

# The Security of UK Nuclear Electricity Supplies

Prepared By

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**Publications**

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Uranium, 1962; Creep, Viscoelasticity and Creep-fracture in Solids, 1979; Irradiation Effects in Crystalline Solids, 1979; (with W. Crosbie) Medical Response to Effects of Ionizing Radiation, 1989; numerous articles in learned jls.

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**Clubs**

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## Summary.

In this Report I give two independent forecasts of the Third Party Liability (TPL) risks of terrorist attack on nuclear installations in the UK. One is based on theory and the other on scenarios.

Recent evidence from the trial of one of the 1993 WTC bombers revealed that Usama bin Laden's terrorist training camps offer instruction in '*urban warfare*' against '*enemy installations*', including power plants. It is likely therefore that the WTC attack of 11/9/01 and the subsequent US attack on Afghanistan will have heightened the risk of a terrorist attack on one of the nuclear installations in the USA, the UK or one of the other states that has supported the USA.

Table of The Risks, Presented By Terrorist Attack, To Nuclear and Allied Installations In The UK (And, For Comparison, Other Countries) Before 11 September 2001 And After The Attacks On The World Trade Center And Pentagon That Occurred On That Date.

I give a Table that I have developed which uses estimates based on political risk before the WTC attack and afterwards. These estimates are current in the world's insurance markets and I have adapted and interpreted them to the nuclear terrorist risk, using information which is quoted in extensive notes to the Table.

The picture is that in the USA, the UK and other countries sympathetic to the USA response to the WTC event, the risk of terrorist attack on nuclear installations is currently significantly higher than before September 11<sup>th</sup> 2001.

Then I present my numerical analysis of the terrorist threat and of the Third Party Liability costs that it will entail. For this purpose I use the forecasts of an EU study known as the Joule study, which was prepared for DG 12 of the CEC in the framework of the EsternE project. I compare this study with a similar one made by the Royal Society and the Royal Academy of Engineers: I was involved personally with the latter. From these two studies I arrive at a value for the mean TPL annual loss, due to both terrorism and other causes, for the whole of the UK nuclear industry.

Terrorists would cause events that resemble accidents that have occurred or could theoretically occur at nuclear installations. They would do this by either external means such as aircraft crash or by internal sabotage.

The NII requirement is that no single cause shall contribute more than one tenth of the risk posed by a given nuclear installation and I assume that this has been the case for terrorism, as the threat of terrorism was perceived before the WTC attack.

Clearly the threat of terrorist attack on nuclear plant is now greater, or is seen as greater, than before the WTC attack. I assume that there are a number of likely targets for terrorism in the world, of which the WTC and the Pentagon were two. Others include some nuclear power stations, particularly in the USA and in countries like the UK that are particularly sympathetic to the USA. I use Bayes theorem to deduce, from the fact of the WTC attack, the increase in the annual TPL loss ascribable to the increased threat of terrorist attack on nuclear power stations. Similar calculations can be made for other likely targets, but as this Report is exclusively concerned with nuclear installations it does not deal with other types of target.

The Basic Safety Objectives (BSO) and Basic Safety Limits (BSL) set by the Nuclear Installations Inspectorate (NII) imply that the product of frequency and accidental dose from a nuclear installation is a constant, for every decade of frequency. Unsurprisingly this requirement, placed on the designers of the plants, results in just this sort of inverse relationship between frequency and dose, when Probabilistic Risk Assessments (PRA) are made of nuclear installations. I therefore assume that such inverse relationships between frequency and consequences apply to nuclear incidents, whether due to terrorists or other causes, for all the nuclear installations that are insured in the UK. This enables the relationship between frequency and TPL terrorist loss to be calculated for the whole of the UK nuclear industry.

—Table Of Values For Third Party Losses In Nuclear Accidents And The Frequencies With Which They Were Expected To Occur **Before** 11 September 2001;

This Table, given below, is then calculated. It is for the whole of the UK nuclear industry:

TPLoss, MGBP	1	10	100	1,000	10,000	100,000
Return						
period,year	11	108	1,083	10,829	108,292	1,082,919

Table Of Values For Third Party Losses In Nuclear Accidents And The Frequencies With Which They Were Expected To Occur **Since** 11 September 2001

The frequencies have increased as a result of the perception that a terrorist attack on a UK nuclear power stations is greater than had been thought, prior to the WTC attack:

TPLoss, MGBP	1	10	100	1,000	10,000	100,000
Return						
period,year	6	57	570	5,700	56,996	569,957

Values, Derived From The Above Tables, For The Average Monthly Cost Of Accidents To Nuclear Installations (Insurance Exposure, here termed *Insured Costs*) And Values, Derived From The Insurance Market, Of The Average Monthly Premium Charged By Nuclear Insurers;

These values are summarized below. The monthly premiums for terrorist TPL which are calculated are 23,086 GBP for the UK nuclear industry taken as a whole:

<b>After September 11th 2001</b>	3 decades, to 140M	
TPLoss, MGBP	<b>***Insured Monthly Costs</b>	<b>****Monthly Premiums</b>
TPLoss/Year, MGBP	<b>43,863</b>	<b>309,990</b>
Non Terror TPLoss/Year, MGBP	<b>20,777</b>	<b>290,836</b>
Terrorist Component of TPLoss/Year, MGBP	<b>23,086</b>	<b>19,155</b>
Return period,year	-	
Frequency/year	-	
<b>Before September 11th 2001</b>	-	
TPLoss, MGBP	-	
TPLoss/Year, MGBP	<b>23,086</b>	<b>290,836</b>
Non Terror TPLoss/Year, MGBP	<b>20,777</b>	
Terrorist Component TPLoss/Year, MGBP	<b>2,309</b>	
Return period,year		
Frequency/year		

A Methodology For Establishing A 'Commercial' Rate For A Premium Covering The Third Party Liability Risk Arising From Terrorist Activity Aimed At Different Types Of Nuclear Installation (Eg Generation Plant, Reprocessing Facilities, Industrial Complexes, Universities);

The results of these calculations are given in a Table of which the following is a summary. Only in the case of URENCO does the premium that I arrive at differ substantially from that proposed by BNI to the DTI:

	<i>This Work</i>	<i>BNI</i>
<i>TPL premiums</i>	<i>Proposed Monthly Premiums for Terrorist TPL</i>	<i>Proposed Monthly Premiums for Terrorist TPL</i>
<i>Magnox Sites</i>	<b>5,327</b>	<b>2,875</b>
<i>BNFL (Sellafield)</i>	<b>5,327</b>	<b>7,600</b>
<i>Amersham International</i>	<b>1,776</b>	<b>538</b>
<i>British Energy</i>	<b>5,327</b>	<b>3,399</b>
<i>URENCO</i>	<b>1,776</b>	<b>56</b>
<i>Transits (BNFL)</i>	<b>1,776</b>	<b>2,292</b>
<i>Transits (URENCO)</i>	<b>1,776</b>	<b>2,396</b>
<b>Sum</b>	<b>23,086</b>	<b>19,155</b>

—A Statement Of Views On The Reasons For The Reluctance Of Commercial Insurers To Cover Such Risks;

Insurers have the following reasons, in my view, for their reluctance to cover TPL due to terrorist attacks on nuclear installations in the UK:

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- Ø The UK is perceived to have attracted such risks by its very positive alignment with the USA in the aftermath of the atrocities of September 11<sup>th</sup> 2001. It seems clear that this was the right thing for the UK to do, but it is seen as making UK nuclear installations more vulnerable to terrorist attack than those of for example Japan, where the situation is as described in an Annex to this Report.
- Ø If the terrorists, on September 11<sup>th</sup> 2001, had targeted nuclear installations with the four planes that they took over, then there could have been four losses, whereas the capacity provided by the commercial nuclear insurance business is based on the assumption, borne out by the analysis in this present Report, that there will be no large losses or at most one.

### Information On A Range Of Realistic Scenarios, I.E. Low, Medium And High Increase In Probabilities Of An Attack Compared To Sept 11, Combined With A Range Of Possible Terrorist Event Scenarios?

Combining the forecasts for terrorist TPL arrived at in accident scenarios with those derived earlier in this Report from the theoretical Joule study and the BSO/BSL requirement we obtain the following Table for the 14 Gwe UK nuclear power program. It will be seen that there is a measure of agreement between these two methods of estimating terrorist TPL and return periods:

	University Minor Source	Co60 Exposure	Transit Accident	Criticality	Core Melt	Major Release of Radioactive Chemicals
<b>Terrorist TPL MGBP</b>	1	30	40	50	500	20,000
<b>Theoretical return period, based on Joule study, years</b>	5	325	433	541	5,415	216,584
<b>Scenario-based Return Period, years</b>	7	214	357	357	3,571	214,286

## **Introduction.**

In this Report I give forecasts of the Security of UK Nuclear Electricity supplies. I include estimates of the effect of terrorist activity, in the wake of the attack on the World Trade Centre and the Pentagon on September 11<sup>th</sup> 2001 and in the light of the war against Iraq.

## The Nuclear Fuel Cycle, Accidents and Normal Operation.

The reliability of supplies of electricity from the nuclear sector depends on the reliability of the nuclear power stations that generate the electricity and the reliability of the factories that manufacture and reprocess the nuclear fuel.

If an accident occurs to plant in the nuclear fuel cycle or to a nuclear power station, then it may result in interruptions to the supply of electricity from nuclear power stations. What will be the relative risks of such accidents for different stages of the Fuel Cycle?

To answer that question the following comparison table, Figure 1, has been prepared, from work done as part of the ExternE project,<sup>1</sup> from the associated Joule study<sup>2</sup>, from the Sizewell B public inquiry,<sup>3</sup> and from the work of a joint Royal Society/Royal Academy of Engineers working party of which I was a member<sup>4</sup>

**Figure 1. TABLE OF RISK-INDICES IN REDUCING ORDER:**

### RISK INDEX

- 37\*: Public Risk due to accidents at a nuclear power station\*\*
- 35: Occupational Risk due to normal operation at a nuclear power station.
- 6.1: Public Risk due to normal operation of Reprocessing Plant.
- 1.8: Public Risk due to normal operation of a nuclear power station.
- 1.4: Public Risk due to normal operation of Sizewell B nuclear power station~~.
- 0.4: Public Risk due to nuclear accidents at Sizewell B nuclear power station.
- 0.4 Public Risk due to nuclear accidents to 1 Gwe of AGR nuclear power stations.
- 0.2: Occupational Risk due to normal operation of Reprocessing Plant.
- 0.1: Accident Risk due to Reprocessing.(This is believed by CEPN to be lower than the Accident Risk due to a nuclear power station although its precise value has not been estimated)

Explanatory notes:

<sup>1</sup> CEPN (1995) DG XII, EXTERNE Project

<sup>2</sup> "Joule Study": Dreicer, M, Fort V. and Manen, P. "Nuclear Fuel Cycle: Estimation of Physical impacts and monetary valuation for priority pathways" Report Number 234. Centre D'Etude sur L'evaluation de la protection dans le domaine nucleaire, CEPN. February 1995. Prepared for DG 12 of the CEC in the framework of the EsternE project.

<sup>3</sup> Sizewell B data are derived from my own work (J H Gittus), quoted by Sir Frank Layfield, (1987) Sizewell B Public Inquiry, HMSO ISBN 011 411 575 3.

<sup>4</sup> NAPAG Report "Energy and the Environment in the 21 st Century" The Royal Society and the Royal Academy of Engineers, London, 1996.

\*: For example a Risk Index of 37 means a dose of 0.37 man.Sv/TWh. Deaths due to the dose occur after an incubation period of five years. The death rate is 6%/man.Sv. A nuclear reactor which typically generates 5.7 TWh/year therefore produces on average  $6\% \times 0.37 \times 5.7 = 0.13$  deaths/year due to accidents. It produces  $6\% \times 0.35 \times 5.7 = 0.12$  deaths/year in the work force due to normal operation.

#: The Public Risk is for members of the Public living within 1000 km of the installation.

\*\* : The nuclear power station chosen is a single PWR at Tricastin.

~: The Public Risk due to normal operation is the Environmental Risk.

~~: Sizewell B. It incorporates additional safety features compared with the standard nuclear power stations considered in this list.

The Joule study considers the physical impact of the entire fuel cycle for nuclear power for the entire world and for up to 100,000 years into the future.

The NAPAG study considers the effects on the UK. Where it discusses future effects of present day releases it looks 500 years into the future (page 57). Figure 2, based on data taken from the Joule Study (CEPN Report 234), shows that such NAPAG estimates will be an order of magnitude lower than the Joule estimates.

In the tables of the Joule Study:

Local means 0 - 100 km

Regional means 100 - 1000 km

Global means over 1000 km.

Short term means 0-1 year

Medium term means 1 - 100 years

Long term means 100 - 100,000 years

Only local impacts occur in the short term.

*Effects of Discount Rate.*

Figure 3 and Figure 4 are similar to Figure 2, but are for discount rates of 3% and 10% respectively. Now there is no disparity between the impact forecast under NAPAG assumptions and that for Joule assumptions. This is because the long term global impact is dominated by the effects of long lived isotopes and the discounted value of those impacts is therefore very small.

Figure 5 is a Summary.

NAPAG's assessment of the physical impact of nuclear power on the UK for 500 years into the future is at odds with the Joule study, in which the impact on the entire world for 100,000 years is forecast.

NAPAG's choice can be justified if the physical impact is measured in monetary terms and a discount rate of order 3% is adopted. Then the NAPAG and Joule studies produce essentially similar forecasts.

**Figure 2. Monetary valuation of physical impact (i.e. the financial loss) for normal operation. mECU/Kwh. zero discount rate.**

Numbers in brackets are collective doses, man.Sv/TWh.

Note that the monetary loss is five times the collective dose.

As the BSO/BSL graphs of dose versus frequency show (see later)^ that the product of the two is a constant, we therefore expect the product of monetary loss versus frequency to be a constant, which is supported by the admittedly limited data.

	Within 1,000km	The Entire World
First 100 years	0.2	0.4
First 100,000 years	0.2 (1)	2.5 (13)

**Figure 3, 3% discount rate.**

	Within 1,000km	The Entire World
First 100 years	0.082	0.082
First 100,000 years	0.095	0.096

**Figure 4. 10% discount rate.**

	Within 1,000km	The Entire World
First 100 years	0.050	0.050
First 100,000 years	0.051	0.051

**Figure 5. SUMMARY.**

*Monetary valuation of physical impact for normal operation. mECU/kWh.*

	Within 1,000km Within 100 years	Entire World Within 100,000 years
0% Discount	0.2	2.5
3% Discount	<b>0.082</b>	0.1

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*Monetary Equivalent of the Third Party Loss per Year for the Whole Nuclear Industry.*

To arrive at figures for the loss/year we proceed as follows:

In order to arrive at a starting point that is consistent with the Royal Society study, we choose 3% discount rate.

We are going to be concerned only with losses within 1,000 km and in less than 100 years, but Figure 5 tells us that at 3% discount, corresponding to assigning present worth to the Third Party Liability costs over the period of up to 100 years during which harms become manifest, there is no effect of time in the range 100 to 100,000 years.

The financial loss is therefore 0.082 mECU/kWh. This is the loss for the sum of the effects of normal operation and accidents.

The information summarized in Figure 1 at the head of this section indicates that 80% of this risk is due to accidents, that is  $0.8 \times 0.082 = 0.0656$  mECU/KwH.

**This is equal to 0.000040 GBP/kWh, (Figure 6)**

*TPL for the UK Nuclear Industry.*

In 2001, the UK generated 90,512,109,000 kWh Gross of electricity from nuclear power stations.

According to these present studies, therefore (This is equal to 0.000040 GBP/kWh, (Figure 6), the total theoretical TPL due to nuclear accidents in the UK in 2001 was therefore  $90,512,109,000 \times 0.000040 = 3,576,864$  GBP.

However this figure is dominated by the assumption, in the Joule study, that for reactors in the Western world, the current frequency of the most severe accident (core melt and gross containment failure) is 20 times higher than contemporary estimates would say. In an Annexe I show how the frequency of this severe accident has fallen over the last 20 years.

The overly pessimistic assumption about the frequency of the most severe accident is illustrated by Figure 7, taken from the Joule study, in which the severe accident ST2, which results in the release of 10% of the core inventory of radionuclides to the atmosphere, is accorded a frequency of  $.00005 \times .19 = 00001$ . That is to say a return period of only 100,000 years. Present estimates put the frequency at below one in 2,000,000 reactor. years. We shall therefore delete the financial risk due to this accident, since to add less than 1/20 th of that risk is insignificant in the present, approximate calculations.

**Figure 7: Joule Study, Features of Two Reactor accidents.**

Source Term,% release	Core melt frequency: /reactor-year	Conditional Probability of stated Source Term	Total Cost, MECU	Cost x Frequency MECU/Ry	Cost, mECU/kWh
ST2 10%	0.00005	0.19	83,252	0.790	0.104
ST23 0.01%	0.00005	0.81	431	0.017	0.0023

The calculation to achieve this is as follows:

The cost of ST2 in Figure 7 has been estimated for zero discount rate. Figure 5 above indicates that at 0% discount rate, our estimate of the total theoretical TPL due to nuclear accidents in the UK in 2001 ( $= 3,576,864$  GBP) must be multiplied by 2/.082, when it becomes 8,942,160GBP. The loss due to ST2, 83,252 MECU, is 50,000 MGBP and the Cost x Frequency (0.790 MECU/Ry) is 475,904 GBP/Ry. This is for one reactor. Year (Ry) at Tricastin, which the Joule study takes to be 1 Ry = 5.7 TWh. So for the 90.512 TWh which the UK nuclear power stations generated in 2001 the loss due to ST2 was  $90.512/5.7 \times 475,904$  GBP = 7,557,022GBP. The loss, net of ST2, is then  $8,942,160\text{GBP} - 7,557,022\text{GBP} = 1,385,138$  GBP.

**Figure 8. Theoretical cost of Third Party Loss due to nuclear accidents in the UK in 2001.**

*To restore this to the value appropriate to 3% discount rate, we multiply by 0.08/2 and obtain 554,055 GBP as our best estimate of the total TPL due to nuclear accidents in the UK in 2001. It must be emphasised that this is a mean figure that includes severe accidents which are forecast to occur with small frequency. It is that sum of money which, over a long period, would just pay the claims that are made over that same period.*

The logarithmic nature of the BSO/BSL versus frequency relationship (see Annex) implies that the TPL, which the Joule study indicates is directly proportionate to dose, is divided equally between the various decades of the loss versus frequency diagram. So for example, if we consider the following 6 decades then the premium for each would be 92,343 GBP per decade (Figure 9).

**Figure 9: Theoretical TPL per decade.**

Loss MGBP	.14 to 1.4	1.4 to 14	14 to 140	140 to 1,400	1,400 to 14,000	14,000 +	Total	<b>.14 to 140</b>
TPL/year GBP	92,343	92,343	92,343	92,343	92,343	92,343	554,055	<b>277,028</b>

The TPL for the layer from 140,000 GBP to 140 million GBP, the layer that is insured, is then 3 x 92,343  
= 277,028 GBP.

## —Table Of Values For Third Party Losses In Nuclear Accidents And The Frequencies With Which They Were Expected To Occur *Before 11 September 2001*;

In order to arrive at the frequencies we simply make use of the BSO/BSL equation given in the Annex:

Frequency x loss = constant.

The constant is 92,343 GBP/Year (Figure 9).

Then the Table is as follows(Figure 10):

**Figure 10 TPL Losses to the UK Nuclear Industry, Before September 11<sup>th</sup> 2001.**

TPLoss, MGBP	1	10	100	1,000	10,000	100,000
TPLoss/Year, MGBP	92,343	92,343	92,343	92,343	92,343	92,343
Return period, year	11	108	1,083	10,829	108,292	1,082,919
Frequency/year	9.2E-02	9.2E-03	9.2E-04	9.2E-05	9.2E-06	9.2E-07

## Terrorist Risks in the UK and Other Countries.

The following Table has been drawn up, drawing on the information appended in the following section of this Report.

In the Table, the lowest risks have the lowest number: so Canada was a country in which the terrorist risk to nuclear installations was lowest before 11/9/01 (risk index = 1) and the Risk has risen (risk index = 2) since then.

**Figure 11: Table of Indices for Political Risk and Terrorist Risk.**

	<i>Terrorist Risk Pre 11/9/01</i>	<i>Terrorist Risk 2003</i>	<i>Political Risk 2003<sup>5</sup></i>	<i>No of units under Operation</i>	<i>Total MW(e)</i>	<i>No. of Units under construction</i>	<i>Total MW(e)</i>
ARGENTINA	3	3	42	2	935	1	692
ARMENIA	4	4	41	1	376	0	0
BELGIUM	1	2	10	7	5712	0	0
BRAZIL	3	3	38	2	1901	0	0
BULGARIA	3	3	26	6	3538	0	0
CANADA	1	2	12	14	9998	0	0
CHINA	4	4	34	3	2167	8	6420
CZECH REPUBLIC	2	2	26	5	2560	1	912
FINLAND	1	1	6	4	2656	0	0
FRANCE	1	2	20	59	63073	0	0
GERMANY	1	2	14	19	21283	0	0
HUNGARY	2	3	20	4	1755	0	0
INDIA	4	5	45	14	2503	2	980
IRAN, ISLAMIC REPUBLIC OF	4	5	41	0	0	2	2111
IRAQ.		7.5	61				

<sup>5</sup> The Indices for Political Risk used in this work have been developed from a Data Base prepared by The PRS Group, Inc, 320 Fly Road, Suite 102, PO Box 248, East Syracuse, NY 13057-0248, USA. The forecasts extend to 2007..

JAPAN	1	2	16	54	44289	3	3696
KOREA, REPUBLIC OF	3	4	25	16	12990	4	3820
LITHUANIA, REPUBLIC OF	3	3	25	2	2370	0	0
MEXICO	3	4	32	2	1360	0	0
NETHERLANDS	1	1	8.5	1	450	0	0
PAKISTAN	5	6	51	2	425	0	0
QAEDA, AL		6					
ROMANIA	4	4	32	1	655	1	650
RUSSIAN FEDERATION	5	5	37	30	20793	2	1875
SLOVAK REPUBLIC	3	3	25	6	2408	2	776
SLOVENIA	3	3	20	1	676	0	0
SOUTH AFRICA	3	3	30	2	1800	0	0
SPAIN	1	2	17	9	7524	0	0
SWEDEN	1	1	8	11	9432	0	0
SWITZERLAND	1	1	8	5	3200	0	0
TAIWAN	4	4	22	6	4884	2	2700
UKRAINE	4	4		13	11207	4	3800
UNITED KINGDOM	1	3	11	33	12498	0	0
UNITED STATES OF AMERICA	1	4	20	104	97860	0	0
<b>Total:</b>				<b>438</b>	<b>353278</b>	<b>32</b>	<b>28432</b>

### Explanatory Text For Table.

ARGENTINA	3	4	2	935	1	692
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The risk in Argentina is moderate. It derives from the unrest caused by a sixth year of recession and has increased as a result of the WTC attack. A revival of growth now looks even less likely, and default on its \$130bn external debt now seems a possibility. Its economy, like others across the region, is likely to suffering from reduced levels of foreign investment. There is no increased threat of actual war on land in any Latin American country resulting from the attacks on the United States, or from the threatened war with Iraq.

ARMENIA	4	4	1	376	0	0
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In the Caucasus taken as a whole, there is unlikely to be any impact on the risks of terrorism, civil unrest or war. This is true of Armenia and also of Georgia and Azerbaijan, despite the fact that this latter is an Islamic nation. The government is firmly pro-Western and its brand of Islam is moderate. Even in the event of the death of its elderly leader there are no extremists ready to step into the breach. That said, there is an increased risk of isolated attacks on and protests against American interests in-country.

BELGIUM	1	2	7	5712	0	0
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The risk in Belgium was low before the WTC event. It has increased slightly since then because of the country's involvement with US and UK interests.

BRAZIL	3	3	2	1901	0	0
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The risk in Brazil was moderate before the WTC event and it has not increased since then.

BULGARIA	3	3	6	3538	0	0
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The risk in Bulgaria was moderate before the WTC event and it has not increased since then.

CANADA	1	2	14	9998	0	0
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There has been an increase in the risk to Canadian nuclear installations as a result of the involvement of Canadian forces in the reprisals against Afghanistan. Canada's stance on Iraq is not considered to increase the terrorist risk in Canada.

CHINA	4	4	3	2167	8	6420
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The risk was moderately high before the WTC event and it remains so. China is opposed to war with Iraq and this does not add to the terrorist threat in China.

China must say it must use legal means to combat ethnic separatist activities, religious extremist forces, violent and terrorist activities, cults, and illegal activities carried out under the guise of religion. They need to continue the campaign against the Falungong cult, and further expose and condemn the anti-human, anti-social and anti-science nature of the cult, which has become a tool for domestic and overseas forces hostile to China's socialist government. They intend to "mete out severe punishment to the small number of criminals while making unremitting efforts to unite, educate and rescue the vast majority of people who have been taken in".

China, South Korea, Japan and Taiwan have all offered their support to Washington's "war" against terrorism, but they are more equivocal in their response to the USA's call for a war against Iraq.

China has a sizeable population of Islamic ethnic minorities, totalling well over 10 million, in the vast stretch of its western regions. What the Chinese authorities fear most is an infiltration of Central Asia's Islamic fundamentalist movement into Xinjiang, adding fuel to the separatist fire. But the fear of civil disturbances in its western regions and its fundamental disagreement with the US over its right to intervene in the internal affairs of other states means that China has not unreservedly sided with Washington's attempts and plans to deal with bin Laden and Saddam Hussein by force. As a result China has pressed for caution and has in both cases insisted that the UN Security Council be involved.

CZECH REPUBLIC	2	3	5	2560	1	912
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The nuclear power plant in Dukovany, southern Moravia, which has been in operation for about 16 years, is not protected against a crash as thoroughly as Temelin, a VVER plant which has been started up in southern Bohemia since October 2001. Police rapid intervention units are on heightened alert and air space is subject to special monitoring as part of security measures the Czech nuclear power plants have adopted following the WTC attacks in the USA.

As aspiring members of the EU and, in the case of Poland, Hungary and Czech Republic, actual members of NATO, all have expressed solidarity with the US and broad support for the principle of military retaliation. For this reason the terrorist risk to the Czech nuclear installations has risen slightly.

FINLAND	1	1	4	2656	0	0
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The risk of terrorist attack was low before the WTC event. Finland has adopted a low-key response to that event and the risk has not increased since the event.

FRANCE	1	2	59	63073	0	0
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France has a raised nuclear terrorism risk because of the large number of militant sympathisers within her borders.

GERMANY	1	2	19	21283	0	0
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*Germany: ECO-Groups Demand Rapid Decommissioning of Nuclear Power Stations (10).*

German environmental group BUND has asked the government to stop discussing the law on nuclear decommissioning in light of recent terrorist attacks in the US and stop the operation of the plants immediately. BUND feels that a law which allows nuclear plants to be in operation for another 20 years is "unacceptable." BUND believes that Germany can decommission its plants very quickly and that more efficient use of energy and conventional reserve capacities could replace nuclear power.

Germany, like France, has a raised nuclear terrorism risk because of the large number of militant sympathisers within her borders.

HUNGARY	2	3	4	1755	0	0
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The Paks station could not withstand a jumbo airstrike and so, at Paks there is a ban on air traffic 2.3 kilometres above and three kilometres around the nuclear power station. The Hungarian air traffic control authority monitors is making sure that this requirement is met. Together with internal armed security guards and security service, a police intervention unit trained in averting terrorist attacks has also been deployed at Paks.

Hungary, as an actual member of NATO, expressed solidarity with the US and broad support for the principle of military retaliation. This has increased the risk of terrorist attack on its nuclear installations.

INDIA	4	5	14	2503	2	980
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Kashmiri militants have contemplated sabotaging Indian nuclear reactors. For its part India enthusiastically leapt behind the US, offering substantial assistance to Washington. Terrorist attacks by militant Islamists in the disputed territory of Indian Kashmir, as well as elsewhere in India, can be expected to increase and there is therefore a possibility, heightened by the WTC event, of terrorist attacks on Indian nuclear installations.

IRAN, ISLAMIC REPUBLIC OF	4	5	0	0	2	2111
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In 1987 Iran threatened attacks against US reactors. In 1980, in a pre-emptive strike, Iran bombed Iraq's unfinished Osirak reactor.

JAPAN	1	2	54	44289	3	3696
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Japan offered their support to Washington's "war" against terrorism. The issue of the threat posed in Japan by terrorist attacks, was raised most recently during the mid-1990s after members of the Aum Shinrikyo cult released sarin nerve gas in the Tokyo underground, but no basic changes were made to Japan's defenses against nuclear terrorism.

The U.S. government having completed a review of a proposed shipment of mixed-oxide (MOX) fuel from Japan to the UK, USNRC Commissioners unanimously approved the shipment. Later the US did not wish the fuel to be shipped, in part because they feared that it will be a target for terrorists. Under the terms of the U.S.-Japan agreement for nuclear cooperation, Japan has to receive U.S. approval for the transfer, including the security arrangements.

The Japanese are following the US lead in their work on terrorism. The USNRC has recommended a programme of work to the US Government and the Japanese Nuclear Safety Commission is preparing plans that are said to resemble this programme. It involves measures to combat air-strikes, sabotage and attacks from the sea.

There is one particular difference: the Japanese do not intend to have armed guards at their nuclear installations. The US stations have guards with visible automatic weapons, as do some of those in the UK. The Japanese say that armed guards would give the impression that their nuclear facilities had some military function, such as the production of nuclear materials for weapons. They are understandably sensitive about this.

The Japan Coast Guard has started patrolling waters near nuclear plants on a round-the-clock basis. At the request of the 14 prefecture governments that host Japan's nuclear plants, the coast guard has dispatched patrol vessels to cover all 17 plants.

The nuclear utilities had planned a drive to have 1-million Japanese visit the country's 52 power reactors during 2002. This plan to encourage more visitors to reactors has been withdrawn by security regulators, instructed by the Japanese government to defend nuclear installations from sabotage.

Japan like South Korea, is not a primary target, however, it has weak security and intelligence gathering ability and lacks experience in dealing with terrorism. Japan's involvement in military action is restricted by its constitution.

KOREA, REPUBLIC OF	3	4	16	12990	4	3820
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South Korea offered support to Washington's "war" against terrorism. It is the proximity of North Korea that makes me rate South Korea so highly from the standpoint of political risk. The increase in rating reflects a harder line recently taken by the North in its dealings with KEDO and the US government.

There are over 100,000 American nationals in South Korea, including 37,000 US troops in about 10 military bases. South Korea put its own army on high alert against attacks on US targets in the country. South Korean President Kim Dae-Jung pledged military support for any US retaliatory strike. But signs of dissent emerged with politicians and civic groups saying South Korea should not rush to send combat forces to back US military action. Riot police stopped one anti-war demonstration outside the US embassy in Seoul. There is considerable risk from terrorist attacks.

LITHUANIA, REPUBLIC OF	3	3	2	2370	0	0
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There is no reason to suppose that the moderate risk of terrorist attack on Lithuanian nuclear installations has been increased following the WTC event.

MEXICO	3	4	2	1360	0	0
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The moderate risk of nuclear terrorist attacks that existed in Mexico prior to the WTC event has increased since then. The US/Mexican border was closed following the WTC attack and Mexican police have arrested a number of suspects in relation to the attacks, the countries of Central America/Caribbean are unlikely to be involved in any Western military action, and wars are not about to be fought within the confines of their borders. Whilst Cuba makes the top five list of countries suspected of supporting terrorists, there is no increase in the risk of War on Land.

NETHERLANDS	1	1	1	450	0	0
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There has been no deterioration in the excellent position in the Netherlands.

PAKISTAN	5	6	2	425	0	0
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The risk of terrorist attack on Pakistan's nuclear reactors was high before the WTC event and, with demonstrations in its streets and Afghan refugees moving toward its borders, Pakistan might have suffered such an attack when the US attacked neighbouring Afghanistan with the assistance of Pakistan's government. The most dire scenarios included civil war and/ or an effort to topple Pakistan's president,

General Pervez Musharraf. Pakistan is now relatively quiet, although tense. Anti-American demonstrations were held in three major cities, including in Karachi and Islamabad. The Council for the Defence of Afghanistan and Pakistan, consisting of 30 religious groups and Islamic parties, called for mass protests in Pakistan. They a vocal minority that has no tolerance for American aggression towards another Muslim country and who view Usama bin Laden as a hero.

ROMANIA	4	4	1	655	1	650
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The risk to Romanian nuclear installations was high before the WTC attack. It has not increased as a result of that attack.

RUSSIAN FEDERATION	5	6	30	20793	2	1875
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Security at nuclear power stations in Russia's northwestern regions, at the Kola station, plants serving nuclear-powered ships and Murmansk region ports. is tight following the terrorist attacks in the United States and developments in the North Caucasus. The Russian nuclear power plants are designed in such a way as to withstand a plane crashing down with an explosive device on board.

*Terrorist attack Exercise Held in Volgodonsk.*

The Atom-2001 operational tactical exercises, held on the orders of the federal antiterrorist commission, ended in Volgodonsk on September 13th. They were held at the Volgodonskaya nuclear power station. According to the training plan, terrorists had infiltrated the station and were attempting to reach the reactor.

*Additional Diesel Installed at Kola Nuclear Power Plant.*

An additional diesel has just been commissioned at the Kola nuclear power plant. It was not designed specifically to address the problems of terrorist attack, but it will provide additional security of power supply to safety equipment in the event that terrorists disconnect the plant from the grid.

*Nuclear Weapons Stores can withstand 40 kiloton Nuclear Bomb.*

Russia's nuclear weapons are stored in silos which are designed to withstand a 40 kiloton nuclear bomb.

Russia is a high-risk target given its ongoing war against Islamic Chechen separatists and the poor levels of security and maintenance for its nuclear assets. In 1995, and then later in 1997-98, Chechen terrorists threatened to seize nuclear reactors and use them as a bargaining counter with the Russia government. Moscow took their warnings seriously and strengthened the security of nuclear infrastructure. Russian politicians are divided on the issue of opening what they now call a "second front" against terrorism, although there is a political consensus behind total moral support of

the US. The "first front" for Russia is Chechnya, where there has been an upsurge of violence in recent days. Overall, domestic implications are likely to be minimal regardless. The exception is in the North Caucasus and Chechnya where the government is, in its own words, already pursuing a war on Islamic terrorism. Related terrorist attacks across Russia can be expected to increase.

SLOVAK REPUBLIC	3	3	6	2408	2	776
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There has been no heightening of the moderate risk of terrorist attack to Slovakian nuclear installations since the attack on the WTC. In Slovakia the government appointed a Coordinator of Ministry Crisis Staffs, following the WTC airstrike. He says that Jaslovske Bohunice near Trnava [western Slovakia] and Mochovce near Levice [southern Slovakia] are both constructed so as to resist an airstrike. In addition, fighter aircraft have been placed on the alert.

SLOVENIA	3	3	1	676	0	0
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There has been no heightening of the moderate risk of terrorist attack to Slovenian nuclear installations since the attack on the WTC.

SOUTH AFRICA	3	3	2	1800	0	0
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In recent years in South Africa there has been clear evidence of an increasing amount of activity by domestic Islamic extremist groups. However, with only a relatively small Muslim population, existing unrest has not been significantly exacerbated by the US attacks.

SPAIN	1	2	9	7524	0	0
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Spain has supported the US attacks on Afghanistan, but that support has only been low key. It is conceivable that the Basque separatist movement will mount a terrorist attack on Spanish nuclear installations in a copy-cat enterprise, but this is not likely.

SWEDEN	1	1	11	9432	0	0
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The attack on the WTC has not significantly affected the excellent rating of Swedish nuclear installations.

SWITZERLAND	1	1	5	3200	0	0
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The WTC attack has not impaired the security of Swiss nuclear installations.

TAIWAN	4	5	6	4884	2	2700
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China, South Korea, Japan and **Taiwan** have all offered their support to Washington's "war" against terrorism. This has increased the risk of terrorist attack on the Taiwanese nuclear installations. The risk was already well above average.

UKRAINE	4	4	13	11207	4	3800
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Political risk is high in the Ukraine. Nevertheless it is not thought that the already high risk of terrorist attack on Ukrainian nuclear plants has been increased by the WTC event or its aftermath. At an international conference on safe nuclear technologies in the 21st century held in the Chernobyl workers'-town of Slavutych through September 14<sup>th</sup>, the subject of terrorism was placed on the agenda in addition to the threat of nuclear accidents. following the WTC Airstrike of September 11<sup>th</sup>.

UNITED KINGDOM	1	3	33	12498	0	0
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The UK has adopted a particularly high profile in the support that it has given to the USA in the USA's fight against terrorism since September 11<sup>th</sup> 2001. Several of the terrorists that crashed the planes had connections with groups in the UK.

*-Republic of Ireland: No Interceptor Aircraft (8).*

The Republic of Ireland has no air defence at all. Its Air Corps has no interceptor aircraft. Indeed, apart from the Government executive jet and the fishery patrol aircraft, it has no military aircraft. As a result of this, it may have been necessary to invite the RAF to defend Irish airspace against possible terrorist attack, or the British government may have demanded this, due to the threat to Sellafield.

*-UK: Stations Resistant to Airstrike.*

*Hartlepool Could Resist Airstrike.*

A BE spokesman says: "In a worst case scenario at Hartlepool, if something did crack you wouldn't be looking at another Hiroshima. It's not like an atomic bomb. While it would be a problem, the authorities are capable of dealing with it."

*Sellafield MOX Plant Given Permission to Operate.*

The Sellafield MOX Plant, SMP, has been given permission to operate, despite claims by Greenpeace that it adds to the risk of nuclear terrorism.

Usama bin Laden planned buy an old Russia nuclear submarine to attack shipments of reprocessed plutonium from the Sellafield nuclear plant. Associates of bin Laden travelled to Sebastopol to enquire about buying a mothballed Soviet submarine with a view to recommissioning it. A number of nations, including Iran, have previously bought submarines from Russia. Since bin Laden's plan came to the attention of the intelligence services unprecedented precautions have been drawn up, including Royal Navy protection for such shipments.

UNITED STATES OF AMERICA	1	4	104	97860	0	0
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In the USA, nuclear plants are neither designed nor operated to anticipate a kamikaze-style attack from a commercial jetliner. They are however designed to resist substantial levels of aircraft impact. There is concern that the spent fuel storage ponds could constitute a greater hazard than the actual reactor, should a jumbo air strike occur.

Mock invasions staged in recent years as part of an NRC counter terrorism program revealed that the security forces at many plants would fail to stop ground-based terrorists before they caused catastrophic damage. The Federal Government initiated a review of nuclear security, both in the civil and military sectors. Security has already been tightened at the nuclear power stations, under the direction of the USNRC.

#### *Exelon Profits Threatened?*

Exelon said, immediately after 11/9/01: "We don't know what are the ramifications of September 11 [terrorist attacks] but theoretically, six months from now, if there aren't large conventions and large hotels filled, [because of terrorist fears] maybe people will not be using as much electricity."

There have been earlier terrorist threats to US nuclear installations. Thus, in 1993, a released mental patient deliberately crashed a car through a door at TMI's turbine building, stopping 63 feet inside the building. He disappeared inside the plant for four hours. In 1987 Iran threatened attacks against US reactors. In February 1993, nineteen days before Islamic militants first attacked the WTC by exploding several bombs in an underground car park, associated individuals are believed to have practised a night-time mock assault on an electric substation in Perry County, Pennsylvania, 30 miles west of the Three Mile Island nuclear plant (TMI). Recent evidence from the trial of one of the 1993 WTC bombers revealed that Usama bin Laden's terrorist training camps offer instruction in 'urban warfare' against 'enemy installations', including power plants.

The rating of the USA has risen dramatically as a direct result of the attack of September 11<sup>th</sup> 2001. Subsequent retaliatory events are believed likely to have maintained the threat, though not increased it further.

Whilst the US reaction may be to increase security at nuclear plants to the highest possible levels, it cannot be assumed the same will occur elsewhere. In the past nuclear plants across the world have not generally had good human security – something true of America and Britain as well as Russia.

Past security improvements have also proved inadequate. After the TMI intrusion, the NRC promulgated what became known as the "*truck bomb rule*" which required plant operators to erect stronger perimeter walls and take other protective measures. But even some of these measures are considered ineffective against the type of powerful truck bomb used by Timothy McVeigh in Oklahoma City, or by Islamic extremists against a US Air Force barracks in Dhahran, Saudi Arabia in 1996. Many barriers are so close to the vital areas of nuclear power plants that an Oklahoma City-sized bomb could still cause a catastrophe. One of the barriers at TMI is only 10 feet from a vital building.

There are certain mitigating factors offsetting this increased risk. For example, there are plenty of other targets - particularly in light of the increased security - that are easier to hit and which could cause significant damage. These include refineries, chemical plants, reservoirs, power stations, pipelines, transmission lines, industries using hazardous materials, or railroad and highway bridges and tunnels.

The NRC chairman in America stated following the attacks in September: "*It is prudent to assume, especially after the horrific, highly co-ordinated attacks of 11 September, that bin Laden's soldiers have done their homework and are fully capable to attack nuclear power plants for maximum effect.*"

In NRC-conducted tests that simulate a terrorist attack, more than 50 percent of plants tested failed and mock intruders were able to simulate core damage.

The NRC has now recommended that the power plants increase security to the "*highest level*", details of which are classified. In the US combat fighters are, for the time being, on standby, ready to intercept and open fire if there is any attempt to repeat the hijacking of a passenger jet. Several US interest groups have outlined other proposals to foil any terrorist bid to destroy US nuclear power plants, including the permanent deployment of anti-aircraft weapons and troops. Other countries in Western Europe are thought to be considering similar steps.

**Figure 12***The Financial Loss Due to Terrorism.*

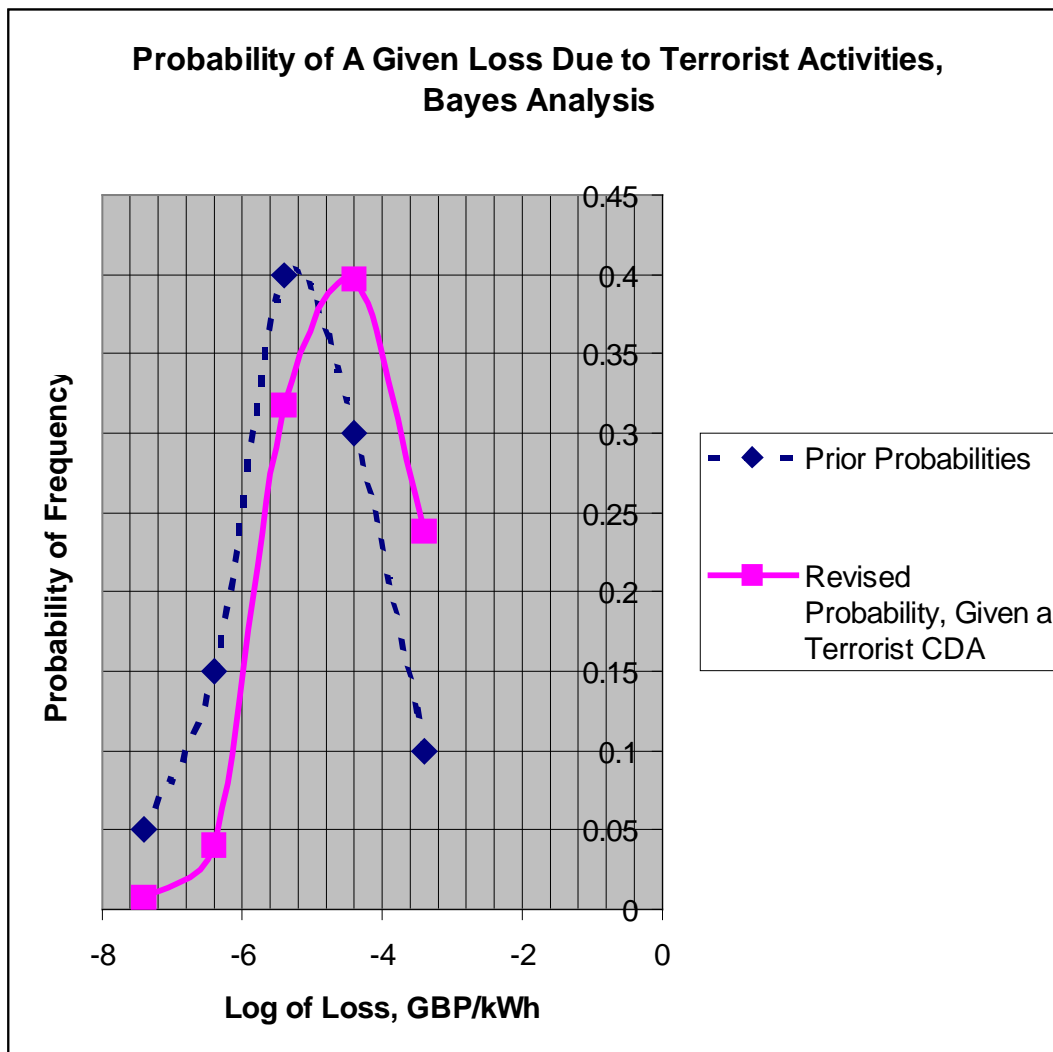
In this section we use Bayes analysis and show that the figure of 0.000040 GBP/kWh arrived at in the previous section is appropriate to the TPL financial loss due to terrorism:

The design requirement of the NII is that no single class of event should contribute more than 10% of the risk due to a nuclear installation. We shall take as our prior estimate of the financial loss due to terrorism, therefore, 0.000040/10 GBP/kWh. The Joule study derives from calculations that are subject to errors, some of which derive from the variability in the reliability of reactor components. In the following figure those errors give rise to a range of values, centred on , 0.000040/10 GBP/kWh. Values greater or less than , 0.000040/10 GBP/kWh have lower probabilities.

Now that the attack on the WTC has taken place, we can use Bayes theorem to update our Prior estimate, and that has been done in the following diagram. In an Annex we argue the case for this: it is simply that instead of demolishing the WTC the terrorist might have struck a nuclear power station.

The posterior distribution so obtained has a peak at about 0.00004 GBP/kWh. This is the value that we shall therefore use in what follows.

*Bayes Theorem: Prior and Posterior Estimates of Loss Due to Terrorism.*



Professor John H Gittus F R Eng. D Sc. D Tech. FIS  
BNFL Consultant.

## Table Of Values For Third Party Losses In Nuclear Accidents And The Frequencies With Which They Were Expected To Occur Since 11 September 2001

This is the third of the customer's requirements.

The table is arrived at as follows:

Before September 11<sup>th</sup> 2001, of the total risk, R, terrorism contributed no more than one tenth,  $T = 0.1 \times R$ . This is because for all nuclear installations, the NII require that no single category or cause of accidents shall contribute more than one tenth of the Risk. The Risk contributed by causes other than terrorism is then  $0.9 \times R$ .

By means of Bayes analysis we have arrived at the hypothesis that, since September 11<sup>th</sup> 2001, our best estimate of the terrorist risk is that it has increased by an order of magnitude (that is by about a factor of ten), to  $10 \times 0.1 \times R = R$ .  
 The Risk contributed by causes other than terrorism remains at  $0.9 \times R$   
 and so the total Risk is now  $R + 0.9 \times R = 1.9 \times R$

That is to say, the total TPL Risk has increased by a factor of 1.9, from 92,343 GBP/Year to  $1.9 \times 92,343 \text{ GBP/Year} = 175,452 \text{ GBP per decade}$ .

The required Table is then:

TPLoss, MGBP	1	10	100	1,000	10,000	100,000
TPLoss/Year, MGBP	175,452	175,452	175,452	175,452	175,452	175,452
Return period, year	6	57	570	5,700	56,996	569,957
Frequency/year	1.8E-01	1.8E-02	1.8E-03	1.8E-04	1.8E-05	1.8E-06

## **Values, Derived From The Above Tables, For The Average Monthly Cost Of Accidents To Nuclear Installations (Insurance Exposure, here termed *Insured Costs*) And Values, Derived From The Insurance Market, Of The Average Monthly Premium Charged By Nuclear Insurers;**

This is the fourth of the customer's requirements. I begin it by giving the conclusion arrived at in this section:

### *Conclusion:*

The *Average Monthly Premium* of 19,155 GBP is the premium for terrorism, following the events of September 11<sup>th</sup> 2001, that British Nuclear Insurance, BNI, proposes to pay the Treasury. Note that it is smaller than the estimate of 23,086 GBP, arrived at in this Report, for the *Average Monthly Cost* of Third Party Losses in Accidents to UK nuclear installations caused by terrorist acts, in the climate that exists following the events of 11 September 2001.

### *Explanatory Notes to the Table:*

In the following Table we present the results of the analysis made in the present Report, together with information secured for the client from British Nuclear Insurance:

The meaning of the row labelled \* is as follows:

- Ø Following the attack on the World Trade Centre of September 11<sup>th</sup> 2001, a nuclear accident leading to an actual Third Party Loss of 1,000,000 GBP (pounds sterling) will occur, in the UK, with a return period of 6 years. This equates to a frequency of 0.17 such accidents per year.
- Ø It may or may not be due to terrorism.
- Ø The average cost, per year, of accidents of this magnitude (i.e. of magnitude 1,000,000 GBP per accident) is 175,452 GBP/Year.
- Ø Of this average cost per year, 92,343 GBP/Year is due to accidents of this magnitude (i.e. of magnitude 1,000,000 GBP per accident) that are caused by terrorism.
- Ø Before the attack on the World Trade Centre of September 11<sup>th</sup> 2001, a nuclear accident leading to an actual Third Party Loss of 1,000,000 GBP (pounds sterling) would have been predicted to occur, in the UK, with a return period of 11 years. This equates to a frequency of 0.092 such accidents per year.

- Ø It might or might not have been due to terrorism.
- Ø The average cost, per year, of accidents of this magnitude (i.e. of magnitude 1,000,000 GBP per accident) was 92,343 GBP/Year.
- Ø Of this average cost per year, 92,343 GBP/Year was due to accidents of this magnitude (i.e. of magnitude 1,000,000 GBP per accident) that were caused by terrorism.

And the row labelled \*\* means:

- Ø ***Following the attack on the World Trade Centre of September 11<sup>th</sup> 2001***, nuclear accidents leading to an actual Third Party Loss of 1,000,000 GBP (pounds sterling) or more will continue to be possible, in the UK.
- Ø Such an accident may or may not be due to terrorism.
- Ø The total cost, per year, of all these accidents will be 1,052,710 GBP/Year.
- Ø Of this total cost per year, 554,058 GBP/Year will be due to accidents that are caused by terrorism.
- Ø Half of this sum, i.e. 277,028 GBP/Year, is calculated to be the cost of the insured accidents, lying in the ***three decades*** (orders of magnitude) (all in GBP):
  - 140,000 to 1.4M;
  - 1.4M to 14 M;
  - 14M to 140M;
- Ø ***Before the attack on the World Trade Centre of September 11<sup>th</sup> 2001***, the total cost, per year of all these accidents would have been thought to be 554,058 GBP/Year.
- Ø Of this total cost per year, 55,406 GBP/Year would have been attributed to to accidents that are caused by terrorism.
- Ø Half of this sum, i.e. 27,703 GBP/Year, would have been calculated to be the cost of the insured accidents, lying in the three orders of magnitude (all in GBP):
  - 140,000 to 1.4M;
  - 1.4M to 14 M;
  - 14M to 140M;

In the Column labeled \*\*\*:

- Ø The Insured Monthly Cost of 43,863 GBP is half of the monthly, total cost of 87,726 GBP. It is half, because only the lower three decades, to 140 MGBP, are insured. The upper three decades, to above 14,000 MGBP, are covered by Government.
- Ø The insured monthly cost of 23,086 GBP is the new figure, arrived at in this Report, for terrorism following the events of September 11<sup>th</sup> 2001. It is our estimate of the monthly premium that would exactly pay claims for TPL due to terrorist acts.

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In the column labeled \*\*\*\*:

- Ø The Monthly Premium of 19,155 GBP is the premium for terrorism, following the events of September 11<sup>th</sup> 2001, that British Nuclear Insurance, BNI, proposes to pay the Treasury. Note that it is smaller than the estimate, arrived at in this Report, of the monthly premium of 23,086 GBP which would exactly pay claims for TPL due to terrorist acts.

Table of Monthly Costs and Premiums.

<b>After September 11th 2001</b>	*						**		3 decades, to 140M	
							Totals	Monthly Costs	<b>***Insured Monthly Costs</b>	<b>****Monthly Premiums</b>
TPLoss, MGBP	1	10	100	1,000	10,000	100,000				
TPLoss/Year, MGBP	175,452	175,452	175,452	175,452	175,452	175,452	1,052,710	87,726	<b>43,863</b>	<b>309,990</b>
Non Terror TPLoss/Year, MGBP	83,109	83,109	83,109	83,109	83,109	83,109	498,652	41,554	<b>20,777</b>	<b>290,836</b>
Terrorist Component of TPLoss/Year, MGBP	92,343	92,343	92,343	92,343	92,343	92,343	554,058	46,172	<b>23,086</b>	<b>19,155</b>
Return period,year	6	57	570	5,700	56,996	569,957		-	-	
Frequency/year	1.755E-01	1.755E-02	1.755E-03	1.755E-04	1.755E-05	1.755E-06		-	-	
<b>Before September 11th 2001</b>								-	-	
TPLoss, MGBP	1	10	100	1,000	10,000	100,000		-	-	
TPLoss/Year, MGBP	92,343	92,343	92,343	92,343	92,343	92,343	554,058	46,172	<b>23,086</b>	<b>290,836</b>
Non Terror TPLoss/Year, MGBP	83,109	83,109	83,109	83,109	83,109	83,109	498,652	41,554	<b>20,777</b>	
Terrorist Component TPLoss/Year, MGBP	9,234	9,234	9,234	9,234	9,234	9,234	55,406	4,617	<b>2,309</b>	
Return period,year	11	108	1,083	10,829	108,292	1,082,919				
Frequency/year	9.20E-02	9.20E-03	9.20E-04	9.20E-05	9.20E-06	9.20E-07				

## **A Methodology For Establishing A 'Commercial' Rate For A Premium Covering The Third Party Liability Risk Arising From Terrorist Activity Aimed At Different Types Of Nuclear Installation (Eg Generation Plant, Reprocessing Facilities, Industrial Complexes, Universities);**

The values in the following Table come from the Analysis in the foregoing sections of this Report.

*Table of Proposed Premiums for Third Party Liability due to Terrorist Attacks on UK Nuclear Installations.*

	BNI	BNI	BNI	BNI	BNI	BNI	This Work	This Work	<i>This Work</i>	<i>BNI</i>
<i>TPL premiums</i>	terror, proposed	monthly premium, TPL terror, proposed	current liability	current liability, monthly	current + terror	terror/ current+terror	Decades	Decades %	<i>Proposed Monthly Premiums for Terrorist TPL</i>	<i>Proposed Monthly Premiums for Terrorist TPL</i>
<b><i>Magnox Sites</i></b>	34,500	2,875	1,150,000	95,833	1,184,500	3%	3	23%	<b><i>5,327</i></b>	<b><i>2,875</i></b>
<b><i>BNFL (Sellafield)</i></b>	91,200	7,600	507,000	42,250	598,200	15%	3	23%	<b><i>5,327</i></b>	<b><i>7,600</i></b>
<b><i>Amersham International</i></b>	6,450	538	215,000	17,917	221,450	3%	1	8%	<b><i>1,776</i></b>	<b><i>538</i></b>
<b><i>British Energy</i></b>	40,783	3,399	1,359,426	113,286	1,400,209	3%	3	23%	<b><i>5,327</i></b>	<b><i>3,399</i></b>
<b><i>URENCO</i></b>	672	56	33,600	2,800	34,272	2%	1	8%	<b><i>1,776</i></b>	<b><i>56</i></b>
<b><i>Transits (BNFL)</i></b>	27,500	2,292	110,000	9,167	137,500	20%	1	8%	<b><i>1,776</i></b>	<b><i>2,292</i></b>
<b><i>Transits (URENCO)</i></b>	28,750	2,396	115,000	9,583	143,750	20%	1	8%	<b><i>1,776</i></b>	<b><i>2,396</i></b>
<b><i>Sum</i></b>	<b>229,855</b>	<b>19,155</b>	<b>3,490,026</b>	<b>290,836</b>	<b>3,719,881</b>		<b>13</b>		<b><i>23,086</i></b>	<b><i>19,155</i></b>

## Notes on this Table:

- Ø The items in the columns labelled BNI were obtained from the General Manager of BNI, Mr Mark Tetley, who was told why they were required. He said that he had given all of these items to DTI.
- Ø The items labelled “This Work” come from the analysis in the present Report.
- Ø To allocate the total Terrorist TPL premiums between BNFL, BE and the other insureds, use has been made of the results of Risk Assessments. These indicate, for example, that claims for nuclear power stations on for example British Energy sites could be higher than the insured limit of 140 MGBP, meaning that premium for the three decades 0.14 to 1.4; 1.4 to 14 and 14 to 140 MGBP is payable. They also indicate that in the case of enrichment plant (URENCO), radio pharmaceutical factories (Amersham) and Transits of both UF6

- 
- Ø (URENCO) and spent fuel (BNFL), most claims are likely to be in the first decade, since the source terms are comparatively low. Premium has therefore been allocated according to the number of decades judged appropriate for each insured.
  - Ø The most significant difference between the premium so calculated and that proposed by BNI is for URENCO where we calculate a premium of 1,776 GBP/month and the Pool calculate just 56 GBP/month.

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## **—A Statement Of Views On The Reasons For The Reluctance Of Commercial Insurers To Cover Such Risks;**

This is another of the customer's requirements.

Insurers have the following reasons, in my view, for their reluctance to cover TPL due to terrorist attacks on nuclear installations in the UK:

- Ø The UK is perceived to have attracted such risks by its very positive alignment with the USA in the aftermath of the atrocities of September 11<sup>th</sup> 2001. It seems clear that this was the right thing for the UK to do, but it is seen as making UK nuclear installations more vulnerable to terrorist attack than those of for example Japan, where the situation is as described in an Annex to this Report.
- Ø If the terrorists, on September 11<sup>th</sup> 2001, had targeted nuclear installations with the four planes that they took over, then there could have been four losses, whereas the capacity provided by the commercial nuclear insurance business is based on the assumption, borne out by the analysis in this present Report, that there will be no large losses or at most one.

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## **Information On A Range Of Realistic Scenarios, I.E. Low, Medium And High Increase In Probabilities Of An Attack Compared To Sept 11, Combined With A Range Of Possible Terrorist Event Scenarios?**

This is the last of the customer's requirements, requested as something that would enable him to build up a matrix under which he could test the implications for insurance premiums of a range of possible views of the real risks.

### *Terrorist Scenarios and The Risk Assessments of Nuclear Installations.*

Most nuclear accidents have their origin in human fallibility. What a well-intentioned person does by error, a terrorist can, in principle, do on purpose. In this section I describe nuclear and related accidents that have occurred and indicate how they could instead have been engineered by terrorists. In this way realistic scenarios are arrived at.

#### *Criticality Accident.*

On 30 September 1999 three workers received high doses of radiation in a Japanese plant preparing fuel for an experimental reactor. Two of the doses proved fatal. The accident was caused by bringing together too much uranium enriched to a relatively high level, causing a "criticality" (a limited uncontrolled nuclear chain reaction), which continued intermittently for 20 hours. A total of 119 people received a radiation dose over 1 mSv from the accident, but only the three operators' doses were above permissible limits, and one of these has since died. The cause of the accident appears to be "human error and serious breaches of safety principles", according to IAEA.

Such an accident could be caused by terrorists, although the details would differ from those in the Japanese accident, which were as follows.

#### **The Tokaimura plant**

The accident was in a very small fuel preparation plant operated by Japan Nuclear Fuel Conversion Co. (JCO), a subsidiary of Sumitomo Metal Mining Co. It was not part of the electricity production fuel cycle, nor was it a routine manufacturing operation where operators might be assumed to know their jobs reasonably well.

The particular JCO plant at Tokai was commissioned in 1988 and processes up to 3 tonnes per year of uranium enriched up to 20% U-235, much more than for ordinary power reactors. The plant supplied various specialised research and experimental reactors. It uses a wet process.

The approved nuclear fuel conversion procedure involved the dissolution of uranium oxide ( $U_3O_8$ ) powder in a dissolution tank, then its transfer as pure uranyl nitrate solution to a buffer column for mixing, followed by transfer to a precipitation tank. This tank is surrounded by a water cooling jacket to remove excess heat generated by the exothermic chemical reaction. The prevention of criticality was based upon the general licensing requirements for mass and volume limitation, as well as upon the design of the process. A key part of the design was a column with a criticality-safe geometry as a buffer to control the amount of material transferred to the precipitation tank.

However, the work procedure was modified three years earlier, without permission from the regulatory authorities, to allow the dissolution of uranium oxide to be performed in stainless steel buckets. The mixing designed to occur in the buffer column was undertaken by mechanical stirring in the precipitation tank, thus bypassing the criticality controls. The shape of the hundred-litre precipitation tank (450mm diameter and 660mm high) enhanced the likelihood of criticality.

### **The accident**

On 30 September 1999 three workers were preparing a small batch of fuel for the JOYO experimental fast breeder reactor, using uranium enriched to 18.8% U-235. It was JCO's first batch of fuel for that reactor in three years, and no proper qualification and training requirements appear to have been established to prepare those workers for the job. At around 10:35, when the volume of solution in the precipitation tank reached about 40 litres, containing about 16 kg U, a critical mass was reached.

At the point of criticality, the nuclear fission chain reaction became self-sustaining and began to emit intense gamma and neutron radiation, triggering alarms. There was no explosion, though fission products were progressively released inside the building. The significance of it being a wet process was that the water in the solution provided neutron moderation, expediting the reaction. (Most fuel preparation plants use dry processes.)

The criticality continued intermittently for about 20 hours. It appears that as the solution boiled vigorously, voids formed and criticality ceased, but as it cooled and voids disappeared, the reaction resumed. The reaction was stopped when cooling water surrounding the precipitation tank was drained away, since this water provided a neutron reflector. Boric acid solution (neutron absorber) was finally added to the tank to ensure that the contents remained subcritical. These operations exposed 27 workers to some radioactivity. The next task was to install shielding to protect people outside the building from gamma radiation from the fission products in the tank. Neutron radiation had ceased.

The radiation (neutron and gamma) emanated almost entirely from the tank, not from any dispersed materials. Buildings housing nuclear processing facilities such as this are normally maintained at a lower pressure than atmosphere so that air leakage is inward, and any contamination is removed by air filters connected to an exhaust stack. In this case particulate radionuclides generated within the conversion building were collected by the high-efficiency particulate air filters, though noble gases passed through the filters. A smoke test on 5 October confirmed that the negative pressure

had been maintained (ie the structural integrity of the building was satisfactory) and that the ventilation system was working. However, owing to the detection of low levels of iodine-131 being released to the environment through the exhaust, it was later decided to stop ventilation and to rely on the passive confinement provided by the building.

Five hours after the start of the criticality, evacuation commenced of some 161 people from 39 households within a 350 metre radius from the conversion building. They were allowed home two days later after sandbags and other shielding ensured no hazard from residual gamma radiation. Twelve hours after the start of the incident residents within 10 km were asked to stay indoors as a precautionary measure, and this restriction was lifted the following afternoon.

### **The effects, and analysis**

The accident was classified by the Japanese authorities as Level 4 on the IAEA International Nuclear Event Scale (INES, see Table below)\*.

The three workers concerned were hospitalised, two in a critical condition. One died 12 weeks later, another 7 months later. The three had apparently received full-body radiation doses of 10-20,000, 6-10,000 and 1-5000 millisieverts (about 8000 mSv is normally a fatal dose). Doses for a further 436 people were evaluated, 140 based on measurement and 296 on estimated values. None exceeded 50 mSv (the maximum allowable annual dose), though 56 plant workers exposed accidentally ranged up to 23 mSv and a further 21 workers received elevated doses when draining the precipitation tank. Seven workers immediately outside the plant received doses estimated at 6 - 15 mSv (combined neutron and gamma effects).

The peak radiation level 90 metres away just outside the nearest site boundary was 0.84 mSv/hr of gamma radiation, but no neutron levels were measured at that stage. The gamma reading then dropped to about half that level after nine hours at which stage 4.5 mSv/hr of neutron radiation was measured there, falling to about 3 mSv/hr after a further two hours, and then both readings falling to zero (or background for gamma) at 20 hours from the start of the criticality.

Neutron dose rates within one kilometre are assumed to be up to ten times the measured gamma rates. Based on activation products in coins from houses near the plant boundary and about 100 m from the reaction, it was estimated that some 100 mSv of neutron radiation would have been received by any occupants over the full period of the criticality. However, the evacuation of everyone within 350 metres of the plant had been ordered 5 hours after the start of the accident. The final report on the accident said that the maximum measured dose to the general public (including local residents) was 16 mSv, and the maximum estimated dose 21 mSv.

While 160 TBq of noble gases and 2 TBq of gaseous iodine were apparently released, little escaped from the building itself. After the criticality had been terminated and shielding was emplaced, radiation levels beyond the JCO site returned to normal.

Only trace levels of radionuclides were detected in the area soon after the accident, and these were short-lived ones. Products from the area would have been as normal,

and entirely safe throughout. Radiation levels measured by the IAEA team in residential areas in mid October were at the normal background levels. Measurement of I-131 in soils and vegetation outside the plant showed them to be well under levels of concern for food.

According to the IAEA, the accident "seems to have resulted primarily from human error and serious breaches of safety principles, which together led to a criticality event". The company conceded that it violated both normal safety standards and legal requirements, and criminal charges are being laid. The fact that the plant is a boutique operation outside the mainstream nuclear fuel cycle evidently reduces the level of scrutiny it attracts.

Japan's atomic energy insurance pool said at the time that it would make a payment to JCO in respect to the accident, *its first such payment ever*. However, this would be limited to one billion yen, with further liability (the total estimated at 13 billion yen – or about 70 MGBP, being met by JCO or its parent company. The plant's operating licence was revoked early in 2000.

Mainstream fuel fabrication plants in Japan are fully automated, engineered to ensure that criticality does not occur, equipped with neutron monitoring systems and fully prepared for any possible criticality accident. Most plants use a dry process in any case, which is intrinsically safer. No major civil reactor uses uranium enriched beyond 5% U-235 and no reactor in the UK uses the high enrichment that was being used in Japan.

### *Previous criticality accidents*

While this was Japan's first such accident, similar criticality incidents have occurred, especially in US and Russian military plants and laboratories. All but two of these were prior to the early 1980s. Three (in 1958 and 1964) were very similar to this accident. The last of these was the single previous criticality accident at a commercial fuel plant, in USA, resulting in one death.

Of all the previous accidents, 37 occurred in connection with research reactors or laboratory work for military projects, resulting in ten deaths. Another 22 occurred in fuel cycle facilities, *all but one military-related*, and resulting in seven deaths. The energy released in each of these accidents ranged from about 0.03 MJ to 3 GJ\*. The energy released in the similar US accident was about 3 MJ, though due to the prolonged criticality here, some 80 MJ was released, equivalent to the combustion of just over two litres of petrol/gasoline.

\* on basis of IPSN report quoting fissions ranging from  $10^{15}$  to  $1.2 \times 10^{20}$ , and each fission yielding  $3 \times 10^{-11}$  Joules. Petrol @ 34 MJ/litre.

The fuel preparation accidents were all in wet processes, due to putting too much uranium-bearing solution in one tank. Mostly these then erupt rather like a saucepan of milk boiling over, and the fission reaction ceases as the material is ejected and dispersed in the immediate vicinity. None of the previous accidents resulted in significant release of radioactivity outside the plants. Practically all were in Russian or

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US plants, and in reviewing these accidents recently the need for a high level of staff training was emphasised.

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*Sources:*

ENS NucNet news # 397-402, 409, 410, 414 & 459/99, 36/00, 169/00 background # 10-12/99.  
 IAEA Report on the Preliminary fact-finding mission , IPSN 1/10/99,  
 Yomiuri Shimbun 4/11/99  
 Atoms in Japan, Dec 1999  
 Science & Technology Agency (Japan)

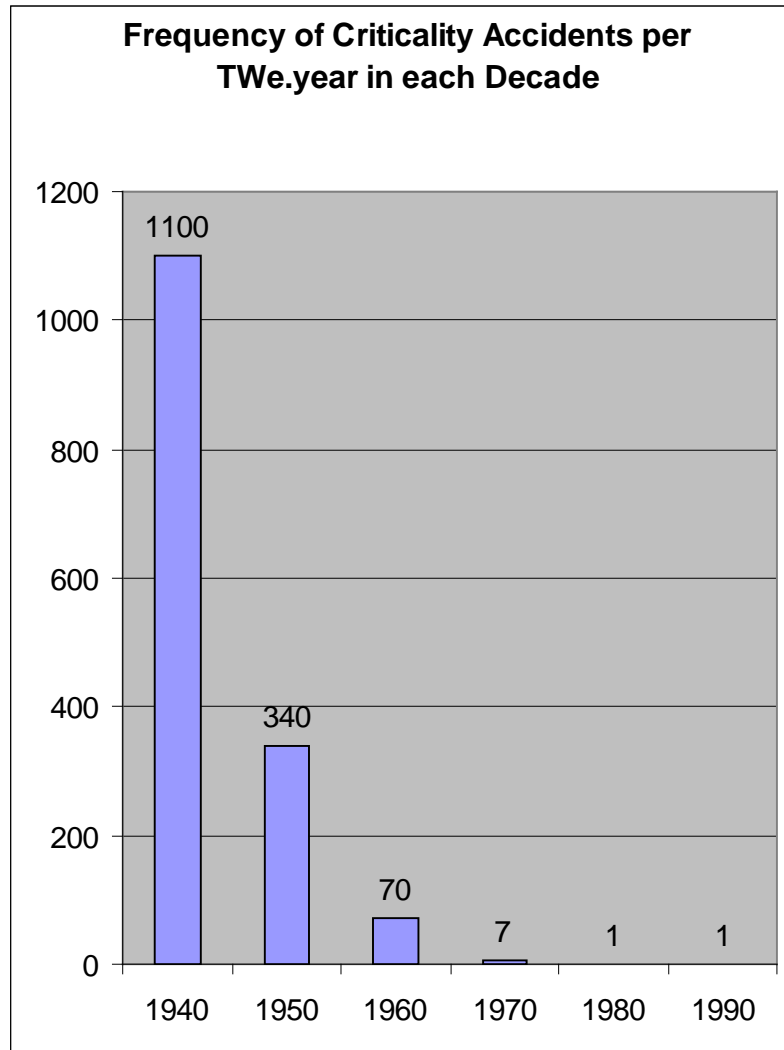
*Third Party Liability and Frequency.*

This was the first occasion on which the Japanese Nuclear Insurance Pool had had to pay a TPL claim. It ultimately amounted to 50 MGBP.

The next graph shows how the frequency of such accidents has fallen over the years. The probability of such an accident occurring due to terrorist attack is consistent with the forecasts that I have made in this Report and indeed provides strong support for those forecasts, which have not been based on actual accident data, but on theory.

Our estimate of the return period, based on the next graph and of the loss, based on the actual sum paid by insurers, then becomes:

Terrorist Act Equivalent to:	Tokai Criticality
Return Period in 14Gwe UK program	357
TPL MGBP	50
Theoretical ret period	541





### *Release of Radioactive Chemicals.*

A massive criticality accident in liquid solutions of the kind that happened at Tokai Mura, but much more powerful, could lead to disruption of the tank containing the material and of the surrounding containment or building, leading to escape of the radioactive solution to the environment.

This appears to have happened at the military plant at Chelyabinsk in Russia, where accidents of the most severe category considered in this Report have taken place.

Terrorist could engineer such accidents, although the probability, as calculated in this Report, is very low. Some details of the position at Chelyabinsk are as follows:

### *Chelyabinsk Accident*

The complex officially known as Chelyabinsk-40 is located in Chelyabinsk province, about 15 kilometers east of the city of Kyshtym on the east side of the southern Urals. It is situated in the area around Lake Kyzyltash, in the upper Techa River drainage basin among numerous other interconnected lakes. Between Lake Kyzyltash and Lake Irtyash is Chelyabinsk-65, the military-industrial city once called Beria, but today inhabitants call it Sorokovka("forties town").

Chelyabinsk-65, was reported to have 83,000 inhabitants and "almost 100,000 people." Chelyabinsk-40, the reactor complex, covers some 90 square kilometres and is run by the production association Mayak("beacon" or "lighthouse"). All the reactors are located near the southeast shore of Lake Kyzyltash and relied on open-cycle cooling: water from the lake was pumped directly through the core.

In 1957 the cooling system of a radioactive waste containment unit malfunctioned and exploded. The tanks were entirely immersed in, and cooled by, water. But the monitoring system was defective. The system failed in one of the tanks, however, and the waste began to dry out. On September 29, 1957 it appears that criticality occurred in the saturated solution of radioactive materials, which exploded with a force equivalent to 70-100 tons of TNT. Seventy metric tons of waste containing some 20 million curies of radioactivity was ejected -- about one-fourth the amount released in the 1986 Chernobyl accident.

About 90 percent of the radioactivity fell out immediately around the vessel. The rest formed a kilometer-high radioactive cloud that was carried through Chelyabinsk, Sverdlovsk, and Tumen provinces.

There were 217 towns and villages with a combined population 270,000 people in the area that was contaminated to greater than 0.1 curies of strontium 90 per square kilometer. By comparison, the total strontium 90 fallout at this latitude from past atmospheric tests is 0.08 curies per square kilometer. Virtually all water supply sources in the area were contaminated. Evacuation of the most highly contaminated areas, where 1,100 people lived, was not completed until 10 days after the accident. Other areas were evacuated a year later, after the population had consumed

radioactive food. In the years following the accident, 515 square miles of land was ploughed under or removed from agricultural use; all except 80 square kilometers was returned to use by 1978.

About 10,000 people lived in the 1,000-square-kilometer area contaminated with more than two curies of strontium 90 per square kilometer. One-fifth of these people eventually showed a reduction of leukocytes in their blood. There are no records of deaths caused by the accident.

### *Cost and Frequency.*

It would be very difficult for terrorists to engineer an accident of this magnitude in the UK.

The best estimate of the TPL loss is given by comparing it with the Chernobyl accident. It is stated that the release of radioactivity was one quarter of that released at Chernobyl. Now the Ukraine Government says that the TPL cost of Chernobyl so far is about 60,000 MGBP. The Ukraine Government is still spending money to compensate those affected by Chernobyl and I estimate that the final cost will be of order 80,000 MGBP. Then, as the TPL cost will be proportionate, to a first estimate, to the amount of radioactivity released, we see that the TPL cost of the Chelyabinsk accident would be 20,000 MGBP. It appears that the Russian Government has not spent as much as this, but this is what we estimate needed to be spent.

The frequency we have to arrive at, independently of the Joule study or the BSO design requirement, since we are going to use these accident scenarios to test the conclusions drawn using Joule and BSO. The accident occurred due to loss of cooling and failure of containment and in plant made to UK design criteria this would involve failure of two strong lines of defence and one weak line of defence (LOD). The return period would therefore be of order three million Gwe.years.

Our estimate of frequency and TPL is therefore as follows:

Terrorist Act Equivalent to:	Chelyabinsk Chemical
Return Period in 14Gwe UK program	214,286
TPL MGBP	20,000
Theoretical ret period	216,584

If it occurred it would have costs at the top end of the scale used in this Report and so would exhaust the 140 MGBP of proposed terrorism TPL.

### *The Station Blackout Incident of the Taiwan Power Maanshan NPP unit 1*

At 00:46 March 18, 2001 a seasonal sea smog, containing salt deposit, caused the malfunction of all four 345 KV power transmission lines in Fengkang and Hengchun region

in southern Taiwan, resulting in the loss of offsite power event at the Maanshan nuclear power plant (NPP) As both the safety-related A/C power systems of unit 1 went out of service and both the emergency diesel generators (EDG) failed to operate, the consequence was a complete loss of power of the two 4.16 KV essential buses at unit. A "3A" rating of site emergency event on domestic scale was announced subsequently. The plant staff, reconnected the essential power at 02:54 by connecting a swing diesel generator and the emergency event was thus called off. Neither radioactive release nor environmental impact was observed throughout the whole duration of the incident.

Such a Station Blackout could be caused by terrorists and if not successfully terminated by the connection of emergency power supplies, such as the "swing diesel" used by the operators at Maanshan, it would lead to damage to the reactor core and the possible release of radioactivity, leading to TPL claims.

As will become clear from the sequence of events, the external power supply became disconnected by accident: terrorist could disconnect it by design. Then there was difficulty in connecting the emergency power supply: terrorists could render such connection difficult.

Terrorist could produce station blackout by intervention on the ground or by crashing an aircraft into the plant. It might be possible to achieve the same objective by beaching a liquid natural gas tanker-ship near a shore-based nuclear power station and releasing gas, which would ignite and damage the power supplies. The Probabilistic Risk Assessments generally take account of such accidents. Instead of occurring accidentally these events could be engineered by terrorists.

Although the unit 1 reactor was not adversely affected throughout this incident, both trains of the safety system did experience a loss of function for as long as two hours and eight minutes. This incident was viewed as the most notable event over the 22-year history of nuclear electricity generation in Taiwan.

### *Sequence of Events.*

The incident leading to the loss of essential AC power (station blackout) at Maanshan NPP unit 1 in Taiwan on March 18, 2001 proceeded as follows:

(1) 03:23, March 17

Unit 1 of the plant lost its 345 KV offsite power and was shut down automatically. Reactor was placed in hot standby condition since then. Although the 345 KV power was restored later on, it remained at an unstable condition.

(2) 00:41, March 18

The plant lost all 4 trains of 345 KV offsite power. The 4.16 KV essential bus A breaker #17 opened and breaker #15 closed automatically, transferring supply from the 161 KV offsite power.

(3) 00:43, March 18

The Dar-Peng 345 KV power was restored while breaker #17 remained open.

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(4) 00:45, March 18

At 00:45:06, switchyard staff closed Gas-cooled breaker (GCB) 3620, getting ready to switch the offsite power from 161 KV to 345 KV manually.

(5) 00:45, March 18

At 00:45:07, a ground fault at the essential bus A of unit 1 occurred, causing breaker 3510 trip. At 00:45:09, breaker 1670 tripped as well. These malfunctions caused the plant lost essential power from offsite sources completely. Two emergency diesel generators (EDG) of unit 1 were unable to provide AC power to both essential buses. The plant entered an alert condition.

(6) 00:49, March 18

The plant staff acknowledged that the control building CO<sub>2</sub> fire extinguisher activated automatically. There was also a report from on-site staff that heavy smoke was coming out from the control building at floor location 46 feet below the control room, where the essential buses were located.

(7) 00:51, March 18

Operator attempted to reconnect 161 KV power to essential bus via breaker 1670, but failed.

(8) 00:56, March 18

The plant on-site firemen rushed to site but lacked of adequate lighting and ventilation equipment. Operator attempted to close breaker 3510 but failed again.

(9) 00:57, March 18

The plant operator connected EDG A to the essential bus A manually. In the meantime, the auxiliary feedwater system was successfully activated by properly operating the turbine-driven pump. The EDG A only provided power for 40 seconds and tripped because of signal failure at the train A essential bus.

(10) 00:58, March 18

According to the Plant Emergency Procedure 570.20, operator started to conduct required procedure to handle the situation of station blackout.

(11) 01:06, March 18

The plant staff attempted to restore the EDG B, but the building was full of smoke and lighting was not sufficient, the plant personnel were not able to get into the switchgear room.

(12) 01:41, March 18

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The plant called the Hengchun local fire department, requesting for additional lighting and ventilation equipment to assist expelling the smoke.

(13) 02:15, March 18

Plant staff decided to connect the swing EDG to the unit 1 4.16 KV essential bus B, and the preparation was ready at 02:50. It was activated manually in EDG control room, but was not successful at the first attempt because of low lube oil pressure. Plant staff judged that the reason was power loss of the constant-temperature oil pump and not equipment failure. A second attempt was then made and was successful.

(14) 02:54, March 18

The swing EDG was connected to train B of the essential bus successfully. The AC power was restored and the emergency condition at unit 1 was then called off.

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### *Core Damage Accident at Three Mile Island.*

This accident provides a realistic model of the core damage and release of radioactive materials that could occur if terrorist successfully engineered a station blackout accident. As with the Maanshan Station Blackout, there were critical operations to be performed by the station operators and in an alternative scenario terrorists could have intentionally misconducted these operations.

Aircraft crash could lead to similar or greater core damage by either causing Station Blackout or by actually disrupting the availability of cooling water supplies.

In the event, at Three Mile Island, there was little release of radioactivity from the plant and a Judge threw out the claims for TPL, so that there were no TPL losses. However if the reactor had had no containment or if the containment had leaked, which is quite possible, then there would have been TPL losses. These would certainly have exceeded 140 MGBP.

### *Details of the Accident.*

On March 28, 1979 at 4:00 AM, a minor malfunction occurred in the system which feeds water to the steam generators at the Three Mile Island (TMI) Unit 2 Nuclear Generating Station. This event led eventually to the most serious commercial nuclear accident in US history and fundamental changes in the way nuclear power plants were operated and regulated.

The accident itself progressed to the point where over 90% of the reactor core was damaged. The containment building in which the reactor is located as well as several other locations around the plant were contaminated.

TMI Unit 2 is located outside of Harrisburg, PA along the Susquehanna River. The reactor system is a Babcock and Wilcox 900 MWe PWR. The system uses once through steam generators and has an unusually small primary coolant system volume.

During routine maintenance of the secondary side, feedwater to the steam generators was interrupted. The loss of feedwater caused the primary system to overheat causing the primary system pressure to increase. The reactor protective system scrambled the reactor but not before the system pressure caused one of the pressure regulating valves to open. This sequence of events was exactly what would be expected in such an event.

Unfortunately, when the pressure in the reactor decreased, the valve failed to completely close resulting in a small break loss of coolant accident (SBLOCA). The emergency core cooling systems actuated as the system pressure continued to drop. Because of an incorrect interpretation of the instrument readings the operators terminated the operation of these systems. This caused the core to eventually overheat. The fuel cladding rapidly oxidized releasing hydrogen to the containment and further accelerating the process. Eventually, a significant portion of the fuel melted and flowed into the lower part of the core and lower reactor vessel head.

Large amounts of radioactive noble gasses were released to the containment atmosphere. Some of these were released to the environment resulting in <100 mrem maximum dose to those nearest TMI. There was no significant release of Caesium or Iodine to the environment.

Despite the severity of the damage, no injuries due to radiation occurred. There were however, significant health affects due to the psychological stress on the individuals living in the area. The defence in depth approach worked resulting in containment of the radioactivity in the containment building and enabling the operators to eventually cool the damaged core and regain control of the system.

### *TPL Claims Rejected*

Within weeks attorneys filed a class action suit against Metropolitan Edison Company (a subsidiary of General Public Utilities) on behalf of all businesses and residents within 25 miles of the plant. Over 2,000 personal injury claims were filed, with plaintiffs claiming a variety of health injuries caused by gamma radiation exposure. The Pennsylvania district court quickly consolidated the claims into ten test cases. Over the next 15 years, the case went to the Supreme Court and back, and through various district and appeals courts. Finally, in June 1996 district court judge Sylvia Rambo dismissed the lawsuit granting summary judgment in favour of the defendants.

The Judge summed up her judgement in the following text:

*“The parties to the instant action have had nearly two decades to muster evidence in support of their respective cases. As is clear from the preceding discussion, the discrepancies between Defendants, proffer of evidence and that put forth by Plaintiffs in both volume and complexity are vast. The paucity of proof alleged in support of Plaintiffs, case is manifest. The court has searched the record for any and all evidence which construed in a light most favorable to Plaintiffs creates a genuine issue of material fact warranting submission of their claims to a jury. This effort has been in vain. The grave consequence of the court's decision to grant summary judgment in favor of Defendants is obvious -- thousands of individuals who believe that they have suffered adverse medical effects as a result of the TMI accident will not have an opportunity to have their claims heard by a jury of their peers. In addressing the merits of Defendants' motion for summary judgment, however, this case is like all otheks that come before he court in that the well articulate standards governing the award of summary judgment guide the court's evaluation of the evidence before it. Those standards combined with the scarcity of evidence of record to support Plaintiffs, claims mandate the result reached by the court today.”*

### *Cost And Frequency.*

Evidently, then it is possible to have a severe core damage accident, of the type that occurred at TMI, but engineered by terrorists, in which there is no TPL loss. However there is a high probability of some leakage from the containment and a significant probability of major leakage from containment.

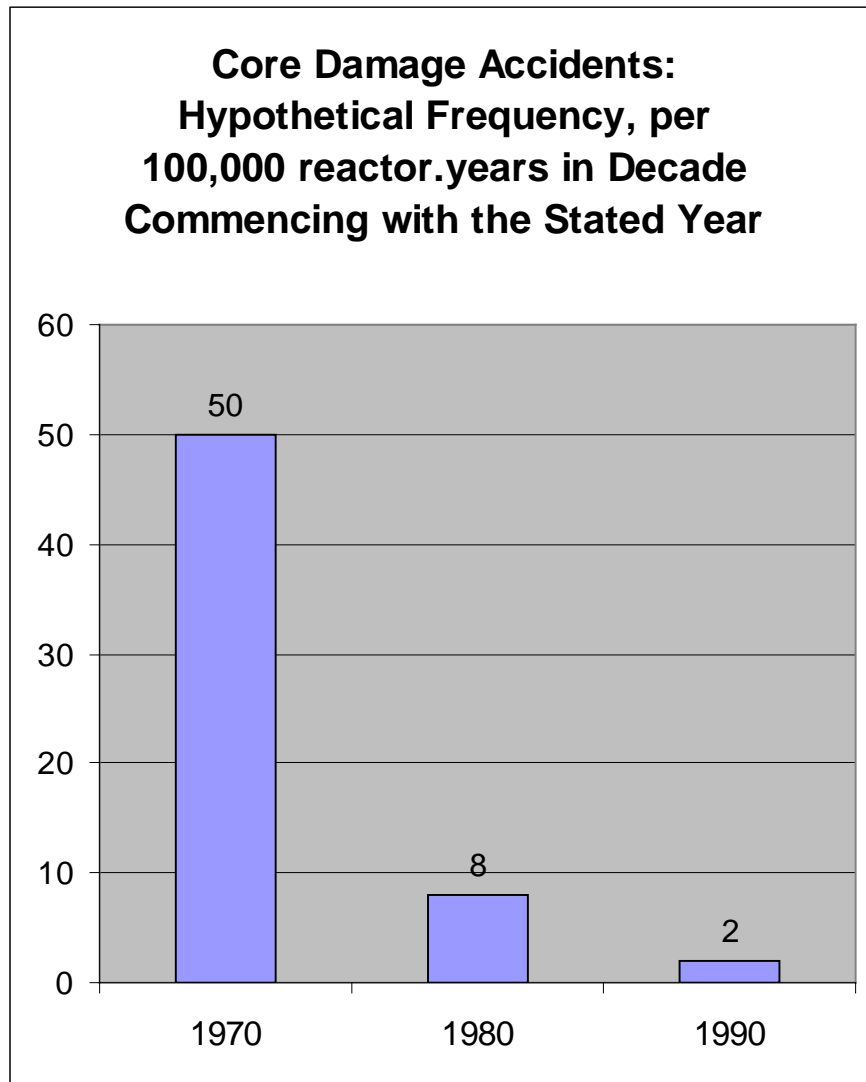
As with all of these scenarios, we wish to arrive at estimates of frequency and TPL loss for an equivalent accident caused by terrorists in the UK. We wish to do this without recourse to the Joule study or the BSO requirement, since we want to use our estimates, based on actual accidents, to test the forecasts of frequency and TPL that we have arrived at using Joule and the BSO design criteria.

The TMI accident is the only one in which such extensive core damage has occurred in the whole of the world's nuclear power program. This would give a return period of 10,000 Gwe.years. However, since the TMI accident many improvements have been made to the UK and foreign reactors and their modes of operation, designed to avoid a repetition of such a severe accident. Bayes analysis, like that performed in this Report, suggests that the return period is now about 50,000 years, a forecast reflected in the current value of return period on the graph in the relevant Annex to this paper. That graph is inserted below.

As for the TPL: the Physical Damage led to a claim which in today's money would be 1,000 MGBP and we shall assume, for want of any better guidance, that such an accident, caused by terrorists in the UK, would lead to a TPL of a half that magnitude, 500 MGBP

Our estimates of return period and TPL then become:

Terrorist Act Equivalent to:	TMI Core Melt
Return Period in 14Gwe UK program	3,571
TPL MGBP	500
Theoretical ret period	5,415



### *Leakage of Radioactivity From Cobalt 60 Source.*

Away from nuclear installations, and in factories where sources are made, there is the possibility of accidents in which TPL occurs due to the leakage of radioactivity from sealed sources. Sources of Cobalt-60 are used to radiograph welds during the construction of buildings. Radiation sometimes leaks accidentally from such a source and terrorists could engineer such a release. Here we give an example of what could occur. It is an account of an accident in Thailand.

#### *Accident in Thailand.*

Radioactive Cobalt-60 contained in a metal canister, mistaken as scrap metal was cut open On February 1st 1999, in a scrap shop in Soi Wat Mahawong community, Samut Prakarn province, Thailand. The workers had dismantled small metal cylinders to get the steel outer case. The material inside gave out a terrible smell, but no one suspected it was dangerous until February 15-17 when the scrap yard owner and his workers found themselves severely ill; nausea, vomiting, skin burns, hair loss, and 3 dogs at the scrap shop died.

Once sent to Samut Prakarn provincial hospital, the doctors assumed that the patients were exposed to high levels of radiation, and informed the Office of Atomic Energy for Peace (OAEP). The search for the source of the radiation began on February 19 and ended on the 21st when the OAEP officers could finally identify and rescue the source - the cylinder-shaped cobalt 60 pellet 1.5 inch long and a half inch in diameter. Further investigation found that this cobalt-60 waste, owned by Kamol Sukosol Electric Company, a private agency importing cobalt-60 for hospitals and industrial factories, was kept in the company's empty car park in Bangkok before being taken to the scrap shop in Samut Prakarn by five peddlers. Jitsen Jantharasaka, one of the five peddlers, said he removed a lead container holding cobalt 60 from a radiotherapy machine. After trying unsuccessfully to remove the outer cover, he sold it to the shop where the cover was cut off. He touched the lead cylinder with his bare hands and shortly afterward felt an itch. Later all five peddlers fell ill; skin burns, fatigue, nausea, hair loss.

The Public Health Ministry concluded that the people who were exposed to the radiation could be divided into four groups;

Group 1: a.) 6 people of the scrap shop (3 already died; Mr. Niphan Phanthukan - an 18-year old worker, died on March 7, Mr. Sudjai Jairew (or Liang Suwandee) - a Laotian worker, died on March 20, and Mr. Kaecha Songsriphipat, the scrap shop owner's husband, died on March 25. b.) 5 peddlers whose skins are burnt by radiation

Group 2: 4 people worked in the scrap shop whose white blood cells were found less than 3,000 cells/cc (they had come to help at the yard after workers

in Group 1 started falling ill from radiation unknowingly)

Group 3: 25 neighbours whose white blood cells are more than 3,000 but less than 5,000 cells/cc

Group 4: 5 pregnant women in the neighbourhood.

### *Frequency and Cost.*

An event of this type could be caused by terrorists. They could obtain a sealed Cobalt-60 source and, with danger to themselves or by some other means, they could use it to harm people. An incident as serious as that described above could exhaust the 140 MGBP TPL limit, depending on the nature of the subsequent litigation.

There have been two other accidents of this type and with similar consequences during the 10,000 Gwe.year world nuclear program, giving a return period of about 3,300 Gwe.years.

As for the TPL loss, several people died in each of the accident and there was contamination. The loss will depend on the litigation but is thought unlikely to be less than 10 or greater than 100 MGBP: say 30 MGBP.

Our estimates of frequency and TPL then become:

	Thailand Co60 Exposure
Terrorist Act Equivalent to:	
Return Period in 14Gwe UK program	214
TPL MGBP	30
Theoretical ret period	325

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### *Minor Release of Radioactivity.*

Terrorists could most easily obtain access to radio pharmaceuticals and other radioactive chemicals. These are used in Hospitals and Universities. An example of an accident involving these materials is given below, and it makes it easy to imagine a minor terrorist act involving the materials.

### *Accident at the University of Surrey.*

An accident occurred in October 1995 to a Physics technician at the University of Surrey, UK, giving rise to 140mSv committed dose and prosecution under IRR85.

Stocks of radiocaesium were held by the Physics Dept for use in a teaching package using a liquid Geiger tube. That teaching experiment was abandoned some time ago but stocks of caesium had been maintained as a useful fission product source. **2. The**

The caesium chloride solution was contained within a standard Amersham P6 multidose vial. They were aware of the risk of aerosol production from syringe needles being withdrawn through rubber septums and had done some modest research on it. That may be the reason for Amersham favouring open vials, but the worker at Surrey was not convinced and so he capped the vial, believing that sterile pharmaceuticals should be closed.

The activity in the vial was thought to be 240MBq at the time of use (later found to be 150MBq) and the manipulation was done in a Controlled Area - the Schedule 2 value at which a Controlled Area is required being 40MBq. Regretfully, the work was done on a shelf bench rather than in the fume cupboard normally prescribed for such work. The technique used was regarded as conventional and routine and was therefore not identified specifically in Local Rules or Systems of Work, nor was it regarded as having any special risk other than from external radiation. For the latter, the vial was kept behind a low wall of 2" lead bricks to reduce the dose rate at 50cm to 0.192 uSv/h. The unshielded dose rate at 50cm was 48 uSv/h. The IP was aware of the need to maintain a good working distance between his face and the source and appreciated the need for shielding but wanted to see the position of the pressure relief needle as it entered the vial. Partly due to the sight constraint and probably mainly due to the hardened condition of the rubber septum, the needle penetrated into the liquid with an unexpected release of liquid from the vial, which had become slightly pressurised.

When the accident was reported several days after it had occurred, the IP was whole-body counted at NRPB. The dose was small so that the IP could continue with his duties but there was a dose restriction for the remainder of the year.

### *Cost and Frequency.*

We are now in the realm of accidents that occur relatively frequently. The University was prosecuted and fined 500 GBP for having permitted this incident to occur, which is a measure of its insignificance.

I think it unlikely that terrorists would engineer such trivial incidents as this and for that reason I recommend a cut-off, here set for convenience of presentation at 14,000 GBP, below which Government would not insure TPL due to terrorist attack on UK installations.

We shall assume a value of 500,000 GBP for the TPL. No such sum was claimed by the person affected at the University because he suffered no significant harm, but a terrorist would obviously spread the contamination deliberately.

As for the frequency, we assume that accidents of this type will occur every 100 Gwe.years. Terrorist acts will occur with this same frequency, or at fourteen times that frequency in the 14 Gwe UK program.

We assume that in the case where the radiochemical is handled by a terrorist he will succeed in causing some harm and contamination- much more damage than the minor accident at the University where the operative was *trying not* to cause harm and contamination. The estimates then become:

	University Minor Source
Terrorist Act Equivalent to:	
Return Period in 14Gwe UK program	7.14
TPL MGBP	0.50
Theoretical ret period	5.41

*Transport Incidents.*

An Annex is attached concerning the transport of radioactive materials. One might imagine that this activity would provide a relatively easy target for terrorists. However there have been few cases of actual TPL as a result of transport accidents and from this I conclude that the frequency of successful terrorist attacks on radioactive transits will also be low.

The IAEA claims that there has been no fatality or serious injury due to radioactive material transport or accidents during such transport. There is a chance of a release of radioactivity and indeed such releases have occurred. However the design of packages is such that such accidental releases have never been big enough to matter.

*Frequency and Consequences.*

I have apportioned more of the TPL terrorist premium to Transport than the analysis here presented would warrant. This is out of caution: the hypothesis that we have adopted is simply that things which resist accidents will resist terrorists and, in the case of radioactive transport, this might be over optimistic.

We assume that a significant terrorist attack on UK Radioactive transits can occur every 5,000 Gwe.years and that a typical value for the TPL is 40 MGBP:

	University Minor Source
Terrorist Act Equivalent to:	
Return Period in 14Gwe UK program	357.14
TPL MGBP	40.00
Theoretical ret period	433.17

## Comparison of TPL Estimates Based on the Joule Study with those Derived From Accident Scenarios.

Combining the forecasts for terrorist TPL arrived at in the foregoing accident scenarios with those derived earlier in this Report from the theoretical Joule study and the BSO/BSL requirement we obtain the following Table for the 14 Gwe UK nuclear power program. It will be seen that there is a measure of agreement between these two methods of estimating terrorist TPL and return periods:

	University Minor Source	Co60 Exposure	Transit Accident	Criticality	Core Melt	Chemical
<b>Terrorist TPL MGBP</b>	<b>1</b>	<b>30</b>	<b>40</b>	<b>50</b>	<b>500</b>	<b>20,000</b>
<b>Theoretical return period, based on Joule study</b>	<b>5</b>	<b>325</b>	<b>433</b>	<b>541</b>	<b>5,415</b>	<b>216,584</b>
<b>Scenario-based Return Period</b>	<b>7</b>	<b>214</b>	<b>357</b>	<b>357</b>	<b>3,571</b>	<b>214,286</b>

## Annex. Bayes Analysis.

### *Summary*

After the terrorist attack on the World Trade Centre and the Pentagon, on September 11th 2001, it became clear that the terrorists could, if they had wished, have crashed one of the Jumbo Jets into a US nuclear power station. In this Annex I show how to estimate the probability of such a terrorist strike, using a prior distribution of probabilities and Bayes' theorem.

We conclude that the **total risk** presented by nuclear installations that fall in the same class of "World Terrorism Targets" as the WTC and the Pentagon is now twice what we previously thought. It is the fact that the WTC and the Pentagon were subject to massive terrorist attacks, of an unprecedented magnitude, that has brought about this revision.

This conclusion is clearly consistent with the views of operators, insurers and regulators round the world, since if they believed that the risk had increased by more than a small factor they would insist on the defuelling of many of the world's nuclear power stations so as to reduce to a much lower level the terrorist risk that they present.

### *Introduction.*

After the terrorist attack on the World Trade Centre and the Pentagon, on September 11th 2001, it became clear that the terrorists could, if they had wished, have crashed one of the Jumbo Jets into a US nuclear power station. In this article I show how to estimate the probability of such a terrorist strike, using a prior distribution of probabilities and Bayes' theorem.

### *WTC and Pentagon as Two of the Class of "World Terrorism Targets"*

The WTC and the Pentagon, together with the White House, which latter was a probable target for the fourth Jumbo on September 11<sup>th</sup>, are in a class that we may term "World Terrorism Targets". The terrorists said as much. They said that the WTC was the symbol of US Capitalism and the Pentagon was the symbol of US Militarism. No doubt the White House would have been described as the symbol of US Political Dominance of the World had it been struck by the fourth Jumbo. Some, but not all of the world's nuclear power stations come in this class: TMI is an obvious case, since the name is known throughout the world and is in fact associated with precisely the kind of disaster that terrorists would seek to duplicate by an air strike or some other

means. An air strike on TMI would have immediately been understood by the world at large, as well as being a potential disaster for the USA.

It seems likely that many of the world's nuclear power stations and some other nuclear plants would be on the target-list of any of the several groups of international terrorists. Indeed this fact is recognised and is being addressed by many different measures aimed at reducing the terrorist risk to these installations.

*On September 11<sup>th</sup> 2001, Two "World Terrorism Targets" Were Struck by Terrorists.*

As soon as we accept that the WTC and the Pentagon were members of the class of objects which we have called "World Terrorism Targets" and TMI and some other US and other nuclear installations are also in the class of World Terrorism Targets" we can define a question. It is this:

"How likely, now that two World Terrorism Targets have been struck, is it that others of these Targets, which include nuclear installations, will be struck?"

By recognising that nuclear installations have, in common with the WTC and the Pentagon, the fact that they are likely targets for international terrorism we have made it possible to place these Targets in a single class, enabling us to deduce the likelihood that another member of the class of Targets, such as a nuclear installation, will be struck some time in the future.

### *Bayes' Theorem.*

In order to deduce the likelihood of a terrorist strike on a nuclear installation, given the WTC air strike, we shall make use of Bayes' theorem. It enables us to use sparse data (air strikes on two targets) to logically-modify our prior belief about the likelihood, in future, of such terrorist acts.

### *The Prior Distribution of The Frequency of Terrorist Strikes.*

In the UK, and elsewhere, the design basis for nuclear installations includes the requirement that no single cause of accidents shall dominate the Risk Assessment or Safety Case. Typically the Regulator will require the designer to ensure that an individual source of Risk contributes no more than one tenth of the total risk presented by the installation. Of course the total Risk is itself the subject of constraints, too.

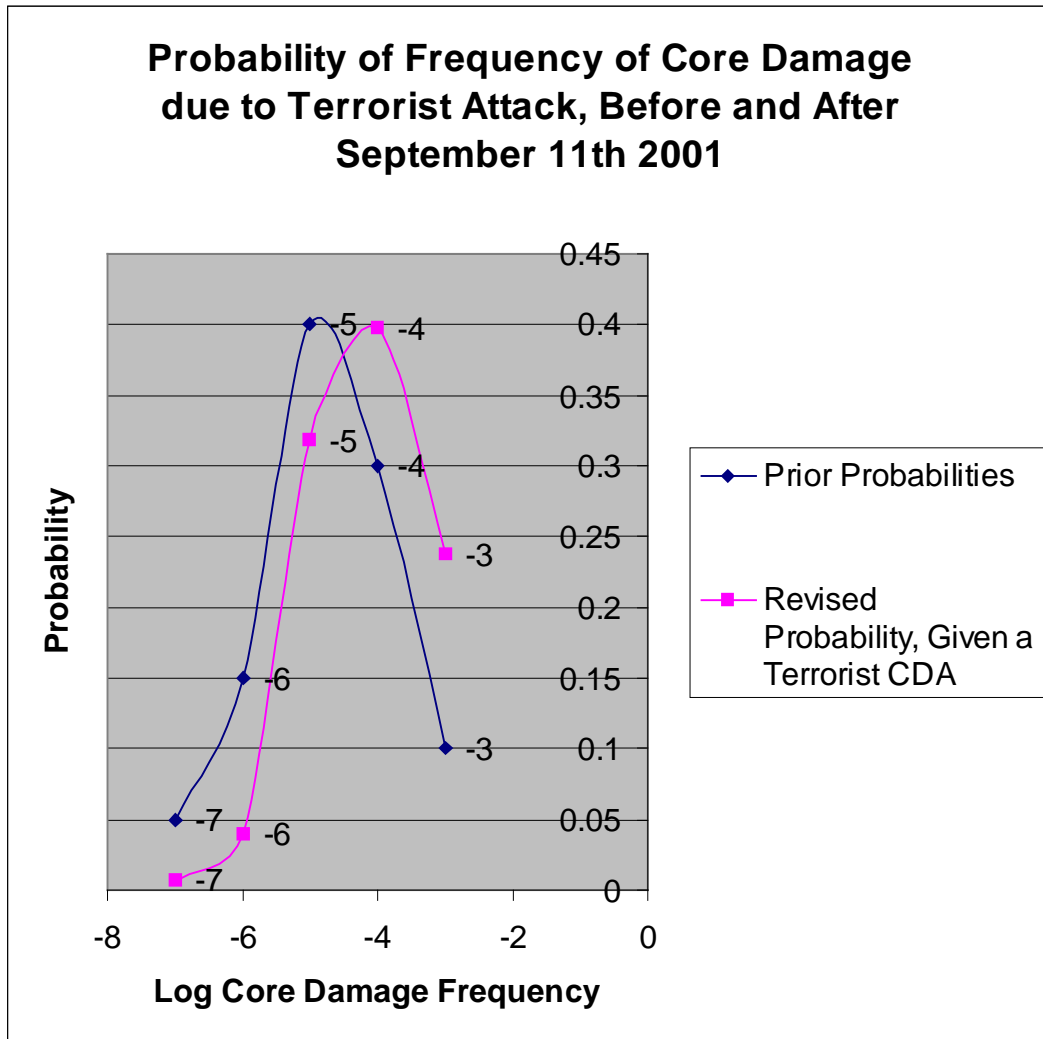
We shall assert that the implication is that terrorism, whether on the grand scale of a Jumbo air strike of some lesser event engineered by someone on the ground, prior to September 11<sup>th</sup> 2001, was believed to contribute no more than one tenth of the risk presented by an individual nuclear installation.

So that the implications of this assertion can be better understood, consider the following alternatives:

- 
- Ø It may be that, for each given class of accident, terrorism constituted one tenth of the risk. Then terrorism will have been thought to comprise one tenth of the total risk, posed by all of the classes of accident taken together.
  - Ø Alternatively one can imagine a case in which all of the accidents that terrorists can produce are placed in a separate category. Then we are asserting that the risk presented by that particular class of accident was thought, prior to September 11<sup>th</sup> 2002, to present one tenth of the total risk.

We can therefore calculate a Prior Distribution of the Probability Density of Estimates of the Frequency of Terrorist Strikes on nuclear installations. It is, in the simplest case which is all that we are here concerned to examine, the Distribution for all sources of Risk, moved one order of magnitude to lower frequencies. This is shown in the following Figure, where it is termed the distribution of *Prior Probabilities*.

Figure: Probability of Frequency of Core Damage due to Terrorist Attack, Before and After September 11<sup>th</sup> 2001



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*Revised Probabilities, Following the September 11<sup>th</sup> Terrorist Attack.*

The above Figure also shows a curve for the **Revised Probability**, given that the WTC attack occurred. Here we take the elementary view that the WTC event might equally have included an attack on TMI. This follows directly from our argument that TMI and the WTC are members of the same class of World Terrorism Targets.

In order to calculate the Revised Probability from the Prior, use has been made of Bayes theorem and the fact that the attack on World Terrorism Targets took place on September 11<sup>th</sup> 2001.

*Conclusion.*

It is concluded that the Terrorist strike on September 11<sup>th</sup> 2001 implies that the frequency with which such strikes can be expected to occur on nuclear power stations and other nuclear targets is an order of magnitude higher than we had previously thought.

We have asserted, nuclear installations were designed so that the calculated contribution of terrorism to the total risk,  $R$ , that they present was no more than one tenth of that risk, that is to say  $R/10$ . The balance of the risk, not attributable to terrorism, was then equal to  $0.9R$ .

Now we conclude that the risk due to terrorism is actually an order of magnitude higher. That is our estimate has increased from  $R/10$  to  $R$ . The non-terrorist risk remains at  $0.9R$  and so the total risk is not  $R$  (as we previously thought) but  $1.9R$ .

We conclude, therefore, that the total risk presented by nuclear installations that fall in the same class of World Terrorism Targets as the WTC and the Pentagon is now twice what we previously thought. It is the fact that the WTC and the Pentagon were subject to massive terrorist attacks, of an unprecedented magnitude, that has brought about this revision

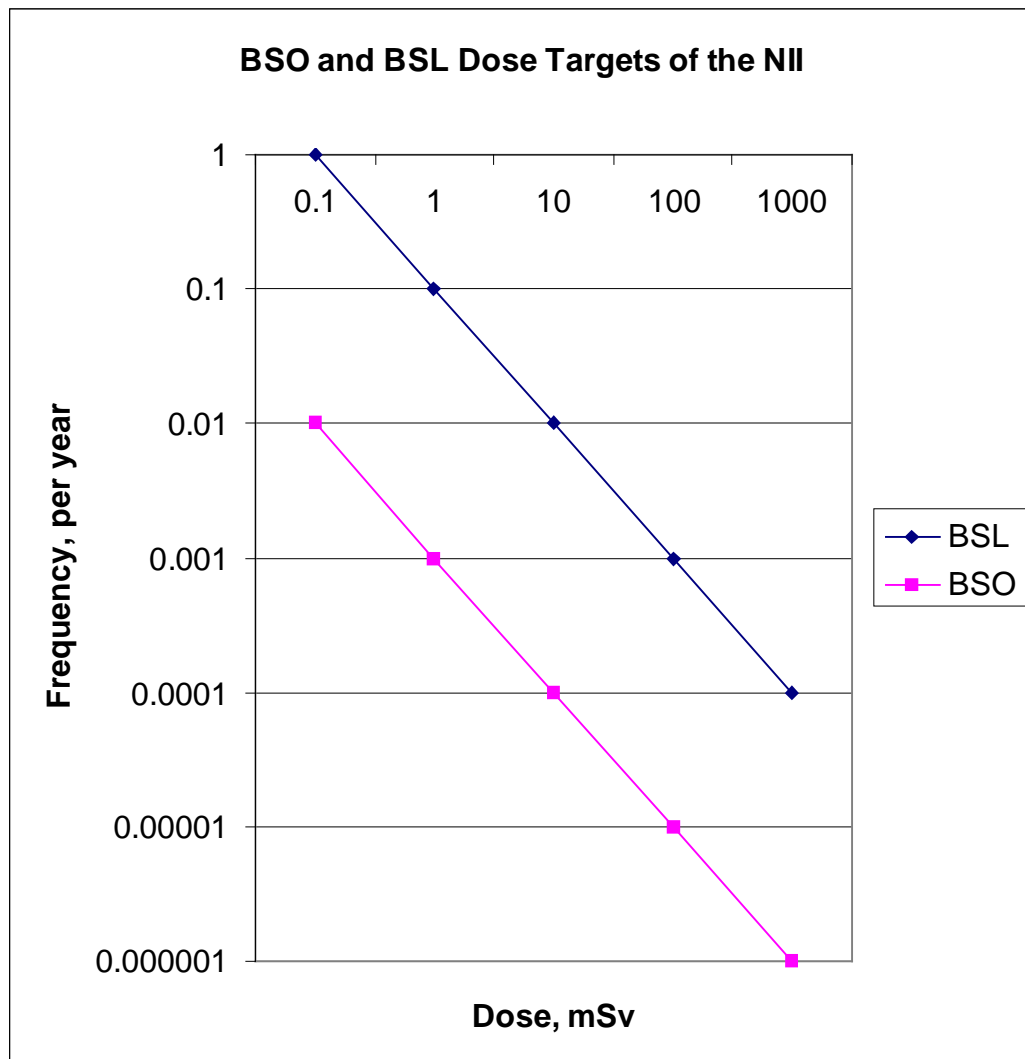
This conclusion is not very sensitive to various assumptions that have had to be made in arriving at it. It is clearly consistent with the views of operators, insurers and regulators round the world, since if they believed that the risk had increased by more than a small factor they would insist on the defuelling of many of the world's nuclear power stations so as to reduce to a much lower level the terrorist risk that they present.

## Annex on BSO/BSL.

The Nuclear Installations Inspectorate, NII, has set Basic Safety Objectives (BSO) and Basic Safety Limits (BSL) for the design and operation of nuclear installations, and for transits and other activities involving radioactivity, in the UK.

These are of the form Radiation Dose x Frequency = Constant.

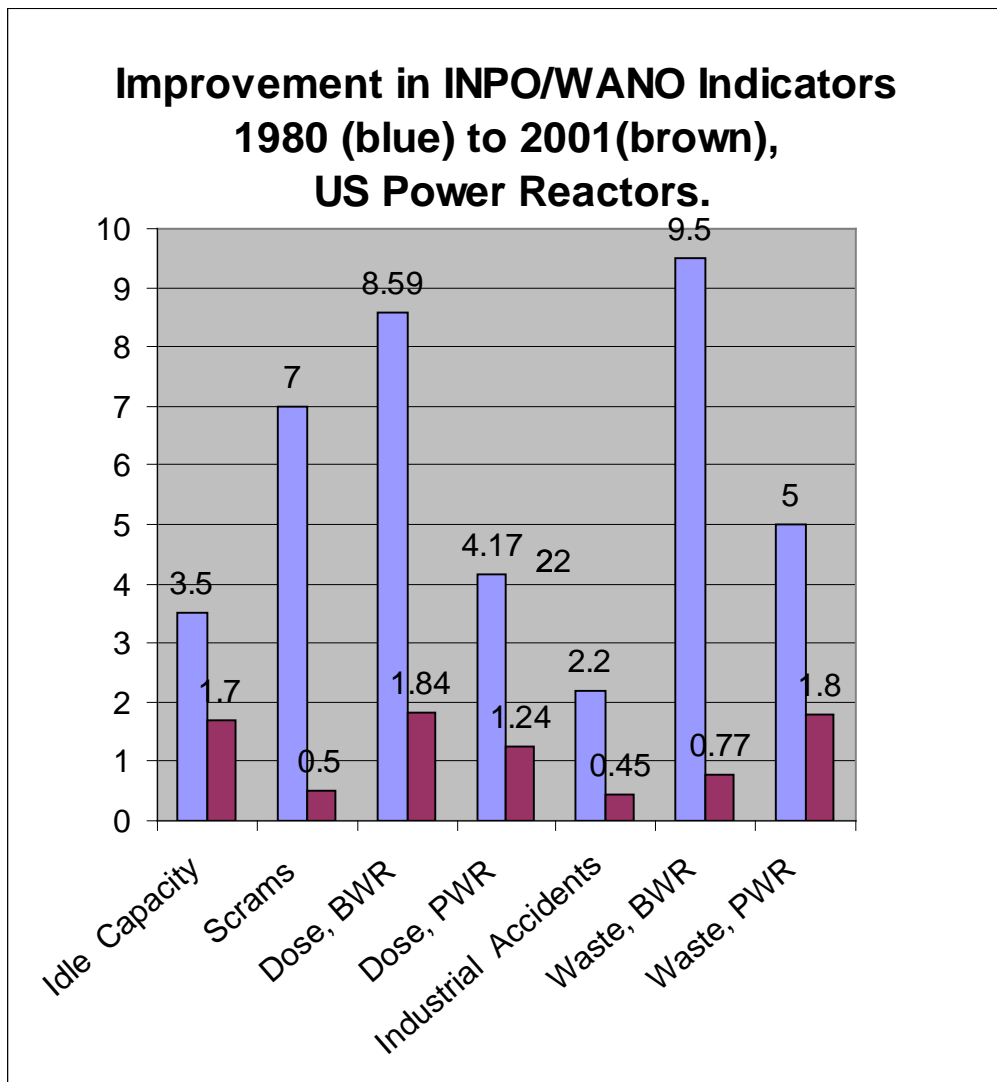
*Figure Showing BSO and BSL.*



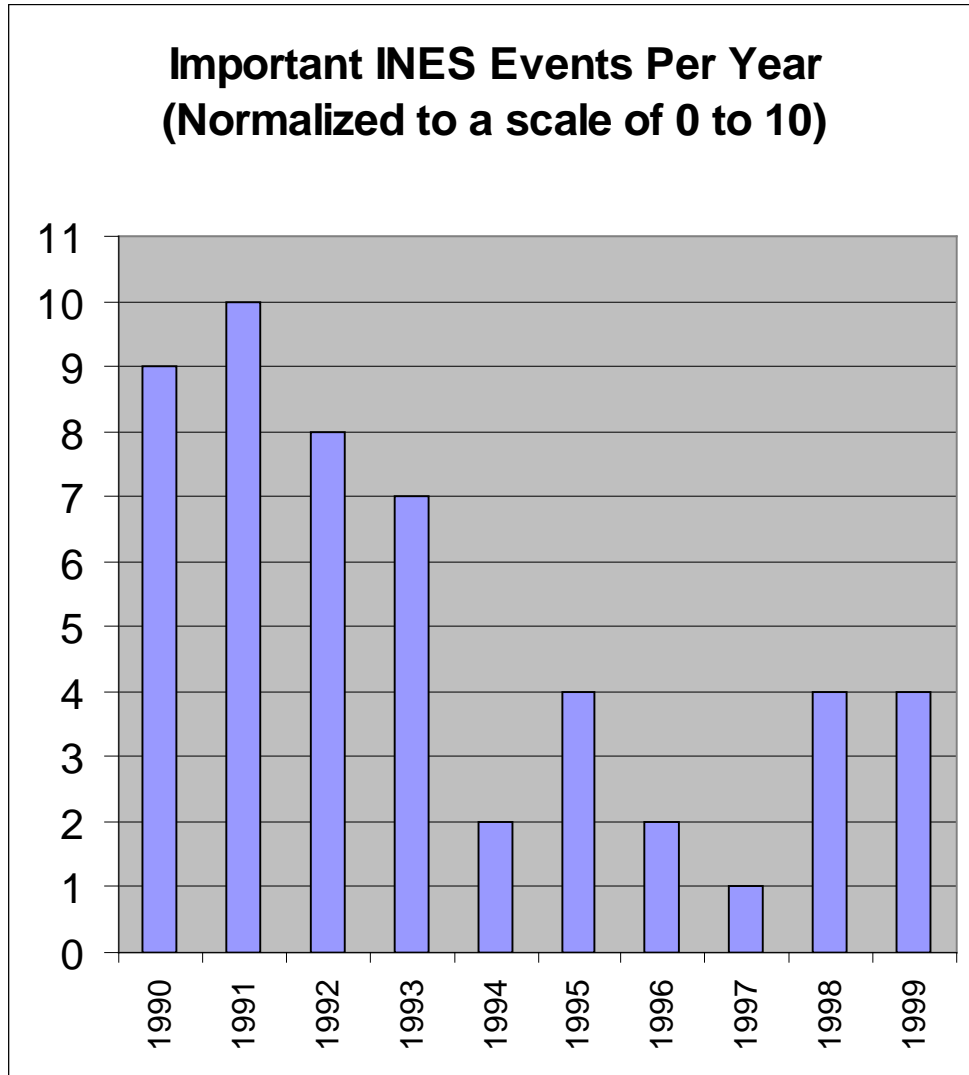
## Annex: Pictorial Review: Improvements in Nuclear Safety.

The frequency of severe accidents has fallen well below that assumed in the Joule analysis, and this is illustrated by the following illustrations:

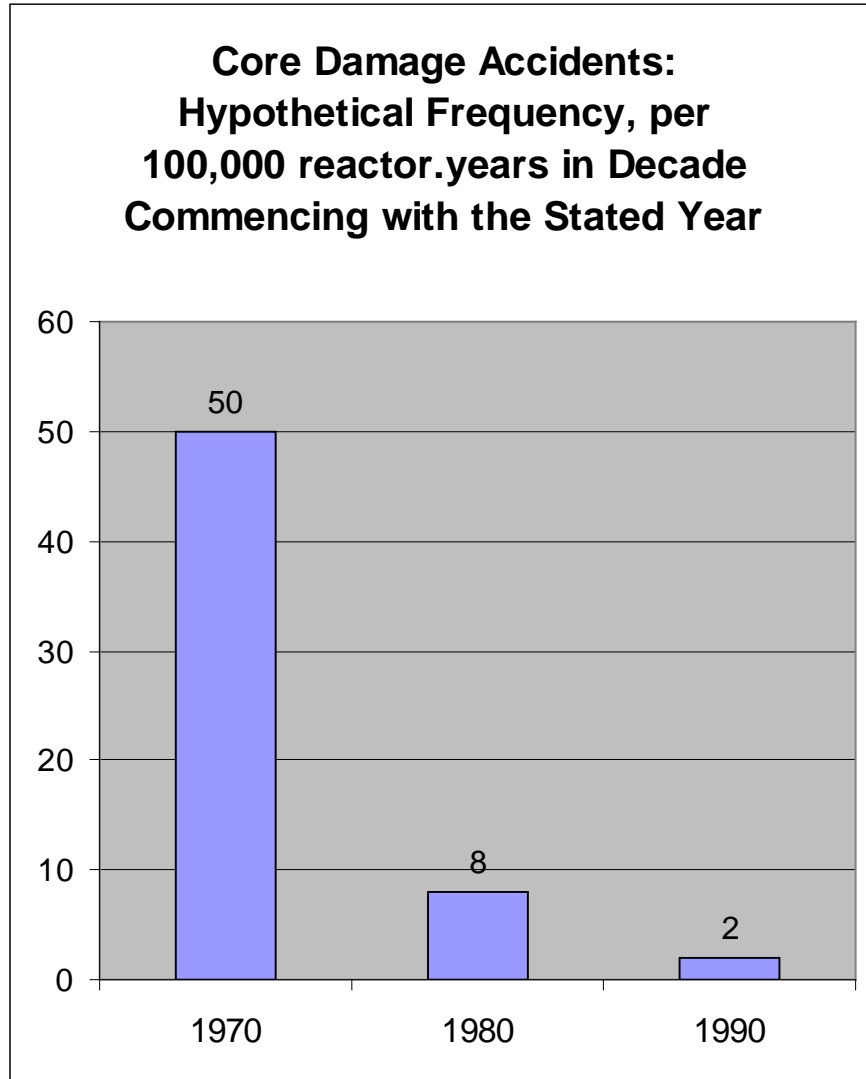
### *Improvements in Selected INPO/WANO Indicators.*



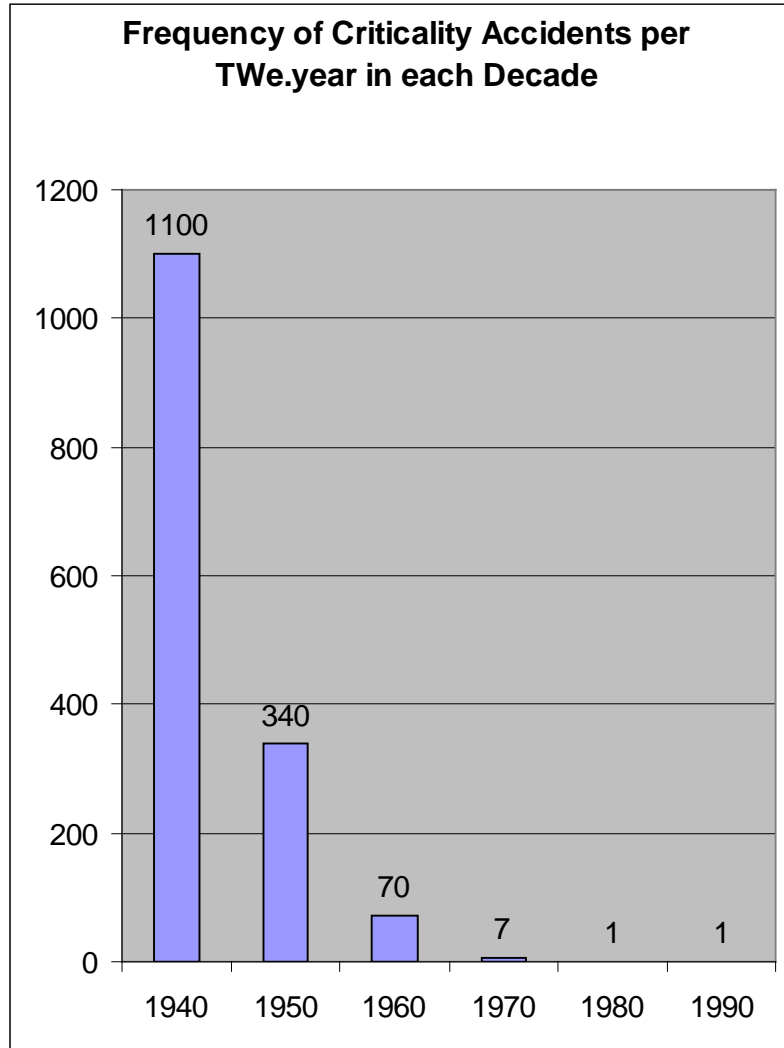
*Reduction in Frequency of Important INES Events.*



*Reduction in Core Damage Frequencies.*



*Fall in the Normalized Frequency of Criticality Accidents.*



## **Annex: Resistance of Nuclear Installations to Terrorist Attack.**

### *Terrorist Component of Accidents, Pre 11/9/01.*

Nuclear Installations are designed so that no individual threat to safety contributes more than one tenth of the risk presented by the installation. It is deduced that this applies to terrorism. The following considerations support this view:

### *The Design Basis of Nuclear Power Reactors.*

*Plant Designed to resist Airstrike.*

Most LWRs and many other types of power reactor are designed to resist the impact of an aircraft. The safety assessment assumes that such an airstrike would be accidental and therefore assigns a very low probability to an impact which breaches the containment.

*-IAEA Analysis: Stations Not Designed against Jumbo Airstrike (4).*

At the 2001 annual Conference of the IAEA, a spokesman said that nuclear power stations, although designed to withstand aircraft crash, are not designed to withstand the impact of a fully laden jumbo jet. In the very unlikely event of a jumbo jet striking the containment full-on there would probably be a serious release of radioactivity. This view is over-pessimistic, since as shown below a formal analysis concluded that the likelihood of the containment being penetrated even if it was struck at the most vulnerable spot is only 33%. Coupled with the unlikely nature of such an accurate strike, it appears that the probability that a jumbo air strike would rupture the containment is low. This conclusion has recently been expressed by the USNRC.

*Design Basis Terrorist Attack is Ground-Based.*

Current USNRC regulations require that nuclear plants be able to defend themselves against a small force of ground attackers equipped with automatic weapons, one or two insiders and truck bombs.

### *The Trials of Airstrike Resistance that have Been Made.*

*Japanese Trial Shows Fighter Airstrike does not penetrate Containment.*

In a recent Japanese trial, a fighter plane was dived into a simulated LWR containment building. It failed to penetrate or crack the containment.

*US Trial shows Containment remains Intact after Fgghter Airstrike.*

In a US trial, a jet fighter bomber was flown into a containment building at 500mph. It only left two marks where the engine hit. The NRC has said the steel and concrete

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containment structures ringing U.S. reactor cores could probably resist penetration even in the event of the crash of a large airliner.

*General Electric Calculated that Jumbo Airstrike had 33% Chance of Penetrating Containment.*

A study by General Electric in 1974 concluded that such an aircraft had 33% chance of breaching a typical US reactor's containment building, depending on where it was struck - the top being the weakest point.

*Containment Would Probably not be Breached: Balance of Plant would Suffer severe Fire Damage.*

Most LWRs and many other types of power reactor are designed to resist the impact of an aircraft. In a recent Japanese trial, a fighter plane was dived into a simulated LWR containment building. It failed to penetrate or crack the containment. A study by General Electric in 1974 concluded that such an aircraft, if it struck the weakest point, had 33% chance of breaching a typical US reactor's containment building. The NRC has said the containment could probably resist penetration even in the event of the crash of a large airliner into the weakest spot in the containment. Given the fact that an engine of the plane is very unlikely to strike the weakest point, causing penetration, the risk of containment failure due to aircraft strike is seen to be very low. The balance of plant, however, could suffer severe damage from the associated fire.

*Old Stations of Russian Design the Least Resistant to Airstrike.*

The older Czech nuclear power station, Dukovany, is less well protected against airstrike than the new VVER at Temelin. This is symptomatic of a general tendency of the earlier reactors of Russian design to be less resistant to airstrike.

*Fighter Aircraft on Alert in Many Countries.*

Fighter aircraft have been placed on the alert in many countries. The implication is that they would shoot down any hijacked plane that threatened to strike at a nuclear installation.

*Anti-Terrorist Exercises in Progress and Planned.*

Anti-Terrorist Exercises are in progress in Russia and planned universally.

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## Annex: The IAEA View on The Terrorist Threat to Nuclear Installations.

IAEA experts have evaluated the risks for nuclear terrorism in these three categories:

**Nuclear facilities:** IAEA experts believe the primary risks associated with nuclear facilities would involve the theft or diversion of nuclear material from the facility, or a physical attack or act of sabotage designed to cause an uncontrolled release of radioactivity to the surrounding environment.

Nuclear facilities are protected by well-trained security forces and are extremely robust, designed to withstand, for example, earthquakes, tornado-force winds and accidental crashes of small aircraft. Although it is not automatic that any attack would result in a release of radioactivity, they are however industrial facilities and as such are not hardened to withstand acts of war.

The extent of damage that could be caused by the intentional crash of a large, fully fuelled jetliner into a nuclear reactor containment or other nuclear facilities is still a matter for analysis. Nuclear facility designs vary from country to country, so studies will have to take specific plant designs into account.

**Nuclear Material:** According to IAEA experts, terrorists obtaining nuclear weapons would be the most devastating scenario. Beyond the difficulty for terrorists to obtain weapon usable material - scientists estimate that 25 kg of highly enriched uranium or 8 kg of plutonium would be needed to make a bomb - actually producing a nuclear weapon is far from a trivial exercise. Scientific expertise and access to sophisticated equipment would be required. However, when the Cold War ended, thousands of highly knowledgeable scientists and engineers previously involved in the Soviet Union's weapons programme were laid off or found their incomes drastically reduced. Another legacy of the Cold War are the disturbing reports, albeit unsubstantiated, of missing nuclear weapons.

The IAEA plans to significantly expand its advisory services and help States upgrade protection of their nuclear materials.

**Radioactive Sources:** IAEA experts are concerned that terrorists could develop a crude radiological dispersal device using radioactive sources commonly used in every day life. The number of radioactive sources around the world is vast: those used in radiotherapy alone are in the order of ten thousand. Many more are used in industry; for example, to check for welding errors or cracks in buildings, pipelines and structures. They are also used for the preservation of food. There is a large number of unwanted radioactive sources, many of them abandoned, others being simply "orphaned" of any regulatory control. An undetermined number of radioactive sources has become orphaned of regulatory control and their location is unknown.

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The accidental contamination of Goiânia, a major city in Brazil, with a medical radiation source exemplifies the potential for a terrorist group to wreak havoc on an urban centre. In September 1987, scrap scavengers broke into an abandoned radiological clinic and stole a highly radioactive caesium 137 source and moved it to a junkyard for sale as scrap. Workers broke open the encasement and cut up the 20-gram capsule of caesium 137 into pieces. The valuable-looking scrap was then distributed to friends and family of workers around the city. Fourteen people were overexposed, and 249 contaminated. Four subsequently died. More than 110,000 people had to be continuously monitored. To decontaminate the area, 125,000 drums and 1470 boxes were filled with contaminated clothing, furniture, dirt and other materials; 85 houses had to be destroyed.

## Annex: Nuclear Third Party Liability in the UK, the USA and Elsewhere.

### *International Framework*

Ever since the first commercial nuclear power reactors were built, there has been concern about the possible effects of a severe nuclear accident, coupled with the question of who would be liable.

Before 1997, the international liability regime was embodied primarily in two instruments:

- the IAEA's **Vienna Convention** on Civil Liability for Nuclear Damage of 1963, and
- the OECD's **Paris Convention** on Third Party Liability in the Field of Nuclear Energy of 1960 which was bolstered by the Brussels Supplementary Convention in 1963.

These Conventions were linked by the **Joint Protocol** adopted in 1988. They are based on the concept of civil law and share the following main principles:

- a. Liability is channelled exclusively to the operators of the nuclear installations;
- b. Liability of the operator is absolute, i.e. the operator is held liable irrespective of fault, except for "acts of armed conflict, hostilities, civil war or insurrection";
- c. Liability of the operator is limited in amount. Under the Vienna Convention the upper ceiling is not fixed\*; but it may be limited by legislation in each State.
- d. Liability is limited in time. Generally, compensation rights are extinguished under both Conventions if an action is not brought within ten years;
- e. The operator must maintain insurance or other financial security for an amount corresponding to his liability or the limit set by the Installation State, beyond this level the Installation State can provide public funds but can also have recourse to the operator;
- f. Jurisdiction over actions lies exclusively with the courts of the Contracting Party in whose territory the nuclear incident occurred;
- g. Non-discrimination of victims on the grounds of nationality, domicile or residence.

\* The Paris Convention set a maximum liability of 15 million Special Drawing Rights - SDR (about US\$ 20 million), but this was increased under the Brussels Supplementary Convention up to a total of 300 million SDRs (about US\$ 400 million), including contributions by the installation State up to SDR 175 million and other Parties to the Convention collectively on the basis of their installed nuclear capacity for the balance.

Following the Chernobyl accident in 1986, the IAEA initiated work on all aspects of nuclear liability with a view to improving the basic Conventions and establishing a comprehensive liability regime. In 1988, as a result of joint efforts by the IAEA and OECD/NEA, the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention was adopted. This broadened the coverage of the two

Conventions combining them into one expanded liability regime. It was also intended to obviate any possible conflicts of law in the case of international transport of nuclear material. It entered in force in 1992.

In 1997 governments took a significant step forward in improving the liability regime for nuclear damage when delegates from over 80 States adopted a **Protocol to Amend the Vienna Convention** and also adopted a **Convention on Supplementary Compensation for Nuclear Damage**. The amended Vienna Convention sets the possible limit of the operator's liability at not less than 300 million SDRs (about US\$ 400 million). The 1997 Convention on Supplementary Compensation defines additional amounts to be provided through contributions by States Parties collectively on the basis of installed nuclear capacity and a UN rate of assessment, basically at 300 SDRs per MW thermal (ie about US\$ 400 million total). Both these changes have yet to be ratified.

The Convention is an instrument to which all States may adhere regardless of whether they are parties to any existing nuclear liability conventions or have nuclear installations on their territories. The Protocol contains a better definition of nuclear damage (now also addressing the concept of environmental damage and preventive measures), extends the geographical scope of the Vienna Convention, and extends the period during which claims may be brought for loss of life and personal injury. It also provides for jurisdiction of coastal states over actions incurring nuclear damage during transport.

In 2001, contracting parties to the Paris and Brussels Conventions agreed new limits on liability: Operators (insured) €700 million, Installation State (public funds) €500 million, Collective state contribution (Brussels) €300 million => total €1500 M. This Protocol is expected to be ratified as soon as states have enacted relevant legislation.

Beyond such provision there is at least a tacit acceptance that the installation state will make available funds to cover anything in excess of these provisions.

#### *US Framework*

**The USA** takes a somewhat different approach. Here, the Price Anderson Act has since 1957 been central to addressing the question of liability for nuclear accidents. It is renewed every ten years or so, with strong bipartisan support, and requires individual operators to be responsible for two layers of insurance cover. The first layer is where each nuclear site is required to purchase US\$ 200 million cover from private insurers. The second layer if required is jointly provided by all US reactor operators. It is funded through retrospective payments of up to \$88.1 million per reactor collected in annual instalments of \$10 million (and adjusted with inflation). Combined, the total provision comes to nearly \$9.5 billion paid for by the utilities. (The Dept. of Energy provides \$9.5 billion for its nuclear activities.) Beyond this cover and irrespective of fault, Congress, as insurer of last resort, must decide how compensation is provided in the event of a major accident.

In 2002, the Act was renewed again by Congress.

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*Other countries*

In the **UK**, the Energy Act 1983 brought legislation into line with revisions to the Paris/Brussels Conventions and set a limit of liability for particular installations. In 1994 this limit was increased to £140 million for each major installation, so that the operator is liable for claims up to this amount and must insure accordingly. . This is covered through a pool comprising 13 insurance companies and 40 Lloyds syndicates. Beyond £140 million, the Paris/Brussels system applies. Beyond £140 million, the Paris/Brussels system applies up to SDR 300 million.

In mainland **Europe**, individual countries have legislation in line with the international conventions and where set, cap levels vary, eg France: FF 600 million, Sweden: SDR 300 million. These will be superseded by the 2001 Euro currency figures above. Germany has unlimited liability and requires DM 1 billion security of which DM 500 million is normally provided by the State.

In **Canada** the Nuclear Liability Act 1976 is also in line with the international conventions and establishes the licensee's absolute and exclusive liability for third party damage. Suppliers of goods and services are given an absolute discharge of liability. At present a limit of C\$75 million per power plant is set on the insurance cover required for individual licensees, but this is under review. Cover is provided by a pool of insurers, and claimants need not establish fault on anyone's part, but must show injury. Beyond the cap level, any further funds would have to be provided by the government.

## **Annex. Nuclear Transits and Transport.**

The IAEA estimates that between 18 million and 38 million packages containing radioactive material are transported annually worldwide. Shipments of radioactive materials are governed by co-operation among inter-governmental bodies and national governments under several international agreements. Inter-governmental bodies such as the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO) provide safety standards or guidelines. The IMO, in accordance with the SOLAS Convention, sets the International Maritime Dangerous Goods Code (IMDG Code) and the ICAO provides the Technical Instructions for Safe Transport of Dangerous Goods by Air. Moreover, there are regional agreements for the transport of hazardous goods by rail and by road - in Europe for example. The IAEA 1985 Regulations which apply to radioactive transport are already incorporated in the "UN Orange Book." These UN Regulations have been adopted by IATA and ICAO and by equivalent International Shipping organisations, so the 1985 IAEA regulations cover International Transport by sea and air globally.

An update, the UN Orange Book, 11<sup>th</sup> edition was published in September 1999. It incorporates the latest, 1996 IAEA regulations. These will be substituted for the 1985 regulations by IATA and ICAO in 2001 and by the Shipping bodies in 2002.

Some countries have legislation for radioactive transport, which probably gives legal force to the IAEA regulations and may go beyond the requirements of those Regulations.

A recent European Commission communiqué on the safe transport of radioactive material in the EU had estimated that member- states transport around one and a half million packages containing such material every year. However, my research reveals that the Netherlands -- a major radioactive materials producer -- accounts by itself for around one million package shipments, and the French radiopharmaceutical industry for more than two million every year.

The IAEA estimates that between 18 million and 38 million packages containing radioactive material are transported annually worldwide.

Canada tops the world league table with total reported package shipments approaching four and a half million per year. The U.S., Japan and Germany rank next, followed by the UK and Norway. The world's leading exporters of radioactive packages are Canada, the UK and Norway, according to released statistics. Export figures for the Netherlands are unavailable. The majority of the package shipments have a very low radioactive content and are classified by the IAEA as 'excepted' packages. This means their transport is not subject to the very stringent IAEA recommendations -- adopted across the world -- relating to the movement of more radioactive material. Nevertheless their movement is highly regulated and subjected to different IAEA guidelines. 'Excepted' packages include radioisotopes for research or medical diagnosis, and radioluminescent clocks or compasses.

The medical profession and industry account for the largest proportion of such packages; they even account for the majority of the more radioactive, non-'excepted' category shipments. The civil nuclear industry is responsible for only a few percent of the world's total.

The IAEA data comes from countries accounting for 80 percent of the world's installed nuclear capacity, 55 percent of the world's GDP (gross domestic product) and 26 percent of the world's population. But the IAEA accepts that even the figures it has been given are an under-estimation. For instance, in 1981 the agency's member-countries recorded 16,500 as the total number of packages transported by sea. However, Egypt reported a through-country transit in the Suez Canal of 52,000 packages. This vast difference occurs because some countries, such as the U.S., do not keep a full record of the number of 'excepted' packages.

In addition, the IAEA has encountered considerable difficulty in collating precise figures because of the recording methods adopted by different countries. Some countries count the transport of a package by a single mode of transport from origin to destination. Others count what is known as a combined shipment which involves the transport of a package by more than one means of transport from its point of origin to its destination. The IAEA is in the process of collecting accurate and uniformly measured statistics.

Meanwhile, besides collecting the best available data, the IAEA has adopted two methodologies to arrive at a meaningful estimate. The first uses GDP to obtain a measure for the volume of package shipments. This approach suggests 8 million non-'excepted' and 10 million 'excepted' (18 million) are shipped per year. The second assumes that population is the best means for making an assessment. This suggests around 17 million shipments of non-'excepted' and 21 million of 'excepted' (38 million) are transported annually. Whichever figure is more accurate, both indicate a much larger shipping volume than previous estimates, which were below 10 million.

#### *UF6 Transport.*

In the 1985 regulations no special requirements were included for UF<sub>6</sub>. This was because of a principal which is that "packages are designed against the major hazard"- the implication being that they are then OK for hazards of lesser importance. In the case of UF<sub>6</sub> the major hazard was seen as being chemical- the formation of HF if a leak occurred. So the packages were taken to have been designed against this (that is to say they were not likely to leak) and it was assumed that the radioactive hazard was in this way also covered.

The 1996 regulations, however, make specific mention of the radioactive hazard associated with the transport of UF<sub>6</sub> and give requirements for the packaging so as to minimise the radioactive hazard. This is still the subject of discussion with member nations and the next revision of the regulations will almost certainly incorporate new revisions for UF<sub>6</sub> transport.

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### *Transport Accidents Involving Nuclear Fuel.*

Around 450 fuel shipments take place every year, with half being moved by train, 40 percent by boat and 10 percent by truck. Between 1978 and 1995, there have been 25 accidents or incidents during the shipment of spent nuclear fuel, 15 involving rail transport, nine involving transport by truck and one involving transport by sea. In all of these, the cargo itself was affected just twice: once in a traffic accident in June 1987 and once during the unloading of a shipment in December 1991. In the traffic accident, the nuclear container fell off a lorry into a roadside ditch. In the shipping accident, a chain broke during unloading, causing a nuclear container to fall onto the ship's deck. In neither case were there any radiation leaks.

The most recent accident of any significance, involving the transport of spent fuel, occurred when a train carrying spent nuclear fuel was derailed in eastern France. It resumed its voyage to Dunkirk and Britain on the 5<sup>th</sup> of February 1997 after 36 hours of repairs and safety tests. The train left Apach at 5.55 p.m. (1655 GMT). The train was allowed to go on its way after safety inspectors determined there had been no radiation leaks from the three wagons which jumped the tracks, each of them loaded with 6.5 tonnes of spent nuclear fuel. Work went on through the night to put the wagons upright and on the rails. The mishap occurred early when the convoy, bound for Britain from Germany, was derailed at Apach. The convoy was carrying 18 spent fuel elements from the Lingen power station in Lower Saxony. The convoy belonged to British Nuclear Fuels Plc and was on its way to Dunkirk for shipment to Britain by ferry. The shipment was on its way to the reprocessing plant at Sellafield in northwestern England.

### *Consequences of Accidents to Radioactive Transport.*

The IAEA claims that there has been no fatality or serious injury due to radioactive material transport or accidents during such transport. There is a chance of a release of radioactivity and indeed such releases have occurred. However the design of packages is such that such accidental releases have never been big enough to matter.

### *The Legal Position.*

Vladimir Boulanenkov of the IAEA Legal Department, Extension 21503, answered my questions on the legal position.

The Paris and the Vienna Conventions are practically identical in respect of radioactive transport. The Conventions apply both to fixed installations and to transport. The Conventions say that the Operator of a nuclear installation has liability for radioactive materials which he sends to a recipient until the recipient assumes liability. The liability of the sender is covered by the Conventions in the same way as the Conventions cover the nuclear installation itself. So there is strict liability and a limit of liability of £ 140 million, above which governments accept liability.

In practical terms most governments require radioactive transport to be insured over and above the requirements of the Conventions. This is because they do not regard the Conventions as adequate.

If the sender is in a State that is not party to the Conventions then there must be a Contract that specifies who has liability and when liability is transferred from the sender to the recipient. The Contract must be signed before the transport takes place.

Canada is a country that has not signed the Conventions, for example. Canada tops the world league table with total reported package shipments approaching four and a half million per year.

## **Annex. Calendar of Nuclear Accidents and Incidents.**

In this Report I have made the point that most of the accidents that have happened at nuclear installations could have been duplicated by the intentional acts of terrorists. So these accidents provide us with a powerful insight into potential scenarios for acts of nuclear terrorism, leading to Third Party Losses. I have deduced six terrorism scenarios from accidents in this calendar, in the text of the present Report. I have deduced the frequency and TPL for each of the six and have shown that these values are in good agreement with the values that I have independently calculated from Joule analysis and the logarithmic relationship between BSO (and BSL) doses and their frequencies.

In this Annex I give a calendar of nuclear incidents and accidents that have occurred world-wide and in the body of the Report I use several of these to construct and evaluate the examples of terrorist scenarios asked for by the client.

### *Calendar.*

1999: On Thursday 30 September at 10:35 am, Japan time a criticality accident occurred at the JCO uranium processing facility at Tokai-mura, about 150 km north-east of Tokyo. The incident has provisionally been given an International Nuclear Event Scale rating of 5.

1999: 22 workers were exposed to radiation during a heavy water spillage at the Wolsong-3 nuclear power unit. The Korean incident apparently occurred late on Monday (October 4th), and involved a spillage of some 40 to 50 litres of heavy water. It occurred during de-assembly of a moderator pump, and the cause appears to have been related to a damaged pump seal. The spilled heavy water has all now been recuperated.

1999: On October 5, a hydrogen gas leak was reported at the power station in Loviisa, some 90 kilometres from Helsinki, Finland, while plant staff were carrying out routine maintenance work on the outside of the building, which involved notably changing hydrogen bottles. According to Leif Ekholm, the deputy head of the town's fire brigade, "this gas leak did not endanger safety at the power plant". He explained that the incident happened during failure to connect a gas pipe to the bottles. The courtyard had been immediately evacuated and the safety valves closed. According to the Finnish nuclear safety authorities (STUK), the leak was quickly stemmed. Both of the Loviisa reactors were in normal operation throughout the whole incident and there was no danger to the safety of the plant neither to the safety of the population or the environment, a statement added. The incident, said STUK, was minor and did not exceed the threshold of early notification via alarm contacts described in bilateral agreements or international conventions and EU arrangements.

1998: In Korea, five reactor shutdowns occurred during the fourth quarter of 1998. Four were attributed to failures in non-safety systems and were classified as IAEA-set Zero Scale Event. The fifth, which happened at Ulchin Unit 1 on Dec. 8th 1998 due to a line break in the essential service water system, was graded at level 1 on the INES

scale. The incident was caused by a line break to the heat exchanger between the component cooling water and the residual heat removal systems. It was the third one rated at level 1 from among 105 shutdowns recorded in Korea since the IAEA scale was introduced in Korea in 1993.

1998: All nuclear reprocessing in Britain stopped. The new Thorp reprocessing plant closed as a result of an accident in 1998 when a pipe carrying nuclear waste was perforated by a sharp metal shard. BNFL had said it expected the repair work to take six weeks, but now says that it does not expect Thorp to be operational before late July, early August. "We know what the problem is and we know how to solve it and we want to do it properly," a spokesman said. BNFL said the extra time required to get Thorp up and running would not cause any problems in meeting contract deadlines. Last month there was talk in the British media that problems at Thorp were putting one billion pounds worth of reprocessing contracts in jeopardy.

1997: James Birch and Martin Tolson received the average annual dosage of plutonium for an ordinary member of the public in a "matter of a few seconds" when a workman dismantling redundant equipment accidentally let up to four grams of plutonium escape. The men were working in a laboratory at the Atomic Weapons Establishment in Aldermaston, Berkshire, when the incident happened.

1996: Leakage of radiation due to human error and technical failure at Dimitrovgrad nuclear research centre (Russia)

1995: Fire due to leakage of sodium coolant from Monju fast breeder reactor, Japanese nuclear industry attempts to cover up full extent of accident, reactor shut-down

1994: Breakdown of cooling system at Kola nuclear power plant (Russia)

1994: Fire at Beloyarsk nuclear power plant (Russia)

1993: Explosion at the Tomsk-7 nuclear complex (Russia)

1993: Spillage of 18,000 litres of heavy water at Darlington nuclear power plant (Canada)

1993: Leak at Kozloduy nuclear power plant, release of radioactive steam (Bulgaria)

1993: Radioactive release from leaking fuel rods at Perry nuclear power plant (USA)

1993: Technical failure at Paluel causes subcooling accident (France)

1993: High pressure steam accident kills one worker and injures two others at Fukushima nuclear power plant (Japan)

1993: Reactor shut-down due to breakdown of cooling system at Kola nuclear power plant (Russia)

1993: Failure of control system at Susquehanna nuclear power plant (USA)

1993: Refuelling machine malfunctions at the Wylfa nuclear power plant (UK)

1993: Fire at Balakovo nuclear power plant (Russia)

1993: Instrumentation and Control failure at Saint Alban nuclear power plant (France)

1992: Leak causes a shut-down at Darlington nuclear power plant (Canada)

1992: Four tons of heavy water spilt at Rajasthan nuclear power plant (India)

1992: Two workers contaminated at Dampierre nuclear power plant (France)

1992: Fire in electro-generator at St. Alban nuclear power plant (France)

1992: Tube leak causes a radioactive release of 12 Curies of radioactivity from Tarapur nuclear power station (India)

1992: Technical failure in shut-down system at Balakovo nuclear power plant (Russia)

1992: Failure of cooling pumps at Kozloduy nuclear power plant (Bulgaria)

1992: Technical failure in pump system at Zaporozhe nuclear power plant (Ukraine)

1992: Software failure in the control computer at Embalse nuclear power plant

(Argentina)

1992: Technical failure at Novovoronezh nuclear power plant (Russia)

1992: Fire at Kola nuclear power plant (Russia)

1992: Incident with radiation leakage, shut-down of reactor at Leningrad nuclear power plant (Russia)

1992: Technical failure at Leningrad nuclear power plant (Russia)

1992: Failure of shut-down system at Ignalina nuclear power plant (Lithuania)

1992: Automatic shut-down due to failure of pump system at Kalinin nuclear power plant (Russia)

1992: Technical failure of reactor shut-down system at Kola nuclear power plant (Russia)

1992: Breakdown of cooling system at Novovoronezh nuclear power plant (Russia)

1992: Technical failure of cooling system at Hatch nuclear power plant (USA)

1992: Reactor shut-down at Kola nuclear power plant (Russia)

1992: Total failure of centralised control system at the Smolensk nuclear power plant (Russia)

1992: Failure of cooling system at Kola nuclear power plant (Russia)

1992: Technical failure at Sizewell A nuclear power plant (UK)

1992: Leak in pipe conducting sea water to cooling system at Leningrad nuclear power plant (Russia)

1992: Technical failure of control system at Leningrad nuclear power plant (Russia)

1992: Reactor shut-down due to failure of cooling system at Novovoronezh nuclear power plant (Russia)

1992: Leakage of radiation due to breakdown of cooling system at Ignalina nuclear power plant (Lithuania)

1992: Temperature rise in storage pool at Gravelines nuclear power plant (France)

1992:

1992: Failure of shut-down system at Novovoronezh nuclear power plant (Russia)

1992: Leakage of radioactive water at Kola nuclear power plant (Russia)

1992: Cracks in cooling system equipment at Brunsbuttel nuclear power plant (Germany)

1992: Radioactive water leakage at Beloyarsk nuclear power plant (Russia)

1992: Six Nuclear Workers Inhaled Plutonium Dust at Trawsfynydd Nuclear Power Station In North Wales. The accidents happened while workers were scraping the inside of the pond as part of the site decommissioning process following the plant's closure in 1991. A spokesman said: "Urine samples are taken twice a year and urine taken in June showed that two workers had breathed in some radioactive material but the levels were very low."

Since then it has emerged that another four workers had inhaled smaller quantities of radioactive dust. BNFL has calculated that the dose to the two worst exposed workers was within safe levels.

1991: Leak of 190,000 litres of water from cooling system, reactor shut-down at Oconee nuclear power plant (USA)

1991: Release of radioactivity from Fukui nuclear power plant (Japan)

1991: Rupture of steam generator pipe causes release of radioactivity at Mihama nuclear power plant (Japan)

1991: Refuelling accident at Wuergassen nuclear power plant (Germany)

1991: Lost of offsite power cause technical failure at "Vermont Yankee" nuclear submarine (USA)

1991: Failure of core cooling system at Belleville nuclear power plant (France)

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1991: Power limited due to error between actual and indicated power at Pickering nuclear power plant(Canada).  
1991: Flaw in cooling system at Wurgassen nuclear power plant (Russia)  
1991: Leakage of radiation at Bilibino nuclear power plant (Russia)  
1991: Reactor shut-down due to break of control system at Sendai nuclear power plant (Japan)  
1991: Steam leakage causes reactor shut-down at Paks nuclear power plant (Hungary)  
1991: Eight control rods show delays in emergency shut- down insertion time at Millstone Point nuclear power plant (USA)  
1991: Automatic shut-down due to technical problems at Sendai nuclear power plant (Japan)  
1991: Incident and steam leak during refueling at Barsebeck nuclear power plant (Sweden)  
1991: Leakage at Kozloduy nuclear power plant (Bulgaria)  
1991: Technical failure at Yugno-Ukrainskaya nuclear power plant (Ukraine)  
1991: Technical failure at Zaporozhe nuclear power plant (Ukraine)  
1991: Offsite power failure at Smolensk nuclear power plant (Russia)  
1991: Fire on board "Sceptre" nuclear submarine in Scotland  
1991: Failure of shut-down system during refuelling at Novovoronezh nuclear power plant (Russia)  
1991: Incident during refueling at Vogtle nuclear power plant (USA)  
1991: Technical failure of shut-down system at Zaporozhe nuclear power plant (Ukraine)  
1991: Technical failure causes automatic shut-down at Kalinin nuclear power plant (Russia)  
1991: Disfunction of automatic shut-down system at Bilibino nuclear power plant (Russia)  
1991: Failure of control system causes reactor shut- down at Kursk nuclear power plant (Russia)  
1991: Technical failure at Beloyarsk nuclear power plant (Russia)  
1991: Failure of control system during refuelling causes reactor shut-down at Smolensk nuclear power plant (Russia)  
1991: Failure of turbo-generator causes reactor shut- down at Balakovo nuclear power plant (Russia)  
1991: Technical failure at Kola nuclear power plant (Russia)  
1991: Reactor shut-down due to technical failure at Kalinin nuclear power plant (Russia)  
1990: Loss of offsite power with multiple equipment failures at Dresden nuclear power plant (USA)  
1990: Pump failure during a shut-down at Gravelines nuclear power plant (France)  
1990: Eight employees receive radiation exposure at Point Lepreau (Canada)  
1990: Flooding of building due to increase of coolant level at Bohunice nuclear power plant (Slovakia)  
1990: During refuelling, five cubic meters of radioactive water spilled at the Fessenheim nuclear power plant (France)  
1990: Cable fire causes loss of control of the position of control rods at Chernobyl nuclear power plant (Ukraine)  
1990: Superphenix Fast Breeder Reactor is closed down due to technical failures (France)  
1990: Cables for reactor control and protection system supply overheat at Bohunice

nuclear power plant (Slovakia)  
1990: Failure of reactor core cooling system at Palisades nuclear power plant (USA)  
1990: Failure of core cooling equipment at Doel nuclear power plant (Belgium)  
1990: Control element discovered damaged at Novovoronezh nuclear power plant (Russia)  
1990: Incident and radiation leakage at Leningrad nuclear power plant (Russia)  
1989: Fire in turbine equipment at Kozloduy nuclear power plant (Bulgaria)  
1989: Eight workers are contaminated at Savannah River reprocessing plant (USA)  
1989: Technical failure of fuel rods at Pickering nuclear power plant (Canada)  
1989: Control rod failure at Gravelines nuclear power plant (France)  
1989: Soviet nuclear submarine "Komsomolets" sinks off Norway  
1989: Fire of pump equipment at Bohunice nuclear power plant (Slovakia)  
1989: Fire in the cables of the cooling pumps at the Bohunice nuclear power plant (Slovakia)  
1989: Spent fuel element dropped in the storage pool and damaged at Kruemmel nuclear power plant (Germany)  
1989: Refuelling accident at Isar nuclear power plant (Germany)  
1989: Instrumentation and control failure at Grand Gulf nuclear power plant (USA)  
1989: Technical failure at Ignalina nuclear power plant (Lithuania)  
1989: Control rod failure at Olkiluoto nuclear power plant (Finland)  
1989: Manual shut-down of WNP nuclear power plant (USA)  
1989: Failure of core cooling system at Dresden nuclear power plant (USA)  
1989: Breakdown of fuel rod control system at Oconee nuclear power plant (USA)  
1989: Technical failure nearly causes core meltdown at Greifswald nuclear power plant (Germany)  
1988: Release of 5000 Curies of tritium gas from the Bruyere le Chatel military nuclear complex (France)  
1988: Increased levels of radioactivity at Bohunice nuclear power plant (Slovakia)  
1988: Technical failure at Zorita nuclear power plant (Spain)  
1988: Damage detected at Atucha nuclear power plant (Argentina)  
1988: Fire at Perry nuclear power plant (USA)  
1988: Fire at Ignalina nuclear power plant (Lithuania)  
1988: Technical failure at Stade nuclear power plant (Germany)  
1988: Accident during refueling on board of Soviet nuclear powered ice-breaker "Lenin"  
1988: Explosion at the Burghfield Atomic Weapons Establishment (UK)  
1988: Four of the eight emergency installations discovered out of order at Brokdorf nuclear power plant (Germany)  
1988: Two control rods jammed at Blayais nuclear power plant (France)  
1988: Reactor shut-down due to failure of control equipment at Pilgrim nuclear power plant (USA)  
1987: Accidental release of 50 tonnes of water from Atucha nuclear power plant (Argentina)  
1987: 249 people are contaminated in Brazil, due to handling discarded nuclear medical equipment, four people subsequently die  
1987: Nuclear transport accident in the UK  
1987: Fire and release of radioactivity at Australian nuclear research facility  
1987: Severe incident at Biblis nuclear power plant (Germany)  
1986: Meltdown of reactor 4 at Chernobyl nuclear power plant; the worst civilian nuclear accident to date.

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1986: Release of 13 tonnes of radioactive carbon dioxide from Transfynydd nuclear power plant (UK)

1986: "Amber alert" (indicating an emergency in one building and a threat to the rest of the plant)" at Sellafield reprocessing plant, UK. Three workers suffer contamination

1986: Release of radiation from Hamm-Uentrop nuclear power plant (Germany)

1986: The power lines to the Palo Verde nuclear power plant are sabotaged (USA)

1986: Twelve people receive 'slight' plutonium contamination while inspecting a store room at Tokaimura nuclear complex (Japan)

1986: Flooding at the Cattenom nuclear power plant (France)

1986: Explosion at Surry nuclear power plant, four people killed (USA).

1985: Explosion and steam leakage killed 14 workers at Balakovo nuclear power plant (Russia)

1985: Emergency cooling system out of order at the Grohnde nuclear power plant (Germany)

1985: Malfunction in the cooling system at Davis Blesse nuclear power plant (USA)

1985: Fire in a barrel of radioactive waste at Karlsruhe nuclear complex (Germany)

1985: Fire at Fukushima nuclear power plant during routine shut-down (Japan)

1985: Accidental radioactive release into the sea from Hinkley Point nuclear power station (UK)

1984: French freighter sinks in the English Channel with 375 tonnes of uraniumhexafluoride on board

1984: Accident at Kozloduy nuclear power plant (Bulgaria)

1984: Emergency cooling system at San Onofere nuclear power plant fails (USA)

1984: Technical failure at Sequoyah nuclear power plant causes spillage of radioactive coolant water. (USA)

1984: Uncontrolled power surge at Bohunice nuclear power plant (Slovakia)

1984: Emergency shut-down of Paks nuclear power plant (Hungary)

1984: Fire at Kalinin nuclear power plant (Russia)

1983: Technical failure causes release of Iodine-131 from Phillipsburg nuclear power plant (Germany)

1983: Failure of automatic shut-down at Salem nuclear power plant (USA)

1983: Incident at Turkey Point nuclear power plant (USA)

1983: Reactor shut-down due to failure of fuel rods at Kursk nuclear power plant (Russia)

1983: Total loss of coolant at Embalse nuclear power plant (Argentina)

1983: Argentinean engineer dies from radiation dose received two days earlier

1983: Technical failure and human error cause accident at Blayas nuclear power plant(France)

1983: Sellafield reprocessing plant discharges highly radioactive wastes directly into the sea (UK)

1982: Release of 100 cubic metres of radioactive water from Salem nuclear power plant (USA)

1982: Steam generator ruptures at R.E. Ginna nuclear power plant (USA)

1981: Release of 300-times the normal discharge level of Iodine-131 at Sellafield reprocessing plant (UK)

1981: Accident at La Hague reprocessing plant (France)

1980: Pump failure causes accidental release of radioactive water at La Hague reprocessing plant (France)

1980: Plutonium transport accident in the USA

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1979: Partial core meltdown at Three Mile Island nuclear power plant (USA)  
1979: Two workers suffer radioactive contamination at Tokaimura nuclear complex (Japan)  
1979: Fire in the generator of the Barsebäck nuclear power plant (Sweden)  
1979: Technical fault at the Oyster Creek nuclear power plant triggers emergency shut-down (USA)  
1978: Fire and loss of reactor control, 8 workers irradiated at Beloyarsk nuclear power plant (Russia)  
1978: Radioactive helium released from Colorado reactor (USA)  
1978: Release of two tons of radioactive steam from Brunsbüttel nuclear power plant (Germany)  
1977: Kozloduy nuclear power plant affected by an earthquake (Bulgaria)  
1977: Temperature increase at Rancho Seco nuclear power plant (USA)  
1977: Sea water runs into the cooling circuit of Hunterston nuclear power plant (UK)  
1976: Two workers killed by radioactive carbon dioxide at Bohunice nuclear power plant (Slovakia)  
1976: Accident at Bohunice nuclear power plant (Slovakia)  
1975: 1.5 million Curies released from Leningrad nuclear power plant (Russia)  
1975: Release of radioactivity from Mihama nuclear power plant (Japan)  
1975: Fire in reactor at Browns Ferry nuclear power plant (USA)  
1974: Explosion and radiation leak at Leningrad nuclear power plant, three people killed (Russia)  
1974: Leakage at Hanford nuclear weapons complex (USA)  
1974 Incident at Beznau nuclear power plant (Switzerland)  
1974: Release of radioactive water at Los Alamos nuclear weapons Laboratory (USA)  
1973: Thousands of cubic meters of radioactive waste flow out of Hanford nuclear weapons complex (USA)  
1973: Container filled with Cobalt-60 lost in the North Sea  
1973: 35 workers at the Sellafield reprocessing plant are contaminated following a technical failure (UK)  
1972: Radioactive water has to be pumped out of the Indian Point nuclear power plant (USA)  
1970: Soviet nuclear submarine sinks with 52 crew members in Indian ocean  
1969: Technical failure at Swiss experimental nuclear reactor causes release of radioactive water  
1969: Fire at Rocky Flats nuclear weapons plant causes plutonium to spontaneously ignite. (USA)  
1969: Fuel elements melt at St Laurent des Eaux nuclear power plant (France)  
1968: Leakage at La Hague reprocessing plant (France) 3-1952: First UK nuclear test  
1967: Release of radioactivity at Grenoble nuclear power plant (France)  
1966: Partial core meltdown at the Fermi fast breeder reactor (USA)  
1966: A B-52 plane crashes in Spain causing plutonium contamination  
1965: 6.5 kg plutonium sludge released from Savannah River reprocessing plant (USA)  
1965: Release of eight cubic metres of cooling water from Savannah River reprocessing plant (USA)  
1961: Explosion in reactor Idaho Falls (USA); three people killed  
1960: Technicians trying to restart a reactor at Savannah River reprocessing plant almost send it out of control (USA)  
1960: Melting of fuel elements cause a release of radioactivity at the Test Reactor at Waltz Mills (USA)

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1959: US plane carrying nuclear weapons crashes and catches on fire  
1958: Accident and release of radioactivity at the Chalk River experimental reactor (Canada)  
1957: 15 kgs of plutonium catch fire at Rocky Flats nuclear weapons complex (USA)  
1957: Many square miles contaminated by accident at the Chelyabinsk nuclear complex (Russia)  
1957: One of two production reactors at Windscale, UK, has a core fire, releasing radionuclides which were calculated to produce 30 cancer deaths over the succeeding 40 years.  
1955: Core meltdown at EBR fast breeder reactor (USA)  
1952: World's first major nuclear reactor disaster, Chalk River experimental reactor (Canada)  
1949: US experiment "Green Run" contaminates communities up to 70 miles away from the Hanford nuclear weapons complex (USA)



## **Annex: The Attitude of Japanese Authorities to the Possibility of Terrorist Strikes against Nuclear Installations.**

### *Resistance to Aircraft Crash.*

Nuclear power stations in Japan come in the top category for resistance to aircraft crash. This is because they are designed to the highest level of resistance to horizontal and vertical acceleration. Typically Japanese nuclear plants will withstand five times the horizontal acceleration that will an average nuclear plant, world-wide. The frequency and intensity of earthquakes in Japan have necessitated this. When the resistance of the main reactor containment building and ancillary buildings to aircraft crash is evaluated, therefore, they prove to be very resistant: more so than the average.

Two critical items of plant are identified in this analysis of the resistance to aircraft crash. They are:

- ◆ The Residual Heat Removal System and Emergency Core Cooling Supply: These items share some of the same pumps and control features and are therefore considered as a single system for the purpose of analysis. Should an aircraft crash into these systems then one of the two methods of removing decay and residual heat from the shut-down reactor will be damaged and perhaps rendered ineffective. Should the alternative system, involving the steam generators in the case of a PWR, also fail then there will be a Core Damage Accident and a large consequent loss.
- ◆ The reactor containment: This contains the reactor and also, in the case of a PWR, the Steam Generators, which are the second of the two systems for removing decay heat (and fission heat) from the reactor. Should a crashing aircraft puncture this concrete containment and damage the reactor then there may be a Core Damage Accident and radioactivity may escape through the broken containment, causing contamination and consequent losses.

A comparison between the reactors in different countries shows that the Japanese reactors are in the most resistant category for accidents in which the Containment is struck by a terrorist aircraft. This is because the Japanese containments are designed to resist the very large forces produced by the frequent, strong earthquakes that occur in Japan.

This comparison shows that it is the German power reactors that are most resistant to accidents in which the RHR/ECCS system(s) are struck by a terrorist aircraft. This is because there have been many accidents in which fighter aircraft have crashed on German soil. More than 100 fighter jets in the German air force crashed during the 1960s and 1970s due to apparent design defects. German reactors have therefore been designed with the RHR/ECCS system(s) in strong concrete bunkers, resistant to aircraft crash. In Japan, too, the RHR/ECCS systems are strongly protected since the

auxiliary building in which they are situated is resistant to strong earthquakes, but not to the extent that is customary in Germany.

*Likelihood of Terrorist Aircraft Attack.*

The issue of the threat posed in Japan by terrorist attacks, was raised most recently during the mid-1990s after members of the Aum Shinrikyo cult released sarin nerve gas in the Tokyo underground, but no basic changes were made to Japan's defences against nuclear terrorism.

*Terrorist Threat to Transport of Spent Fuel, MOX and Radioactive Waste between UK and Japan.*

The U.S. government has completed a review of a proposed shipment of mixed-oxide (MOX) fuel from Japan to the U.K. USNRC Commissioners unanimously approved the shipment. Now, it appears that the US does not wish the fuel to be shipped, in part because they fear that it will be a target for terrorists. Under the terms of the U.S.-Japan agreement for nuclear cooperation, Japan has to receive U.S. approval for the transfer, including the security arrangements. The fuel, which British Nuclear Fuels plc (BNFL) sent to Kansai's Takahama-4 in 1999, is being returned to the U.K. unused because it was among the fuel for which BNFL had falsified quality control data.

*Measures Being Taken to Reduce the Terrorist Threat to Japanese Nuclear Installations.*

The Japanese are following the US lead in their work on terrorism. The USNRC has recommended a programme of work to the US Government and the Japanese Nuclear Safety Commission is preparing plans that are said to resemble this programme. It involves measures to combat air-strikes, sabotage and attacks from the sea.

There is one particular difference: the Japanese do not intend to have *armed* guards at their nuclear installations. The US stations have guards with visible automatic weapons, as do some of those in the UK. The Japanese say that armed guards would give the impression that their nuclear facilities had some military function, such as the production of nuclear materials for weapons. They are understandably sensitive about this.

The Japan Coast Guard has started patrolling waters near nuclear plants on a round-the-clock basis. At the request of the 14 prefecture governments that host Japan's nuclear plants, the coast guard has dispatched patrol vessels to cover all 17 plants.

The nuclear utilities had planned a drive to have 1-million Japanese visit the country's 52 power reactors during 2002. This plan to encourage more visitors to reactors has been withdrawn by security regulators, instructed by the Japanese government to defend nuclear installations from sabotage. More restricted access to Japanese nuclear installations will impede efforts by Japanese utilities to win public acceptance for their plan to burn MOX fuels in power reactors.

## Annex. The International Nuclear Event Scale, INES

### *The International Nuclear Event Scale*

Level, Descriptor	Off-Site Impact	On-Site Impact	Defence-in-Depth Degradation	Examples
<b>7 Major Accident</b>	<i>Major Release:</i> Widespread health and environmental effects			Chernobyl, Ukraine, 1986
<b>6 Serious Accident</b>	<i>Significant Release:</i> Full implementation of local emergency plans			-
<b>5 Accident with Off-Site Risks</b>	<i>Limited Release:</i> Partial implementation of local emergency plans	Severe core damage		Windscale, UK, 1957 (military). Three Mile Island, USA, 1979.
<b>4 Accident Mainly in Installation</b> either of:	<i>Minor Release:</i> Public exposure of the order of prescribed limits	Partial core damage. Acute health effects to workers		Saint-Laurent, France, 1980 (fuel rupture in reactor). Tokai-mura, Japan, Sept 1999.
<b>3 Serious Incident</b> any of:	<i>Very Small Release:</i> Public exposure at a fraction of prescribed limits	Major contamination, Overexposure of workers	Near Accident. Loss of Defence-in-Depth provisions	Vandelllos, Spain, 1989 (turbine fire, no radioactive contamination)
<b>2 Incident</b>	nil	nil	Incidents with potential safety consequences	
<b>1 Anomaly</b>	nil	nil	Deviations from authorised functional domains	
<b>0 Below Scale</b>	nil	nil	No safety significance	

Source: International Atomic Energy Agency

