they remain in the contaminated area, the size of the particles released by the explosion and the type of radioactivity emitted by the radioisotopes in the bomb. However, a low-level exposure to radiation spread by a dirty bomb would only slightly increase the long-term risk of cancer.

Irrational public fear of radiation

Deaths and injuries caused by the blast effects of the conventional explosives and long-term cancers from radiation would likely be minimal. The true impact of a dirty bomb would be the enormous social, psychological and economic disruption caused by radioactive contamination. It would cause considerable fear, panic and social disruption, exactly the effects terrorists wish to achieve. The public fear of radiation is very great indeed, some say irrationally so.

The explosion of a dirty bomb could result in the contamination of an area of a city and the surrounding areas with radioactivity. Areas as large as tens of square kilometres could be contaminated with radioactivity to levels above those recommended by the National Radiological Protection Board (NRPB) for the exposure of civilians to radioactivity. It is highly unlikely that the public would be content to allow radiation levels above the levels set by the NRPB to remain over a long period .The area would therefore have to be evacuated and decontaminated.

The degree of contamination would depend on the amount of high explosive used, the amount and type of radioisotope released during the explosion of the bomb, the nature of the device used to spread the radioactivity, whether it was exploded inside a building or outside, the speed and direction of the wind, the general weather conditions, and the size and position of buildings near the detonation site.

The size of the radioactive particles released by the device will determine how far they are carried by the wind and how easily people inhale them. Radioactivity will be carried away on people's clothes and spread by vehicles passing through the contaminated areas. People may also ingest radioactivity by eating contaminated food and drinking contaminated water.

The intensity of radiation is measured in curies. The NRPB recommends that radiation levels not exceed between 1 and 27 microcuries (one millionth of a curie) per square metre, depending on the size and solubility of the radioactive particles. The radioactivity, or specific activity, of caesium-137 is 90 curies per gram, cobalt-60 is 1000 curies per gram, strontium-90 is 140 curies per gram and plutonium is 15 curies per gram. A simple calculation shows that if, for example, one gram of caesium-137 were evenly distributed to the maximum NRPB level of 27 microcuries per metre squared it would cover $3.3km^2$.

In practice any radioactive material would not be uniformly distributed. Instead it would probably fall over a cigar-shaped geographical area in the direction of the prevailing wind with radiation hotspots throughout.

Decontamination is likely to be very costly (costing millions of pounds) and take weeks or, most likely, many months to complete. There are no effective ways to decontaminate buildings contaminated with significant amounts of radioactivity; the buildings may, in practice, have to be demolished. If a dirty bomb were detonated in, for example, London's Oxford Street or in the City of London, the cost would be huge, potentially many hundreds of millions of pounds.

Such is the public fear of ionising radiation that even relatively small levels of radioactive contamination on or in buildings, on roads or footpaths, or on public areas and detectable with a Geiger counter would be publicly unacceptable. Decontamination would have to be virtually complete. Roads and walkways in contaminated areas, for example, would have to be re-surfaced.

The maximum amount of disruption would be caused by the detonation of a dirty bomb in the financial centres of London, namely the City and Docklands, or a major transportation node such as Heathrow airport. In the early 1990's the Provisional IRA conducted a widespread economic bombing campaign including three large conventional bombs exploded in the City of London outside the Baltic Exchange in April 1992, in the City of London in Bishopsgate in April 1993 and in Canary Wharf in Docklands in February 1996. These bombs caused estimated damages of £2,000 million and had a substantial effect on tourism and the re-insurance market (Rogers, 2000:1-30).

Available radioactive sources

There are literally millions of radioactive sources used worldwide in medicine, industry and agriculture; many of them could be used to fabricate a dirty bomb. Radioactive materials are stored in thousands of facilities in the United Kingdom, and other industrialised countries. They are often not kept securely. Terrorists should be able to acquire radioactive material.

An average size British hospital will have several types of radioisotopes suitable for use in a dirty bomb ranging from the microcurie level for diagnosis, to the millicurie level for therapy and the curie level for radiotherapy. Blood transfusion centres, for example, have significant quantities of caesium-137 to irradiate all transfused blood to prevent transfusion-related 'graft versus host disease' or GVHD.

The International Atomic Energy Agency (IAEA) recently secured a powerful cobalt-60 source abandoned in a former hospital. Soon afterwards in Uganda, the IAEA secured a source that was stolen for illicit resale. And the IAEA is searching through remote areas of the Republic of Georgia to locate and recover a number of missing powerful strontium sources.

Even in the United States and Europe, where security is relatively strong, thousands of radioactive sources have been lost or stolen; their present whereabouts are unknown. Clearly, the lack of security on radioactive materials around the world is a major cause for concern.

II. Could terrorists make a nuclear weapon?

"Nothing could have anything like the impact of a nuclear explosion, which could be more physically damaging, psychologically shocking, and politically disruptive that any event since World War II. Although the casualties from a single act of nuclear terrorism might not match those of a nuclear war, they would still dwarf other forms of terrorism by many orders of magnitude and could easily exceed those of most conventional wars." (Despres, 1987) 322

After the recent terrorist attacks on 11 September 2001 in New York and Washington and the attacks by the AUM group on the Tokyo underground, using the nerve agent sarin, the next rung on the terrorist ladder of escalation of violence may well be the fabrication and use of a nuclear weapon. The AUM group was, in fact, considering doing just that. The group contained a number of nuclear physicists well able to fabricate a nuclear weapon and were tying to acquire the fissile material to do so.

A terrorist group may steal a nuclear weapon from the arsenal of a nuclear-weapon power. It is said that a Russian nuclear weapon may fall, or may have fallen, into the wrong hands. A Russian organised criminal group, for example, may steal a nuclear weapon and sell it to a terrorist group. A major reason for concern is that it appears that no complete inventory of the large number of nuclear weapons, 20,000 or so, in the ex-Soviet nuclear arsenal was made. In particular there is concern that some Soviet atomic landmines, or so-called 'suitcase bombs', that were carried by infantrymen and known in the United States as Atomic Demolition Munitions are unaccounted for. These nuclear weapons are thought to have an explosive yield of around one kiloton.

But it is not only the ex-Soviet nuclear arsenal that is of concern. As plutonium from civil nuclear programmes becomes more available worldwide, it is becoming increasingly possible for a terrorist group to steal, or otherwise illegally acquire, civil plutonium that could be used to fabricate a nuclear explosive device. Today there are approximately 300 tonnes of separated civil plutonium and 20 tonnes of civil highly enriched uranium. The world's militaries have approximately 1,700 tonnes of highly enriched uranium and 250 tonnes of plutonium, the vast majority of this, around 95%, is owned by the USA and Russia. A nuclear weapon can be made from less than 10kg of plutonium.

Another cause for concern is evidence that fissile materials are being smuggled out of Russia. For example, in December 1994, the Czech authorities seized three kilograms of highly enriched uranium. And there are reports that security police confiscated nearly 40 kilograms of weapons-grade uranium in December 1993 in Odessa in the Ukraine. And during 1994, more than 400 grammes of weapons-grade plutonium were seized in Germany. A black-market in fissile materials is known to exist (Schmid, 1999).

Designs of primitive nuclear explosives

In a primitive nuclear weapon the plutonium would normally be in the form of a sphere. The critical mass of a sphere of civil plutonium is about 13 kilograms (see Appendix I).

Terrorist groups are likely to be satisfied with a nuclear explosive device that is far less sophisticated than the types of nuclear weapons demanded by the military. The military demand that their nuclear weapons are highly reliable and explode with an explosive yield that can be accurately predicted. They want to be sure that their nuclear weapons will go off and to know the explosive power of the weapon. A terrorist group would be much less demanding and satisfied with a relatively unsophisticated device, much easier to design and fabricate than the very sophisticated nuclear weapons required by the military.

A nuclear weapon consists of a mass of plutonium that is less than critical. A system is used to make this mass super-critical. This is achieved by a technique called implosion. In the implosion design, the plutonium is surrounded by conventional high explosives. When detonated, the high explosive uniformly compresses the sphere of plutonium. The compression reduces the volume of the sphere of plutonium in the weapon and increases its density. The critical mass of the plutonium is inversely proportional to the square of the density. The original less-than-critical mass of fissile material will, after compression, become super-critical, and a fission chain reaction will begin. The trick is to hold the super-critical mass of plutonium together long enough to get a sufficient number of fission reactions to produce a nuclear explosion before the weapon is blown apart.

A primitive nuclear explosive using plutonium

When spent civil nuclear power reactor fuel elements are reprocessed in a reprocessing plant, the plutonium comes out as plutonium dioxide. Plutonium dioxide can be converted into plutonium metal using a relatively simple chemical process.

A primitive nuclear device could be constructed using either plutonium in metal form or plutonium dioxide, as the crystalline powder or, perhaps more conveniently, sintered into solid form. The critical mass of plutonium dioxide is considerably greater than that of the metal.

The critical mass of plutonium dioxide crystals is about 35 kilograms (Lovins, 1990), if in spherical shape; while that of plutonium metal using the plutonium normally produced in a civil nuclear-power reactor is about 13 kilograms (Lovins, 1990). A terrorist group prepared to convert the dioxide to the metal would, therefore, need to acquire significantly less plutonium dioxide.

A bare sphere of plutonium dioxide (density = 11.46 grams per cubic centimetre) having a critical mass would be about 18 centimetres in diameter; a bare sphere of plutonium metal having a critical mass would be about 10.7 centimetres in diameter (density = 19.84 grams per cubic centimetre).

The tamper/reflector

If the plutonium sphere is surrounded by a shell of dense material, such as beryllium, uranium or lead, neutrons that escape from the sphere without producing a fission event are reflected back into the sphere, able to cause more fission. A reflector, therefore, reduces the critical mass. The reduction may be considerable. A thick reflector will reduce the critical mass by a factor of two or more. Lead would be the material of choice for the terrorist owing to its widespread availability and malleability.

Because the shell of reflecting material is heavy, it also acts as a tamper. When the high explosives are detonated, the shock wave causes the tamper to collapse inwards. The tamper's inertia helps hold together the plutonium during the explosion to prevent the premature blowing apart of the fissioning plutonium and thereby to obtain a larger explosion.

The high explosive

The high explosive could, for example, be TNT or HMX. But it is more likely that a terrorist group would use a plastic explosive, such as semtex. A plastic explosive is easier to handle and can be moulded into a spherical shape around the plutonium sphere ensuring more even compression of the plutonium. About 400 kilograms of plastic explosive, moulded around the reflector/tamper placed around the sphere of plutonium, should be sufficient to compress the plutonium to the required degree.

The plutonium dioxide sphere would be surrounded by the reflector/tamper, possibly a five-centimetre thick shell of lead. The reflector/tamper would then be surrounded by the 400-kilogram shell of plastic explosive (density = 1.4 grams per cubic centimetre). If constructed from 18 kilograms of plutonium dioxide (about half the 35 kg needed without a tamper/reflector and comprising a sphere with a radius 7.2 centimetres), a lead reflector/tamper; and plastic explosive, the assembled device would have a radius of 41.3 centimetres.

If seven kilograms of plutonium metal were used instead, and the plutonium sphere (radius 4.38 centimetres) was surrounded by a five-centimetre shell of lead and 400-kilograms of plastic explosive, the radius of the total device would be 41 centimetres. A large number of detonators (say, about 50) would be inserted symmetrically into the plastic explosive so that the distance between each detonator and the surface of the plutonium sphere was about constant. This would be likely to give a roughly symmetrical shock wave to compress the plutonium sphere.

An electronic circuit generating a high-voltage square wave pulse of approximately four kilovolts and with a fast rise-time could be used to fire the detonators simultaneously. A remote radio signal or timer is likely to be used to trigger the electronic circuit.

The explosive yield

The size of the nuclear explosion from such a crude device is impossible to predict. But even if it were only equivalent to the explosion of a few tens of tonnes of TNT it would completely devastate the centre of a large city. It is very possible that such a device would explode with an explosive power of at least a hundred tonnes of TNT. (The effects of an explosion with a power equivalent to that of 100 tonnes of TNT are described in Appendix II). Even one thousand tonnes or more equivalent is possible, but unlikely. The explosive power of the device will depend mainly on how close to critical the mass of the plutonium sphere was and how effectively the conventional high explosives compressed it.

The dispersion of the plutonium

The explosion of a primitive nuclear weapon would use only a small fraction of the plutonium in it; the rest would not be fissioned and would be released into the atmosphere and dispersed. Even if the device, when detonated, did not produce a significant nuclear explosion, the explosion of the chemical high explosives would disperse the plutonium widely. If an incendiary material, such as an aluminium-iron oxide (thermite), were mixed with the high explosives, the explosion would be accompanied by a fierce fire.

The unfissioned plutonium would be dispersed by the explosion or volatilised by the fierce heat. When plutonium burns it is mostly dispersed as small particles of plutonium dioxide. These would be taken up into the atmosphere in the fire-ball and scattered far and wide downwind.

A large fraction of the particles are likely to be smaller than three microns (millionths of a metre) in diameter, and could, therefore, be breathed into, and retained by, the lung. Here they would be very likely to cause lung cancer by irradiating the surrounding tissue with alpha-particles.

Once dispersed into the environment, plutonium dioxide is insoluble in rainwater and would remain in surface dusts and soils for a very protracted period indeed. The half-life of the plutonium isotope plutonium-239, the predominant isotope in civilian plutonium, is 24,400 years.

These factors would combine to render a large part of the city uninhabitable until decontaminated, a procedure which could take many months or years. The threat of dispersion of many kilograms of plutonium makes a crude nuclear explosive device a particularly attractive weapon for a terrorist group, the threat being enhanced by the general population's fear of radioactivity.

III. Reducing the risk of the terrorist use of dirty bombs and primitive nuclear weapons

A number of recent events have clearly shown that nuclear materials and technology are becoming increasingly available to terrorists as well as states. Certain international measures to reduce the risk that terrorists will acquire dirty bombs and nuclear weapons could and should be taken.

An important step would be the strengthening of the Nuclear Non-Proliferation Treaty (NPT), particularly by improving the international safeguards system applied by the International Atomic Energy Agency (IAEA). An opportunity to do this will be the NPT Review Conference in New York in May 2005. Another important step would be the negotiation of a treaty banning the further production of fissile materials for nuclear weapons, the so-called fissile material cut-off treaty.

Also important is the control of the illegal supply of nuclear materials and technology to terrorists and countries. Recent disclosures about the network, set up by Pakistan's leading nuclear scientist Abdul Qadeer Khan, to supply nuclear technology and information about the enrichment of uranium to produce the fissile material for nuclear weapons and even to provide designs of nuclear weapons indicate the urgent need to control such activities.

And regional cooperation is needed to control the illegal smuggling of nuclear materials, particularly from Russia and other former Soviet Republics. A nuclear black-market exists and much more effort should be made by national, regional and international agencies to stop it. This will require the investment of very significant financial and manpower resources.

Some specific measures to reduce the risk that terrorists will fabricate dirty bombs have been suggested by The Federation of American Scientists (FAS). They include: *"Fund research aimed at finding alternatives to radioactive materials. A research program aimed at developing inexpensive substitutes for radioactive materials in functions such as food sterilization, smoke detection, and oil well logging should be created and provided with adequate funding. Expand the use of radiation detection systems. Systems capable of detecting dangerous amounts of radiation are comparatively inexpensive and unobtrusive. High priority should be given to key points in the transportation system, such as airports, harbors, rail stations, tunnels, highways. Routine checks of scrap metal yards and landfill sites would also protect against illegal or accidental disposal of dangerous materials."*

The FAS points out that:
"An effective response to a radiological attack requires a system capable of quickly gauging the extent of the damage, identifying appropriate responders, developing a coherent response plan, and getting the necessary personnel and equipment to the site rapidly. First responders and hospital personnel need to understand how to protect themselves and affected citizens in the event of a radiological attack and be able to rapidly determine if individuals have been exposed to radiation. There is great danger that panic in the event of a radiological attack on a large city could lead to significant casualties and severely stress the medical system."

The FAS concludes that:
"We must face the brutal reality that no technological remedies can provide complete confidence that we are safe from radiological attack. Determined, malicious groups might still find a way to use radiological weapons or other means when their only goal is killing innocent people, and if they have no regard for their own lives".

Securing nuclear materials

To effectively counter nuclear terrorism it is important to prevent terrorists from acquiring fissile materials, plutonium and highly enriched uranium, to fabricate a primitive nuclear explosive and from acquiring significant quantities of radioisotopes, particularly caesium-137, strontium-90, cobalt-60 and plutonium, to build a dirty bomb. The protection of these radioactive materials is clearly of the utmost importance.

Improving the security of nuclear materials is not an easy task – particularly in a democracy. The degree of security that can applied in a hospital using, for example, large radioactive sources for therapy or in an industrial establishment, using large radioactive sources for, for example, x-raying large structures, is obviously limited. But at the very least establishments using large radioactive sources should apply security measures such as keeping strict inventories, providing securely locked storage facilities and security guards.

Stopping reprocessing

Society may decide that the risks of nuclear terrorism, and the awesome potential consequences of it, are such that some nuclear activities should be given up. An obvious example is the reprocessing of spent nuclear-power reactor fuel to separate the plutonium from it and the use of this plutonium to produce mixed-oxide (MOX) fuel for use as fuel in nuclear reactors instead of uranium dioxide. MOX is produced in a MOX plant by mixing plutonium dioxide and uranium dioxide.

The use of plutonium or MOX in a dirty bomb and the use of plutonium to fabricate a primitive nuclear explosive should be prevented at all costs. Spent nuclear-power reactor fuel elements are so radioactive that they are self-protecting. Any human that went near them would die very quickly. But when plutonium is removed from them in a reprocessing plant it is much easier to handle. The safest thing is, therefore, to leave permanently the plutonium in spent reactor fuel elements.

The risk of diversion or theft of MOX fuel pellets or whole MOX fuel assemblies by personnel within the industry or by armed and organised terrorist groups is an awesome possibility. It must be emphasised that the plutonium in only a few MOX fuel pellets would be enough to make an effective dirty bomb. The pellets are cylindrical in shape and only about 1cm long and 1cm in diameter. They contain approximately 5% of plutonium by weight and weigh roughly 8 grams. Much more MOX would be required to fabricate a primitive nuclear weapon. An entire typical MOX fuel assembly would be required to get 7-8kg for a plutonium nuclear weapon. These are about nine metres long and weigh several tonnes.

But if it acquired enough MOX fuel by diversion or theft, a sophisticated terrorist group would have little difficulty in making a crude nuclear explosive. The necessary steps of separating the plutonium from the uranium in MOX, converting it into plutonium dioxide, converting the dioxide into plutonium metal, and assembling the metal or plutonium dioxide together with conventional high explosive to fabricate a primitive nuclear weapon are not technically demanding and do not require materials from specialist suppliers. The information required to carry out these operations is freely available in the open literature.

The storage and fabrication of MOX fuel assemblies, their transportation and storage at conventional nuclear-power stations on a scale currently envisaged by the nuclear industry will be extremely difficult to safeguard and protect. The risk of theft of MOX is probably greatest when it is being transported. The international trade in MOX, involving the global transport of MOX, increases this risk considerably.

The importance of good intelligence

The importance of effective intelligence in countering nuclear (or chemical or biological) terrorism cannot be over estimated. Monitoring the communications of terrorist groups – the activity known as signal intelligence (SIGINT) – has been crucial to this end. Modern terrorists can, however, take steps to protect their communication systems, including, for example, the use of encryption, frustrating the efforts of SIGINT.

The penetration of terrorist groups by undercover intelligence agents or double agents (human intelligence or HUMINT) is, therefore, of critical importance. In fact, counter-terrorism is likely to succeed only if HUMINT can be made effective. The infiltration of fundamentalist terrorist groups is, to say the least, not easy.
These groups are generally aware of the danger of penetration by intelligence agents and organise themselves in ways which makes such penetration very difficult indeed. They often operate in small groups in which each individual knows the other is the group extremely well.

Experience shows that setting up effective intelligence activities against terrorist groups is extremely challenging. Rivalries between intelligence agencies within countries and lack of cooperation in intelligence matters between countries seriously reduce the effectiveness of intelligence. Effective and single leadership of national agencies and international cooperation between national agencies are the keys to good counter-terrorism intelligence.

The intelligence and security agencies, in their fight against the new terrorism, face an awesome task that will require the acquisition of any new technological developments relevant to counter-terrorist activities, a close study of new terrorist threats, and, perhaps most importantly, an imaginative approach to the issues.

Appendix I

The construction of a primitive nuclear weapon

A nuclear explosion occurs when a large amount of energy, produced by nuclear fission, is released in a very short time. The nuclear energy is produced by a nuclear fission chain reaction. In a nuclear weapon, a fission chain reaction is produced using one of two isotopes, called fissile isotopes – plutonium-239 and uranium-235. A terrorist group is most likely to use plutonium because it is more widely available than uranium.

For the construction of a nuclear weapon, the important plutonium isotope is plutonium-239. A plutonium-239 nuclei undergoes fission when it absorbs (capture) any neutron, even one moving very slowly. When a plutonium-239 nucleus captures a neutron, the isotope plutonium-240 is formed which is very unstable and rapidly fissions. The nucleus of plutonium-240 splits into two nuclei, called fission products. In addition, neutrons are emitted during the fission process; on average, between 2 and 3 neutrons are emitted. During the fission process, energy is also given off.

Energy is released during fission because it invariably happens that the total sum of the masses of the two fission products and the fission neutrons is less than the mass of the plutonium-240 nucleus. According to Einstein's equation, the energy emitted during a fission event is equal to this mass difference multiplied by the square of the velocity of light ($E = mc^2$). Although the mass difference is very small, the square of the velocity of light is a huge number and, therefore, the amount of energy given off is relatively large.

Critical mass

If at least one of the neutrons produced when a nucleus undergoes fission produces the fission of another nucleus, a fission chain reaction is produced. The aim of the nuclear weapon designer is to maintain the fission chain reaction for a long enough time to produce an explosion with the sort of explosive power he requires. The minimum mass of plutonium that can sustain a nuclear fission chain reaction is called the critical mass.

If a mass of plutonium is increased above the critical level, the number of neutrons produced by the fission chain reaction increases rapidly. Some of the neutrons will escape through the mass of plutonium and others will be lost in other ways. These lost neutrons will, of course, not contribute to the fission chain reaction. When the rate of production of neutrons exceeds all neutron losses, a supercritical mass is created, and a rapid and uncontrollable increase in the number of neutrons within the mass of plutonium occurs. So many fissions occur, in such a short time, that a nuclear explosion results.

Appendix II

Effects of a 100-tonne nuclear device exploded in a city

The largest conventional bombs used in warfare so far had explosive powers equivalent to about ten tonnes of TNT. The largest terrorist explosion so far has been equivalent to about two tonnes of TNT. A nuclear explosion equivalent to that of 100 tonnes of TNT in an urban area would be a catastrophic event, with which the emergency services would be unable to cope effectively. Exploded on or near the ground, such a nuclear explosive would produce a crater, in dry soil or dry soft rock, about 30 metres across.

For small nuclear explosions, with explosive powers less than a few kilotons, the lethal action of radiation covers a larger area than that affected by blast and heat. The area of lethal damage from the blast produced by a 100-tonne nuclear explosion would be roughly 0.4 square kilometres; the lethal area for heat would be about 0.1 square kilometres; and that for prompt radiation would be roughly 1.2 square kilometres.

Persons in the open within 600 metres of such an explosion would very probably be killed by the direct effects of radiation, blast, or heat (Rotblat, 1981). Many other deaths would occur, particularly from indirect blast effects from the collapse of buildings, from being thrown into objects or from falling debris. Heat and blast will cause fires, from broken gas pipes, petrol in cars, and so on. The area and extent of damage from fires may well exceed those from the direct effects of heat.

A nuclear explosion at or near ground level will produce a relatively large amount of early radioactive fall-out. Heat from fires will cause the radioactive particles to rise into the air; they will then be blown downwind, eventually falling to the ground under gravity at rates and distances depending on the velocity of the wind and the weather conditions.

The area significantly contaminated with radioactive fall-out and with plutonium not fissioned in the explosion will be uninhabitable until decontaminated. The area concerned may be many square kilometres and it is likely to take a long time to decontaminate it to a level sufficiently free of radioactivity to be acceptable to the public.

An explosion of this size, involving many hundreds of deaths and injuries, would paralyse the emergency services. They would find it difficult even to deal effectively with the dead. Many, if not most, of the seriously injured would die from lack of medical care. In the UK, for example, there are only a few hundred burn beds in the whole National Health Service. There would be considerable delays in releasing injured people trapped in buildings, for example.

And, even for those not trapped, it would take a significant time to get ambulances through to them and then to transport them to hospital. Therefore, a high proportion of the seriously injured would not get medical attention in time to save them. Experience shows that, when large explosions occur in an urban area, panic sets in which also affects the trained emergency personnel. This panic would be considerably exacerbated by the radioactive fall-out accompanying a nuclear explosion.

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About the author

Dr. Frank Barnaby is a Nuclear Issues Consultant to Oxford Research Group (ORG), and has been on ORG's Council of Advisers since its inception. He is a nuclear physicist by training and worked at the Atomic Weapons Research Establishment, Aldermaston between1951-57. He was on the senior scientific staff of the Medical Research Council when a lecturer at University College London (1957-67). He was Executive Secretary of the Pugwash Conferences on Science and World Affairs in the late 1960s and Director of the Stockholm International Peace Research Institute from 1971-81. He was Guest Professor at the Free University, Amsterdam (1981-85) and Visiting Professor at the University of Minnesota in 1985. He is now a freelance defence analyst, and is a prolific author on military technology. In addition to the numerous Briefing Papers he has written for Oxford Research Group and other organisations, his books include: *The Invisible Bomb* (Tauris, 1989*), The Gaia Peace Atlas* (Pan, 1989), *The Automated Battlefield* (Sidgwick & Jackson, 1987), *Star Wars* (Fourth Estate, 1987), *Future Warfare* (Michael Joseph, 1986) and *The Role and Control of Military Force in the 1990s*. Frank is also a regular commentator on nuclear and global security issues in both the national and international media.

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