OXFORD • RESEARCH • GROUP

Report on the Legal Liabilities for Civil Plutonium Incidents

James K. Woolley, LLB. MA
June 2000

1. Introduction

This note addresses the legal liabilities that might arise in two possible scenarios involving civil plutonium separated from spent reactor fuel elements at Sellafield:

(1) the illegal acquisition of plutonium from the plutonium store at Sellafield or from a mixed-oxide (MOX) fuel assembly by diversion or theft leading to the construction and explosion of a primitive nuclear device in an urban area; and
(2) an accident involving an aircraft carrying plutonium in its cargo which crashes and catches fire.

Both events are assumed to take place within the territory of the UK and effects are assumed to be similarly, if artificially, restricted. They are described in more detail in Annex 1. This analysis commences with a general description of the statutory framework for liability for nuclear accidents.[1] It then considers the extent to which the current framework applies to the scenarios concerned and then lastly considers the shortcomings, i.e. the extent to which the current framework either has no application or is deficient. It includes an appendix (Annex 2) with costs that have been attributed to a number of actual and theoretical accidents involving nuclear materials.

2. The Legal Framework

2.1 General

The legal position is governed by statute, the Nuclear Installations Act 1965 as amended. This limits and regulates the liability of the operator of a nuclear site for events on and, to a degree, off that site in the event of a relevant incident. The State assumes financial responsibility for the consequences of accidents over a monetary limit currently set at £140 million [2].

2.2 The International background

To understand the Nuclear Installations Act 1965 (the "NIA") it is necessary to appreciate a little about the international context. The relevant legal provisions for the UK are contained in sections 7 to 21 of the NIA. This legislation is intended to meet the requirements of the Paris Convention on Third Party Liability in the Field of Nuclear Energy of 1960 ("the Paris Convention") as supplemented by the Brussels Supplementary Convention of 1963 (the "Brussels Convention").

2.2.1 The Paris and Brussels Conventions

These Conventions were concluded under the auspices of the Paris-based Organisation for Economic Co-operation and Development (OECD). The United Kingdom is a party to both Conventions[3]. The purpose of the Paris Convention of 1960 was to harmonise national legislation with regard to third party liability and insurance against atomic risks and to establish national regimes for liability and compensation in the event of a nuclear incident[4]. The Convention establishes the liability of the operators of nuclear plant for personal injury and damage to property as a result of a nuclear incident. That liability will arise if the damage is caused by the accident, so that no proof of fault or negligence on the part of the operator is required [5]. This corresponds to what is usually described as absolute liability in the English law of tort.

The Paris Convention limits the liability of the operator to 15million Special Drawing Rights ("SDRs", a unit of account used by the International Monetary Fund) in respect of a nuclear incident[6]. Contracting States might establish greater or lesser amounts but in no event less than 5 million SDRs. The Brussels Supplementary Convention increased the total compensation available to 300 million SDRs per incident, equivalent to some £260 million[7]. The Paris Convention requires that operators shall take out insurance cover or other financial security up to the limit of liability specified [8].

2.2.2 The Vienna Convention

The Vienna Convention on Civil Liability for Nuclear Damage of 1963 was negotiated under the auspices of the Vienna-based International Atomic Energy Agency (IAEA), an Agency of the United Nations. It is of potentially worldwide application rather than being confined to OECD countries. The purpose of the Convention, like that of the Paris Convention, is to provide for minimum protection under national law against damage resulting from certain peaceful uses of nuclear power. The Vienna Convention follows the same principles as the Paris Convention in that it provides for absolute liability on the part of the nuclear operator and permits the State within which the installation exists to limit the extent of the liability but not to a sum less than 5 million US dollars in respect of any one incident.[9] The Vienna Convention also states that the operator shall be required to maintain insurance or other financial security covering his liability for nuclear damage in the amount or type which the State in which the installation exists shall specify.

None of the parties to the Paris Convention are parties to the Vienna Convention although the United Kingdom is a signatory and did express the intention to ratify the Convention but never has.

2.2.3 Revisions after the Chernobyl Treaty.

The Chernobyl accident exposed major systemic deficiencies in the application and content of the Vienna Convention and the Paris Convention. (Almost all of these persist and are addressed in section 4.) The IAEA subsequently initiated a review of the Vienna Convention.

One deficiency was the very poor geographic coverage.[10] Another was the absence of any reciprocity between the two Conventions.[11] There were also major problems regarding (a) the limited definition of what damage qualified for compensation and (b) the totally inadequate amount of compensation. The Protocol to Amend the Vienna Convention on Civil Liability for Nuclear Damage of 1997 seeks to address both these points. The definition of nuclear damage has been made extendable beyond personal injury and damage to property to cover:

- Economic loss
- The costs of measures of reinstatement of impaired environment

- Loss of income deriving from an economic interest in any use or enjoyment of the environment incurred as a result of a significant impairment of that environment, and
- The costs of preventive measures, and further loss or damage caused by such measures.

But these additional heads of compensation apply only "to the extent determined by the law of the competent court" of the State party. So no common agreement has been reached on this and there is no binding requirement whatever to cover such losses and the Protocol is not yet in force in any event.

As for compensation levels, these are to be increased to 300 million SDRs and to be supported by an international inter-State pooling mechanism created by the 1997 Convention on Supplementary Compensation for Nuclear Damage, when this comes into force. This is designed to provide assistance to the State with primary liability from other State parties. This is a similar mechanism to that contained in the Brussels Convention.

The Protocol will not come into force until it has five contracting parties. Currently it has only two.[12] The Convention on Supplementary Compensation also requires five contracting parties with significant nuclear capacity before it comes into force: so far it has only two.[13] By contrast with this IAEA activity, the OECD's Nuclear Energy Agency and its constituent Member States including the UK have not amended the Paris Convention but are still, some 14 years after the Chernobyl accident, discussing matters.

2.2.4 General Principles
The Paris and Vienna Conventions thus have four principal common features.

1. They establish the principle of absolute liability on the part of the nuclear operator;
2. They permit the limitation on that liability to a maximum sum in respect of a particular incident;
3. They require the operator to obtain insurance cover or other financial security in respect of the liability;
4. They eliminate liability falling on anyone else apart from an operator: a system known as "liability channelling" to avoid multiple claims and multiple insurance.

As explained below each of these features has become a part of the United Kingdom law.

<u>2.3 UK law</u>

2.3.1 Liability of site operator
Section 7 of the NIA imposes a basic obligation on every holder of a nuclear site licence. It requires the licensee to ensure that no occurrence[14] on the site involving nuclear matter causes (a) injury to any person or (b) damage to any property except that of the licensee. The liability is absolute: a person who has suffered damage need not establish any fault or negligence on the part of the licensee. The liability also

extends to any occurrence involving nuclear matter in the course of carriage on behalf of the licensee and to nuclear matter that has been on the site as described in part 3.

2.3.2 Compensation
The Act provides that compensation shall be payable to anyone who has suffered injury or damage caused by a breach of the duty imposed on persons with a nuclear site licence and on certain others. The compensation is made payable if the injury or damage was incurred in the UK[15].

The amount of compensation which any operator may be liable to pay in respect of any one occurrence is limited to £140 million. The Secretary of State for Energy may prescribe an increased limit [16]. The operator is required to maintain insurance cover (or some other means of cover) in respect of his potential third party liability up to £140 million. If claims are brought which in aggregate exceed the £140 million limit of liability for any one occurrence, then the Government must make available funds to ensure that claims are satisfied up to a total of 300 million SDRs [17]. If the total claims exceed 300 million SDR the Act provides that they shall be satisfied by the Secretary of State for Energy to such extent and out of funds provided by such means as Parliament may determine [18]. In other words the matter is left for the discretion of Parliament. The existence of and the amount of any further claims against the Secretary of State under this second stage may be determined by the High Court [19].

A limitation period of 30 years is imposed on claims for compensation, i.e. the claim cannot be entertained if made more than 30 years from the date of the occurrence which gave rise to the claim [20]. There is an overall limitation period of 30 years for claims under the statutory provisions. Claims made more than ten years after the occurrence but within the overall 30-year limitation period are made to the Secretary of State for Energy and are satisfied out of the 300 million SDR sum or out of such further funds as Parliament may determine. It is because of these prescribed periods that the compulsory insurance has to provide cover up to £140 million not only in respect of the current cover period but also in respect of any cover period within the previous ten years [21].

The liability under the Nuclear Installations Act 1965 replaces (subject to minor exceptions) any liability which would have existed at common law as a result of a nuclear accident [22]. So claims against the operator in tort at common law are extinguished in favour of the statutory liability.

In summary if anyone can show that injury or damage has been caused within the UK by an incident in the United Kingdom, that person has a claim which can be asserted within the next 30 years after the incident :

1. On the site operator during the first ten years up to a maximum for all claims arising out of the incident of £140 million (for which liability third party insurance cover has to be maintained);
2. On a 300 million SDR fund which the Government must make available, and
3. On such other sums as Parliament may determine.

All other liability in respect of the incident is excluded.

3. Application of UK liability regime to the scenarios.

3.1 The illegal acquisition of plutonium or mixed-oxide (MOX) fuel leading to the construction and explosion of a primitive nuclear device.

The "occurrences" for which the site operator is to be liable are of three kinds:

- on-site;
- off-site whilst "in the course of carriage on behalf of the (site operator)"; and
- any other occurrence off-site as described. (Section 7(2))

Plainly an explosion does not fall into the first two categories. Does it fall into the third? This category refers to an occurrence involving nuclear matter which is not excepted matter (which) has been previously on the relevant site or in the course of carriage.

An "occurrence" for the purpose of section 7(2) is not defined[23]. In principle an explosion using materials from MOX fuel rods would be "an occurrence".

Nuclear matter is defined as:
"(subject to any exceptions which may be prescribed) (a) any fissile material in the form of uranium metal, alloy or chemical compound (including natural uranium), or of plutonium metal, alloy or chemical compound, and any other fissile material which may be prescribed; and (b) any radioactive material produced in, or made radioactive by exposure to the radiation incidental to, the process of producing or utilising any such fissile material as aforesaid;" [24]
Plutonium from the Sellafield store or extracted from MOX fuel rods would fall within that definition.

Excepted matter is defined as:
"nuclear matter consisting only of one or more of the following, that is to say — (a) isotopes prepared for use for industrial, commercial, agricultural, medical, scientific or educational purposes; (b) natural uranium; (c) any uranium of which isotope 235 forms not more than 0.72 per cent; (d) nuclear matter of such other description, if any, in such circumstances as may be prescribed (or, for the purposes of the application of this Act to a relevant foreign operator, as may be excluded from the operation of the relevant international agreement by the relevant foreign law);" [25]
Materials extracted from plutonium or mixed oxide fuel rods would not fall within that definition and do not fall within the prescribed exceptions. [26]

Assistance in determining whether the notion of an occurrence extends to a terrorist act can be obtained by posing the following questions.

- What is the plain meaning of the words?
- As the NIA is intended to be in conformity with the Paris and Vienna Conventions, do they cover this kind of incident?
- What do other legal experts have to say on this?

The plain meaning:
An occurrence involving a terrorist explosion certainly qualifies as an occurrence in the sense of an event, incident or happening as defined by the OED. When the 1965 Act was introduced as a Bill it was understood that this was to provide "that

occurrences covered are no longer restricted to those which take place on the licensed site or in the course of carriage within the United Kingdom;"[27].

Consistency with the Conventions:
When the Minister introduced the Bill containing this extension, he said

"The Bill deals with the establishment of an international system governing civil liability for injury or damage arising from the use of nuclear energy. It is necessary so that we can amend our law, to enable us to ratify three international Conventions in the field of nuclear energy."[28]

He explained that the three Conventions which the UK had signed were the Paris Convention, the Vienna Convention and the Brussels Convention supplementary to the Paris Convention [29]. Although the UK ratified the Paris and Brussels Conventions but not the Vienna Convention, it is clear that the Nuclear Installations Act was intended to be consistent with both Paris and Vienna conventions. This intention to achieve consistency with both Conventions was confirmed when the Nuclear Installations Act 1969 was passed to correct inconsistencies with the Treaties: *"... our ratification of the Conventions ... means that our domestic law must be consistent with their provisions."[30].*

So what do the Treaties say?
(i) Article 3 of the Paris Convention provides that "(a) The operator of a nuclear installations shall be liable, in accordance with this Convention…upon proof that … (the damage) was caused by a nuclear incident in such installation or involving nuclear substances coming from such installation …" (otherwise than in circumstances of authorised carriage or other).

Article II of the Vienna Convention provides for the operator to be liable for "a nuclear incident (a) in his installation; or (b) involving nuclear material coming from or originating in his nuclear installation…" (otherwise than in four sets of circumstances of involving activity intended by the operator).

This seems to confirm that it is sufficient if the material came from the installation even if this was not authorised by the operator, as would occur in the case of theft or hijacking of material followed by its use in an explosive device. These Convention articles appear to be implemented through sections 7(2)(c) and 10(1)(b) NIA.

(ii) The Paris Convention exempts the operator from liability in the event of "damage caused by a nuclear incident directly due to an act of armed conflict, hostilities, civil war or insurrection.."[31]. The Vienna Convention also provides that "No liability … shall attach to an operator for nuclear damage caused by a nuclear incident directly due to an act of armed conflict, hostilities, civil war or insurrection."[32] These Articles make it clear that a nuclear incident can be such in principle even where the act is due to an act intended to cause damage (whilst exempting the operator from liability for particular instances). These Convention requirements are drawn more narrowly in section 13(4)(a) NIA which excludes liability for an occurrence "attributable to hostile action in the course of any armed conflict, including any armed conflict within the UK"

(iii) Article 8(b) of the Paris Convention currently deals with time limits for claims "(i) in the event of damage caused by a nuclear incident involving nuclear fuel or radioactive products or waste, which at the time of the incident have been stolen…". Article VI 2 of the Vienna Convention contains a similar provision. This also establishes that an incident can involve nuclear fuel or radioactive products that have been stolen. The requirement can also be found similarly expressed in section 15(2) NIA.

(iv) The Paris Convention refers to "damage caused by an incident result(ing) from an act or omission done with the intention of causing damage.."[33]
The Vienna Convention contains a similar reference[34]. This also establishes that an incident may consist of an act of intentional damage. The NIA contains a parallel provision in section 13(6).

Other Legal Experts:
According to Michael Barnes QC, the Inspector at the Public Inquiry into the last proposal to construct a nuclear reactor in the UK,

"Injury or damage caused by hostile enemy action is excluded from the ambit of liability, but accidents caused by terrorism or sabotage could, it seems, give rise to liability."[35]

According to Professor Lopuski:
"The wording of the war exoneration as determined by the Vienna Convention and the Paris Convention does not cover explicitly terrorism. While generally speaking terrorism should be distinguished from "civil war or insurrection", in some cases, it may be difficult to draw a distinction between terrorism and civil war because terrorism may be one of the ways of waging the civil war."[36]

On the basis of the above it seems reasonable to conclude that an incident involving an explosion utilising stolen radioactive material from the Sellafield plutonium store or from MOX fuel rods produced at Sellafield would be the liability of the Sellafield site operator, the wholly Government-owned BNFL, provided the incident fell short of being part of an insurrection or civil war. [37]

3.2 An accident involving an aircraft carrying plutonium in its cargo.
The issue of a liability here is more straight-forward: an incident during authorised transport is clearly provided for within the legislation. Some complexity however does attend the allocation of liability between UK operator and foreign operator. In principle the division of responsibility for incidents involving nuclear non-excepted matter during carriage within UK territory where the carriage takes place away from a nuclear site is as follows:

- The UK site operator is liable where the carriage is undertaken either (a) on the UK operator's behalf or (b) where the material is carried (i) from a non-Paris Convention country and (ii) with the agreement of the UK operator (iii) to its site[38].
- A Paris-convention foreign operator is liable where the carriage is either (a) on that foreign operator's behalf or (b) where the material is (i) in transit to that

operator (ii) from a non-Paris-convention country (iii) with the agreement of that operator[39].

- A non-Paris-convention foreign operator is liable where the carriage is on that foreign operator's behalf (section 11)

On this basis, plutonium being carried on behalf of BNFL would be that company's liability. Plutonium being carried on behalf of a German customer of BNFL would be the German company's responsibility and plutonium being carried on behalf of a Japanese company, would be the Japanese company's responsibility. Where BNFL is returning plutonium to a customer in Germany or Japan, liability would seem to turn on the question of whether that carriage is on behalf of BNFL or on behalf of the overseas customer. Arguments might turn on the nature of the return contracts.

4. The deficiencies of the current liability regime.

The Chernobyl accident revealed the following deficiencies in the Paris/Vienna liability regime:

1. Insufficient compensation;
2. An over-restrictive definition of "nuclear damage";
3. Overly brief time limits for the submission of claims;
4. Difficulties in the proof of causation and of damage;
5. Excessive exonerations and lack of provision for compensation if an exoneration applies;
6. Lack of priorities in the distribution of compensation;
7. The difficulty and expense of private law suits conducted by individual victims;
8. The inability of municipal courts to deal with possibly thousands of claimants, as well as with complex scientific and technical evidence. [40]

All these points are very relevant to the present scenarios and to deficiencies in the UK liability regime. It is worth emphasizing that the UK does not need to wait for international Conventions or Protocols to be agreed before it can introduce improvements to modernise its own nuclear liability regime but it has chosen to take no legislative action since Chernobyl apart from altering the financial liability ceilings.

1. Insufficient compensation

Section 2.3.2 above explained the limited liability of the operator of £140 million and the taxpayers residual responsibility through the Government for up to some £260 million (300 SDRs). It is not appropriate that tax-payers' should shoulder the responsibility for risks attendant upon a commercial operation above £140 million. In any event the ceiling of £260 million is far too low. For example the cost of the 1979 Three Mile Island accident was £3800 million, and the cost of the Chernobyl accident has been put at between £1950 million and £200,000 million. Modernising the liability regime would involve abolishing the ceiling on liability. Annex 2 to this Note considers some of the figures for compensation suggested for real and hypothetical accidents.

2. An overly restrictive definition of "nuclear damage"

The following losses were not covered by the Paris/Vienna Conventions or the Nuclear Installations Act 1965 at the time of Chernobyl and remain uncovered today:

- The costs of precautionary, preventive or protective measures e.g. evacuations, relocations, radiation monitoring, medical expenses, emergency service costs, food marketing and consumption restrictions, loss of agricultural goods;
- Economic losses consequent upon the occurrence but not consequent upon specific damage to claimant's property or person;
- The cost of damage to the wider unowned environment;
- Economic loss or loss of profit as a result of contamination to the wider (unowned) environment (e.g. tourism);
- Decline in property prices;
- The cost of cleaning up contaminated land;
- Psychological damage.

Modernising the liability regime would involve explicit provision for all these heads of damages including damage to the environment and natural resources.
In Merlin v. BNFL, a Cumbrian homeowner sought compensation from BNFL for plutonium contamination of his property [41]. The court found that the mere presence of radionuclides in his house did not constitute physical damage. Despite the loss in value of the house, compensation was not recoverable. By contrast in Blue Circle Cement v AWE[42] intermingling of radioactive substances in soil amounts did constitute physical damage so that compensation for the damage and the loss in sale value of premises was recoverable. The cases are in many ways contradictory and illustrate the uncertainty complained of.

3. Time limits for submitting a claim
The Paris/Vienna regimes provide for ten-year limitations. In the UK this applies to claims against the operator but as the operator is only insured for the first ten years, for a further 20 years claims may be brought directly against the Government. Modernising the liability regime would involve abolishing any time limit for bringing claims given the very long periods that can run before impacts manifest themselves.

4. Difficulties in the proof of causation and damage
(i) ill health and death:
Proof of causality is notoriously difficult to establish. The extent of physical harm may not become apparent for decades and when cancers do appear they may be indistinguishable from cancers with other causes.
In Reay v BNFL[43] the Plaintiffs were unable to prove that the acute lymphatic leukaemia and the non-Hodgkins lymphoma which had affected two children - the first fatally - had been caused by BNFL's operations. An excess number of cancers in the Sellafield area and epidemiological research associating leukaemia with paternal preconception irradiation at Sellafield were not sufficient to establish causation. Without presumptions that e.g. presence at a particular incident will be presumed to be responsible for any subsequent cancer unless shown otherwise, claims are very difficult to establish. At Sellafield a BNFL occupational scheme provides for employees to obtain compensation for radiation injuries without proof of cause. Merely being exposed to a particular radiological hazard ought to be the basis for modernising statutory liability as well.

(ii) damage to property:

The level of contamination sufficient to constitute "damage" is not adequately defined. This is illustrated by the cases of Merlin and Blue Circle mentioned above.

5. Exonerations
It is not satisfactory that there should be uncertainty about whether an occurrence falls within or without the concept of "insurrection" as in the present hypothetical case. The same act may or may not establish liability depending on the existence of hostile activity against the background of which the particular act takes place.

6. Lack of priorities in the distribution of compensation
There is no indication in the Conventions or the Nuclear Installations Act as to how funds are to be distributed in the event of insufficient funds as between e.g. early and late claimants, those severely injured and those with property damaged.

7. The difficulty and expense of private law suits.
The length, procedural complexity and expense involved in a private law suit are significant obstacles as the case of Reay showed. This was one of the longest running personal injury cases on record which had major impacts on legal aid policy in view of its expense and which has contributed to the recent curtailment of funds for all civil legal aid cases. Obtaining and retaining access to appropriate lawyers, scientific experts, technologists over perhaps a period of fifteen years for a complex law suit presents formidable problems.

8. The inability of municipal courts to deal with possibly thousands of claimants, as well as with complex scientific and technical evidence.
The courts are not well equipped to deal with a massive number of claims arising out of a disaster as events in the 80s and 90s showed. Here the major complicating factor is causation. The physical, if not the psychological. effects of a ship sinking or a fire or a football disaster are very much more readily demonstrable than radiation injuries which may arise at any time over the lifetimes of the victims. The scope for disagreement over claims is huge.

5.Conclusion

Both scenarios appear to be alluded to in the UK liability legislation, but with some uncertainty attaching to the terrorist act. However the applicability in principle of the legislation is of very little comfort in view of its multiple and manifest deficiencies. The implications for a community affected by a nuclear accident contaminating a wide area are very worrying. Businesses appear to have no remedy for the purely economic impacts and decontamination costs appear irrecoverable from the nuclear operator in the absence of "physical" damage to property or person. The cost of evacuation, the damage to a city's economic prosperity, the loss of use of buildings pending decontamination where this was possible, their loss in value, the economic disruption, in fact all the major consequences of such an accident do not appear to be catered for. It follows that a location affected by such an incident would be massively disadvantaged. A radical overhaul of the legislation is well overdue, as is the full assumption of the risks to communities created by BNFL of which the two scenarios are examples.

Annex 1: Scenarios for incidents involving civil plutonium

Two possible scenarios for incidents involving civil plutonium separated from spent reactor fuel elements at Sellafield are (1) the illegal acquisition of plutonium or mixed-oxide (MOX) fuel and the construction of a primitive nuclear explosive and (2) an accident involving an aircraft carrying plutonium in its cargo.

(1) Nuclear terrorism
Having obtained plutonium oxide from the plutonium store at Sellafield or a MOX fuel assembly by diversion or theft, a terrorist group would have little difficulty in making a crude atomic bomb. If plutonium oxide (PuO2) itself is stolen it could be used directly to produce a nuclear explosive or converted into plutonium (Pu) metal, which could then be used to make a nuclear explosive.

MOX contains a mixture of uranium oxide and PuO2. The necessary steps of separating PuO2 from uranium oxide (UO2) in MOX are straightforward chemistry. And so is the conversion of PuO2 into plutonium metal. The construction of a primitive nuclear explosive from the Pu metal or PuO2 is not technologically demanding. These operations do not require materials from specialist suppliers. The information required to carry them out is freely available in the open literature.
The operations would require some sophistication. Terrorist organizations 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 21 December 1988, required considerable planning and scientific skills. And so did the construction of the nerve gas weapon used in the Tokyo underground by the AUM group on 20 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.
The size of the nuclear explosion from a crude nuclear device made by a terrorist group 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 center 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.

Effects of the explosion of a primitive nuclear explosion with an explosive yield equivalent to that of 100 tonnes of TNT.
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 (25). 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.

Effects of a 1000-tonne nuclear explosion
The British Cabinet Office has calculated the effects of a primitive nuclear explosive detonated at ground level in atypical city. The explosion was equivalent to that produced by 1,000 tonnes of TNT, a possible but unlikely explosive yield from a crude nuclear weapons. Within one minute, people outdoors on 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 instance 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 some ten kilometres downwind wind 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 which could take years.

(2) An accident involving an aircraft carrying plutonium

If an aircraft carrying plutonium crashes and catches fire, the plutonium (Pu) is likely to be scattered far and wide. This would have serious consequences for people in the area concerned. Pu is a very toxic material. This toxicity arises mainly from its radiological effects; its chemical toxicity is similar to that of the heavy metals and is considerably less than its radiological toxicity. The radiological hazard of Pu arises mainly from the ionising radiation delivered to various internal organs of the body when Pu is ingested or inhaled into the body. Plutonium delivers a negligible external radiation dose to the skin because it emits mainly alpha particles that do not generally have sufficient energy to penetrate the skin.

Generally speaking, for the intake of a given amount of Pu, that which is inhaled is much more hazardous than that which is ingested. Pu is more easily absorbed into the blood stream through the lungs than through the gastrointestinal (GI) tract. Inhaled Pu will irradiate the lung; ingested Pu will irradiate the walls of the GI tract. Ingested and inhaled Pu may migrate via the blood stream to concentrate selectively in the liver and bones. The health effects of Pu may be short-term (acute) or long-term (chronic). Inhalation, for example, may lead to acute pulmonary oedema. Long-term effects include an increased risk of cancer. Inhalation of Pu will expose the lung tissue to irradiation by alpha particles, increasing the risk of lung cancer. Some plutonium may eventually be carried from the lung to other organs (mainly the liver and the skeleton) where the radiation will increase the risk of cancer at these new sites.

The inhalation of 0.047 mg of Pu normally produced in a nuclear-power reactor (reactor-grade Pu), has a very high probability (virtually a certainty) of producing a cancer. A PuO_2 particle containing 0.047 mg of Pu would have a diameter of 200 microns (1 micron is 1/1,000,000 metre or 1/10,000 centimetres.) It would not be possible to inhale such particles deep into the lung, where the lung tissue can absorb them. Any particle bigger than about 3 microns is not inhaled and is said to be not respirable. To inhale a total of 0.047 mg, it would be necessary to inhale about 300,000 3-micron PuO_2 particles. This is a lot of particles. But a very large number of respirable particles could be produced if a fire disperses PuO_2 and explosion caused by an aircraft accident, about 30 per cent of the PuO_2 may be respirable. In a hot fire, up to a few per cent of the Pu metal burnt will be converted into respirable PuO_2. If, for example, 2 kilograms of PuO_2 is dispersed, about 600 grams might be respirable. Assuming that all the particles are 3 microns in diameter, about 4 trillion (million million) of them will be produced.

An averagely active person breathes about 1.5 cubic metres of air a minute. Assuming that 2 kilograms of PuO2 are blown up in an explosion and that the 600 grams of respirable PuO2 are uniformly dispersed through a cube of air, 500 metres on the side. The concentration of Pu in the air is then 0.0048 mg per cubic metre. A person breathing this air for 1 hour would inhale 1.5 x 0.0048 = 0.0072 mg. A person breathing for 6 hours would inhale about 0.047 mg of Pu, enough to cause a fatal cancer. The level of land contamination with Pu isotopes which would require decontamination (by, for example, the removal of top soil) depends on the circumstances. The National Radiological Protection Board (NRPB) recommends that land contaminated by more than about 1,000,000 Bq per square metre. Of relatively insoluble radioactive fine particles, like PuO2, will require evacuation until it is decontaminated. If evenly distributed, a kilogram of reactor-grade Pu will contaminate nearly 550 square kilometres to this level. After the accident, the particles, which have fallen to the ground, are still a potential health hazard. If the particles are disturbed, or blown by the wind, they can become airborne again and will remain a health hazard until the area is decontaminated.

Annex 2 Estimated costs of real and theoretical accidents

A. Actual accidents

1/2. Palomares and Thule:

Accidents involving nuclear weapons occurred at Palomares, Spain, in 1967 and Thule, Greenland, in 1968. Each cost around $500 million. More than one bomb was involved on each occasion although plutonium was dispersed not by explosion but by impact with the ground and fire. Also sparsely populated regions were involved [44]. It was reported that at Palomares, around 1500 tons of topsoil and vegetation had to be removed for safe disposal and at Thule thousands of tons of ice and snow.

3.Three Mile Island:

This accident caused only very small releases of radioactivity but is estimated to have cost between US$ 2 and 4 Billion [45].

4. Chernobyl:

The official Soviet Economic Forecasting Agency calculated direct costs to the Soviet Union of between £1.95 and £3.1 Billion. Western commentators have estimated the direct cost to be in the order of £6 Billion. The Supreme Soviet originally set aside 26 billion roubles (around £26 billion) to try to cover all the associated costs[46]. The Head of the Soviet Fire Service, making an estimate including long-term costs of treating those suffering from radiation sickness and other illnesses, calculated a figure of £200 Billion[47]. Medever in "The Social and Environmental Impact of The Chernobyl Accident"[48], reported that the total costs of the accident had increased from 2 billion roubles in 1986 to 17 billion roubles in 1991. Attempts to assess the costs up to the year 2000, have suggested figures ranging from 170-215 billion roubles. In the Ukraine the size of the 1993 "clean up" budget for the ongoing effects of the Chernobyl disaster has been greater than the entire defence budget (Wood[49]). The cost to countries outside the former USSR has been between 1.5 to 4 billion dollars. Medevev concludes that the Chernobyl accident was the "most expensive industrial accident in modern history"[50]. The very lowest estimate of the total costs of the accident by 1991 was $6 billion US. The massive operation to try to make settlements affected by the Chernobyl accident reinhabitable, highlighted many of the technical problems which would be encountered as a result of a nuclear accident in a populated part of the UK.

5. Goiana:
If an urban environment is involved, then the problems of decontamination could be far more complex and costs correspondingly greater. In 1987 at Goiana, Brazil the dispersal of only 100 grams of Caesium-137 of 1400 curies radioactivity from a medical radiography machine required the removal of 3,500 cubic metres of soil and the demolition of 7 houses[51].

B. Theoretical Accidents
1.US Estimates:
The US Government Rasmussen Report in 1975 estimated that a major accident could cause $14 Billion in property damage and 3300 immediate deaths.[52] This report included a prediction of 4500 cancer deaths in the subsequent 10-40 years and 5100 genetic defects in later generations. This report was criticised from within the Government and by the independent scientific community because long term health effects cited were considered to be 50 times too low[53]. The Pace University Center for Environmental Legal Studies (US) in an estimate produced for the US Department of Energy and the New York State Energy Research and Development Authority put potential costs (as at 1990) at between US$ 613 billion and US$ 652 billion [54]. However this estimate excluded:

- Personal compensation for cancer;
- Other health damage;
- Psychiatric trauma costs;
- Environmental costs;
- Property damage except to agriculture;
- All losses of profit;
- All lost electricity production;
- All capital asset replacements;
- All evacuation and clean-up costs.

The US government has assessed that around 100 square kilometers could be contaminated if the conventional explosives of a nuclear warhead detonated, costing around $500 million dollars (£260 million) to clean up[55].

2. UK estimates:
Estimates of costs of a major nuclear accident in the UK, were provided to the Sizewell Inquiry. Earth Resources Research and Friends of the Earth estimated 3000 early cancer deaths and short term attributable costs of £15 Billion to the U.K. alone [56].

3.German estimates:
A report produced by Prognos AG for the German Federal Ministry of Economics estimated the cost for a worst case accident scenario for the Biblis-BPWR (soviet designed) power station including the expected costs of cancer deaths at US$ 6.8 Trillion [57].

Notes

[1] It adopts for the most part the general analysis of this issue to be found in the Report of Michael Barnes QC, the Inspector at the Hinkley Point Public Inquiries 1990 (see Chapter 30 Nuclear Insurance)
[2] Amount increased to this figure by SI 1944 No 1909 from 1st April 1994
[3] The UK and thirteen other States are parties to the Paris Convention. The United Kingdom and ten other States are parties to the 1963 Brussels Supplementary Convention
[4] A "nuclear incident" is defined in Article 1(a)(i) of the Paris Convention
[5] Article 4, op cit
[6] Article 7(b) Paris Convention; an SDR was worth £0.86654 as at 15th May 2000
[7] Article 3(a) Brussels Convention
[8] Article 10(a) Paris Convention
[9] Article V 1 Vienna Convention
[10] Few states were parties to either of the Conventions, e.g. Japan and the USA. At the end of March 2000 the Vienna Convention on Civil Liability for Nuclear Damage had thirty-two State Parties.
[11] The Paris and Vienna Conventions were completely mutually exclusive: victims in the territory of Parties to one Convention could not sue in the territory of parties to the other. To redress this the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention was agreed in 1988. As of end March 2000, twenty-one States had become Parties.
[12] As at March 2000 Morocco and Romania have contracted and there are fourteen signatories: Argentina, Belarus, Czech Republic, Hungary) Indonesia, Italy, Lebanon, Lithuania, Morocco, Peru, the Philippines, Poland, Romania, and Ukraine.
[13] Morocco and Romania have contracted and there are thirteen signatories: Argentina, Australia, Czech Republic, Indonesia, Italy, Lebanon, Lithuania, Morocco, Peru, the Philippines, Rumania, Ukraine, and the United States at the end of March 2000.
[14] Whilst the Paris Convention uses the term "incident", the NIA uses the term "occurrence"
[15] Or in a country bound by the Paris Convention (or the Vienna Convention where that country has ratified the Joint Protocol relating to the Application of the Vienna and Paris Conventions)
[16] section 16(1)(a) NIA 1965
[17] section 18(1) NIA 1965
[18] section 16(3) NIA 1965
[19] section 16(4) NIA 1965
[20] section 15(1) NIA 1965
[21] sections 16(3)(b),(5) (19(1) NIA 1965
[22] section 12(1)(b) NIA 1965
[23] An occurrence is defined for the purpose of other sections, namely sections 16(1) and (1A), 17(3) and 18 of the Act as follows: "(a) in the case of a continuing occurrence, means the whole of that occurrence; and (b) in the case of an occurrence which is one of a succession of occurrences all attributable to a particular happening on a particular relevant site or to the carrying out from time to time on a particular relevant site of a particular operation, means all those occurrences collectively. [section 26])
[24] section 26 NIA 1965
[25] section 26 NIA 1965
[26] The Nuclear Installations (Excepted Matter) Regulations 1978 (SI 1978 No 1779)
[27] Hansard, 4th March 1965, col 1282, per the Earl of Bessborough
[28] Lord Stonham, op cit, col 1273.
[29] op. cit. col 1275
[30] Hansard 21 April 1969, col 333
[31] Article 9

[32] Article IV 3 (a)
[33] Article 6(f)(i)
[34] Article IV 2.
[35] Inspector's Report of the Hinkley Point Public Inquiries, 1990 Chapter 30 Nuclear Insurance, p869
[36] Nuclear Accidents Liabilities and Guarantees OECD 1993 p192
[37] An extremely complex provision suggests that a Paris-convention foreign nuclear site operator (e.g. with a site in Germany but not Japan) may be liable for an occurrence in the UK involving material that has previously been (i) on the foreign operator's site or (ii) carried on its behalf but has not (i) reached any UK operator's site or a Paris-convention foreign operator's site or (ii) been the subject of authorised carriage in a Paris-convention country including the UK or (iii) been in non Paris-convention territory (see section 10(i)(b) NIA 1965)
[38] section 7(2)(b) NIA 1965
[39] section 10 (1)(a) NIA 1965
[40] In addition the accident exposed further deficiencies: 9. insufficient coverage geographically; 10. lack of harmonization between the Paris and Vienna conventions and among the parties of each convention; 11. exclusion of military facilities; 12. the lack of recognition of State responsibility for activities within its jurisdiction or control, and the corresponding incentive for States to ensure that their nuclear facilities are as safe as possible. Points 9 to 11 are very important, but not to the present discussion and point 12 is complex and no progress has been achieved on this since the Chernobyl accident.
[41] 1999 JEL Vol 11 No 2 p321
[43] [1994] Env.L.R. 320
[44] Gregory and Edwards A Handbook of Nuclear Weapons Accidents (University of Bradford 1988); Steadman and Hodgkinson, Nuclear Disasters and the Built Environment Report to the Royal Institute of British Architects 1990
[45] Review of Estimates of the Costs of Major Nuclear Accidents prepared for the 9th Session of the Standing Committee on Nuclear Liability of the IAEA, 7th-11th February 1994, Greenpeace International
[46] Bulletin of Atomic Scientists Sep 1990
[47] Statement of Case for the Hinkley Point Public Inquiry, Greenpeace, p84
[48] "The Costs of Major Nuclear Accidents" COLA Special Briefing No 3 Nov 1993, Fred Barker
[49] op. cit.
[50] op.cit.
[51] Atom 388 Feb 1989
[52] "Unavailable at any price Nuclear Insurance" from Environmental Policy Centre 1980, Keiti Kehoe
[53] op.cit. p3
[54] Review of Estimates of the Costs of Major Nuclear Accidents prepared for the 9th Session of the Standing Committee on Nuclear Liability of the IAEA, 7th-11th February 1994, Greenpeace International
55. Report of the US Armed Services Committee Panel on Nuclear Weapons Safety
56 Statement of Case for the Hinkley Point Public Inquiry, Greenpeace, para 86
[57] Review of Estimates of the Costs of Major Nuclear Accidents prepared for the 9th Session of the Standing Committee on Nuclear Liability of the IAEA, 7th-11th February 1994, Greenpeace International