Exhibit 11

SEC-16

Potential Terrorist Misuses of Plutonium and MOX

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This paper shows that a terrorist organisation could relatively easily extract the plutonium and fabricate a nuclear explosive having first acquired MOX fuel [containing a mixture of uranium oxide (UO2) and plutonium oxide (PuO2)]. The chemical extraction of the plutonium from MOX fuel pellets and the preparation of PuO2 are first described. A description of a method to convert PuO2 to plutonium metal follows. Designs for making nuclear explosives using either PuO2 or plutonium metal are then discussed.

These operations would require some sophistication. Terrorist organisations are, however, certainly capable of sophisticated planning and the application of scientific principles. The construction of the conventional explosive device that destroyed the PanAm jumbo jet over Lockerbie on 21st December 1988 required considerable planning and scientific skills, as did the construction of the nerve gas weapon used in the Tokyo underground by the AUM group on 20th March 1995. It is a sobering fact that the fabrication of a primitive nuclear explosive using reactor-grade plutonium, obtained from MOX, would require no greater skill than that for the production and use of the two terrorist weapons mentioned above.

1. Preparation of pure PuO2 from MOX fuel assemblies

The fuel pellets in MOX fuel assemblies are composed entirely of pure reactor-grade plutonium and depleted uranium both present as dioxides and fused together by heat to form a ceramic. The material is designed to be soluble in fairly concentrated nitric acid for ease of reprocessing.

Plutonium and uranium have quite different chemistries and a variety of industrial- and analytical- scale methods have been devised for their separation. These processes [known as the PUREX (1,2,3) and TRUEX processes (4,5)] have been developed for the industrialscale separation of these elements from *irradiated* nuclear fuel, and are probably the most complex processes in Industrial Chemistry.

The complexity of these processes means that terrorists are unlikely to seek to replicate them. The technological considerations are, however, vastly simpler if *unirradiated* MOX elements are acquired instead of irradiated conventional nuclear fuel as a source of plutonium for several reasons:

1. The plutonium concentration is very much higher in MOX than in irradiated conventional fuel;

2. The chemistry is vastly simplified as there are only three elements present in place of the complex mixture in irradiated fuel;

3. The radiation handling hazards are greatly reduced;

4. Ruthless terrorists are likely to be unconcerned about operator safety or about avoiding environmental

pollution except to the extent that accidents or releases might reveal their clandestine activity.

The procedures required for the chemical separation of plutonium from uranium in MOX fuel pellets would be simple and well within the technological capabilities of a moderately sophisticated terrorist organization (6). The preparation of Sarin for the attack on the Tokyo underground (7) involved considerably more sophisticated chemistry and greater acute danger to the operators than that required for the separation of plutonium from MOX. The chemistry is less sophisticated than that required for the illicit preparation of designer drugs.

None of the concepts involved in understanding how to separate the plutonium are difficult; a second-year undergraduate would be able to devise a suitable procedure by reading standard reference works, consulting the open literature in scientific journals and by searching the World Wide Web.

Sufficient plutonium to check and refine procedures can easily be extracted from mud collected from the Ravenglass estuary and contaminated by discharges from the Sellafield reprocessing plant (6) while depleted uranium can be purchased in several forms from most suppliers of laboratory chemicals. With small quantities of these test materials and a simple laboratory it would only take a chemistry graduate with some experience in actinide chemistry a relatively short time to refine the procedures outlined in this article. It would be easy to do this without arousing suspicion by using environmental chemistry as a front.

For a separation procedure to be suitable for illicit use it must:

- Produce PuO2 of 99 per cent purity;

- Have a recovery efficiency of 92.9 per cent or better (9);

- Not require the use of highly specialised equipment difficult to obtain or assemble or which would arouse suspicion;

- Use readily available reagents, which do not arouse suspicion;

- Minimise the handling and transfer of highly toxic plutonium and uranium solutions;

- Result in no tell-tale discharges to the environment;

- Produce the finished PuO2 within two weeks and ideally within seven days of the theft of the fuel elements to minimise the chances of detection;

- Not require more than two assistants working under the supervision of a graduate chemist.

We have assumed that a well funded terrorist group would not be unduly constrained by cost, would have the services of a chemist with experience in actinide chemistry and would have access to standard laboratory equipment.

2. The chemical extraction of the plutonium from MOX fuel pellets

Three types of method have bend developed that meet all of the criteria listed above and are briefly described below:

1. Use of cationic or anionic (positively- and negatively-charged) *ion-exchange resins* (10, 11, 12);

2. A *'carrier' method* based on that originally used by Glenn Seaborg in 1941 at the University of Chicago wartime Metallurgical Laboratory for the first separation of plutonium (8) and subsequently with great effect at the Hanford Plutonium Separation Plant in the United States;

3. *Use of chelating resins* (13, 14, 15) which bind metal ions.

Ion-exchange resins

An ion-exchange method would be the simplest and could be used to separate plutonium of high purity with acceptable efficiency in a rapid, single-stage, single-batch process (12). Suitable resins are extensively used in industry for water softening, waste treatment and resource recovery.

They are available 'off-the-shelf' in tonne quantities with short delivery dates and several different types of resin are likely to prove suitable. These resins are highly suited to the recovery of plutonium from MOX fuel and are outlined in a confidential version of this report sent to the Department of Trade and Industry.

Carrier methods (8,16)

The second approach, using a 'carrier', is another method that might be used by terrorists. The reagents required are all readily available from the suppliers of industrial chemicals. The chemicals required (lanthanum nitrate or sulphate) find application in arc lighting, lighter flints, and as an additive to alloys, cast iron, and specialised glasses. The purchase of lanthanum salts in relatively large amounts is therefore unlikely to arouse suspicion.

The process is more complicated than the use of an ion-exchange resin and would require much more handling of extremely toxic materials in batch quantities. A more detailed description of achieving the required recovery efficiency and purity are outlined in the confidential version of this report sent to the Department of Trade and Industry.

Chelating resins (13,14,15)

These should yield plutonium of excellent purity with a yield of up to 99.9 per cent (13,14,15). The equipment required for the use of chelating resins is simple. Some of the chelating agents used have a wide range of industrial uses and would not arouse suspicions from industrial suppliers but some additional chemistry and trouble is necessary to prepare a working chelating resin (13,14,15). Some chelating resins are available 'off-the-shelf' but some of these may arouse suspicion if attempts were made to purchase them in large quantities. This is a relatively new approach and information necessary is less complete in the literature. This is, therefore, unlikely to be the preferred method for a terrorist group.

3. Preparation of plutonium metal from PuO2

A primitive nuclear explosive can be constructed from PuO2 (see below) prepared by heating in air the plutonium salts prepared by one of the above methods. Although such a device would certainly be an effective means of dispersing plutonium widely, its nuclear explosive yield may be smaller and less predictable than a device constructed from metallic plutonium. Clandestine groups may, therefore, decide to prepare plutonium metal from the PuO2. This chemical conversion is outlined in are outlined in the confidential version of this report sent to the Department of Trade and Industry.

4. The design of crude nuclear explosives using PuO2 or plutonium metal

Two or three people with appropriate skills could design and fabricate a crude nuclear explosive. They would not need to have access to classified literature. Amory B. Lovins (17), for example, has published all the nuclear physics data needed to design a crude nuclear device.

The critical mass of a fissile material, such as plutonium, is the minimum mass necessary to sustain a nuclear-fission chain reaction. If the mass is more than critical (i.e., it is super-critical) the fission chain reaction is sustained for as long as the mass of plutonium remains super-critical. A nuclear explosion occurs when a mass of plutonium that is less than critical is compressed by a symmetrical shock wave to make it super-critical. Such compression reduces the volume of the mass of plutonium, increasing its density. If the mass of plutonium is held together long enough, a sufficient number of fission reactions will take place to produce enough energy for an explosion.

A nuclear device could be constructed using either PuO2 or plutonium in metal form. But the critical mass of PuO2 is considerably greater than that of the metal. The critical mass of reactor-grade plutonium in the form of PuO2 crystals is about 35 kilograms (18), if in spherical shape; while that of reactor-grade plutonium metal is about 13 kilograms. A terrorist group prepared to convert the plutonium oxide to the metal would, therefore, need to acquire significantly less PuO2. A bare sphere of reactor-grade PuO2 having a critical mass would be about 18 centimetres in diameter; a bare sphere of plutonium metal having a critical mass would be about six centimetres in diameter. The sphere could be placed in the centre of a mass of a conventional high explosive to compress it to super-criticality.

The critical mass can be reduced and the size of the explosion increased by using a 'reflector/tamper': a shell of material, such as beryllium or uranium, that surrounds the plutonium sphere.

The high explosive

The high explosive could be TNT, 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 enough.

If PuO2 is used it could be contained in a spherical vessel, or it could be cast into two hemispheres by melting it at very high temperatures in suitable moulds. The moulded hemispheres of PuO2 would be placed on top of each other to make a sphere with their flat surfaces separated by one centimetre of a compressible material such as expanded polystyrene. The sphere would be surrounded by the reflector/tamper, and then surrounded by plastic explosive. The assembled device would have a radius of about 40 centimetres constructed from 18 kilograms of PuO2.

If seven kilograms of Pu metal were used instead, and the Pu sphere (with a radius of just 4.8 centimetres) was surrounded by a five-centimetre shell of beryllium and 400-kilograms of plastic explosive, the radius of the total device would be just less than 40 centimetres. A large number of detonators (say, about 50) would be inserted symmetrically into the plastic explosive to give a roughly symmetrical shock wave to compress the plutonium sphere. The detonators would be fired simultaneously by an electronic circuit. A remote radio signal or timer would 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. Such a device would,

however, have a strong chance of exploding with an explosive power of at least a hundred tonnes of TNT. Even one thousand tonnes or more equivalent is possible, but unlikely. The effects of an explosion equivalent to 100 tonnes of high explosive are outlined in Appendix I. 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

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. A high proportion of the plutonium is likely to remain unfissioned and would be dispersed by the explosion or volatilised by the fierce heat. Much of the plutonium is likely to be dispersed in this way as small particles of PuO2 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 in diameter, and would, therefore, be able to 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. This is why inhaled plutonium is so highly toxic.

Once dispersed into the environment, PuO2 is insoluble in rainwater and would remain in surface dusts and soils for a protracted period. The half-life of the plutonium isotope Pu-239, the predominant form in civilian plutonium is 24,400 years. When the extended nature of the decay chain is taken into consideration this means that the material will, in effect, stay radioactive forever.

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 effects of plutonium dispersion are further discussed in Appendix I. 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 justifiable fear of radioactivity.

5. Conclusions

Having obtained a MOX fuel assembly 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, converting it into PuO2, converting the oxide into plutonium metal, and assembling the metal or PuO2 together with conventional explosive are not technologically 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 envisaged by the nuclear industry will be extremely difficult to safeguard. The risk of diversion or theft of fuel pellets or whole fuel assemblies by personnel within the industry or by armed and organised terrorist groups is a terrifying possibility.

APPENDIX I

Effects of the explosion of a primitive nuclear explosion

100-tonne nuclear explosion

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 (19). 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 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.

1000-tonne nuclear explosion

The British Cabinet Office has calculated the effects of a primitive nuclear explosive detonated at ground level in a typical city. The explosion was equivalent to that produced by 1,000 tonnes of TNT, a possible explosive yield from a crude nuclear explosive. Within one minute, people outdoors or near windows inside houses would be killed by thermal radiation (heat) up to a distance of 200 metres from the point of detonation. Within one minute, blast would kill people up to a distance of 800 metres, and initial nuclear radiation would kill people up to a distance of 1 kilometre.

People within two kilometres would be injured by blast and those within one kilometre would be injured by heat. Communications equipment would be damaged by the nuclear electromagnetic pulse up to a distance of about two kilometres and electronic equipment would be damaged or disrupted up to a distance of about ten kilometres, with severe consequences for fire services, police headquarters, and hospitals. The electromagnetic pulse would affect motor vehicles out to about ten kilometres.

Assuming a 24 kilometre per hour wind, ionising radiation levels from radioactive fallout within an area of about 15 square kilometres would be high enough to cause radiation sickness in the short term to those exposed in the open, and in some cases to those in buildings. This area would extend to some ten kilometres downwind and would have a maximum width of about two kilometres. Furthermore, radiation levels in an area of about 400 square kilometres would be such that certain counter-measures would have to be taken to

protect people from the long-term effects of exposure to radiation - for example, fatal cancers. This area would extend some 80 kilometres downwind. The most serious source of radioactive contamination from any crude nuclear explosive device is likely to arise from the dispersal of plutonium. If one kilogram of plutonium is uniformly distributed it will contaminate about 600 square kilometres to a level of one micro-curie per square metre, the maximum permissible level allowed for plutonium by international regulations. This means that a very large area will have to be evacuated and decontaminated, an expensive procedure that could take years.

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Note

Some recent official statements imply that plutonium produced in nuclear-power reactors - and therefore that which could be obtained from MOX - cannot be used in nuclear weapons or nuclear explosive devices. For example, Ryukichi Imai, former Japanese Ambassador for Non-Proliferation, stated that:

"Reactor-grade plutonium is of a nature quite different from what goes into the making of weapons . . . Whatever the details of this plutonium, it is quite unfit to make a bomb." (1)

This statement is incorrect, as Robert Seldon of Lawrence Livermore Laboratory explains:

"All plutonium can be used directly in nuclear explosives. The concept of . . . plutonium which is not suitable for explosives is fallacious. A high content of the plutonium 240 isotope (reactor-grade plutonium) is a complication, but not a preventative." (2)

The Director General of the International Atomic Energy Agency, Hans Blix, stresses that his organization:

"...considers high burn-up reactor-grade plutonium and in general plutonium of any isotopic composition...to be capable of use in a nuclear explosive device. There is no debate on the matter in the Agency's Department of Safeguards." (3)

And at a conference in Vienna in June 1997, Matthew Bunn, who chaired the US National Academy of Sciences analysis of options for the disposal of plutonium removed from nuclear weapons, made a crucially important statement based on recently declassified material "of unprecedented detail on this subject":

"For an unsophisticated proliferator, making a crude bomb with a reliable, assured yield of a kiloton or more -- and hence a destructive radius about one-third to one-half that of the Hiroshima bomb -- from reactor-grade plutonium would require no more sophistication than making a bomb from weapon-grade plutonium. And major weapon states like the United States and Russia could, if they chose to do so, make bombs with reactor-grade plutonium with yield, weight, and reliability characteristics similar to those made from weapon-

grade plutonium. That they have not chosen to do so in the past has to do with convenience and a desire to avoid radiation doses to workers and military personnel, not the difficulty of accomplishing the job. Indeed, one Russian weapon-designer who has focused on this issue in detail criticized the information declassified by the US Department of Energy for failing to point out that in some respects if would actually be easier for an unsophisticated proliferator to make a bomb from reactor-grade plutonium (as no neutron generator would be required)." (4)

That plutonium containing about 20 per cent of Pu-240 can be used to fabricate nuclear weapons was proved by the British who exploded two such devices in 1953 (5) and by the Americans who exploded at least one such device in the 1960s (6).

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